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ASCERTAINING ROLE AND IMPORTANCE OF ARTIFICIAL DIET AND BOTANICALS MEDIATED SERIFEED FOR THE STRENGTHENING OF SERICULTURE INDUSTRY

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The nutritional value of mulberry leaves depends on a number of agroclimatic conditions, and any nutrient deficiency in the leaves reduces the silkworm's ability to produce silk. A diet rich in nutrient-dense leaves is necessary for the better growth and development of silkworm larvae as well as the production of high-quality cocoons. The additional sources of nutrients are required to fulfil the nutritional requirements in many insects, that will help to assess the importance of and the impact of various fortification agents in silkworm nutrition. Numerous efforts have been done in recent years to increase the quantity and quality of silk. These efforts have included adding nutrients to the leaves, spraying with antibiotics, juvenile hormone (JH), plant products, and steroids, employing JH-mimic principles, or using plant extracts. To improve silk quality and quantity, mulberry leaves have been treated with a variety of nutrients for silkworm feeding. In sericulture research, fortification and supplementing of mulberry leaves are relatively new methods. The sericulture industry has taken use of how nutrition affects the way silk glands work, which has an impact on how they function economically, to increase silk production. The current review was aimed to explore numerous medicinal botanicals, artificial diet-based silkworm rearing, and various artificial diet preparation elements.

Keywords: Botanicals; fortified feed; artificial diet; sericulture; silkworm productivity; economy.

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1. INTRODUCTION

Sericulture is a well-known cottage enterprise based on agriculture. It entails raising silkworms for the purpose of producing raw silk, which is the yarn made from cocoons spun by specific insect species. Sericulture's main tasks include growing food plants to feed the silkworms that spin silk cocoons and reeling the cocoons to unwind the silk filament for uses like processing and weaving. Mulberry and Non-mulberry are the two major subsectors of sericulture. Producing silk from mulberries is the focus of mulberry sericulture, while producing silk from eri, tasar, and muga is the focus of non-mulberry sericulture.

Silkworm, *Bombyx mori* L. is monophagus. It eats only mulberry only due to the presence of a chemical Morin [1]. The nutritional value of mulberry leaves has a significant impact on the growth and development of larvae as well as the subsequent creation of cocoons. By enhancing the silkworm's commercial traits, nutrition plays a crucial part in sericulture. The mulberry leaf provides practically all of the nutrients needed for the monophagous silkworm to grow. The only plant used as nourishment is the mulberry (*Morus* sp.), which is crucial to the development of the silkworm and ultimately to the output and productivity of silk. The quantity and quality of leaves have an impact on the silkworm's growth and development, as well as the quantity and quality of cocoons and raw silk produced.It is true that mulberry leaf protein, which is of the highest quality for successful cocoon development, accounts for about 70% of the silk protein produced by mulberry silkworms [2]. The most recent methods in sericulture research involve supplementing or fortifying mulberry leaves. Studies are being conducted to determine the effects of nutrient supplement fortification, including the addition of proteins, carbs, amino acids, vitamins, sterols, hormones, antibiotics, and others, to improve performance and increase the productivity, quantity, and quality of cocoons [3]. Feeding silkworms with nutritionally enriched leaves improved their growth and development as well as the economic qualities of the cocoons [4]. Numerous compounds, including vitamins, minerals, amino acids, soya protein, hormones, and plant extracts, have been added to mulberry leaves as supplements to enhance the characteristics of the cocoon, including the silkworm's reproductive capability [5]. Several initiatives to strengthen the leaves with various advantageous elements and combinations of nutrients have been made in recent years [6] to enhance the quality of cocoon crop. *Aloe vera, Moringa oleifera, Ocimum sanctum,* and other medicinal plant extracts have produced a range of responses in silkworms and have been shown to have an impact on their economic characteristics, including body weight, cocoon weight, shell weight, shell ratio, and thread length in *Bombyx mori* [7]. The dietary supplementation of tender coconut water can be used to improve economic performance of silkworm, *Bombyx mori* Linn [8].

2. MEDICINAL BOTANICAL EXTRACT AS A SUPPLEMENTARY SERI FEED

It is well known that the nutrient content of mulberry leaves influences the growth and development of silkworm larvae as well as the economic characteristics of cocoons. Plant extracts were the first major advancement in the study of silkworm nutrition. It is usual practice to fortify mulberry leaves using plant extracts. In tropical nations like India, increasing silk output is accomplished by fortifying mulberry leaves with plant extracts to boost the nutrition of silkworms (Jeyapaul et al. 2003). Mulberry leaf supplemented *Spirulina* as a feed to *B. mori* orally found to be effective in enhancing the larvae and cocoon characters (Sangamithirai et al. 2014). *Zingiber officinale*, *Lantana camera* and *Acorus calamus* fortified mulberry leaves increased the silk quality of silkworm (Manjunatha et al. 2017). Selin et al. (2018) studied the impact of *Spirulina* and ashwagandha on the biochemical and economic characteristic of *B.mori*.

Mulberry leaves have been sprayed with various nutritional compounds prior to feeding in a number of studies to improve their quality. Despite the fact that the majority of the information on methodology, the concentration of different compounds, as well as the dose and time of fortification, is available, only a limited amount of success has been obtained in its practical use. Several dietary components, including starch, glucose, sucrose, calcium carbonate, calcium phosphate, and calcium lactate [9], glycocoll, vitamin A and B [10], choline, yolk of hen's egg, soybean oil, soybean protein glycine (Subburathinam and Krishnan, 1998), grape juice, wheat flour, tender coconut water, plant extracts [11] and honey have been tried in various concentrations [12]. To raise silkworms, adequate nutrition is necessary, and treating mulberry leaves with leaf extracts of specific plants can boost the production of silk even when there is little available food, resulting in financial gains. The nutritional quality of the leaves provided to the worms has a significant impact on their ability to grow healthily, which in turn affects their economic characteristics and grain age metrics (Krishnaswami et al. 1971). In sericulture research, mulberry leaves have recently been supplemented or fortified [11].

The effect of plant extracts on mulberry *Bombyx mori* L. silkworm nutritional efficiency observed that plant-treated silkworm batches had significantly greater food assimilation rates, assimilation efficiencies, and conversion rates. Batches that were treated with *Coffea arabica* (1:25 concentration) exhibited noticeably increased feed conversion metrics. (Jeyapaul et al. 2003). The effects of white Kwao-(*Peuraria Krua'smirifica*) ethanolic extracts, that are rich in phytoestrogen, on the Thai Multivoltine silkworm, *Bombyx mori* L.'s toxicity, larval maturation, and cocoon character were observed by Chawna et al. [13].

Hiware [14] studied the impact of feeding silkworm (*Bombyx mori* L.) larvae on mulberry leaves that have been infused with mother tincture of *Nux vomica*. He discovered favorable effects on the weight of the larva, cocoon, shell, and pupa, the ratio of silk, the average filament length and denier, and the number of reel breakages. This study suggests that *Nux vomica* treatment enhances biological parameters of *B. mori* L. The silkworm appeared to be unaffected, and there was little any mortality during rearing. *Nux vomica* may affect the worms' digestive systems, but it appears that this may be a cheap and efficient way to increase silk production that may be used on a farm-by-farm basis.

Nguku et al. [15] studies demonstrate that royal jelly-infused mulberry leaves were used to feed *Bombyx mori* L. silkworm larvae in their fourth instar. A meal supplemented with royal jelly greatly raised the weights of the larvae, cocoons, and pupae but had no discernible impact on the weights or denier of the shell. Royal jelly can be added to mulberry leaves to increase silk's potential for commercial use and can be used in sericulture to increase production.

Venkatesh Kumar et al. [16] has examined the impact of blue green algae (*Spirulina*) on the quantitative cocoon characteristics of the silkworm, *Bombyx mori* L., including cocoon weight, shell weight, pupal weight, shell percentage, and silk filament length. Bombycidae, a genus of Lepidoptera. For the study, one control and three treatments (foliar sprays at 100ppm, 200ppm, and 300ppm) were used. When compared to control, 100 ppm, and 200 ppm concentrations, single cocoon weight, single shell weight, pupal weight, and silk filament length are all significantly higher at 300 ppm concentration.

Hiremath et al. [17] has studied the accumulated lipid content of silkworms raised on mulberry leaves with organic nutrition management at various phases of development. The cooperating supplements principle, which states that supplemental or substitute sources of nutrients are needed to work in conjunction with the commonly recognized food stuff of the species in order to fulfil the nutritional requirements in many insects, can be used to assess the importance of research on the effects of various fortification agents in silkworm nutrition.

Rajashekaragouda et al. [18] observed that plant extracts from *Tribulus terrestris* L. and *Psoralea corylifolia*, among others, have a growth-promoting impact on silkworm. Deshmukh and Khyade [19] noticed that *B. mori* larvae in their last instar gained weight after receiving Aloe tonic treatment. Murugan et al. [11] reported that adding most botanicals to a medium concentration (5%) effectively increases several favorable aspects of silkworm rearing. It was discovered during the current investigation that *O. sanctum* concentration at 2% was quite effective. Rajeswari and Isaiarasu [20] suggested that leaf extracts of *Moringa oleifera* showed high larval growth (1974±53 mg/ larva). Patil et al. [21] reported that *Parthenium* root extract induced silkworms to consume more food, increasing the weight of the larvae, cocoons, and pupae. *P. corylifolia* extract enhanced the silkworms' economic traits [22]. Murugesh and Mahalingam [23] reported that the cocoon characteristics of *B. mori* were enhanced by *T. terrestris* leaf extract.According to Chavan et al. [24] the economic properties of *B. mori* can be improved by using a plant extract from *Clerodendrum multiflorum*. The quality and quantity of silk in *B. mori* were improved when mulberry leaves were added in the form of an aqueous extract of *Vigna unguiculata* (Saravanan et al. 2011). Pardesh and Bajad [25] reported that *Xanthium indicum* L. extract at a moderate concentration (2.5%) promoted growth in the *B. mori* silkworm.

3. IMPORTANT FOOD INGREDIENTS NEEDED FOR SILKWORMS RAISING

3.1 Protein as Essential Nutrients for Larval Growth

The mulberry leaf protein is the direct source of over 70% of the silk proteins produced by silkworms Narayanan et al. [26]. A few workers explained how important protein is to the diet of silkworms for their growth and the creation of silk. Arai and Ito [27] demonstrated that the protein in mulberry leaves can influences the development of the larvae. It has been discovered that dietary protein may be increased to an optional level (Horie et al. 1971) and that supplementing low-nutritional proteins with their limiting amino acids [28] can hasten silkworm growth. The growth and improvement of the silkworm's economic characteristics are known to be facilitated by dietary sources of protein rich in soy [29]. Horie and Watanabe [30] observed that adding soybean meal to the diet of silkworms can enhance the weight of the larvae and the new silk glands. Krishnan et al. (1995) revealed that adding hydrolyzed soy protein (P-soyatase) to the diet lowered the time that larvae spent in their larval stage and enhanced the accumulation of haemolymph protein (SP-1, a female-specific protein, and SP-2, an arlyphorin), larval weight, and cocoon characteristics. Moustafa et al. [31] examined the nutritional impact of the semi-artificial diet's tested amount of dietary soybean and mulberry leaf powder. The effects of dietary protein on larval development and silk production were discovered by El-Sayed [32] and El-Hattab [33]. Small or low molecular weight peptides positively impacted silkworm development and silk output [34,35].

3.2 Use of Vitamin C and Vitamin B as Nutrition for Silkworm

L-ascorbic acid (vitamin C) has historically been recognized as being essential for the growth and development of *Bombyx mori*. In fact, ascorbic acid is abundant in mulberry leaves [36] and it has a stimulatory impact on silkworm voluntary eating during the first instar stage [37].

Vitamins C and B, which act as coenzymes in the metabolism of amino acids and antioxidants, can help larvae develop more quickly and more productively by increasing the quantities of amino acids in their tissues [38]. They noticed that that ascorbic acid-fortified leaves had higher leaf consumption than control leaves; essentially, the amount of vitamin C in tissues and bodily fluids depends greatly on the amounts consumed with food.

Additionally, Suprakash and Pal [39] showed that vitamin B complex considerably enhanced growth and development, having a positive impact on the cocoon's economic traits. Improvements in the efficiency of dietary nitrogen conversion into the cocoon shell may be responsible for the enhancement of the experiment's cocoon and silk properties. As a result of enhanced vitamin availability and the beneficial antibacterial impact of honey on the development of various bacteria, the cocoon and filament characteristics may have risen due to the silk glands' higher protein conversion efficiency.

Sarker et al. [40] who reported that supplementation of mulberry leaves offered to silkworm with ascorbic acid (1%) and vitamin B complex (0.5%) improved cocoon yield and silk filament quality. Bee honey is also very advantageous; it raises child development and silk filament quality. When mulberry leaves are supplemented with vitamin B, silkworms gain weight and are more resistant to adverse environmental circumstances. Vitamin B12 may also stimulate the production of nucleic acids and proteins in the silk gland of silkworms [41]. Riboflavin increases the amount of silk produced while also decreasing the excretion of choline and uric acid, and at the end, its derivatives are sprayed on mulberry leaves to aid silkworms in producing more fiber [42].

One of the B vitamins, folic acid, often known as folate, is crucial for the healthy development of the spine, brain, and skull in larvae. It is also thought to be vital for insects' nucleic acid production. The body's glycogen content did not greatly rise when folic acid was added to the diet of silkworm larvae, but the amount of haemolymphtrehalose did significantly increase [43]. Etebari et al. [44] revealed that hyper vitaminosis has several adverse consequences in addition to increasing the weight of the larva and cocoon. The intake of food by silkworm larvae was not significantly affected when mulberry leaves were supplemented with vitamin E [45].

3.3 Different Salts' Effects on the Development and Growth of Silkworms

In general, salt may be a growth constraint for insects [46], regardless of the kind of food composition. The early formation of cocoons, the development of the cocoon characteristics, and the silkworms' reproductive potential were all greatly boosted by the salt. Nickel chloride, potassium iodide, and copper sulphate nutritional supplements improved the silkworm's economic characteristics. According to reports, nickel chloride significantly accelerated the development of silkworm larvae, pupae, adults, and subsequent cocoon production [47]. However, larger salt concentrations had a lasting impact on these variables. After feeding silkworm larvae with mulberry leaves supplemented with nickel and zinc, the weight of the cocoon was increased [48].

3.4 Application of Sterol for Silkworm Development

Insects require dietary sterols, as they are unable to produce sterols from scratch, insects need to consume dietary sterols [49]. Since cholesterol is used not only as a component of cell membranes but also as a precursor to the moulting hormones ecdysteroids [50], sterols are essential to insects' survival and growth. For *Bombyx* larvae [51], the -sitosterol found in mulberry leaves and its conversion to cholesterol are essential. Sitosterol appears to have a role in the nutritional control of sterol needs as well as the activation of biting [52] and food choices. As a result, the sterol requirements of *B. mori* should provide vital details about the connection between dietary control and feeding behaviour.

Nayer and Fraenkel [53] examined the distribution of sterols in an artificial diet and in *Bombyx* larvae to address the molecular conversion of -sitosterol in *Bombyx* larvae. On the basis of analytical data from preparative gas chromatography, substantial sterol components of the midgut, epidermis, silk gland, and hemolymph of *Bombyx* larvae fed with mulberry leaves were documented considerably earlier.

4. ARTIFICIAL DIET: AN ALTERNATIVE AND INNOVATIVE FOOD FOR SILKWORM

The first successful artificial diet-based silkworm rearing took place in 1960. At that time, larval growth was subpar, mortality was high, development was sluggish, and cocoons were tiny when raised on an artificial diet. Getting high-quality cocoons on a laboratory scale and raising the silkworm on artificial feeds are currently not too challenging.

4.1 Artificial Diet and its Composition

Artificial diets were created in order to obviate the need for special mulberry gardens, which are maintained to suit the specialized nutritional needs of immature instar silkworms. Contrary to early expectations, the widely used and productive silkworm hybrids that are economically exploited in India and their parental strains could not take the artificial diet and had a poor FR (Feeding Response). It was found that the only solution to this bottleneck was to alter the silkworms' selection response for their eating behavior [54,55]. Therefore, it was intended for commercial breeds to eventually adapt to feeding on artificial diets through selection.

In the end, this would make it easier to provide a standard artificial diet for all the developed hybrids. When Japan had the same issue with the Sawa J silkworm strain and their odd eating behaviour, attempts were undertaken to develop unique silkworm strains for exclusively artificial diet rearing. Sawa J's polyphagous character allowed for the subsequent development of specific strains and commercial hybrids for artificial diet rearing [56]. In their publications, different authors' fake diet formulations were reported. After 24 years of ongoing study, Hamamura [52] discovered that mulberry leaves included the attractive element citral, the biting factor-sitosterol, the swallowing factor cellulose powder, the supplemental factors (potassium diphosphate, sugar, inositol, and silicasol) in agar agar jelly pure form were prepared.

According to Watanabe [57], the fresh leaf aldehyde also attracted the *Bombyx mori* silkworm in addition to the fresh leaf alcohol.

The water-soluble portion of mulberry leaves include chlorogeninc acid, which Yamada and Kato [58] studied, while Hamamura et al. [52] studied the significance of polyphenolic acid in silkworm development. Arai and Ito [27] stated that a blend of the mulberry leaf protein's amino acids was used in place of soybean powder in the fake diet after being assessed.

L-ascorbic acid (vitamin C) has traditionally been thought to be essential for *Bombyx mori*'s growth and development. The only food source for silkworms is mulberry leaves [36], really contains considerable levels of ascorbic acid, but they are unable to synthesize it. The amount of ascorbic acid often added to silkworm food (enrichment) ranges from 1 to 2 percent of the dry weight of the artificial diet, which is thought to be the ideal ascorbic acid content26. Based on the research of Cappellozza et al. [59], it appears conceivable to omit ascorbic acid from artificial feed formulations, at least during the fifth instar stage, without impacting output, larvae mortality, or the length of the larval cycle. Additional research will clarify how ascorbic acid works. The mechanism of ascorbic acid needs in various silkworm strains will be clarified by further research. In relation to the biological function of silk manufacturing, the potential use of ammonia by the silkworm *Bombyx mori* seems intriguing [60-62]

In order for the silkworm larvae to withstand the threat of amino-acidemia, Akao [63], hypothesized that the production of silk was a kind of excretion of extra amino acids. This was postulated because most larvae perished before pupating when the silk glands from third- or fourth-instar larvae were removed. The *Bombyx mori* silkworm uses ammonium nitrogen for silk synthesis in a similar way to how non-essential amino acids are used [64]. Two different artificial diets have recently been employed to streamline the creation of prepared meals from dried diets. One type of diet, called "Pellet diet," is made with a twin-spindle extruder and may be given to silkworms by soaking it in a quantity of water right before usage. Another one is notably “Yuneri diet” may be supplied to the silkworms by combining with hot water at roughly 80o C without steaming [65].

5. PREBIOTICS AND NANOSERIFEED

Singh et al. [66] observed improvement in larval body weight, cocoon weight, shell weight and pupation percentage of silkworm larvae when fed on mulberry leaves treated with *Lactobacillus plantaram*. However there are no studies on the colonization of *L. plantarum* in silkworm, gut. Masthan et al. [67] observed that two probiotics namely *Spirulina* and Yeast significantly promotes the cocoon characters and silk quality, when compared to *Lactobacillus acidophilus* and *Lactobacillus sporogens*.

Nanotechnology is emerging out as the greatest imperative tools and has positive impact in the advancement of functional feed which deliver the nutrients effectively. Nanotechnology a rapidly evolving field affords novel ways to enhance the growth and production in the field of nutrition. Applications of nanotechnology studies in nutrition of silkworm are limited. Considering the key role played by vitamin absorption in silkworm nutrition and development, Kamala and Karthikeyan [68] studied the effects of supplementation of riboflavin nanoparticle on the growth and the economic traits of the silkworm, *B. mori* L. They reported that nanoparticles of vitamin B2 showed a positive impact and significantly enhanced the growth of the larvae (28.985%), silk gland weight (111.392%) and silk yield (194.44%) when compared to control.

Kamala and Karthikeyan 2019 Studied the effect of Nanoparticles of Alanine on the Growth and Development of Mulberry Silkworm, *Bombyx mori* L. they reported enhanced growth of the larvae, silkgland weight and cocoon parameters. Joyce and Sabura [69] studied Influence of Mushroom Silver Nanoparticles Enriched Mulberry, a Feed Supplement of Silkworm *Bombyx mo*ri L. on its Growth Parameters and found significant results on rearing performance. Nanoparticles of aminoacids significantly enhanced the growth of the larvae, silkgland weight and cocoon parameters when compared to control. So amino acid nanoparticles can be used as a fortification agent for improving the silk production [70-72].

6. CONCLUSION

Due to the expense of the food, it was commonly believed that artificial diets could not be utilized to raise silkworms through all stages of development in order to produce silk. However, this method could be feasible with the creation of low-cost artificial diets and the breeding of polyphagous silkworms. The invention of artificial diets, the development of a rearing system, a cost-benefit analysis of the silkworm rearing system on artificial diets throughout the instars, and the efficient generation of silkworm eggs are all now being studied theoretically and practically. A refurbished technology, the new way of raising silkworms on artificial diets is anticipated to spread quickly in sericulture. The quality of mulberry leaf must be raised before artificial diet quality may be increased. Since feeding silkworms with mulberry leaves is the main reason for mulberry production in most Asian nations, a thorough investigation of the effects of mulberry leaf salt accumulation on silkworm growth and development is necessary. However, further study is required to clarify more details in this field, including significant proteome investigations, systematic biology-based research, and genomic analysis. The capacity of various organic and inorganic components, such as ammonia absorption and usage by *Bombyx mori* in connection to silk creation, has to be further investigated. Additionally, understanding the genetic basis of mulberry salinity tolerance through the discovery of QTLs would make it easier to use molecular markers to choose the best parents for cross-hybridizations and to screen hybrids at an early developmental stage. Exploring the genetic differences in salt tolerance present in agricultural plants and their wild cousins should also be a priority. Recent advancements in genetics, tissue culture, transgenesis, and linkage mapping have demonstrated that research in the upcoming years will unquestionably modify the ability of mulberry to tolerate salt. The development of methods by which the mulberry plant may control excessive ion absorption and translocation in leaves must also be prioritized.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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