***Review Article***

**Enhancing Performance of *Bombyx mori* L. *via* Nutrient-Fortified Mulberry Leaves**

**ABSTRACT**

The silkworm, *Bombyx mori* L., is a monophagous insect that depends exclusively on mulberry (*Morus* spp.) leaves for its nutritional requirements, which are critical for optimal growth, development and silk production. The nutritional quality of mulberry leaves directly influences larval performance, cocoon characteristics and silk yield. This review highlights the fundamental role of essential nutrients *viz.*, carbohydrates, proteins, lipids, amino acids, vitamins, minerals and water in silkworm physiology. Deficiencies or imbalances in these components can adversely affect metabolic efficiency, increase disease susceptibility and reduce cocoon productivity. Recent advancements in feed fortification strategies, including the supplementation of mulberry leaves with probiotics (*Lactobacillus*, *Bacillus* spp.), plant extracts (*Aloe vera, Ocimum sanctum* and *Tinospora cordifolia*), amino acids, vitamins, minerals and protein-rich additives, have shown significant improvements in larval weight, cocoon quality and silk gland development. Nutritional indices such as food consumption, digestibility and conversion efficiency provide quantitative measures of dietary effectiveness. Furthermore, nutritional interventions have been found beneficial in silkworm disease management, enhancing resistance to pathogens and reducing mortality. The synthesis of current findings underscores the importance of nutrient-enriched feeding protocols in sericulture, aiming to optimize rearing performance and improve the economic traits of silkworms. This comprehensive review provides insights into the nutritional requirements and supplementation strategies to support sustainable and high-yield sericulture practices.

*Keywords: Bombyx mori, nutrition, fortification, economic traits*

**INTRODUCTION**

Silkworm *Bombyx mori* L. is a monophagous in nature due to the presence of a natural polyphenol, morin (Zhang *et al*., 2018), relying exclusively on mulberry leaves to obtain all the nutrients required to build their bodies, sustain and spin cocoons. Mulberry leaves provide essential proteins, vitamins and other nutrients, which are critical for the synthesis of silk proteins. The quality and quantity of mulberry leaves, along with environmental factors play a crucial role in determining the production of raw silk spun by larvae before pupation, forming cocoons.

“Nutrition is a fundamental and essential component for all living beings. Similar to other organisms, silkworms are highly sensitive to nutritional factors. Research has shown that the amount and quality of mulberry leaves directly affect the growth rate, developmental period, body weight and survival rate of silkworm larvae. Additionally, these factors influence the fecundity, longevity, movement and competitive ability of the adult moths. If the required nutrients are not present in the mulberry leaves, silkworms are more susceptible to diseases. This leads to a decreased effective rate of rearing, as higher mortality rates are observed in silkworms reared on poor-quality food” (Borah & Praban, 2020). Although mulberry leaves are considered a complete diet for silkworms, deficiencies may occur due to various reasons, such as environmental conditions or poor cultivation practices.

“The nutritional status of mulberry leaves can be improved by enriching them with additional nutrients. Fortification of mulberry leaves with complementary compounds has been shown to significantly enhance larval growth and improve post-cocoon characteristics. Nutritional requirements are defined as the chemical components of ingested food that are essential for normal metabolism and the development of insects. Essential nutrients such as carbohydrates, proteins, lipids, vitamins, amino acids and water are naturally present in the food plants of silkworms” (Borah & Praban, 2020).

To address these nutritional challenges, a series of investigations have been conducted to enhance the nutritional value of mulberry foliage. These studies have focused on incorporating various nutrients such as proteins, vitamins, amino acids, minerals, hormones and antibiotics into mulberry leaves. These enhancements aim to improve the performance of silkworms, resulting in higher yields and superior quality cocoons.

**Importance of nutrient supplementation in silkworm**

Nutrition is a crucial factor that significantly influences the growth and development of the silkworm, *Bombyx mori* L. The nutritional components of mulberry leaves have a direct impact on the overall growth of silkworms, contributing to increased larval, pupal and cocoon weights, as well as enhanced silk quality. Both the quantitative and qualitative characteristics of cocoons depend on the quality and quantity of mulberry leaves provided. Supplementing mulberry leaves with enriched nutritional components positively affects silkworm growth, development and silk production (Etebari & Matindoost, 2004). The primary nutrition for silkworms is derived from feeding on mulberry leaves. The detailed composition of mulberry leaves is presented in Table 1.

**Table 1: Nutritional composition of mulberry leaves (Shubhajit et al, 2020)**

|  |  |  |  |
| --- | --- | --- | --- |
| Sl. No. | Nutritional Components and phytochemicals | Quantity | Reference |
| 1 | Total phenolic (TP) | 8.76-20.26 mg gallic acid equivalents (GAE) per g dry weight (dw) | (Yu *et al*., 2018) |
| 2 | Total flavonoid content (TF) | 21.36-56.41 mg rutin equivalents (RE) per g dry weight (dw) | (Yu *et al.,* 2018) |
| 3 | Total soluble sugars (TSS) | 58.71-150.31 mg per g dry weight (dw) | (Yu *et al*., 2018) |
| 4 | 1-Deoxynojirimycin (1-DNJ) | 0.20-3.88 mg per g | (Ji *et al*., 2016) |
| 5 | Total phenols | 12.81-15.50 mg gallic acid equivalents (GAE) per g dry weight (dw) | (Sanchez *et al.,* 2015) |
| 6 | Caffeoylquinic acids | 6.78-8.48 mg per g dry weight (dw) | (Sanchez *et al*., 2015) |
| 7 | ABTS | 10.6-13.15 mg Trolox per g dry weight (dw) | (Sanchez *et al.,* 2015) |
| 8 | DPPH | 10.62-12.64 mg Trolox per g dry weight (dw) | (Sanchez *et al*., 2015) |
| 9 | Total soluble carbohydrates | 3.1 g per 100 g fresh weight (fw) | (Dimitrova *et al*., 2015) |
| 10 | Reducing sugars | 1.5 g per 100 g fresh weight (fw) | (Dimitrova *et al*. 2015) |
| 11 | Fructose and glucose | 0.3 g per 100 g fresh weight (fw) | (Dimitrova *et al.,* 2015) |
| 12 | Sucrose | 1.1 g per 100 g fresh weight (fw) | (Dimitrova *et al*., 2015) |
| 13 | Crude proteins | 15.31-30.91 per cent | (Butt *et al*., 2008) |
| 14 | Crude fat | 2.09-7.92 per cent | (Butt *et al.,* 2008) |
| 15 | Crude fibre | 9.9-13.85 per cent | (Butt *et al*., 2008) |
| 16 | Neutral dietary fibre | 27.6-43.6 per cent | (Butt *et al*., 2008) |
| 17 | Total ash | 11.3-17.24 per cent | (Butt *et al*., 2008) |
| 18 | Ascorbic acid | 100-200 mg per 100 g | (Butt *et al*., 2008) |
| 19 | Beta-carotene | 8.44-13.13 mg per 100 g | (Butt *et al*., 2008) |
| 20 | Oxalates | 183 mg per 100 g | (Butt *et al*., 2008) |
| 21 | Phytates | 156 mg per 100 g | (Butt *et al*., 2008) |
| 22 | Tannic acid | 0.13-0.36 per cent | (Butt *et al*., 2008) |
| 23 | Iron (Fe) | 19-50 mg per 100 g | (Butt *et al*., 2008) |
| 24 | Zinc (Zn) | 0.72-3.65 mg per 100 g | (Butt *et al.,* 2008) |
| 25 | Calcium (Ca) | 786.66-2,726.66 mg per 100 g | (Butt *et al*., 2008) |
| 26 | Phosphorus (P) | 970 mg per 100 g | (Butt *et al.,* 2008) |
| 27 | Magnesium (Mg) | 720 mg per 100 g | (Butt *et al*., 2008) |

**Major nutritional requirement of silkworm**

Nutrition is an essential component of life, without which no living organism can survive. It is crucial for maintaining a healthy, disease-free life and the same holds true for silkworms. The nutritional requirements of silkworms are the chemical components of ingested food that are essential for normal metabolism and development. In general, these requirements can vary based on developmental stages, sex and physiological stress. Key nutrients such as carbohydrates, proteins, lipids, vitamins, amino acids and water are vital for silkworms. Fortunately, these essential nutrients are naturally present in mulberry leaves, which serve as their primary food source (Borah & Praban, 2020).

The term "probiotics" is derived from the Latin word *pro*, meaning "for" and the Greek word *bios*, meaning "life," collectively signifying "for life." It has been scientifically defined in various ways to denote live microorganisms that, when administered in adequate Probiotics are the live microbial food supplements beneficially affecting host by improving the microbial balance and enhanced rapid cellular growth and development. The characters of silkworms and cocoons were found to be enhanced with the mulberry leaf supplemented with spirulina (Venkataramana, 2003). According to Singh *et al*. (2005), probiotic *Lactobacillus* supplementation improved the cocoon production of mulberry silkworm *Bombyx mori*. Mala & Vijila (2018) stated the silkworms supplemented with *Bacillus licheniformis* recorded maximum larval weight, cocoon weight, shell weight, pupal weight, effective rate rearing, shell ratio, filament length and silk productivity, followed by *Bacillus licheniformis* + *Bacillus niabensis* (106 cfu/ml). The same researchers reported that the body's innate defence mechanisms were stimulated by probiotics, increasing the production of the antimicrobial peptide defences in the intestines. The growth and economic parameters of silkworm has been elevated with the supplementation of probiotic bifilac at three different concentrations (1%, 2% and 3%), among which 2% recorded maximum effective rate rearing (96.85%), larval weight (5.39 g), cocoon weight (1.81 g), shell weight (0.408 g), silk weight (0.378 g), shell length (0.408 g) and finer denier (3.88) besides larval mortality being reduced (3.64%) when compared with control (Anisha *et al.,* 2022). “The silkworm larvae were fed on mulberry leaves treated with four different kinds of probiotics feed supplements *viz*., spirulina, azolla, yeast and soya milk at five different concentrations (1, 2, 3, 4 and 5%) each was supplemented to silkworm hybrid, PM x CSR-2 from fourth instar onwards through mulberry leaves. Among the probiotics evaluated, Azolla demonstrated superior performance across all larval parameters, including larval weight one day prior to spinning, fifth instar duration, total larval period, effective rate of rearing, and fresh weight of silk glands on the day of 50% spinning” (Shruti *et al*., 2019). Kalokhe *et al.* (2021) evaluated the effects of different probiotic treatments such as, Baker’s yeast (*Saccharomyces cerevisiae*) at 1% and 1.5%, Spirulina at 1%, 1.5% and 2% and their combinations at 1% and 1.5% on the economic traits of *Bombyx mori* reared on the V‑1 mulberry variety at the Sericulture Research Unit, VNMKV, Parbhani. Results showed that the spirulina + yeast (1.5%) combination produced the heaviest cocoons (1.84 g), closely followed by yeast 1.5% (1.76 g) and Spirulina + yeast 1% (1.74 g). For shell weight, yeast 1% topped at 0.440 g, with yeast 1.5% a close second (0.413 g), both outperforming the control (0.313 g). Shell percentage was highest with yeast 1% (27.09%), while Spirulina 1.5% and yeast 1.5% also performed well (around 23–24%). The longest filament (1,216.7 m) was observed in the yeast 1% treatment, followed by yeast 1.5% and Spirulina + yeast 1.5%. Filament weight peaked with yeast 1.5% (0.363 g) and yeast 1% (0.357 g), while the finest silk (lowest denier 2.44) was achieved using Spirulina 2%. Overall, Baker’s yeast, particularly at 1–1.5%, notably improved cocoon and silk shell quality and Spirulina, especially in combination with yeast, offered a balanced improvement in both yield and silk fineness.

**Role of nutrition supplementation in silkworm disease management**

“In nature, a number of plants have been found to harbour antiviral substances. administration of seed extract of *Plectranthes corylifolia* and leaf extract of *P. ambonicus* to third instar silkworms resulted into reduction in mortality due to grasserie disease (Manimegalai & Chandramohan, 2006). Antifungal activity of certain botanicals in which the highest growth inhibition and lowest sporulation of *Beauveri bassiana* were observed with *Phyllantus niruri”* (Savitha & Bhaskar, 2005). According to Shuba & Bhaskar (2006), the leaf extract of *Adhathoda vasica, P. niruri, P. corylifolia, Tribulus terrestris and Withania somniferum* when supplemented through mulberry leaf to BmNPV infected larvae, were able to inhibit multiplication of BmNPV.

**Nutritional Indices for measuring food intake and utilization**

“Nutrition may be studied both qualitatively and quantitatively. Qualitative nutrition deals exclusively with nutrients needed from the chemical aspect. It was some time before significant attention was paid to quantitative nutrition due to the technical difficulties in measuring food utilization. However, today it is known that food intake and utilization is a basic condition for growth, development and reproduction. Food quantity and quality consumed in the larval stage affects growth rate, development time, body weight and survival, as well as influencing fecundity, longevity, movement and the capacity of adults to compete” (Parra *et al.,* 2012).

“The performance of silkworm is evident by the digestion and assimilation of the nutritional materials present in mulberry leaves. The life cycle routine of the silkworm from identical genetic stock varies significantly based on nutritional quality of mulberry leaves. As such, the amount of food consumed and the quantity digested by the silkworms have a direct effect on its physiological performance and silk production. Pioneering research has proved that deficiency of certain nutrients or imbalance of nutrient on the diet affects the digestibility and metabolic activity of larvae. The amount of food consumed and the quantity digested by the silkworms will have direct effects on its performance, mating success and reproduction. Deficiency of certain nutrients or a nutritionally imbalanced diet affects the digestibility and metabolic activity of larvae” (Waldbauer, 1968).

Food consumption indices are as follows, (Manu *et al.,* 2020)

1. Ingesta (I) = Dry weight of leaf fed (g) - Dry weight of left over leaf (g)
2. Digesta (D) = Dry weight of leaf ingested (g) - dry weight of litter (g)
3. Consumption index (C.I.) = F/TA

[F = Fresh weight of food eaten (g), T = Duration of feeding (days), A = Mean fresh weight of larvae during feeding period (g)]

1. Growth rate (G.R.) = G/TA

[G = Fresh weight gain of larvae during feeding period (g), T = Duration of feeding (days), A = Mean fresh weight of larvae during feeding period (g)]

1. Conversion of ingested food (ECI) = Weighed gained/ Wt. of food ingested X 100
2. Conversion of digested food (ECD) = Weight gained /Wt. of food digested x 100
3. Approximate digestibility (A.D) = $\frac{I-F}{I}×100$ [F= weight of faeces(g)]
4. Coefficient of metabolism (COM) = $\frac{D-G}{D}$

**Carbohydrates**

Carbohydrates serve as a primary energy source for the majority of insects. For silkworms, they are a crucial source of fuel. These compounds can be transformed into lipids and can also aid in the synthesis of amino acids. Various carbohydrates, particularly sugars, act as potent feeding stimulants. A functional carbohydrate may sometimes seem ineffective if it is not consumed properly (Dadd, 1985; Genc *et al*., 2002; Nation, 2022).

“Carbohydrates are highly significant for silkworms but not indispensable, as they can be synthesized from lipids or amino acids” (Nation, 2022). “The utilization of different carbohydrates varies based on the silkworm’s ability to break down polysaccharides. The nutritional effects of carbohydrates were analyzed either by studying their impact on weight gain and survival or by evaluating the rate of conversion into blood trehalose or fat body glycogen, both of which are the primary carbohydrates found in the body, when each compound was administered orally to the larvae without additional nutrients. Since certain sugars exhibit strong feeding-stimulant effects on silkworm larvae, there was a concern about obtaining misleading results when synthetic diets with various sugars were compared. Similar to other insect species, silkworm larvae did not display specific carbohydrate requirements, although some compounds were metabolized more efficiently than others. In general, pentoses were poorly metabolized. Among the hexoses tested, glucose, fructose and mannose were well-utilized. Disaccharides, including sucrose, cellulose and maltose, demonstrated uniformly high efficiency. Trisaccharides, *viz.*, melezitose and raffinose, exhibited significant value. Among sugar alcohols, only sorbitol was metabolized effectively. The breakdown of polysaccharides depended entirely on the silkworm strains, particularly on the presence or absence of amylase in the digestive fluids. Additionally, the nutritional value of various oligosaccharides was shown to correlate with the presence or absence of specific glycosidase enzymes” (Ito & Tanaka, 1959).

**Proteins**

Most insects likely require an optimal amount of proteins in their diet to achieve maximum growth, but this varies significantly among different species. Proteins are utilized for structural functions, as catalysts (enzymes), as receptors and for transport and storage purposes (Vanderzant, 1974). Insects digest dietary proteins to obtain amino acids, essential for cellular structure and metabolic regulation. In silkworms, proteins interact with enzymes and hormones to support physiological functions. Female silkworms require proteins for ovary and egg development via juvenile hormone (JH) synthesis, while males typically do not need proteins for sperm maturation. Nutritional requirements vary with age, sex and physiological conditions (Nation, 2022).

**Amino acids**

Silkworm larvae utilize amino acids from mulberry leaves for growth, development and cocoon production. Essential amino acids required for their survival include arginine, histidine, leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, aspartic acid and glutamic acid (Vasuki & Basavanna, 1969). These amino acids cannot be synthesized or are produced in insufficient amounts and must be obtained from the diet. These amino acids, also required by other insects, are vital for silkworm survival and development. Without them, growth ceases (Shamsuddin, 2009). Proline, considered semi-essential, supports partial growth in its absence. Non-essential amino acids alanine, cystine, glycine, serine and tyrosine are also crucial for promoting optimal growth. Their nutritive role is evident even when acidic amino acids are already included in the diet. Fibroin, the protein in silk fibers, is derived from alanine, serine, glycine and tyrosine sourced from the silkworm’s food. Among these, alanine plays a key role in glucose, tryptophan and organic acid metabolism. Amino acids are fundamental to silkworm nutrition and development (Vasuki & Basavanna, 1969).

**Lipids**

Lipids include fatty acids, alcohols, steroids, their esters, phospholipids and related compounds. Silkworms can convert carbohydrates into lipids, synthesize them and store them in body tissues (Nation, 2022). Fatty acids, phospholipids and sterols are essential components of cell membranes and perform various physiological roles. Polyunsaturated fatty acids, such as linoleic and linolenic acids, are crucial for silkworm growth and development (Genc *et al.,* 2002). Deficiency in these fatty acids leads to wing deformities and scales adhering to the pupal case during moth emergence. Trace amounts of lipids or sterols in the diet enhance growth and development (Felton & Summers, 1993). Silkworms require dietary sterols, as they cannot synthesize sufficient quantities to meet their physiological demands. Sterols are essential for cellular membranes and serve as precursors for molting hormone synthesis. A sterol-deficient diet prevents molting, leading to death in early instars (Nation, 2022; Genc *et al.,* 2002).

**Water**

Phytophagous insects consume diets rich in water, with variations across species. In silkworms, water constitutes over 75 per cent of their body, essential for all physiological processes, particularly digestion. Water, as a universal solvent, enables nutrient absorption, facilitates biochemical reactions, transports nutrients and waste and regulates body temperature, maintaining stability (Shamsuddin, 2009).

**Fibre**

Fibre is not classified as a nutrient. It mainly consists of cellulose and lignin, which are types of polymeric carbohydrates. Its consumption is crucial as it plays a regulatory role and helps sustain normal peristaltic activity in the intestines, facilitating the elimination of waste products (Etebari & Matindoost, 2004).

**Vitamins**

Vitamins are organic bioactive compounds that primarily function as coenzymes or cofactors in enzymatic and catalytic reactions. They are vital for regulating cellular physiological functions and metabolism. Silkworms predominantly require vitamin B complex and ascorbic acid for their growth and development. Essential vitamins within the B complex for silkworms include choline, inositol, nicotinic acid, pantothenic acid, pyridoxine, riboflavin, thiamine, biotin and folic acid (Vasuki & Basavanna, 1969).

**Minerals**

Minerals can act as a limiting factor for insect growth, particularly concerning dietary composition. The addition of salts significantly enhances developmental stages, improves cocoon quality, accelerates cocoon production and boosts the reproductive potential of silkworms. Supplementation with nickel chloride, potassium iodide and copper sulfate has been shown to enhance the economic traits of silkworms. Nickel chloride notably promotes the growth of larvae, pupae and adults, leading to increased cocoon production, though excessive salt concentrations have adverse effects (Ito & Nirminura, 1966). Feeding silkworm larvae with mulberry leaves fortified with nickel and zinc has been reported to increase cocoon weight (Wright, 1984).

**Impact of protein supplements on silkworm rearing parameters and cocoon productivity**

Sharma *et al*. (2023) investigated “the silkworm bivoltine double hybrid FC1 × FC2 [(CSR6 × CSR26) × (CSR2 × CSR27)] which was reared on mulberry leaves fortified with proteins namely drone brood, protinex and their combinations to study its effects on larval growth parameters and on economic growth parameter called Gland-Body Ratio. Protinex (10%) concentration caused the significant influence on larval body length, larval body weight and larval body perimeter of silkworm in terms of Overall Growth Rate by 46.56, 295 and 48.54 per cent with compound periodical growth rate of 6.32, 24.58 and 6.52 per cent, respectively. Moreover, in protinex (10%) and drone brood (6%) concentrations the impact on Gland-Body Ratio was found more pronounced when compared to other concentrations”.

**Impact of amino acid supplements on silkworm rearing parameters and cocoon productivity**

Mulberry leaves enriched with different amino acids like essential amino acids (Arai and Ito, 1964; Ito, 1967; Inokuchi *et al.,* 1967), glycine (Sharadha and Bhat, 1956; Ravi *et al*., 1994; Saad *et al*., 2019), tyrosine, phenylalanine and alanine (Nagarajan & Radha, 1990), glycine, serine and alanine (Mustafa & Elkaraksy, 1990), aspartic acid (Kabila *et al*., 1994), glycine, phenylalanine, serine and aspartic acid (Vadivel, 1995), alanine and asparginine (Radjabi *et al*., 2010), arginine and histidine (Chakrabarthy & Kaliwal, 2012) and serine (Gokul, 2015) showed an elevation of silkworm growth, cocoon characters, reeling and silk productivity (Kamada & Ito, 1984). Ramesh *et al.* (2018) found that feeding *Bombyx mori* V instar larvae with MR2 mulberry leaves treated with 0.25% L-serine significantly improved pupal, cocoon and economic traits compared to control and other supplement-treated groups. Key improvements included increased larval body weight, cocoon length, width, weight, cocooning percentage, cocoon shell weight, shell ratio, silk filament length and denier. The results indicate that L-serine acts as a silk-yield stimulant, enhancing silk production, making it beneficial for the sericulture industry. Murgesh *et al*. (2021) reported that supplementation of glycine (10 ppm), alanine (100 ppm) and serine (100 ppm) through mulberry leaves during the fifth instar significantly improved the larval, cocoon and silk reeling traits of *Bombyx mori*. This treatment recorded the highest fifth instar larval weight (4.48 g), ERR (96.50%), silk productivity (6.38 cg/day), silk gland weight (1.12 g), silk gland length (31.05 m), cocoon weight (2.63 g), shell weight (0.60 g), pupal weight (2.03 g), shell ratio (22.81%), filament length (1220 m) and filament weight (0.440 g). Protein levels in the silk gland (64.70 mg/g) and haemolymph (48.50 mg/ml), as well as fibroin (420 mg/shell) and sericin (107.05 mg/shell) content, were also highest in this treatment. The study concluded that amino acid-fortified mulberry leaves significantly enhance the growth and silk traits of silkworms. Muzamill *et al.* (2023) reported that the average weight of the 5th instar silkworm and the ratio of silk gland to body weight were significantly (P˂0.05) higher in the experimental silkworms fed with mulberry leaves fortified with amino acids and significant elevation of commercial traits of silkworms. Further, silkworms fed with 1% alanine-supplemented mulberry leaves showed a positive effect on the commercial and biological traits of *Bombyx mori.*

**Impact of vitamin supplements on silkworm rearing parameters and cocoon productivity**

Horie & Ito (1963) studied the vitamin requirements of silkworms and observed the resumption of growth. Etebari & Matindoost (2005) studied the impact of multivitamins as food supplements on the biological and economic features of silkworm *Bombyx mori* and noticed a 4.7 per cent elevation in cocoon weight and number of eggs, but the study also indicated a relatively low hatching percentage. Balasundaram *et al.* (2013) investigated the supplementation of Vitamin C on silkworms and observed feed efficacy and enhancement of growth and suggested that this elevation may be due to the presence of growth stimulants in vitamin C. Ahsan *et al.* (2015) studied the impact of vitamins B and C on growth and development of silkworms during the 3rd to 5th instar and noticed a significant increment of different growth indices. Brahma *et al.* (2018) investigated the effect of vitamin C and E on silkworm *Bombyx mori* and found that the vitamin C supplementation resulted in a higher concentration of silk gland protein than vitamin-E supplementation. Gad (2022) reported that the supplementation of folic acid (Vitamin B9) elevated the cocoon weight (1.98 g), shell weight (0.498 g) and silk percentage (25.15%) with reference to control (1.55 g, 0.369 g and 23.81%). Soliman (2024) demonstrated that a mixture of vitamins improved the performance of the silkworm, *B. mori* (Chinese hybrid-9f7x). Vitamin concentrations of 2, 4, 6 and 8 mg/ml were tested. Results showed that the concentration of 8 mg/ml was the most effective treatment. The weights of fifth instar larvae increased to 2.125 g compared to 2.000 g in the control. Pupal weights were 0.800 g compared to the control (0.711 g). Mortality percentages of fifth instar larvae decreased to 6.25 per cent compared to the control (7.50%). The duration of the fifth instar larvae was reduced to 9.15 days compared to the control (9.65 days). Cocooning percentages increased to 93.69 per cent compared to the control (90.05%). Silk productivity improved to 2.38 cg/day compared to 1.89 cg/day in the control. Cocoon weights increased to 1.186 g compared to the control (1.031 g), while cocoon shell weights rose to 0.218 g compared to the control (0.183 g). The cocoon shell ratio also improved to 18.38 per cent compared to the control (17.74%).

**Impact of mineral supplements on silkworm rearing parameters and cocoon productivity**

Etebari *et al.* (2003) conducted experiment using five treatments *viz.*, 1%, 5% and 10% concentrations of multi-mineral mixtures (nitrogen, phosphorus and potassium), along with normal and distilled water as controls. Mulberry leaves (Shien Ichenoise variety) were supplemented from the fourth instar by spraying mineral solutions once daily. Results showed that mineral treatments significantly increased larval weight, total haemolymph protein, cocoon, shell and pupal weights especially in females. However, silk gland weight and uric acid levels showed no significant changes. The 10% treatment notably increased egg production but reduced hatching percentage. Oral supplementation of potassium permanganate at concentrations of 30, 50 and 100 µg to fifth instar larvae of the CSR2 × CSR4 race of *Bombyx mori* led to a significant increase in glycogen content in the fat body and trehalose levels in the haemolymph. Protein content in the fat body was significantly elevated across all treated groups, while haemolymph protein showed a significant increase only at the 30 µg dose. Additionally, total lipid content in the fat body was significantly enhanced in all treatment groups. These findings suggest that potassium permanganate supplementation stimulates metabolic activity, thereby altering the biochemical composition of the fat body and haemolymph in *B. mori* (Bhattacharya & Kaliwal, 2004). Devi & Yellamma (2013) conducted a study to assess the effects of selected trace elements and supplements such as, zinc, pyridoxine (vitamin B6) and the hormone, methoprene on the economic parameters of silkworm cocoons. In the experiment, silkworm larvae were divided into five groups *viz.*, four experimental groups were fed with mulberry leaves fortified individually with zinc chloride, pyridoxine, methoprene and a combined dose (Zn + B6 + Methoprene), while one control group was fed with untreated leaves. The findings revealed that all three supplements, especially when administered as a mixed dose, significantly improved cocoon quality and quantity. This demonstrated the modulatory role of these compounds in enhancing silk production. Murgesh *et al*. (2021) demonstrated “a study aimed at increasing cocoon yield by fortifying mulberry leaves with minerals such as zinc sulphate, magnesium sulphate and potassium chloride at different concentrations (10, 25, 50, 100 and 200 ppm) and feeding them to *Bombyx mori* larvae. The oral application of minerals through mulberry leaves to silkworm larvae during late-age instars significantly improved larval and cocoon economic parameters. Among the five concentrations tested, zinc sulphate at 100 ppm, magnesium sulphate at 200 ppm and potassium chloride at 100 ppm recorded significantly higher mature larval weight, effective rate of rearing (ERR), cocoon weight, pupal weight, shell weight and shell ratio compared to the control. Per os administration of minerals also significantly reduced the fifth instar larval duration”. Stephanraj (2024) investigated “the effects of nickel sulfate supplementation on the growth and cocoon quality of silkworm (*Bombyx mori* L.). The experiment was conducted at a silkworm-rearing center in Palayamkottai, India, from December 2022 to January 2023. Silkworms were fed Victory-1 (V1) mulberry leaves soaked in different nickel sulfate solutions (100 ppm, 300 ppm and 500 ppm). Larval weight, duration, cocoon weight, shell weight, shell ratio and pupal weight were measured for 10 healthy silkworms with good quality cocoons selected from each treatment group. Compared to the control group, supplementation with 500-ppm nickel sulfate solution significantly improved silkworm growth performance (weight) and economic traits (cocoon weight and quality)”.

**Impact of feed fortification supplements on the nutritional indices traits of silkworm**

Many attempts have been made in recent years to supplement mulberry leaf with plant extracts to improve the quality of the leaf and the feeding efficiency of silkworms, which further helps in the production of the cocoons and the quality of the silk. Gouda (1991) studied the effect of plant extracts taken from weeds on silkworm, *Bombyx mori* and observed the elevation of fecundity in *silkworm.* Benchamin & Jolly (1984) and Murugan *et al.* (1999) stated that the production of silk from silkworms has been influenced by the supplementation of plant extracts. Barthakur & Arnold (1991) noticed the effect of supplementation of ascorbic acid, minerals, vitamins, sugars and amino acids on silk productivity. Murugan *et al.* (1999) stated that the growth and development of silkworm *Bombyx mori* has been increased by the supplementation of aqueous plant extracts of *Lantana camera, Tridax procumbens*, *Clerodendrum* sp. and *Croton sparsiflours.* Leaf extract supplemented through the mulberry leaf once during the 3rd and 4th instars and twice during the 5th instar showed higher larval weight, a decrease in larval mortality and an increase in cocoon weight, shell weight and shell ratio. Sujatha & Rao (2003) reported that the rearing period of *B. mori* has been reduced when silkworms were fed with the mulberry leaf supplemented with *Eucalyptus globulus* leaf extract (0.1%, 1%, 2% and 5%). Mala and Vijila (2021) demonstrated that fortifying mulberry leaves enhances silkworm dietary efficiency, improving health, cocoon quality and silk yield. Silkworms fed with *Aloe vera* (100%) recorded the highest nutritional indices, including improved digestibility (36.92%), relative growth rate (0.049) and efficiencies in ingesta-to-larva (23.35%), cocoon (19.97%) and shell (9.67%) conversion, with minimal excreta and feed requirements. *Tinospora cordifolia* (2%) also showed significant benefits compared to the control. The plant extracts positively influenced silkworm metabolism, enhancing both the quality and quantity of nutritional traits. Hajam (2024) evaluated the effects of fortifying mulberry leaves with 1%, 2% and 3% concentrations of *Aloe vera*, *Ocimum sanctum* and *Withania somnifera* on silkworm *Bombyx mori.* Among the treatments, 3% *Ocimum sanctum* (T6) showed the best results, significantly enhancing dietary efficiency, haemolymph biochemical constituents and economic traits like cocoon yield, shell percentage and raw silk output. 3% *Withania somnifera* (T9) and 3% *Aloe vera* (T3) also improved growth and silk quality. Control groups performed the lowest across all parameters, confirming the benefits of plant extract fortification.

**CONCLUSION**

Nutrition plays a pivotal role in the growth, development and productivity of the silkworm *Bombyx mori.* As a monophagous insect, its dependence on mulberry leaves makes the quality and composition of its diet critically important. The presence of essential nutrients such as carbohydrates, proteins, lipids, amino acids, vitamins and minerals in mulberry foliage directly affects larval performance, cocoon quality and silk yield. However, environmental factors and suboptimal cultivation practices can lead to nutrient deficiencies, adversely impacting silkworm health and increasing vulnerability to diseases. The strategic fortification of mulberry leaves with probiotics, plant extracts, proteins, amino acids, vitamins and minerals has emerged as an effective approach to enhance silkworm performance, improve silk gland development and boost cocoon productivity. Additionally, these supplements contribute to better disease resistance and higher rearing success. The use of nutritional indices further enables the quantitative assessment of food utilization efficiency. Therefore, adopting nutritionally enriched feeding practices in sericulture not only improves biological and economic traits of silkworms but also contributes to sustainable and profitable silk production systems.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declares that NO generative AI technologies such as large language models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

**REFERENCES**

Ahsan, M. K., Khan, A. R., & Ferdous, T. (2015). Growth and development of the mulberry silkworm, *Bombyx mori* L. on vitamin B and C supplemented diet. *Bangladesh Journal of Zoology*, 41(2), 199-206.

Anisha, S. P., Yasmin, N., and Devi, E. S.V. (2022). Supplementation of mulberry leaves with probiotic bifilac on economic traits of silkworm (*Bombyx mori*). *International Journal of Food Science and Nutrition*, 11(12), 86-90.

Arai, N., & Ito, T. (1964). Amino acid requirements of silkworm, *Bombyx mori* L. *Journal of Sericultural Science of Japan*, 33, 107–110.

Balasundaram, D., Prabu, P. G., Selvisabhanayakam, V., Mathivanan, & Ramesh, V. (2013). Studies on the nutritional supplementation of vitamin C treated MR 2 mulberry leaves fed by V instar larvae of silkworm, *Bombyx mori* (L.) in relation to feed efficacy and growth rate. *International Journal of Research in Biotechnology and Biochemistry*, 3(1), 11-18.

Barthakur, N. N., & Arnold, N. P. (1991). Chemical analysis of emblic (*Phyllanthus emblica* L.) and its potential as a food source. *Scientia Horticulturae*, 47(1-2), 99-105.

Benchamin, K. V., & Jolly, M. S. (1984). Studies on ingestion, digestion and conversion efficiency in polyvoltine and bivoltine silkworm breeds (*Bombyx mori* L.). In *Proceeding of the 3rd Oriental Entomology Symposium* (pp. 195-206).

Bhattacharya, A., & Kaliwal, B. B. (2004). Influence of the mineral potassium permanganate on the biochemical constituents in the fat body and haemolymph of the silkworm, *Bombyx mori* L. *International Journal of Industrial Entomology and Biomaterials*, 9(1), 131-135.

Borah, S. D., & Praban, B. (2020). A review of nutrition and its impact on silkworm. *Journal of Entomology and Zoology Studies*, 8(3), 1921-1925.

Brahma, U. R., Pattnaik, S., & Barik, B. P. (2018). Impact of vitamin C and E supplementation on 5th instar larvae of CSR2 x CSR4 silkworm *Bombyx mori* L. *Research Journal of Life Science, Bioinformatics, Pharmaceutical and Chemical Sciences*, 4(6), 408-414.

Butt, M. S., Nazir, A., Sultan, M. T., & Schroën, K. (2008). *Morus alba* L. nature's functional tonic. *Trends in Food Science and Technology*, 19(10), 505–512.

Chakrabarthy, S., & Kaliwal, B. B. (2012). Application of arginine, histidine and their mixture on economic traits of the silkworm, *Bombyx mori* L. *DAV International Journal of Science*, 1(2), 107-111.

Dadd, R. H. (1985). Nutrition: Organisms. In Kerkut, G. A., & Gilbert, L. I. (Eds.), *Comprehensive Insect Physiology, Biochemistry and Pharmacology* (Vol. 4, pp. 313-390). Pergamon, Oxford: National Academy Press.

Dimitrova, M. P., Petkova, N. T., Denev, P. P., & Aleksieva, I. N. (2015). Carbohydrate composition and antioxidant activity of certain *Morus* species. *International Journal of Pharmacognosy and Phytochemical Research*, 7(3), 621-627.

Etebari, K., & Fazilati, M. (2003). Effects of feeding on mulberry’s supplementary leaves with multi-mineral on some biological and biochemical characteristics of silkworm (*Bombyx mori*). *Isfahan University of Technology-Journal of Crop Production and Processing*, 7(1), 233-244.

Etebari, K., & Matindoost, L. (2004). Effects of hypervitaminosis of vitamin B3 on silkworm biology. *Journal of Biosciences*, 29, 417-422.

Etebari, K., & Matindoost, L. (2005). Application of multi-vitamins as supplementary nutrients on biological and economical characteristics of silkworm *Bombyx mori* L. *Journal of Asia-Pacific Entomology*, 8(1), 107-112.

Felton, G. W., & Summers, C. B. (1993). Potential role of ascorbic oxidase as a plant defense protein against insect herbivory. *Journal of Chemical Ecology*, 19, 1553-1568.

Gad, R. S. (2022). Impact of folic acid as dietary supplementation on biological and economic characteristics of mulberry silkworm *Bombyx mori* (Lepidoptera: Bombycidae). *Egypt Journal of Plant Protection Research Institute*, 5(4), 420-425.

Genc, H., Phaon, C., & Phyciodes, P. (2002). Life cycle, nutritional ecology and reproduction (Doctoral dissertation). University of Florida, Gainesville, FL, USA.

Gokul, M. (2015). Effect of exogenous supplementation of amino acids and minerals on economic traits of silkworm, *Bombyx mori* L. (M.Sc. thesis). Tamil Nadu Agricultural University, Coimbatore.

Gouda, R. R. (1991). Studies on methods to increase silk yield of *Bombyx mori* L. (Ph.D. thesis). Tamil Nadu Agricultural University, Coimbatore.

Hajam, O. A. (2024). Studies on the dietary fortification of silkworm (*Bombyx mori* L.) using plant extracts (Doctoral dissertation). SKUAST Kashmir.

Horie, Y., & Ito, T. (1965). Nutrition of the silkworm, *Bombyx mori*—X. Vitamin B requirements and the effects of several analogues. *Journal of Insect Physiology*, 11(12), 1585-1593.

Inokuchi, T., Horie, Y., & Ito, T. (1967). Nutrition of the silkworm, *Bombyx mori* – XIX. Effects of omission of essential amino acids in each of the second to the fifth instars. *Bulletin of Sericulture Experimental Station,* 22, 195.

Ito, T. (1967). Nutritional requirements of the silkworm *Bombyx mori* L. *Proceedings of the Japan Academy*, 43, 57-61.

Ito, T., & Nirminura, M. (1966). Nutrition of silkworm *Bombyx mori*. *Bulletin of Sericultural Experimental Station*, 20, 373.

Ito, T., & Tanaka, M. (1959). Beta-glucosidase of the midgut of the silkworm *Bombyx mori*. *The Biological Bulletin*, 116(1), 95-105.

Ji, T., Li, J., Su, S. L., Zhu, Z. H., Guo, S., & Qian, D. W. (2016). Identification and determination of the polyhydroxylated alkaloids compounds with α-glucosidase inhibitor activity in mulberry leaves of different origins. *Molecules*, 21(2), 206.

Kabila, V., Subburathinam, K. M., & Sulochanachetty, J. (1994). Growth and economic characters of silkworm, *Bombyx mori* L. on feed enriched with neutralized aspartic acid. *Indian Journal of Sericulture*, 33(1), 80-81.

Kalokhe, G. D., Latpate, C. B., & Matre, Y. B. (2021). Effect of probiotics on economic traits of mulberry silkworm. *International Journal of Advanced Biochemistry Research*, 8(10S), 1301-1307.

Kalokhe, G. D., Latpate, C. B., & Matre, Y. B. (2024). Effect of probiotics on economic traits of mulberry silkworm. *International Journal of Advanced Biochemistry Research*, 8(10), 1301-1307.

Kamada, M., & Ito, S. (1984). Growth promoting effect of plant hormones on silkworms. *Journal of Agricultural and Chemical Society of Japan*, 58, 779-784.

Mala, N., & Vijila, K. (2018). Beneficial effects of *Bacillus licheniformis* and *Bacillus niabensis* on growth and economic characteristics of silkworm, *Bombyx mori* L. *International Journal of Chemical Studies*, 6(2), 1750-1754.

Manimegalai, S., & Chandramohan, N. (2006). Efficiency of botanicals against grasserie disease of silkworm, *Bombyx mori* L. *Serecologia*, 46, 15-25.

Manu, H. N., Prashanth, J., Chaitra, S., & Jagadeeshkumar, T. S. (2020). Evaluation of various parameters of consumption indices of the silkworm hybrids administered with cholesterol content during 5th instar silkworm. *Journal of Entomology and Zoology Studies*, 8(4), 922-928.

Murugan, K., Jayabalan, D., Senthil Kumar, N., Babu, R., Siva Ramakrishnan, S., & Senthil Nathan, S. (1998). Anti-feeding and growth inhibitory potency of neem limonoids against *Helicoverpa armigera* Hubner. *Insect Science and its Applications*, 18(3).

Murugan, K., Jeyabalan, D., & Senthil Kumar, N. (1999). Growth promoting effect of plant compounds on silkworm. In *Proceedings of National Seminar on Tropical Sericulture* (pp. 107-108).

Murugesh, K. A., Aruna, R., & Chozhan, K. (2021). Influence of amino acids on the economic characters of silkworm, *Bombyx mori* L. *Madras Agricultural Journal*, 376-382.

Murugesh, K. A., Chozhan, K., & Aruna, R. (2021). Enhancement of larval and cocoon traits of silkworm, *Bombyx mori* L. through the application of amino acids. *Journal of Entomology and Zoology Studies*, 9(1), 2198-2203.

Mustafa, S. M., & Elkaraksy, I. A. (1990). The effect of certain amino acids on silkworm, *Bombyx mori* L. *Agricultural Research Review*, 66(1), 105-109.

Muzamil, A., Tahir, H. M., Ali, A., Bhatti, M. F., Munir, F., Ijaz, F., Adnan, M., Khan, H. A., & Qayyum, K. A. (2023). Effect of amino acid fortified mulberry leaves on economic and biological traits of *Bombyx mori* L. *Heliyon*, 9(10), e21053.

Nagarajan, P., & Radha, N. V. (1990). Supplementation of amino acids through mulberry leaf for increased silk production. *Indian Silk*, 29(4), 21–22.

Nation, S. J. L. (2022). Insect physiology and biochemistry (pp. 623). CRC Press.

Parra, J. R., Panizzi, A. R., & Haddad, M. L., (2012). Nutritional indices for measuring insect food intake and utilization. *Insect bioecology and nutrition for integrated pest management*, 13, 38. CRC Press.

Radjabi, R., Ebadi, R., Mirhoseini, S. Z., & Nair, S. (2010). Effect of leaves enrichment with amino acid supplementary nutrients on *Bombyx mori* L. *Academic Journal of Entomology*, 3(1), 45-51.

Ramesh, V., Pushparaj, K., Ganesh Prabu, P., & Rajasekar, P. (2018). Nutritional supplementation of amino acid L-serine on silkworm *Bombyx mori* (L.) larvae in relation to growth rate and silk production. *Research Journal of Life Science, Bioinformatics, Pharmaceuticals and Clinical Sciences*, 4(5), 301-312.

Ravi, K. N., Shankar, K. A., Puttaraju, T. B., & Puttasamy, B. (1994). Effect of feeds supplementation on silkworm growth, cocoon weight and silk quality. In *Second National Symposium on Prospects and Problems of Sericulture in India* (p. 63). Department of Zoology, Madras University, Vellore.

Saad, M. S. I., Helaly, W. M. M., & Sheikh, E. A. E. (2019). Biological and physiological effects of pyriproxyfen insecticide and amino acid glycine on silkworm, *Bombyx mori* L. *Bulletin of the National Research Centre*, 43, 145-151.

Sanchez-Salcedo, E. M., Mena, P., Garcia-Viguera, C., Hernandez, F., & Martinez, J. J. (2015). (Poly)phenolic compounds and antioxidant activity of white (*Morus alba* L.) and black (*Morus nigra* L.) mulberry leaves: Their potential for new products rich in phytochemicals. *Journal of Functional Foods*, 18, 1039-1046.

Savitha, L. B. G., & Bhaskar, R. N. (2005). Efficiency of medicinal botanical extracts on growth and development of *Beauveria bassiana* infecting mulberry silkworm, *Bombyx mori* L. *Environment and Ecology*, 23, 851-855.

Shamsuddin, M. (2009). *Silkworm physiology: A concise textbook* (pp. 1–212). Daya Publishing House, Delhi.

Sharada, K., & Bhat, J. V. (1956). Effect of chloromycetin and glycine on the growth and reproduction of silkworm, *Bombyx mori* L. *Journal of Indian Institute of Science*, 38, 196-197.

Shruti, A. J., Hadimani, D. K., Sreenivas, A. G., & Beladhadi, R. V. (2019). Effect of probiotic feed supplements to mulberry silkworm, *Bombyx mori* L. for larval growth and development parameters. *International Journal of Chemical Studies*, 7(3), 3914-3919.

Shuba, K., & Bhaskar, R. N. (2006). Effect of botanicals treatment duration on cocoon parameters of PM x CSR2. *Environment and Ecology*, 24, 667-669.

Singh, K. K., Chauhan, R. M., Pande, A. B., Gokhale, S. B., & Hedge, N. G. (2005). Effect of use of *Lactobacillus plantarum* as a probiotic to improve cocoon production of mulberry silkworm, *Bombyx mori* (L). *Journal of Basic and Applied Sciences*, 1, 1-8.

Soliman, N. H. (2024). Improving the silkworm, *Bombyx mori* L. cocoon yield by supplying the larval stage diet with a vitamin mixture. *Egyptian Academic Journal of Biological Sciences. A, Entomology*, 17(1), 61-65.

Stephenraj, D., Vignesh, M., & Sivanesh, H. (2024). Improvement of silkworm (*Bombyx mori* L.) growth and cocoon quality using nickel sulfate supplementation. *Uttar Pradesh Journal of Zoology*, 45(11), 182-189.

Sujatha, K., & Rao, A. P. (2003). Effect of *Curcuma longa* on the commercial characters of multivoltine silkworm. *Journal of Experimental Zoology, India*, 6(1), 109-111.

Vadivel, K. (1995). Effect of supplementation of amino acids on economic characters of silkworm, *Bombyx mori* L. (M.Sc. thesis). Tamil Nadu Agricultural University, Coimbatore, 32-49.

Vanderzant, E. S. (1974). Development, significance and application of artificial diets for insects. *Annual Review of Entomology*, 19, 139-160.

Vasuki, K., & Basavanna, H. M. (1969). Variety difference in the content of total and soluble minerals of mulberry leaves. *Silkworm Information Bulletin*, 1, 31-35.

Venkataramana, P., Rao, T. V. S. S., Reddy, P. S., & Suryanarayana, N. (2003). Effect of spirulina on the larval and cocoon characters of silkworm *Bombyx mori* L. *Proceedings of the National Academy of Sciences, India*, 73(1), 89-94.

Waldbauer, G. P. (1968). The consumption and utilization of food by insects. *Advances in Insect Physiology*, 5, 229-288.

Wright, M. D. (1984). Zinc: effect and interaction with other cations in the cortex of the rat. *Brain Research*, 311, 343-347.

Yu, Y., Li, H., Zhang, B., Wang, J., Shi, X., & Huang, J. (2018). Nutritional and functional components of mulberry leaves from different varieties: Evaluation of their potential as food materials. *International Journal of Food Properties*, 21(1), 1495-1507.

Zhang, Q., Zhang, F., Thakur, K., Wang, J., Wang, H., & Wei, Z. J. (2018). Molecular mechanism of anti-cancerous potential of morin extracted from mulberry in Hela cells. *Food and Chemical Toxicology*, 112, 466-475.

Shubhajit Sarkhel, Dronachari Manvi and Ramachandra CT. Nutrition importance and health benefits of mulberry leaf extract: A review. J Pharmacogn Phytochem 2020;9(5):689-695. DOI: 10.22271/phyto.2020.v9.i5j.12310