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Content

Volume 59 | Number 2 | 2019

Review Paper

Impact of rearing season, host plants and their interaction on economic traits of *Antheraea mylitta*
Impact de la saison d'élevage, des plantes hôtes et de leurs interactions sur les caractères économiques de *Antheraea mylitta*

Narendra Kumar Bhatia 50

Research Papers

Genetic assessment of resistance to grasserie in silkworm (*Bombyx mori* L.) through generation means analysis

Evaluation génétique de la résistance à la grasserie chez le ver à soie (*Bombyx mori* L.) par l'analyse des moyennes des générations

Sahereh Joezy-Shekalgorabi, Seyyede Azadeh Javadi-Taklimi and Ramin Seighalani 75

Correlation between vitellogenin receptor gene expression and fecundity in silkworm, *Bombyx mori*

Correlation entre l'expression du récepteur du gène de la vitellogénine et la fécondité chez *Bombyx mori*

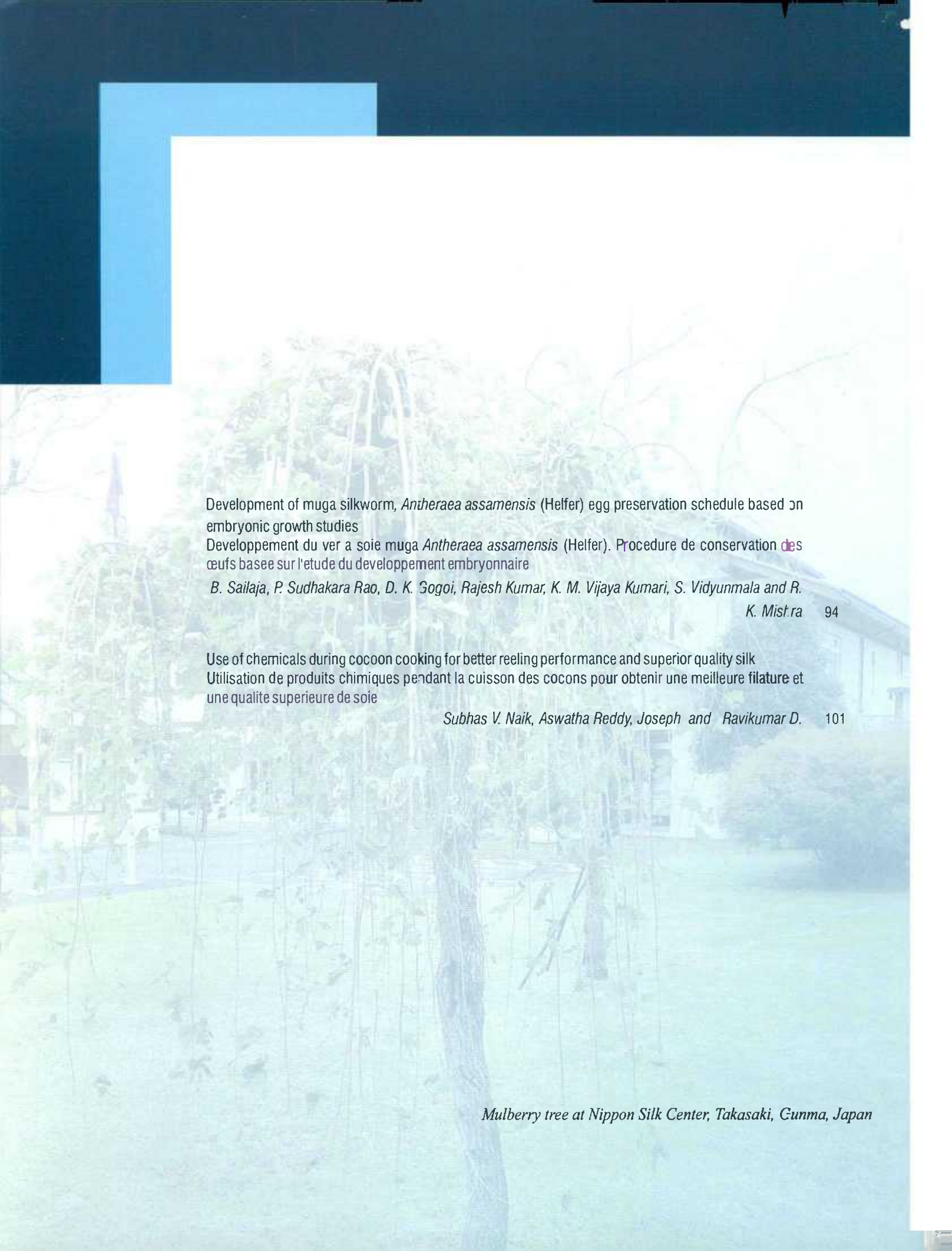
Dyna Susan Thomas, Chitra Manoharan, Ashok Kumar Kasukurthi, Gourab Roy, Vijayan Kunjupillai,

Ravikumar Gopalapillai and Kalidas Mandal 82

Impact assessment of less friction jacquard in silk handloom weaving

Evaluation de l'impact du jacquard faible friction dans le tissage artisanal de la soie

K. M. Abdul Kadhar, V. K. Rameshbabu, M. G. Mahesh and S. V. Naik 88



Development of muga silkworm, *Antheraea assamensis* (Helfer) egg preservation schedule based on embryonic growth studies

Developpement du ver a soie muga *Antheraea assamensis* (Helfer). Procedure de conservation des œufs basee sur l'etude du developpement embryonnaire

B. Sailaja, P. Sudhakara Rao, D. K. Gogoi, Rajesh Kumar, K. M. Vijaya Kumari, S. Vidyunmala and R.

K. Mishra 94

Use of chemicals during cocoon cooking for better reeling performance and superior quality silk

Utilisation de produits chimiques pendant la cuisson des cocons pour obtenir une meilleure filature et une qualite superieure de soie

Subhas V. Naik, Aswatha Reddy, Joseph and Ravikumar D. 101

Mulberry tree at Nippon Silk Center, Takasaki, Gunma, Japan



Review Paper

IMPACT OF REARING SEASON, HOST PLANTS AND THEIR INTERACTION ON ECONOMIC TRAITS OF *ANTHERAEA MYLITTA*

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ABSTRACT

Tropical tasar silkworm, *Antheraea mylitta* (Lepidoptera: Saturniidae) is a polyphagous, silk producing forest insect of commercial importance in India. Forest dependent people rear its larvae on different forestry host plants twice or thrice in a year for meagre household income. Larvae of *A. mylitta* feed on many forest tree species, but always show a great degree of selectivity as a function of its behavioural responses to physical structure and chemical features of the host plants. Cocoon crop of *A. mylitta* is influenced by heterogeneity of tasar food plants and climatic conditions of the habitat. The role of host plants, temperature, humidity, rainfall, photoperiod and other climatic variables on the growth and development of insects have clearly been demonstrated. This article entails an in-depth analysis on the implications of various forestry host plants, ecological factors and nutritional attributes of *A. mylitta*, which may provide selective information to the researchers, people associated with tropical tasar culture of the country and forest managers, who are particularly concerned with improvement of the livelihood function of the forest to its dependents.

Key words: Biotic and abiotic factors, food utilization, forest silkworm, growth and development, Indian tasar, silkworm nutrition.

INTRODUCTION

The practice of exploitation and commercialization of tropical tasar silkworm, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) originated in India, and the tribal communities of Chotanagpur are their inventors. *A. mylitta* is a polyphagous, silk producing insect of commercial importance, widely distributed in moist deciduous, semi evergreen, dry deciduous and tropical dry deciduous forests in India (Rao, 2001). Poor people in forest fringe area commercially rear the larvae of this silk producing insect on different forest tree species for small household income. The tasar culture provides livelihood to 1.65 lakh tribal people in Jharkhand, Chhattisgarh, Odisha, Madhya Pradesh, West Bengal, Uttar Pradesh, Maharashtra, Bihar and Andhra Pradesh states (Reddy, 2010) with total raw silk production of 3268.00 MT (CSB,

2018). *A. mylitta* is commercially exploited, only in India.

In nature, *A. mylitta* has opted forty-five forest tree species as primary, secondary and tertiary food plants (Srivastav and Thangavelu, 2005) and have built up sixty-four different forms of ecological populations called ecoraces (Rao *et al.*, 2003). The polyphagous nature of the tasar silkworm is a boon for many rural tribal folk in central India, as their livelihood are linked with the collection and sale of nature grown, wild tasar cocoons (Nayak *et al.*, 2000; Hansda *et al.*, 2008; Ojha *et al.*, 2009). *A. mylitta* completes its life cycle twice or thrice in a year depending on the biotic and abiotic factors, and accordingly, the race is recognised as bivoltine (BV) or trivoltine (TV). Daba (BV) and Sukinda (TV) are the most commercially exploited ecoraces of *A. mylitta*, which is a prerogative of India. *A. mylitta* hatches and multiplies in its natural

habitat during favourable season and the life cycle synchronises with the available forestry host plants and develops an appropriate voltinism according to the prevailing agro-climatic conditions (Thangavelu, 2000).

The cocoon of *A. mylitta* shows considerable variation in its colour, size, shape, pupal weight, shell weight, and the silk output (Jolly *et al.*, 1974, 1979). Such variations in the cocoons mainly occur due to the variation of race, climatic conditions, food plants, altitude *etc.* (Nayak and Guru, 1998). Several workers have reported that host plants influence the weight gain by larva, survival percentage, growth index, pupal weight, adult emergence and fecundity (Singh and Byas, 1975; Dubey *et al.*, 1981). All these studies underscore that lesser larval developmental period, more larval weight gain, and higher percentage of adult emergence are the major criteria to determine the superiority of a host plant on any other one. There have been a number of studies on the biological parameters of different insects grown on different host plants under different environmental conditions (Etman and Hooper 1979; Bae *et al.*, 1997; Guan and Chen 1999).

Insect - host plant interaction- a historical preview

The foundations for the study of insect-host plant relationships were clearly defined by Charles T. Brues in 1920's (Brues, 1920, 1924). Brues used three categories of phytophagous insects; insects, which feed on a single host plant species, Brues called them monophagous, while those insects that feed on a definite few host plant species, he called oligophagous and the insects, which feed on a wide variety of host plant species, were called polyphagous. *A. mylitta* is a polyphagous insect and has opted forty-five forest tree species, categorised based on the order of preference as primary, secondary and tertiary food plants (Srivastav and Thangavelu, 2005).

The knowledge amassed on insect-host plant relationship has provided insights into the food preference by insects with regard to its nutritional value. Erstwhile, Hiratsuka (1920) carried out a comprehensive quantitative study on digestion and utilization of mulberry leaf by *Bombyx*

mori. Thereafter, Evans and Goodliffe (1939) worked on utilization of food by insects. Earlier studies on utilization of food by insects were not clearly described because several indices were used to report more or less the same measurement in different names (Hopkins, 1912; Evans and Goodliffe, 1939; Crowell, 1941; Smith, 1959). Study of the effects of host plants on the biology of insects is important in understanding the host suitability under different environmental conditions (Xue *et al.*, 2009).

It is Thangavelu (1992) who for the first time, emphasised the need for conservation of wild sericigenous insects in Himalayan states of India. He highlighted the importance of systematic research on various aspects of non-mulberry silks, because studies on the host plant interaction of sericigenous insects are necessary for better management and development of the sericulture industry (Sinha *et al.*, 2000). Siddiqui *et al.* (2006) stressed that conservation of *A. mylitta* in different pockets of forest under different geographical and climatic areas is necessary and some of the commercial ecoraces of *A. mylitta viz.*, Raily, Modal, Bhandara, Sukinda, Daba and Andhra local are being maintained in different forest areas of central India; but it is lacking in Uttarakhand, a prospective state. As suggested by many sericulturists, the specific climatic and geographical pockets in India can serve as new natural habitat for forest silkworm (Sinha *et al.*, 2000; Naik *et al.*, 2010). Deka and Kumari (2013) stressed that in order to increase the raw silk production of *A. mylitta*, exploitation of all the ecoraces should be initiated and their food preferences established through comparative study of the effects of different food plant species under new agro-climatic conditions.

Cocoon crops of *A. mylitta* are influenced by the season, host plants and their interactions (Venugopal and Krishnaswami, 1987). Over generations, *A. mylitta* have adapted to different environmental conditions and different ecoraces with phenotypic variations are reported from India, out of which only Daba and Sukinda eco races are mainly contributing for country's tasar raw silk (Rao *et al.*, 2004; Hansda *et al.*, 2008; Ojha *et al.*, 2009; Reddy *et al.*, 2010).

During the last fifty years, many articles were published on insect-host plant interactions of Daba ecorace of bivoltine tropical tasar silkworm, *A. mylitta*, and all these studies were mainly carried out on *Terminalia arjuna*, *T. tomentosa*, and *Shorea robusta* in traditional tasar silk producing states of India, viz., Jharkhand, Odisha, Chhattisgarh, Andhra Pradesh and West Bengal.

Major areas of studies conducted so far on *A. mylitta* include: morphology of the larva (Narasimhanna and Jolly, 1969; Narasimhanna *et al.*, 1969), influence of temperature and photoperiod on termination of pupal diapause (Jolly *et al.*, 1970), effect of habitat and food (Prasad, 1980), effect of the egg refrigeration on hatching (Dash *et al.*, 1988; Nayak and Dash, 1989), growth and leaf yield of Asan and Arjun (Nayak *et al.*, 1988) and larval energetics on different food plants (Dash and Dash, 1989; Dash *et al.*, 1996; Dash, 2001), occurrence of deformed cocoons (Dash and Nayak, 1990), rearing performance of *A. mylitta* on artificial diet (Akai *et al.*, 1991), effect of food plants on cocoon crop performance (Dash *et al.*, 1992, 1994), preservation of seed cocoons (Kapila *et al.*, 1992), voltinism (Nayak *et al.*, 1992), rearing and cocooning (Ojha *et al.*, 1994), abnormal tasar cocoons (Mohanty and Behera, 1998), effect of starvation on larva (Dash *et al.*, 1988), cocoon and post cocoon phase (Rao and Samitha, 2000), bioenergetics during diapause (Satpathy, 2003), effect of outdoor cocoon preservation (Chakrabarty *et al.*, 2003), reassuring livelihood functions of the forests to their dependents (Bhatia and Yousuf, 2013 a), forest insect industry in collaborative forest management (Bhatia and Yousuf, 2013 b), assessment of climatic suitability of Dehradun to introduce forest based rearing of *A. mylitta* in Uttarakhand (Bhatia and Yousuf 2013 c) and parasitic behaviour of *Xanthopimpla pedator* on *A. mylitta* (Bhatia and Yousuf 2013 d)

A comprehensive review of literature in the above line was undertaken and the highlights, particularly on the effect of rearing season, host plants and their interaction on biological and economic parameters of tropical tasar silkworm, *Antheraea mylitta*, are discussed as under.

Effect of rearing seasons on biological and economic traits of insects, especially *A. mylitta* Drury

Seasonal characteristics indicate the inter-annual variation in temperature, humidity, sunshine, rainfall, etc. of a particular place, which is governed by different geographical parameters (Murthy *et al.*, 1996). Seasonal variations impact the biology and development of an insect (Odum, 1983; Ouedraogo *et al.*, 1996). Temperature influences everything that an organism does (Clarke, 2003) and humidity has a bigger role on embryonic development (Tamiru *et al.*, 2012).

Environmental temperature, being the major abiotic factor, regulates the body temperature of a caterpillar that determines the rates of feeding, fecundity, and mortality (Casey, 1981; Wellington *et al.*, 1999). Temperature is probably the single most important environmental factor that influences behaviour, development, survival, reproduction, and geographical distribution of insects (Benchamin and Jolly, 1986; Shiva Kumar *et al.*, 1997). All the insect species have their own choice of temperature regimes for usual growth wherein very high temperature levels slow down the growth that may lead to developmental malfunction, affecting larval ecdysis and adult emergence (Chapman, 2002). Temperature regimes and different levels of relative humidity are known to play an important role in the life cycle of an insect and its adaptability to the local climate. Developmental time of an insect is inversely related to temperature (Tamiru *et al.*, 2012). Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al.*, 2002) and that is why, most of the insect's forewarning and forecasting models are based upon accumulated degree-days from a base temperature and bio-fix point. Yokoyama (1963) estimated that with a 2 °C rise in temperature, insects might experience one to five additional life cycles per season. Most researchers seem to agree that warmer temperatures result in more types and higher populations of insects (Coviella and Trumble, 1999; Hunter, 2001; Hamilton *et al.*, 2005). It has been reported that the temperature has highly significant effects on all developmental parameters

of insect than humidity and rainfall (Bhat and Bhattacharya, 1978). Among the various environmental factors that influence the silkworm cocoon crops, the most important are temperature followed by humidity.

Second abiotic factor that has significant impact on the performance of insects in terrestrial environments is humidity. Humidity interacts with free water availability and with the water content of the food plants. There is no limiting range of humidity and most insects can develop at any humidity provided they are able to control their water balance (Hunter, 2001). Humidity shows mostly an indirect effect on growth and development. Under too dry conditions, the leaves wither very fast and become unsuitable for insect feed, resulting in retarded growth of larvae, which makes them weak and easily susceptible to diseases and other adverse conditions. During egg incubation, it is important that humidity should be maintained at 80 % on an average for normal growth of embryo. If humidity falls below 70 % during incubation, it affects hatching (Singh *et al.*, 2009). Studies have also indicated the combined effects of temperature and relative humidity (Getu, 2007; Tamiru *et al.*, 2012).

Rainfall alters the functioning of microhabitat, which along with soil and other environmental factors affects foliage status and water levels, which consequently affect on performance of insect (Mattson and Haack, 1987). Chemically, the variation from succulent leaves to mature is so large that it may halve the growth rate of Lepidopteran larvae (Rauscher, 1981).

Fluctuation in temperature, humidity and other seasonal factors prevents insects from attaining their physiologically potential life history performance (Slansky and Scriber, 1985). However, forest insects display a remarkable range of adaptations to changing environments and maintain their internal temperature (thermoregulation) and water content within tolerable limits, despite wide fluctuations in their surroundings, because impact of temperature is modified by habitat and other physical conditions (Singh *et al.*, 2009). Temperature, humidity, air circulation, gases and

photoperiod *etc.* show a significant interaction in their effect on the physiology of silkworm depending upon the combination of factors and developmental stage, affecting growth, development, productivity and quality of silk (Singh *et al.*, 2009).

Green *et al.* (1996) mentioned that the ecological range of most organisms especially the ectothermic animals is determined by the available food, ambient temperature, humidity *etc.* According to Krishnaswami (1978), the silkworm rearing seasons are broadly classified as spring, summer, and rainy crops, based on the temperature, humidity, and rainfall. Identification of the best rearing season is a prerequisite for the success of seri-business in a given area. Sengupta (1988) opined that the success of sericulture in Japan could be attributed to the identification of the suitable rearing seasons.

Sinha and Chaudhury (1992) asserted that phenological parameters of *A. mylitta* are mostly dependent on the ambient temperature and relative humidity available during the period of larval and pupal development; hence, the developmental pattern of *A. mylitta* is season specific. Dash *et al.* (1994) found cocoon crop of *A. mylitta* in winter as better than those of rainy and autumn seasons. Srivastava *et al.* (1998) reported that environmental conditions are the main cause of variability in *A. mylitta*, because the fecundity, hatchability, cocoon weight, shell weight, absolute silk yield, filament length, denier, and sericin percentage varied significantly during different rearing seasons.

Sengupta *et al.* (2002) observed that all the commercial characters of Daba ecorace (BV) of *A. mylitta* viz., cocoon weight, shell weight, shell %, cocoon volume, filament length, denier, average silk recovery percentage and silk yield/1000 cocoons were significantly higher in second rearing season than the first one. Similarly, Deka *et al.* (2011) found better performance of Daba ecorace (TV) of *A. mylitta* in spring season followed by autumn, winter, and summer season.

Dash *et al.* (1994) assessed cocoon crop performances of

the Indian wild tasar silkworm, *A. paphia* on different food plants viz., *T. tomentosa*, *T. arjuna* and *S. robusta* during different rearing seasons in agro-climatic condition of Durgapur, Odisha. They evaluated cocoon crop performances in terms of effective rate of rearing (ERR), total cocoons yielded, cocoon weight, pupa weight and shell weight for each category of food plant in each rearing season. Their results showed that cocoon crop performances were better in autumn crop (September-October) than in rainy (July-August) and winter (November-December) seasons. The larval form of tropical tasar silkworm can invade diverse habitats, utilise food sources of many forest tree species and can feed and grow at phenomenal rates (Rath *et al.*, 2004). However, under suboptimal environmental conditions, *A. mylitta* D. larvae can survive for delayed period at much slower growth rates (Jolly *et al.*, 1974). Due to outdoor mode of forest based rearing, the larvae of *A. mylitta* may suffer heavy loss due to predators, parasitoids, and diseases. It is estimated that on an average, 30 % of total crop loss due to various diseases is observed per year (Sahay *et al.*, 2008). Silkworm diseases form a major constraint in realizing full crop yield (Kumar and Naik, 2011).

Tanaka (1951) remarked that the rainy season is unsuitable for rearing of *B. mori* due to high RH and varying temperature. Krishnaswami *et al.* (1973) reported that temperature and RH exceeding 20- 26 °C and 60-70 %, respectively, affected the cocoon quality of *B. mori*. Jolly *et al.* (1974) remarked that heavy rainfall disrupted spinning resulting in inferior cocoons. Sarkar (1980) stated that sudden fluctuation in temperature is harmful to rearing of *Philosamia ricini* worms. Ullal and Narasimhanna (1987) reported that high temperature followed by severe weather fluctuation resulted in poor cocoon quality in *B. mori*. Barah *et al.* (1988) studied variation in cocoon characters of *A. assama* during different seasons and found that cocoons produced in different seasons are not uniform in their commercial characters. It was found by Kar *et al.* (1998) that the commercial traits of eri silk moth, *Samia ricini* such as cocoon, shell and pupal weights vary significantly during

summer and winter seasons. Naik *et al.* (2010) found significant difference in growth index of eri silkworm with respect to host plants, seasons, and their interaction. Rahmathulla and Suresh (2012) concluded that *B. mori* made physiological adaptations during summer season to withstand suboptimal condition. Tamiru *et al.* (2012) found that temperature, relative humidity (RH) and their interaction significantly affected the developmental time, adult longevity, and potential fecundity of *Chilo partellus*.

Information on the effect of season and rearing condition on different parameters of rearing has also been reported on other groups of insects (Cunnington, 1985; Johansen, 1997), mulberry silkworm (Krishnaswami *et al.*, 1971 a, b; Mathur *et al.*, 1995) and non-mulberry silkworms (Choudhary, 1981; Sinha and Chaudhury, 1992; Sahu, *et al.*, 1998; Situmorang, 2002; Das *et al.*, 2004).

Host plant nutrients and its effect on biological success of *A. mylitta*

The suitability of a host plant to an insect depends upon the presence of balanced nutrition in the plant for proper growth and development of insect. Larva of non feeding adult insects is a voracious feeder, hence their growth rate, developmental time, final body weight, survival and reproduction traits are influenced to a great extent not only by the climate and rate of feeding but also equally by the food quality (Rath *et al.*, 2006). That is why maximum potential fitness of any insect is only possible when the larva obtain adequate amount of necessary nutrients in a suitable relative balance (Slansky and Scriber, 1985). As nutrients can influence all aspects of insect performance, the larvae must ingest adequate amount of necessary nutrients to achieve maximum potential fitness (Rath, 2005). Matsumara *et al.* (1958) reported that out of the various factors responsible for success of silkworm cocoon crop, leaf quality stood first by contributing 38.2 %.

Many plants are known to synthesise a variety of chemicals, which are not an essential ingredient in plant metabolism and presumably, they are stored in any

convenient place within the plant structure. These kinds of substances have been called secondary metabolic products (Price, 1997), which can be utilised by the insects as cues to identify the plant for feeding and breeding purposes. It would appear that, aside from the sugars and perhaps some salts (Butler, 1940), insects are guided to their natural foods by the tastes and odours of various chemical substances, which themselves have no nutritive value (Uvarov, 1928). In general, the nutritional factors do not directly decide the acceptance or rejection of food plants. On the other hand, some nutrients like amino acids and sugars may act as feeding stimulants (Dethier, 1966). Dadd (1960) opined that instances of poor growth in insects might not be due to the nutritional inadequacy of the diet but to a low rate of intake due to the absence of a non-nutrient phagostimulant.

The availability of essential nutrients in tasar food plant is vital for successful life cycle, cocoon quality, metamorphosis to moth stage and reproductive activity of *A. mylitta* (Pattanayak and Dash, 2000; Reddy *et al.*, 2009). The foliar nutrition of tasar food plant can enhance the effective rate of rearing (ERR), because feed quality has direct correlation with health and growth of larvae for better crop yields in terms of cocoon and shell weights, silk content, and silk filament length (Dash *et al.*, 1992; Yadav and Mahobia, 2009). Significant positive correlation has been reported between chemical compositions of mulberry leaf and larval health as well as cocoon characters (Venkataramu, 1986). Benchamin and Jolly (1986) also reported that growth and development of the silkworm larvae and subsequent cocoon crop production depend on leaf quality, especially the nutrient contents. The quality of the leaves of host plant varies significantly with factors such as soil fertility, agronomical practices, planting system and environmental condition (Bongale *et al.*, 1991; Datta, 1992).

The water content of mature leaves provides a useful quantitative index of plant growth form (Scriber and Slansky, 1981). Water forms a large proportion of insect tissues and survival depends on the ability to maintain

water balance in the body. The water content in insects ranges from less than 50 % to more than 90 % of the total body weight and there may be much variation within the same species even when reared at identical conditions (Mathur and Lal, 1994). Rath (2010) found that the dietary water is very closely associated with number of feeds/day that plays a crucial role in the growth in *A. mylitta* as in other herbivorous Lepidopteron larvae (Slansky and Scriber, 1985). It was also found that consumption of food of lower water content could result in significant reduction in relative growth rate and efficiencies of conversion of digested food (Reese and Beck, 1978; Timmins *et al.*, 1988). Benchamin and Jolly (1986) reported that silkworm larva prefers to consume the leaves that contain high moisture and less dry matter. Periaswamy (1994) also reported that water content of leaf plays a significant role on food utilization and growth in phytophagous insects.

The next important element for proper growth and development of insects is Nitrogen (Scriber, 1982). Rearing performance of *A. mylitta* larvae are strongly correlated with the water and nitrogen content of the leaves (Prasad *et al.*, 2004). Further, proteins are the ubiquitous organic nitrogenous compounds that are involved in all the structure and function of the cells (Chapman, 1998). Slansky (1982) reported that protein is required for adult maintenance and supply the energy and nutrients for provisioning the eggs and egg production in insects.

Earlier studies (Narayanan *et al.*, 1967; Krishnaswami *et al.*, 1970; Sudo, 1981; Bongale *et al.*, 1991) proved that tender leaves are having more water as well as protein content. Protein content of the tender leaves is absorbed by the epithelium tissue of the silkworm gut and is transferred to the body matter as well as for the cocoon formation. Machii and Katagiri (1991) reported that mulberry varieties containing higher contents of protein in leaves have higher production efficiency of cocoon shell. It was found by Krishnaswami (1978) and Singhvi and Bose (1991) that the *B. mori* larvae when fed with protein rich mulberry leaves resulted in significant enhancement in its larval, cocoon and shell weight.

Carbohydrates occupy a very important place especially in the metabolism of phytophagous insects. It is the most commonly distributed and widely occurring compounds in plants with enormous variations in their quantity and quality (Sinha *et al.*, 1998). Carbohydrates are utilized by the silkworm as an energy source and for synthesis of both lipids and amino acids. The degree of fat body glycogen and haemolymph trehalose is also dependent on the carbohydrate contents in diet of silkworm (Ito, 1967). Sinha *et al.* (1998) found significantly higher quantity of total sugar in *T. tomentosa* (7.9 %) followed by *T. arjuna* (5.7 %) and *S. robusta* (5.3 %).

Carbohydrate, protein, and lipid are known to be the main sources of energy at the time of larval-larval, larval-pupal and pupal-adult transformation (Krishnaswami, 1978; Thangamani and Vivekanandan, 1984). Availability of these nutritional components has been reported to be on higher side in *T. alata*, *T. tomentosa*, *T. arjuna* and *L. speciosa* than *T. bellirica*, *T. chebula* and *L. tomentosa* (Sinha and Jolly, 1971; NISCAIR, 1976; Agarwal *et al.*, 1980), which improves the larval and cocoon characters of *A. mylitta* accordingly, on these host plants (Sinha *et al.*, 1986).

Quite contrary to the role of nutritional elements, higher crude fibre content in the leaves of forestry host plants of *A. mylitta*, is known to cause detrimental effect on silkworm nutrition (Krishnaswami, 1978). Crude fibre is the ash free material largely composed of cellulose and lignin, which cannot be digested by the silkworm larvae. It is not included under nutrient, but its intake along with diet is essential because of regulatory function that helps to maintain the peristaltic movement of the intestine to remove waste products from it (Sinha *et al.*, 1998). Digestibility of Lepidopteran insect is affected by imbalanced diet or by the presence of high content of crude fibre in the food (Waldbauer, 1964).

Amino acids are the next most important constituents in silkworm nutrition (Ito, 1967). *A. mylitta* extracts amino acids from the leaves of host plants and produce silk thread (Jolly *et al.*, 1974). Amino acids, obtained from the

leaf, are utilized by the silkworm larvae for body growth, development, and cocoon formation. Sinha *et al.* (1998) reported twenty-three amino acids in *T. tomentosa*, *T. arjuna* and *S. robusta*. They found that, though the number of amino acids was the same in all these plants; leaves of *T. arjuna* contain higher quantity of total amino acids (61975 µg/g dry leaf powder) followed by *T. tomentosa* (61250 µg/g dry leaf powder). Dhavalikar (1962) reported the presence of seventeen amino acids in raw silk of *A. mylitta*.

In a comparative biochemical study of *T. tomentosa* and *T. alata*, Sinha *et al.* (2007) found that non-hairy leaves of *T. alata* are better than hairy leaves of *T. tomentosa*. The moisture level, total carbohydrate, protein, amino acid and mineral content was found higher in non-hairy leaves than the hairy leaves; however, total fibre content was found higher in hairy leaves of *T. tomentosa* and lower in non-hairy leaves of *T. alata*.

Ponnuvel *et al.* (1996) reported that biochemical constituents of oak (*Quercus serrata*) leaves vary with season. They recorded maximum moisture (71.9 %) and crude protein (10.2 %) levels in spring season and the levels declined sharply as season progressed. Whereas, minimum crude fibre content (0.9 %) was found in spring season and maximum (9.96 %) during autumn season.

The relationship between foliar constituents of castor genotypes and economic parameters of eri silkworm was also investigated (Jayaramaiah and Sannappa, 1998). The larval duration, weight, survivability, and effective rate of rearing (ERR) were observed to have significant positive relationship with moisture and nutritional content of the host plant. A positive significant relationship was established between foliar constituents of the host plant and weight of cocoons, pupae, shell weight and shell percentage. Grainage parameters such as moth emergence, fecundity, and hatchability also showed significant positive relationship with nutritional components of the host plant fed to the eri silkworm.

Suitability of different forest tree species for growth and development of *A. mylitta*

Green plants are the indispensable foundations for all the

ecosystems that harness the energy of sun light and by photosynthesis, produce energy rich sugars that are the foods for insects (Waldbauer, 1996, 2003). The relationship between phytophagous insects and plants is essentially nutritional, because phytophagous insects visit the plant solely to procure food for themselves or for their progeny (Bhattacharya and Pant, 1976). What an insect eats and how much it eats largely determine its ecological role and its economic significance for human beings (Trager, 1953). Moreover, not everything that an insect ingests as food can serve as a source of nutrients (Brues, 1940).

The success of an insect depends significantly upon an optimal diet in both quantity and quality (Hassell and Southwood, 1978). The rate of food consumption is influenced by the physical and chemical nature of food and the physiological state of insects (Waldbauer, 1968). The amount, rate and quality of food consumed by a larva influences its performance *i.e.*, growth rate, developmental time, final body weight, dispersal ability, mating success, timing and extent of reproduction, and probability of survival. This influence can also carry over to affect adult performance such as, when a larva suffers reduced growth, it produces a small-sized adult with reduced fecundity. These influences can also carry over to affect subsequent larval performance that affects the quality of offspring produced (Slansky, 1985). Decreased food abundance in nature has an adverse effect on development, metabolism, and reproduction (Slama, 1964; Slansky, 1980; Grabstein and Scriber, 1982).

Forestry host plants of *A. mylitta* are known to differ greatly with their nutrient profile that affects its growth and development (Kohli *et al.*, 1969; Sinha and Jolly, 1971; Agarwal *et al.*, 1980; Sinha *et al.*, 1992; Puri, 1994). The rate of intake of an acceptable food is determined by a complex sequence of processes (Gordon, 1999). The food preference in the insects is governed by the presence of chemicals. They may be secondary substance like glycosides, alkaloids and essential oil as described by Dethier (1947) or sugars (Lipke and Fraenkel, 1956) and amino acids (Thorsteinson, 1960). According to

Bhattacharya and Pant (1976), no single factor controls the acceptance of host tissue by the insect; rather, a combination of the factors, such as presence or absence of phagostimulants, phagodeterrents, specific nutrients, toxins, and growth inhibitors decides the suitability of plant species as food materials for insects.

The larval feeding status of any polyphagous commercial insect has impact on food storage and budgeting for biological activities to combat the adverse or to excel during favourable conditions (Chapman, 1998; Chaudhuri, 2003; Hazarika *et al.*, 2003; Saikia *et al.*, 2004; Behmer, 2006; Cizek *et al.*, 2006; Radjabi *et al.*, 2009). Variation in the quality of larval food can have a negative impact in larval weight gain, developmental time and survival as well as adult performances (Scriber and Slansky, 1981; Slansky and Scriber, 1985). The qualitative and quantitative importance of food in connection with negative effects has also been recognized (Kozhanchikov, 1950; Barnes, 1955; Legay, 1958, Muthukrishnan and Delvi, 1974; Slansky, 1993).

Studies were undertaken by several scholars to assess the suitability of different host plants for polyphagous insects by offering them several alternative host plants. In their study, parameters, such as comparative feeding, relative growth rate, larval weight gain, pupal weight, adult emergence, fecundity *etc.*, were the main criteria to determine the most suitable food plant for a polyphagous insect (Basu, 1944; Srivastava, 1959; Dubey *et al.*, 1981). Studying these parameters enable better understanding towards insect-host plant interactions and its effect on growth and development (Srivastava, 1959).

The role of host plant is an important factor in regulating insect population (Umbarihowar and Hastings, 2002) as the life cycle characteristics of herbivores may be affected by variation in host plant traits, for example, the life history parameters, longevity, fecundity and survival may be influenced by the variation in host plant quality (Awmack and Leather, 2002). The development and reproduction of insects correlate directly with the quantity and quality of the food they consume, and the ingestion of

this food depends on its availability, acceptance, digestion, and assimilation (Garcia, 1991).

Ahsan and Griyaghey (1973) undertook first systematic study on the effect of different host plants on rearing performance of *A. mylitta* at Central Tasar Research and Training Institute, Central Silk Board, Ranchi during 1972-73. They conducted outdoor rearing of *A. mylitta* on seven forestry host plants viz., *T. arjuna* (Arjun), *T. tomentosa* (Asan), *S. robusta* (Sal), *Careya arborea* (Kumbi), *L. parviflora* (Sidha), *Q. serrata* (Oak) and *Z. jujuba* (Ber) in the agro-climatic condition of Ranchi. Their basic criteria for evaluating different host plants was based on the time taken for the first instar larvae of *A. mylitta* to reach pupal and adult stage, per cent pupa formation, adult emergence, gain in body weight and sex ratio.

Jolly *et al.* (1974) reported that the larvae of *A. mylitta* D. differ greatly in their adult form, not only in outer structure but also in characteristics of musculature, nervous system, tracheation, and many internal organs when fed on different forestry host plants.

Tripathi *et al.* (1988) have reared the larvae of *A. mylitta* on nine species of forestry host plants in the agro-climatic conditions of Jharkhand and found that *T. tomentosa*, *S. robusta* and *T. arjuna* trees support better growth of larvae, leading to formation of cocoons of large size and greater yield of tasar yarn than other forestry host plants, viz., *L. parviflora* and *C. arborea*. They further reported that transfer of *A. mylitta* larvae from inferior to superior host plant species result in heavy mortality of the larvae and reduction in cocoon yield.

Dash *et al.* (1992) studied the effect of rearing seasons and different food plants viz., *T. tomentosa*, *T. arjuna*, *S. robusta*, *Z. Jujuba*, *L. parviflora* and *A. latifolia* on cocoon crop performance of *A. mylitta* under the agro-climatic conditions of Durgapur, Odisha. *S. robusta* appeared uneconomical in terms of total cocoon production in spite of superior cocoon formation with regard to its hard shell thickness. Overall performance of

A. mylitta was found superior on *T. tomentosa* than all other food plants. The gradation of food plant with regard to performance (total raw silk production) was, in the following decreasing order of productivity: *T. tomentosa*, *T. arjuna*, *Z. Jujuba*, *S. robusta*, *L. parviflora*, and *A. latifolia*.

Srivastava *et al.* (1994) tested the efficiency of rearing of muga, eri and tropical tasar silkworm on different host plants and found that host plant significantly affected the rearing and grainage traits of all the non-mulberry silkworms. Their observations with regard to silk ratio and number of eggs per laying of *A. mylitta* revealed that *S. robusta* and *Z. jujuba* fed cocoons had higher silk ratio and also higher number of eggs per laying than the other two primary host plants viz., *T. tomentosa* and *T. arjuna*. However, survival of *A. mylitta* larvae on *S. robusta* and *Z. jujuba* was quite low in comparison to *T. tomentosa* and *T. arjuna*. Hence, based on total silk yield and fecundity, *T. tomentosa* and *T. arjuna* were found to be the most efficient host plants for commercial tasar silkworm rearing. Rath *et al.* (1997) also found significantly higher consumption, assimilation, growth and respiration of *A. mylitta* on *T. tomentosa* than *T. arjuna*. But significantly higher feeding rate was observed on *T. arjuna* during II and V instar over *T. tomentosa*.

Ricinus communis was identified as a potential host plant for rearing of *A. mylitta* (Patil, 1998). He found that the growth parameters and the cocoon characters of the tasar silkworm reared on castor leaves were normal. In his study, *A. mylitta* completed its life cycle in 71 to 85 days. The incubation period, larval and pupal duration ranged from 8 to 10 days, 33 to 40 days and 30 to 35 days, respectively. Further, the effective rate of rearing, weight of mature larvae, cocoon, shell, and pupae ranged from 70-85 per cent, 30 -35 g, 10 -12 g, 1.2 -1.5 g and 8 -9 g, respectively. The fecundity ranged from 250 to 275 eggs.

Kumar *et al.* (2011) carried out a bioassay of *A. mylitta* with different accessions of *T. arjuna* (18), *T. tomentosa* (9), *T. chebula* (1) and *Anogeissus latifolia* (1) during first rearing season of July-August 2010 and reported larval

weight of 40.55 g on *T. tomentosa*, followed by 40.4 g, 39.4 g and 32.8 g on *T. arjuna*, *A. latifolia*, and *T. chebula*, respectively. However, maximum larval period was 30 days on *T. chebula*, whereas, 29 days on *A. latifolia*, 28 days on *T. tomentosa* and 27 days on *T. arjuna*.

Deka and Kumari (2013) assessed the effect of six food plant species viz., *T. tomentosa*, *T. arjuna*, *T. bellirica*, *T. chebula*, *L. speciosa* and *L. parviflora* on rearing performance and cocoon characteristics of *A. mylitta* in the agro-climatic conditions of Ranchi, Jharkhand and found that the leaves of *T. arjuna*, *T. tomentosa* and *L. speciosa* possess more leaf moisture, chlorophyll, protein and carbohydrate contents to support better larval growth of *A. mylitta* in comparison to its rearing on *T. bellirica*, *T. chebula* and *L. parviflora*. Their study indicated the commercial perspective of *L. speciosa* as alternative primary food plant for forest based rearing of *A. mylitta* in agro-climatic conditions of Ranchi. Further, Kumar *et al.* (2012) studied the effect of different forestry host plant viz., *Terminalia arjuna*, *T. bellirica*, *T. chebula*, *T. tomentosa*, *L. parviflora* and *L. speciosa* on larval duration (days), larval weight (g), cocoon weight (g), shell weight (g) and shell % of Daba ecorace of *A. mylitta* during first crop of July-August under agro-climatic condition of Ranchi. They revealed the significant impact of host plants on all the studied parameters.

The economic viability of *A. mylitta* on *L. parviflora* food plant in comparison with *T. tomentosa* plant in the agro-climatic conditions of Jharkhand was analyzed by Reddy *et al.* (2012). The effective rate of rearing (ERR), cocoon and silk yield were reported lower in *L. parviflora*, while the other commercially important characters such as, larval, cocoon and shell weight, pupation and shell % have shown improvement over that on *T. tomentosa*. Their study indicated that the commercial prospective of *L. parviflora* might be explored in Jharkhand as alternative food plant for *A. mylitta* during exigencies.

Besides silkworm, literature is also available on effect of host plants on growth and development of other insects. Smith and Nethcott, (1951) studied the effects of various

food plants on the rearing of *Melanoplus mexicanus* and reported that consumption and utilisation rate differs with different food plants. Barbosa and Jane (1979) reported that the development and survival of gypsy moth (*Lymantria dispar*) larvae is strongly influenced by the host plant upon which they feed. Carne (1966) studied the growth and food consumption of *Paropsis atomaria* larvae and reported that the larvae ingested largest quantity of food during second instar. Xue *et al.* (2009) studied the effects of different host plants on larval and pupal development and survival, and longevity and fecundity of adults of *Spodoptera litura* and found that all of the biological parameters were significantly affected by the host plants.

Reproductive potential of *A. mylitta* on different forestry host plants

The fertility of an adult insect depends in whole or in part upon the adequacy of its nutrition during the larval stages (Waldbauer, 1968). Lepidopteran insects meet their total food requirements during larval stages to accumulate sufficient food energy to tide over the non-feeding adult stage and to lay eggs (Rath, 2005). *A. mylitta* take neither food nor water during the adult stage, so all the nutritional requirement during adult life of a week or two and for the development of hundreds of eggs by the female is obtained from food stored during larval life (Trager, 1953).

Reproduction in insects is very closely related to nutritional status of the host plant (Rath, 2000). Food deprivation during the larval period had a negative impact on the fecundity in many insects including sericigenous species (McGinnis and Kasting, 1959; Bhanot and Kapil, 1973; Muthukrishnan *et al.*, 1978; Srivastava *et al.*, 1982; Nath *et al.*, 1990; Rath *et al.*, 2004). Awmack and Leather (2002) opined that the host plant quality is a key determinant of the fecundity of herbivorous insects. Host plant qualities such as carbon, nitrogen, and defensive metabolites directly affect the potential and achieved herbivore fecundity. Host plant quality also affects insect reproductive strategies viz., egg size, the allocation of

resources to eggs, and the choice of oviposition sites.

The pupal weight of eri silkworm *S. cynthia ricini* on castor was found to influence the adult longevity (Nagalakshamma, 1987). The longevity of male and female moths influences the grainage performance of *B. mori* L. (Rajanna *et al.*, 1999; Krishnaprasad *et al.*, 2002) and *A. mylitta* (Rath *et al.*, 2007). The effect of various food plants on longevity and fecundity of adults of *D. oblique* has also been reported by Pandey *et al.* (1968).

There are reports that incubation period of silkworm egg vary with variation in host plant species (Jolly *et al.*, 1979; Sarkar, 1980; Reddy *et al.*, 1989; Naik *et al.*, 2010). Sengupta and Singh (1974) recorded the shortest incubation period (8 days) of eri silkworm, *S. cynthia ricini* when fed on castor.

Mishra *et al.* (1997) studied the reproductive behaviour of *A. mylitta* reared on *T. tomentosa*, *T. arjuna* and *S. robusta* plants in different seasons in Durgapur Orissa, India and reported that the type of food plants as well as seasonal variations affect the reproductive behaviour in terms of per cent emergence, pairing, fecundity and egg hatchability.

Reddy *et al.* (2010) reported the influence of host plants on the total pairing percentage of *A. mylitta*. Pairing percentage was found significantly higher on *T. tomentosa* (70.4%) than *L. parviflora* (60.8%).

Bogawat (1967) studied the biology of mustard saw fly, *Athalia proxima* (Hymenoptera: Tenthredinidae) on twelve different host plants and reported that pre-oviposition period of *Athalia proxima* was not affected, but the fecundity was found variable with the host plants. Bhardwaj and Kushwaha (1976) found that the pupae formation and the adult emergence of *Amsacta Lineola* got affected when offered five different host plants. Singh (1976) described that when *Utetheisa pulchella* was fed with leaves of *Crotalaria juncea* and *Heliotropium indicum*, it resulted in variations in the adult emergence ranging from 71 to 88%.

Economic traits of cocoon and silk production efficiency of *A. mylitta* on different forest tree species

Influence of host plant and rearing season on productivity of silk substance has been reported in silkworms (Ueda *et al.*, 1971; Hough and Pimental, 1978; Pillai *et al.*, 1987; Lindroth and Hemming, 1990). Sinha and Sinha (1994) have provided detailed genetic analysis of quantitative traits of *A. mylitta*. Silk producing insects present a great deal of variation in colour and morphological characters when fed on different host plants (Lefroy, 1909; Crotch, 1956; Pandey, 1995). Better the food quality, greater would be the chances of getting good cocoon harvest in *A. mylitta* (Sinha *et al.*, 1986). The cocoon shell weight and cocoon shell percentage were found highly influenced by the type of food plants and the environment of the silkworms' rearing (Siddiqui *et al.*, 2006).

According to Abraham *et al.* (2004), tropical tasar silk is superior in quality to other silks including mulberry, muga, and eri. Akai (1998) reported that cocoon filament of *A. mylitta* is the thickest among all the silkworm species and with a porous structure that is the most suitable for fashionable clothing and sport-wear.

Srivastava *et al.* (1994) suggested that silk ratio is the second most reliable economic character after effective rate of rearing for assessing the efficacy of forestry host plants for *A. mylitta*. Devaiah and Dayashankar (1982) reported that cocoon weight and shell weight largely depend on type of hosts provided to the silkworm.

Panda (1972) collected tasar seed cocoons of *A. paphia* from different regions of Odisha, separated them according to their peduncle characters, colour, and sex, and further calculated the correlation coefficient values for different characters. He also reported that live weight of female cocoons of *A. paphia* were significantly more than that of males, irrespective of variety and colour.

Sengupta *et al.* (2002) recorded significantly higher filament length of Daba (Bivoltine) ecotype of *A. mylitta* in second rearing season (959.750 ± 119.486 m) than first

crop (517 ± 50.697 m). Srivastava (1986) found that the Sal fed cocoons of *A. mylitta* were superior in silk ratio, while effective yield of cocoons was low. Efficacy of Arjun towards cocoon weight was found higher but low for effective yield and silk ratio. Further, Asan has shown better performance for cocoon yield, cocoon weight, and silk ratio.

Kumar *et al.* (2011) reported that *T. tomentosa* fed larvae of *A. mylitta* produced the highest cocoon weight of 13.45 g in comparison to the larvae fed on *T. arjuna* (12.37 g), *A. latifolia* (12.48 g) and *T. chebula* (10.70 g). They found maximum shell weight of *A. mylitta* cocoon on *T. tomentosa* (2.06 g) followed by *T. arjuna* (1.78 g), *A. latifolia* (1.67 g) and *T. chebula* (1.19 g) during first rearing season rearing in Ranchi agro-climatic condition. They also recorded that *A. latifolia* fed larvae produced maximum shell percentage of 14.27 % followed by *T. tomentosa* (14.02 %), *T. arjuna* (13.71 %) and *T. chebula* (11.4 %).

Dash *et al.* (2012) evaluated the length, breadth, and weight of pupa of *A. mylitta* reared on different forestry host plants viz., *T. alata*, *T. arjuna*, *S. robusta*, *Z. jujuba*, *L. parviflora*, *A. latifolia*, *T. bellirica*, and *S. cumini* in rainy season at lower, medium, and higher altitudes in Odisha. Their study was a revelation that *A. mylitta* larvae reared on *S. robusta* possessed significantly highest values of all the pupal growth parameters. The gradation of eight food plants in respect of the pupal growth of *A. mylitta* was found as *S. robusta* > *T. alata* > *T. arjuna* > *Z. jujuba* > *L. parviflora* > *A. latifolia* > *T. bellirica* > *S. cumini*.

Rath *et al.* (1997) found significant variation in silk productivity of *A. mylitta* reared on *T. tomentosa* and *T. arjuna*. His results indicated that the larvae fed on *T. tomentosa* produced more silk than *T. arjuna*. Thus, *T. tomentosa* proves its comparative superiority over *T. arjuna*.

Raja Ram and Sharadchandra (1998) reared eri silkworm on the leaves of castor and kesseru and observed the

highest cocoon weight of 2.45 g on castor followed by 2.19 g on kesseru. Reddy *et al.* (1989) studied pupal weight, cocoon yield, shell percentage and reproductive parameters of *S. cynthia ricini* on castor, tapioca, *Plumeria* and *Ailanthus* and found the highest shell percentage of 12.10 on castor. Xue *et al.* (2009) reported that larval food directly affects size and weight of the pupae of *S. litura* with the female one always being heavier than the male.

Conclusion

This review provides an insight into various aspects of insect-host plant relationship, its ecological interferences and the ultimate impact on various economic traits, especially of *A. mylitta* that forms the basis for livelihood improvement potential of this forest insect industry. Recognizing the role of *A. mylitta* in livelihood support to the poor families and contribution of this activity in forest conservation, Ministry of Environment, Forest and Climate change, Government of India has issued guidelines under the Forest (Conservation) Act, 1980 that says – plantation of forestry host plant for tropical tasar seri-business is a forestry activity, provided that such plantation does not involve any felling of the trees and while undertaking such plantations, at least three forest tree species are planted of which no single species covers more than 50 % of the total planted area. The one-stop compilation of scientific information on the impact of rearing seasons, forest tree species and their interaction on economic traits of *A. mylitta* will serve as guidelines for location-based introduction of tropical tasar culture for the forest-dependent people, especially of tropical forest areas of our country, to improve their means of livelihood.

REFERENCES

- Abraham G., Thomas G. and Babu C. R. (2004) Induction of bio-molecules in mature leaves of *Terminalia arjuna* due to feeding of *Antheraea mylitta* Drury. *The Scientific World Journal*, 4: 887-891.

- Agarwal S. C., Jolly M. S. and Sinha A. K. (1980) Foliar constituents of secondary food plants of tasar silkworm *Antheraea mylitta* D. *Indian Forester*, **106** (12): 847-851.
- Ahsan M. M. and Griyaghey U. P. (1973) Effect of rearing with different food plants In: *Annual Report 1972-73*, Central Tasar Research and Training Institute, Ranchi, Jharkhand, India, pp. 41-43.
- Akai H. (1998) Global scenario of wild silk. *Indian Silk* **7**: 18-20.
- Akai H., Suto M., Ashoka K., Nayak B. K. and Jagannatha Rao C. B. (1991) Rearing of *Antheraea mylitta* with newly developed artificial diet. *Wild Silkmoth*, **89-90**: 121-127.
- Awmack C. S. and Leather S. R. (2002) Host plant quality and fecundity in herbivorous insects. *Annu. Rev. Entomol.*, **47**: 817-844.
- Bae S. D., Park K. B. and Oh Y. J. (1997) Effects of temperature and food source on the egg and larval development of tobacco cutworm *Spodoptera litura* Fabricius. *Korean J. Appl. Entomol.*, **36**: 48-54.
- Bale J. S., Masters G. J., Hodkinson and Awmack C. (2002) Herbivory in global climate change research, direct effects of rising temperatures on insect herbivores. *Glob. Chang. Biol.*, **8**: 1-16.
- Barah A., Phukan S. N. and Samson M.V. (1988) Variation in cocoon characters of *Antheraea assama* Ww during different seasons. *Sericologia*, **28** (2): 215-218.
- Barbosa P. and Jane G. (1979) Suitability, digestibility and assimilation of various host plants of the gypsy moth, *Lymantria dispar* L. *Oecologia*, **43** (1): 111-119.
- Barnes O. L. (1955) Effect of food plants on lesser migratory grasshopper. *J. Econ. Entomol.*, **48**: 119-124.
- Basu A. C. (1944) Effect of different foods on the larval development of the moth *Prodeni litura* Fb (Lepidoptera: Noctuidae). *J. Bombay Nat. Hist. Soc.*, **44** (1&2): 275-288.
- Behmer S. T. (2006) Insect Dietary Needs, Plants as Food for Insects. *Encyclopaedia of Plant and Crop Science*, **12**: 1-4.
- Benchamin K. V. and Jolly M. S. (1986) Principles of silkworm rearing. In: *Proceedings of Seminar on Problems and Prospects of Sericulture*, Mahalingam S. (Ed.), Vellore, India, pp. 63-108.
- Bhanot J. P. and Kapil R. P. (1973) Effect of starvation on fecundity and hatchability of the eggs of *Acaropsis docta* (Berlese). *Indian J. Entomol.*, **35**: 67-69.
- Bhardwaj S. C. and Kushwaha K. S. (1976) Effect of host plants on the larval and post-larval development of the hairy caterpillar *Amsacta lineola* Fabricius. *Indian J. Entomol.*, **38**(3): 230-232.
- Bhat N. S. and Bhattacharya A. K. (1978) Consumption and utilization of soyabean by *Spodoptera litura* (Fabr) at different temperatures. *Indian J. Entomol.*, **40**: 16-25.
- Bhatia N. K. and Yousuf M. (2013 a) Reassuring livelihood functions of the forests to their dependents: Adoption of collaborative forest management system over Joint forest management regime in India. *Ann. Forest Res.*, **56** (2): 377-388.
- Bhatia N. K. and Yousuf M. (2013 b) Forest insect industry in collaborative forest management: an overview. *Int. J. Indust. Entomol.*, **27**(1): 166-179.
- Bhatia N. K. and Yousuf M. (2013 c) Assessment on climatic suitability of New Forest, FRI, Dehradun to introduce forest based rearing of tropical tasar silkworm, *Antheraea mylitta* Drury in Uttarakhand, India. *Ann. Entomol.*, **31** (1): 55-66.
- Bhatia N. K. and Yousuf M. (2013 d) Parasitic Behaviour of *Xanthopimpla pedator* Fabricius (Hymenoptera: Ichneumonidae) on Tropical Tasar Silkworm, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) reared on Seven Forestry Host Plants in Uttarakhand, India. *Int. J. Indust.*

- Entomol.*, **27** (2): 243-264.
- Bhattacharya A. K. and Pant N. C. (1976) Studies on the host plant relationships, consumption and utilization profile in insects. *Proc. Natl. Acad. Sci. India*, **46** (B), 273-301.
- Bogawat J. K. (1967) Biology of mustard saw fly on different host plants. *Indian J. Entomol.*, **29** (3): 270-274.
- Bongale U.D., Chaluvachari M. and Narahari Rao B.V. (1991) Mulberry leaf quality evaluation and its importance. *Indian Silk*, **30**: 51-53.
- Brues C. T. (1920) The selection of food plants by insects with special reference to Lepidoptera larvae. *Am. Nat.*, **54**: 313-322.
- Brues C. T. (1924) The specificity of food plants in the evolution phytophagous insects. *Am. Nat.*, **58**: 127-144.
- Brues C. T. (1940) Food preferences of the Colorado potato beetle *Leptinotarsa decemlineata* Say. *Psyche*, **47**: 38-43.
- Butler C. G. (1940) The choice of drinking water by the honeybee. *J. Exp. Biol.*, **17**: 253-261.
- Carne P. B. (1966) Growth and food consumption during larval stages of *Paropsis atomaria* (Coleoptera: Chrysomelidae). *Entomol. Exp. Appl.*, **9**: 105-112.
- Casey T. M. (1981) Behavioural mechanism of thermoregulation. In: *Insect thermoregulation*, Heinrich B. (Ed.), John Wiley and Sons, New York, pp. 79-114.
- Chakrabarty D., Gupta R. and Chatterjee K. K. (2003) Effect of outdoor preservation of tasar seed cocoon on pupal survival and reproductive behavior of Daba ecorace of *A. mylita*. *Indian J. Seric.*, **42** (2), 160-164.
- Chapman R. F. (1998) *The insects: Structure and Function*. Cambridge University Press, Cambridge, pp. 788.
- Chapman R. F. (2002) *The Insects: Structure and Function*. Cambridge University Press, Cambridge, pp. 242-386.
- Chaudhuri M. (2003) Studies on the relationship between silk yield, yield components and rearing environment of muga silkworm *Antheraea assama* Ww. *Sericologia*, **43**: 349-354.
- Chaudhuri, 2003;
- Choudhary S. N. (1981) *Muga silk industry*. Directorate of Sericulture and Weaving, Government of Assam, pp. 71-73.
- Cizek L., Fric Z. and Konvicka M. (2006) Host plant defences and voltinism in European butterflies. *Ecol. Entomol.*, **31**: 337-344.
- Clarke A. (2003) Costs and consequences of evolutionary temperature adoption. *Trends Ecol. Evol.*, **18** (11): 573-581.
- Coviella C. and Trumble J. (1999) Effects of elevated atmospheric carbon dioxide on insect plant interactions. *Conserv. Biol.*, **13**: 700-712.
- Crotch W. J. B. (1956) *Silkmoth rearers handbook*. Amateur Entomologists' Society, p. 155.
- Crowell H. H. (1941) The utilization of certain nitrogenous and carbohydrate substances by the southern army worm *Prodenia litura*. *Cram. Ann. Ent. Soc. Am.*, **34**: 503-512.
- CSB (2018) State-wise Silk production during 2017-18. *Annual Report 2017-18*, Central Silk Board, Ministry of Textiles, Government of India, Bangalore, India, pp. 92-93.
- Cunnington A. M. (1985) Factors affecting oviposition and fecundity in the grain mite *Acarus siro* (Acarina: Acaridae) especially temperature and humidity. *Exp. Appl. Acarol.*, **4**: 327-344.
- Dadd R. H. (1960) Observations on the palatability and utilization of food by locusts with particular reference to the interpretation of performances in growth trials using synthetic diets. *Entomol. Exp. Appl.*, **3**: 283-304.

- Das P., Bhattacharya P. R., Unni B. G. and Deka P. C. (2004) Consumption and utilisation of food (*Persea bombycina*) in relation to larval development and silk protein biosynthesis by semi-domesticated muga silkworm, *Antheraea assama*. *Indian J. Seric.*, **43** (1): 57-65.
- Dash A. K. (2001) Rainy season energy budget of larva of Indian tasar silk moth *Antheraea mylitta* Drury (Saturniidae) living in wild Sal (*Shorea robusta*) host plant. *Int. J. Wild Silkmoth & Silk*, **6**: 1-7.
- Dash A. K. and Dash M. C. (1989) Energetics of the Indian tasar silkworm *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) raised on Asan (*Terminalia tomentosa*) food plant. *Int. J. Wild Silkmoth & Silk*, **2**: 165-172.
- Dash A. K., Jena K. and Behera B. (2012) Altitudinal effect on growth of pupa of Indian tasar silk insect *Antheraea mylitta* Drury (Saturniidae) reared in rainy season. *Bull. Indian Acad. Seric.*, **6**: 81-88.
- Dash A. K., Mishra S., Nayak B. K. and Dash M. C. (1988) Studies on effect of starvation stress on hatchlings of tasar silk insects *Antheraea mylitta* Drury. *Annual Report, Sericulture Research Station, Orissa*, **5**: 42-44.
- Dash A. K. and Nayak B. K. (1990) Seasonal variation of occurrence of deformed cocoons of the tasar silk moths *Antheraea mylitta* (Drury) and *Antheraea paphia* (L) (Saturniidae) in India. *J. Lepid. Soc.*, **44** (1): 34-36.
- Dash A. K., Nayak B. K. and Dash M. C. (1992) The effect of different food plants on cocoon crop performance in the Indian tasar silkworm *Antheraea mylitta* Drury (Lepidoptera: Saturniidae). *J. Res. Lepid.*, **31** (1-2): 127-131.
- Dash A. K., Nayak B. K. and Dash M. C. (1996) Energetics of the Indian tasar silkworm *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) raised on Arjun (*Terminalia arjun*). *Int. J. Wild Silkmoth & Silk*, **2**: 37-40.
- Dash A. K., Patro P. C., Nayak B. K. and Das M. C. (1994) Cocoon crop performance of the Indian wild tasar silkworm *Antheraea paphia* (Lepidoptera: Saturniidae) reared on different food plants. *Int. J. Wild Silkmoth & Silk*, **1**: 72-74.
- Datta R. K. (1992) *Guidelines for bivoltine silkworm rearing*. Central Silk Board, Bangalore, India, p. 18.
- Deka M., Dutta S. and Devi D. (2011) Impact of feeding of *Samia cynthia ricini* Boisduval (Lepidoptera: Saturniidae) in respect of larval growth and spinning. *Int. J. Pure Appl. Sci. Technol.*, **5** (2): 131-140.
- Deka M. and Kumari M. (2013) Comparative study of the effect of different food plant species on cocoon crop performance of tropical tasar silkworm (*Antheraea mylitta* Drury). *Int. J. Res. Chem. Environ.*, **3** (1): 99-104.
- Dethier V. G. (1947) *Chemical Insect Attractants and Repellents*. Lewis and Co., London.
- Dethier V. G. (1966) Feeding behaviour. *Symposia of Royal Entomological Society of London*, **3**: 47-57.
- Devaiah M. C. and Dayashankar K. N. (1982) Effect of different host plants on the economic traits of eri silkworm *Samia cynthia ricini* Biosduval (Lepidoptera: Saturniidae). *National Seminar on Silk Research and Development*, pp. 25-32.
- Dhavalikar R. S. (1962) Amino acid composition of Indian silk fibroins and sericins. *J. Sci. Indian Res.*, **21**: 261-263.
- Dubey A. K., Mishra U. S. and Dixit S. A. (1981) Effect of host plant on the developmental stages of gram pod borer, *Heliothis armigera* (Hubner). *Indian J. Entomol.*, **43** (2): 178-182.
- Etman A. and Hooper G. H. S (1979) Developmental and reproductive biology of *Spodoptera litura* (F) (Lepidoptera: Noctuidae). *J. Aust. Entomol. Soc.*, **18**: 363-372.
- Evans A. C. and Goodliffe E. R. (1939) The utilization of mealworm *Tenebrio molitor* L (Coleop.). *Proc. R. Soc. Am.*,

- 14: 57-62.
- Garcia M. A. (1991) *Ecologia nutricional de parasitoides e predadores terrestres*. In: *Ecologia nutricional de insetos e suas implicacoes no manejo de pragas* Sao Paulo, Panizzi A. R. and Parra J.R.P. (Ed.), Manole, p. 359.
- Getu E. D. (2007) Comparative studies of the influence of relative humidity and temperature on the longevity and fecundity of the parasitoid, *Cotesia flavipes*. *J. Insect Sci.*, **19**: 1536-2442.
- Gordon H. T. (1999) Growth and development of insects. In: *Ecological Entomology*, Huffaker C. B. and Gutierrez A. P. (Ed.), John Wiley & Sons, Inc New York, pp. 55-82.
- Grabstein E. M. and Scriber J. M. (1982) The relationship between restriction of host plant consumption and post ingestive utilization of biomass and nitrogen in *Hyalophora cecropia*. *Entomol. Exp. Appl.*, **31**: 202-210.
- Green N. P. O., Stout G. W. and Taylor D. J. (1996) *Biological Science*. Cambridge Low Price Edition, pp. 675-677.
- Guan B. B. and Chen O. J. (1999) Biology and Ecology of *Spodoptera litura*. *Acta Entomol.*, **8**: 57-61.
- Hazarika U., Barah A., Phukan J. C. D. and Benchamin K.V. (2003) Study on the effect of different food plants and seasons on the larval development and cocoon characters of silkworm, *Samia cynthia ricini* Boisduval. *Bull. Indian Acad. Seric.*, **7** (1): 77-85.
- Hamilton J. G., Dermody O., Aldea M., Zangerl A. R. and Rogers A. (2005) Anthropogenic changes in tropospheric composition increase susceptibility of soybean to insect herbivory. *Environ. Entomol.* **34** (2): 479-485.
- Hansda G., Reddy R. M., Sinha M. K., Ojha N. G. and Prakash N. B. V. (2008) *Ex situ* stabilization and utility prospects of Jata ecorace of tropical tasar silkworm, *Antheraea mylitta* Drury. *Int. J. Indust. Entomol.*, **17**: 169-172.
- Hassell M. P. and Southwood T. R. E. (1978) Foraging strategies of insects. *Annu. Rev. Ecol. Syst.*, **9**: 75-98.
- Hiratsuka E. (1920) Researches on nutrition of silkworm. *Bull. Seric. Exp. Stn.*, **1**: 257-315.
- Hopkins F. G. (1912) Feeding experiments illustrating the importance of accessory factors in normal dataries. *J. Physiol.*, **44**: 452-460.
- Hough J. A. and Pimentel D. (1978) Influence of host foliage on development, survival and fecundity of gypsy moth. *Environ. Entomol.*, **7**: 97-102.
- Hunter M. D. (2001) Effects of elevated atmospheric carbon dioxide on insect-plant interactions. *Agric. Forest Entomol.*, **3**: 153-159.
- Ito T. (1967) Nutritional requirements of the silkworm *Bombyx mori*. *Proc. Jpn. Acad. Ser. A*, **43**: 57-61.
- Jayaramaiah M. and Sannappa B. (1998) Correlation coefficient between foliar constituent of castor genotypes and economic parameters of the eri silkworm, *Samia cynthia ricini* Boisduval (Lepidoptera: Saturniidae). *Proceedings of Third International Conference on Wild Silk Moths*, Bhubaneswar, Odisha, International Sericultural Commission, November 11-14, pp. 162-164.
- Johansen N. B. (1997) Influence of temperature on development, fecundity and survival of the cabbage moth, *Mamestra brassicae* (Lepidoptera: Noctuidae) in relation to the improvement of forecasting and control methods. *J. Appl. Entomol.*, **121**: 81-88.
- Jolly M. S. (1965) Scope of inter-specific hybridisation in *Antheraea*. In: *Proceedings of World Congress on Silk Production*, Central Silk Board, Bangalore, pp. 1-8.
- Jolly M. S., Sen S. K. and Ahsan M. N. (1974) *Tasar culture*, Ambica Publishers, Bombay, p. 266.
- Jolly M. S., Sen S. K., Sonwalker T. N. and Prasad G. K. (1979)

- Non-mulberry silk. *FAO Manuals on Sericulture Vol. (4) Non-mulberry Silks*, Food and Agriculture Organization of the United Nations, Rome, pp. 1-179.
- Jolly M. S., Sinha S. S. and Razdan J. L. (1970) Influence of temperature and photoperiod on termination of pupal diapauses in the tasar silkworm (*A. mylitta* D). *J. Insect Physiol.*, **17**: 753-760.
- Kapila M. L., Chaudhury A., Dubey O. P., Chaudhuri C. C. and Sinha S. S. (1992) Studies on the preservation of seed cocoons of the tasar silkworm, *Antheraea mylitta* D during diapauses. *Sericologia*, **32** (4): 579-591.
- Kar J. K., Guru B. C. and Nayak B. K. (1998) Influence of season on the life span and commercial traits of cultivated eri silk moth, *Samia ricini* Donovan. *Proceedings of Third International Conference on Wild Silkmooths*, Bhubaneswar, Odisha, International Sericultural Commission, November 11-14, pp. 59-60.
- Krishnaswami S., Narasimhanna M. N., Suryanarayana S., Kumararaj S. (1973) *Sericulture Manual Part-2*. FAO Agricultural Services, pp. 1-131.
- Kohli R. K., Jolly M. S. and Khan A. M. (1969) Foliar constituents of food plants of tasar silkworm, *Antheraea mylitta* D. *Indian Forester*, **95** (9): 614-617.
- Kozhanchikov I. V. (1950) Fundamental features of food utilization in the Asiatic locust. *Izv. Akad. Nauk. SSSR Biol.*, **4**: 73-86.
- Krishnaprasad N. K., Sannappa B. and Varalakshmi R. (2002) Effect of multiple mating on grainage performance of newly evolved bivoltine breeds of *Bombyx mori* L. *B Indian Acad Seric.*, **6**: 50-55.
- Krishnaswami S. (1978) New technology of silkworm rearing. *Indian Silk*, **16** (12): 7-15.
- Krishnaswami S., Ahsan M. M. and Sriharan T. P. (1970) Studies on quality of mulberry leaves and silkworm cocoon production Part 2, Quality difference due to maturity. *Indian J. Seric.*, **9**: 11-17.
- Krishnaswami S., Kumara S., Vijayaraghavan K. and Kasiviswanathan K. (1971 a) Silkworm feeding traits for evaluating the quality of mulberry leaves as influenced by variety spacing and nitrogen fertilizations. *Indian J. Seric.*, **10**: 70-89.
- Krishnaswami S., Sriharan T. P. and Ahasen A. M. (1971 b) Ecological studies on silkworm rearing to prevent crop losses in adverse seasons in West Bengal. *Indian J. Seric.*, **10**: 72-76.
- Kumar K. K. P. and Naik S. S. (2011) Development of polyvoltine bivoltine hybrids of mulberry silkworm *Bombyx mori* L tolerant to BmNPV. *Int. J. Zool. Res.*, **7**: 300-309.
- Kumar R., Gargi and Hembrom I. (2012) Bioassay studies in *Terminalia* sp., *Lagerstroemia parviflora* and *L. speciosa*. In: *Annual Report 2011-12*, Central Tasar Research and Training Institute, Ranchi, Jharkhand, India, pp. 4-5.
- Kumar R., Gargi and Hembrom I. (2011) Bioassay studies of *Antheraea mylitta* in different accessions of *Terminalia arjuna* (18), *T. tomentosa* (9), *T. chebula* (1) and *Anogeissus latifolia* (1) during July-August 2010. In: *Annual Report 2010-11*, Central Tasar Research and Training Institute, Ranchi, Jharkhand, India, pp. 2-5.
- Lefroy H. M. (1909) *Indian insect life- A manual of the insects of plains (tropical India)*. Published under the authority of the Government of India, Thacker Spink & Co., W. Thacker & Co., 2 Creed Lane, London, p. 773
- Legay J. M. (1958) Recent advances in silkworm nutrition. *Ann. Rev. Entomol.*, **3**: 75-86.
- Lindroth R. L. and Hemming J. C. (1990) Response of the gypsy moth to aspen phenolic glycosides. *Biochem. Syst. Ecol.*, **15**: 685-690.
- Lipke H. and Fraenkel G. (1956) Insect nutrition. *Ann. Rev.*

- Entomol.*, **1**: 17-44.
- Machii H. and Katagiri K. (1991) Varietal differences in nutritive values of mulberry leaves for rearing silkworms. *Jpn. Agric. Res. Q.*, **25** (3): 202-208.
- Mathur S. K. and Lal S. B. (1994) Effects of temperature and humidity on the adaptability of insects. *Indian Textile J.*, **136**: 34-47.
- Mathur S. K., Pramanik D. R., Sen S. K. and Rao S. (1995) Effect of seasonal temperature and humidity on ovulation, fecundity and retention of eggs in silkworm *Bombyx mori* L. (Lepidoptera: Bombycidae). *Records of Zoological Survey of India*, **95**: 57-64.
- Matsumura S., Tanaka S., Kosaka and Suzuki S. (1958) Relation of rearing condition to the ingestion and digestion of mulberry leaves in the silkworm. *Bull. Seric. Exp. Stn.*, **73**: 1-40.
- Mattson W. J. and Haack R. A. (1987) The role of draught stress in provoking outbreaks of phytophagous insects. In: *Insect Outbreaks*, Barbosa P. and Schultz J. C. (Ed.), Academic press, San Diego, pp. 365-407.
- Mc Ginnis A. J. and Kasting R. (1959) Nutrition of pale western cutworm *Agrotis orthogonia* Morr (Lepidoptera: Noctuidae). *Can. J. Zool.*, **37**: 259-266.
- Mishra C. S. K., Nayak B. K. and Das M.C. (1997) Studies on the reproductive behaviour of the Indian tasar silk moth, *Antheraea mylitta* (Saturniidae) reared on *Terminalia tomentosa*, *Terminalia arjuna* and *Shorea robusta* plants in different seasons. *Int. J. Wild Silkmoth & Silk*, **3**: 71-73.
- Mohanty P. K. and Behera B. (1998) Abnormal tasar cocoons. *Indian Silk*, **37** (8): 30-31.
- Murthy G. V. S., Venu P. and Sanjappa M. (1996) Climate. In: *Flora of India-Introductory volume Part I*, Hajra P. K., Sharma B. D., Sanjappa M. and Sastry A. R. K. (Ed.), Botanical Survey of India, Calcutta, p. 538.
- Muthukrishnan J. and Delvi M. R. (1974) Effect of ration level on food utilization in grasshopper, *Poecilocerus pictus*. *Oecologia*, **16**: 227-236.
- Muthukrishnan J., Mathavan S. and Navarathina J. V. (1978) Effect of restriction of the feeding duration on food utilisation emergence and silk production in *Bombyx mori* L. (Lepidoptera: Bombycidae). *Ital. J. Zool.*, **12**: 87-94.
- Nagalakshamma K. (1987) Investigation on some aspects of seed technology in Eri silkworm *Samia cynthia ricini* Boisduval. *M. Sc. (Agriculture) Thesis*, University of Agricultural Sciences, Bangalore, p. 84.
- Naik C. M., Patil G. M., Murthy C., Awaknavar J. S., Shekharappa and Alagundagi S. C. (2010) Development and economic cocoon parameters of eri silkworm, *Samia cynthia ricini* Boisduval (Lepidoptera: Saturniidae) as influenced by new hosts. *Karnataka J. Agric. Sci.*, **23** (5): 716-721.
- Narasimhanna M. N. and Jolly M. S. (1969) Arrangement of tubercular setae in tasar silkworm *Antheraea mylitta* D. *Bull. Entomol.*, **10**: 150-152.
- Narasimhanna M. N., Jolly M. S. and Sinha B. R. P. (1969) Frequency of occurrence of lateral shining spots in *Antheraea mylitta* D. *Indian J. Heredity*, **7**: 49-52.
- Narayanan E. S., Kasivishanathan K. and Iyenger M. N. S. (1967) Preliminary observations on the effect of feeding leaves of varying maturity on the larval development and cocoon characters *Bombyx mori*. *Indian J. Seric.*, **1**: 109-113.
- Nath T. N., Nath S., Shamsuddin M. and Subba Rao G. (1990) Effect of food deprivation on dry matter utilization, shell and cocoon weight and fecundity of multivoltine silkworm *Bombyx mori* L race Nistari. *Indian J. Seric.*, **29**: 174-181.
- Nayak B. K. and Dash A.K. (1989) Effect of refrigeration on egg incubation period of the tasar silk insect, *Antheraea mylitta* Drury (Saturniidae). *J. Lepid. Soc.*, **43** (2): 152-153.

- Nayak B. K., Dash A. K., Sasmal A. K. and Dash M. C. (1988) Studies on growth and leaf yield of the primary tasar food plants, Asan (*Terminalia tomentosa*), Arjun (*T. arjuna*) and Sal (*Shorea robusta*) of different age groups. *Annu. Rept. St. Seric. Res. Stn. Ori.*, **5**: 13–14.
- Nayak B. K., Dash A. K., Patro K. B. G. (2000) Biodiversity conservation of wild tasar silk moth *Antheraea paphia* L. of Simlipal biosphere reserve and strategy for its economic utilization. *Int. J. Wild Silkworm & Silk*, **5**: 367-370.
- Nayak B. K., Dash A. K., Dash M. C. and Akai H. (1992) Environmental regulation of voltinism in *A. paphia* Linn (Lepidoptera: Saturniidae), the Indian tasar silk insect. *Wild Silkworm*, **4**: 47–56.
- Nayak B. K. and Guru B. C. (1998) Studies on cocoon biometry of the bivoltine tasar silkworm *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) reared at Bangiriposi. *B Indian Acad. Seric.*, **2** (1): 31-34.
- NISCAIR (1976) *The Wealth of India - An Encyclopaedia of India's Raw Material Resources Vol X*. Council of Scientific and Industrial Research -National Institute of Science Communication and Information Resources (CSIR-NISCAIR), New Delhi, pp. 157-177.
- Odum E. P. (1983) *Basic Ecology*. Holt Saunders International Edition, Tokyo, Japan, p. 244.
- Ojha N. G., Reddy R. M., Hansda G., Sinha M. K., Suryanarayana N. and Prakash N. B. K. (2009) Status and potential of Jata a new race of Indian tropical tasar silkworm (*Antheraea mylitta* Drury). *Acad. J. Entomol.*, **2** (2): 80-84.
- Ojha N. G., Sinha S. S., Singh M. K. and Sharan S. K. (1994) Rearing and cocooning of tropical tasar silkworm, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) in indoor condition. *Int. J. Wild Silkworm & Silk*, **1** (2): 257–260.
- Ouedraogo P. A., Sou S., Sanon A., Monge J. P., Huignard J., Tran B. and Credland P. F. (1996) Influence of temperature and humidity on populations of *Callosobruchus maculatus* (Coleoptera: Bruchidae) and its parasitoid *Dinarmus basalis* (Pteromalidae) in two climatic zones of Burkina Faso. *B Entomol. Res.*, **89**: 695-702.
- Panda N. (1972) Biometrical Studies on the Tassar Silk Cocoon (*Antheraea paphia* L.) of Orissa. *Indian Forester*, **98** (7): 427-431.
- Pandey N. D., Yadava D. R. and Teotia T. P. S. (1968) Effect of different food plants on larval and post larval development on *Diacrisia obliqua* Walk. *Indian J. Entomol.*, **30** (3): 229-234.
- Pandey R. K. (1995) Do leaf tannins affect non-mulberry silkworm? *Indian Silk*, **34** (8): 21-23.
- Patil G. M. (1998) Castor *Ricinus communis* L. - A potential new host of tropical tasar silkworm, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae). *Proceedings of the third international conference on wild silkworms*, pp. 51-53.
- Pattanayak J. and Dash A. K. (2000) Allocation of energy for cocoon and pupal life of matured larva of *Antheraea mylitta* (Drury), the Indian tasar silk insect. *Sericologia*, **40**: 657-660.
- Periaswamy K. (1994) *Problems and prospectus of sericulture*. PBS Publishers and Distributors, Noida, Uttar Pradesh, India, pp. 293-307.
- Pillai V., Krishnaswami S. and Kashivishwanathan K. (1987) Growth studies of silkworm *Bombyx mori* L. in tropical conditions. *Indian J. Seric.*, **16**: 32-45.
- Ponnuvel K. M., Noamani M. K. R., Luikham R. and Singh K. C. (1996) Seasonal variation in biochemical constituents of oak *Quercus serrata* leaf. *Proc. Natl. Acad. Sci. India*, **66** (B): 283-287.
- Prasad B. C., Rath S. S., Nagedra S., Sinha B. R. R. P. (2004) Cashew, another food plant for tropical silkworms. *Indian Silk*, **3**: 17-18.

- Prasad G. K. (1980) Effect of habitat and food on the evolutionary trends in genus *Antheraea* as evident from taxonomic relationship (Silkworm). *Indian J. Ecol.*, **1**: 52-60.
- Price P. W. (1997) *Insect Ecology*. John Wiley & Sons, Inc New York, pp. 73-104.
- Puri G. S. (1994) The foliar constituents in some tree species of *Shorea robusta* forests of the Shivalik, UP, India. *Indian Forester*, **80** (11): 692-699.
- Radjabi R., Ebodi R., Mirhoseini S. Z. and Nair S. (2009) Effects of feeding alanine-enriched mulberry leaves on the economic characters of the silkworm *Bombyx mori* (Lepidoptera: Bombycidae). *Formos Entomol.*, **23**: 73-78.
- Rahmathulla V. K. and Suresh H. M. (2012) Seasonal variation in food consumption, assimilation and conversion efficiency of Indian bivoltine hybrid silkworm, *Bombyx mori*. *J. Insect Sci.*, **12** (82): 1-14.
- Raja Ram and Sharadchandra M. V. (1998) Effect of different types of diet of Dighloti, Majankuri Som and Soalu on the rearing of muga silkworm, *Antheraea assamai* Westwood. *Proceedings of Third International Conference on Wild Silkmooths*, Bhubaneswar, Odisha, International Sericultural Commission, November 11-14, pp. 95-66.
- Rajanna K. L., Jagadeesh N., Gowda P., Nair B. P. and Samson M.V. (1999) Performance of pure Mysore x bivoltine hybrid combinations of silkworm, *Bombyx mori* L. *Indian J. Seric.*, **38**: 113-118.
- Rao A. P. and Shamitha G. (2000) Cocoon and post cocoon studies on outdoor and total indoor reared tasar silkworm, *Antheraea mylitta* D. *Uttar Pradesh J. Zool.*, **20** (3): 213 - 218.
- Rao J. V. K., Singh R. N. and Shetty K. K. (2003) Catalogue of wild silkworms and their host plants in India. In: *Proceedings of the National Workshop on Vanya Silk Culture and Forestry*, Rana A. K., Bisht N. S., Khatri R. K., Khanna D., Siddiqui A. A. and Babulal (Ed.), Forest Research Institute, Indian Council of Forestry Research and Education, New Forest, Dehradun, India, pp. 1-8.
- Rao K. V. S. (2001) Tasar crop planning in Bastar plateau of Chhattisgarh. *Indian Silk*, **40** (5): 11-13.
- Rao K. V. S., Mahobia G. P., Roy G. C. and Sinha B. R. R. P. (2004) Relevance of in-situ conservation of wild tasar (*Antheraea mylitta* Drury) in India. *Indian J. Ecol.*, **31**: 127-131.
- Rath S. S. (2000) Studies on growth and development of *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) fed on three different natural host plants. *Int. J. Wild Silkmooth & Silk*, **5**: 99-103.
- Rath S. S. (2005) Effect of quantitative nutrition on adult characters and reproductive fitness in *Antheraea mylitta* Drury. *Int. J. Indust. Entomol.*, **10** (1): 19-24.
- Rath S. S. (2010) Impact of quantitative feeding on nutritional parameters of fifth instar larvae of *Antheraea mylitta*. *Int. J. Indust. Entomol.*, **20** (2): 69-74.
- Rath S. S., Singh M. K. and Suryanarayana N. (2006) Change in rate of feeding and assimilation in *Antheraea mylitta* fed on two major food plants and its effect on silk production and reproduction. *Agricultural Journal*, **1** (1): 24-27.
- Rath S. S., Singh R. M. K. and Suryanarayana N (2007) Effect of mating delay and mating duration on reproductive performance of *Antheraea mylitta*. *Int. J. Indust. Entomol.*, **14**: 113-119.
- Rath S. S., Sinha B. R. R. P. and Sinha S. S. (1997) Age specific changes in reproductive potential and longevity in female moths of *Antheraea mylitta* D (Lepidoptera: Saturniidae). *Indian J. Seric.*, **36** (1): 39-42.
- Rath S. S., Sinha B. R. R. P. and Thangavelu K. (2004) Nutritional efficiency in *Antheraea mylitta* D during food deprivation. *Int. J. Indust. Entomol.*, **9**: 111-115.

- Rausher M. D. (1981) Host plant selection by *Battus philenor* butterflies, the role of predation nutrition and plant chemistry. *Ecol. Monograph*, **51**: 1-20.
- Reddy D. N. R., Kotikal Y. K. and Vijayendra M. (1989) Development and silk yield of eri silkworm, *Samia cynthia* (Lepidoptera: Saturniidae) as influenced by the food plants. *Mysore J. Agric. Sci.*, **23**: 506-508.
- Reddy R. M. (2010) Conservation need of tropical tasar silk insect, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae)-strategies and impact. *J. Entomol.*, **7** (3): 152-159.
- Reddy R. M., Hansda G., Ojha N. G. and Suryanarayana N. (2009) Utility scope of hybridization in seed production of tropical tasar silkworm, *Antheraea mylitta* Drury. *Sericologia*, **49**: 547-551.
- Reddy R. M., Rupesh C., Mohan R. K., Angadi B. S. and Sivaprasad V. (2012) Commercial prospective of *Lagerstroemia parviflora* (Roxb) as choice food plant of tropical tasar silkworm, *Antheraea mylitta* (Drury). *Int. J. Res. Chem., Environ.*, **2** (1): 70-73.
- Reddy R. M., Sinha A. K., Kumar R. and Prasad B. C. (2010) Parental combination and rearing season compatibility for silk yield in tropical tasar silkworm, *Antheraea mylitta* Drury. *World Applied Sci. J.*, **9** (8): 855-859.
- Reese J. C and Beck S. D. (1978) Interrelationship of nutritional indices and dietary moisture in the black cutworm (*Agrotis ipsilon*) digestive efficiency. *J. Insect Physiol.*, **24**: 473-479.
- Sahay A., Ojha N. G., Kulshrestha V., Singh G. P., Roy D. K. and Suryanarayana N. (2008) Application of sodium hypochlorite for controlling virosis and bacteriosis in tasar silkworm, *Antheraea mylitta* D. *Sericologia*, **48** (1): 71-79.
- Sahu A. K., Singh B. B. and Das P. K. (1998) Phenological studies in muga silkworm, *Antheraea assama* Ww (Lepidoptera: Saturniidae) in relation to its rearing and grainage behaviour. *Proceedings of third international conference on wild Silkmoths*, International Sericultural Commission, November 11-14, pp. 25-28.
- Saikia S., Handique R., Pathak A. and Das K. (2004) Rearing performance of muga on the primary and secondary food plants with an attempt for the revival of now extinct mejankari silk heritage of Assam. *Sericologia*, **44**: 373-376.
- Sarkar D. C. (1980) *Ericulture in India*. Central Silk Board, Bombay, p. 51.
- Satpathy S. (2003) Studies on bioenergetics of tasar silkworm, *Antheraea mylitta* D during diapauses. *Indian J. Seric.*, **42** (1): 32-34.
- Scriber J. M. (1982) The behaviour and nutritional physiology of southern armyworm larvae as a function of plant species consumed in earlier instars. *Ent. Exp. Appl.*, **31**: 359-369.
- Scriber J. M. and Slansky F. (1981) The nutritional ecology of immature insects. *Annu. Rev. Entomol.*, **26**: 183-211.
- Sengupta D., Srivastava A. K. and Ghosh S. S. (2002) Studies on commercial and technological characters of different ecoraces of *A mylitta* D commercially available in India. In: *Annual Report 2001-02*, Central Tasar Research and Training Institute, Ranchi, Jharkhand, India, pp. 59-60.
- Sengupta K. (1988) Bivoltine rearing in the plains and plateaus of South India. *Indian Silk*, **27** (7): 25-27.
- Sengupta K. and Singh K. (1974) An evaluation of the efficiency of different food plants and their combinations for the rearing of eri silkworm, *Philosamia ricini* Hutt. *Proceedings of the First International seminar on Non-Mulberry Silks*, p. 189.
- Shiva Kumar C., Sekharappa B. M. and Arangi S. K. (1997) Influence of temperature and leaf quality on rearing performance of silkworm, *Bombyx mori* L. *Indian J. Seric.*, **36** (2): 116-120.

5: 182-186.

- Siddiqui A. A., Babulal, Sharma A. K., Chauhan T. P. S. and Khatri R. K. (2006) Breeding park for tasar silkworm in Uttarakhand: a feasibility. *Indian Silk*, **45** (7): 12-15.
- Singh B. N. (1976) Development of *Utetheisa pulchella* Linn on *Crotalaria juncea* and *Heliotropium indicum*. *Indian J. Entomol.*, **38** (4): 398-400.
- Singh H. N. and Byas (1975) Larval development of *Prodenia litura* F in relation to certain cultivated plants. *Indian J. Entomol.*, **37** (1): 1-6.
- Singh T., Bhat M. M. and Khan M.A. (2009) Insect adaptations to changing environments - temperature and humidity. *Int. J. Indust. Entomol.*, **19** (1): 155-164.
- Singhvi N. R. and Bose P. C. (1991) Sericin - a deciding factor for the quality of cocoons and raw silk. *Indian Silk*, **4** (5): 26-28.
- Sinha A. K., Choudhary S. K., Brahmachari B. N. and Sengupta K. (1986) Foliar constituents of the food plants of temperate tasar silkworm, *Antheraea proylei*. *Indian J. Seric.*, **25** (1): 42-43.
- Sinha A. K. and Chaudhury A. (1992) Factors influencing phenology of different broods of tropical tasar silk moth, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae) in relation to its emergence and post emergence behaviour. *Environ. Ecol.*, **10** (4): 952-958.
- Sinha A. K. and Jolly M. S. (1971) Foliar constituents of the food plants of tasar silkworm, *Antheraea mylitta* D. *Indian Forester*, **97** (5): 261-263.
- Sinha S. S. and Sinha A. K. (1994) Genetic analysis of quantitative traits in *Antheraea mylitta*. *Int. J. Wild Silkmoth & Silk*, **1** (2): 177-181.
- Sinha U. S. P., Bajpayee C. M., Sinha A. K., Chari B. N. B. and Sinha B. R. R. P. (2000) Food consumption and utilization in *Antheraea mylitta* Drury larvae. *Int. J. Wild Silkmoth & Silk*, **5**: 182-186.
- Sinha U. S. P., Sinha A. K., Chaudhary S. K., Prasad J. and Suryanarayana N. (1998) Comparative study on the nutritive value of the food plants of tasar silkworm, *Antheraea mylitta* Drury. *Proceedings of the third international conference on wild silkmths*, pp. 281-284.
- Sinha U. S. P., Sinha A. K., Srivastava P. P. and Brahmachari B. N. (1992) Studies on the variations in chemical constituents in relation to maturity of leaves in three primary food plants of tropical tasar silkworm, *Antheraea mylitta* D. *Indian J. Seric.*, **31** (1): 83-86.
- Sinha U. S. P., Sinha A. K. and Suryanarayana N. (2007) A comparative biochemical study of hairy and non-hairy leaves of *Terminalia tomentosa*. *Sericologia*, **47** (3): 331-336.
- Situmorang J. (2002) Wild silk industry as new revenue to increase farmer's income and for environmental conservation. *Proceedings of International Conference on Wild silkmths*, 23rd-26th April 2002, Yogyakarta, Indonesia, pp. 1-16.
- Slama K. (1964) Hormonal control of respiratory metabolism during growth, reproduction and diapause in female adults of *Pyrrhocoris apterus* L (Hemiptera). *J. Insect Physiol.*, **9**: 283-303.
- Slansky F. (1980) Effect of food utilization on food consumption and reproductive allocation by adult milkweed bugs. *J. Insect Physiol.*, **26**: 79-84.
- Slansky F. (1982) Insect nutrition, an adaptationist's perspective. *Fla. Entomol.*, **65**: 45-71.
- Slansky F. (1985) Food Consumption and Utilization. In: *Comprehensive Insect Physiology, Biochemistry and Pharmacology, Vol. 4 Regulation, Digestion, Nutrition, Excretion*, Kerkut G. A. and Gilbert L. I. (Ed), Pergamon Press, Oxford, pp. 87-163.

- Slansky F. (1993) Nutritional Ecology, the fundamental quest for nutrition. In: *Caterpillars*, Stamp N. E. and Casey T. M. (Ed.), Chapman and Hall, London, p. 587.
- Slansky F. and Scriber J. M. (1985) Food consumption and utilisation. In: *Comprehensive Insect Physiology, Biochemistry and Pharmacology Vol. 4*, Kerkut G. A. and Gilbert L. I. (Ed.), Pergamon Press, New York, pp. 88-163.
- Smith D. S. (1959) Utilization of food plants by the migratory grasshopper, *Melanoplus bilituratus* (Walker) (Orthoptera: Acrididae) with some observations on the nutritional value of the plants. *Ann. Entomol. Soc. Am.*, **52**: 674-680.
- Smith D. S. and Nethcott F. E. (1951) The effect on the grasshopper, *Melanoplus mexicanus* Sauss (Orthoptera: Acrididae) of varying the nitrogen content in its food plant. *Can. J. Zool.*, **1** (29): 297-304.
- Srivastava P. K. and Thangavelu K. (2005) *Sericulture and Seriodiversity*. Associated Publishing Company, New Delhi, India, pp. 192-202.
- Srivastava A. D., Mishra S. D. and Poonia F. S. (1982) Effect of food deprivation on larval duration, cocoon shell weight and fecundity of eri silk moth, *Philosamia ricini* Hutt (Lepidoptera: Saturniidae). *Indian J. Seric.*, **21**: 11-15.
- Srivastava A. K., Naqvi A. H., Roy G. C. and Sinha B. R. R. P. (1998) Temporal variation in qualitative and quantitative character of *Antheraea mylitta* Drury. *Proceedings of third international conference on wild Silkmooths*, International Sericultural Commission, November 11-14, Bhubaneswar, Odisha, pp. 54-56.
- Srivastava A. K., Sinha A. K., Bishwa, Singh M. K., Bakshi R. P. and Sinha S. S. (1994) Efficiency of rearing on different host plants in three non mulberry silkworms. *Int. J. Wild Silkmooth & Silk*, **1** (2): 241-244.
- Srivastava B. K. (1959) Growth potential of *Laphygma exigua* in relation to certain food plants. *Madras Agric. J.*, **46** (7): 255-259.
- Srivastava P. K. (1986) Terminalia and tasar culture; yesterday today and tomorrow. *Indian Silk*, **26** (5): 35-37.
- Sudo M. (1981) The relation between the leaf quality at different orders and silkworm growth and cocoon quality. *J. Seric. Sci. Jpn.*, **50**: 306-310.
- Tamiru A., Getu E., Jembere B. and Bruce T. (2012) Effect of temperature and relative humidity on the development and fecundity of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae). *Bull. Entomol. Res.*, **102**: 9-15.
- Tanaka Y. (1951) Studies on hibernation with special reference to photoperiodicity and breeding of Chinese silkworm. *J. Seric. Sci. Jpn.*, **19**: 358-371.
- Thangamani R. and Vivekanandan M. (1984) Physiological studies and leaf analysis in the evaluation of best mulberry varieties. *Sericologia*, **24** (3): 317-324.
- Thangavelu K. (1992) Wild sericigenous insects of India: a need for conservation. *Wild Silkmooth*, **91**: 71-77.
- Thangavelu K. (2000) *Lessons on tropical tasar*. Central Tasar Research and Training Institute, Central Silk Board, Ranchi, India, p. 104.
- Thorsteinson A. J. (1960) Host selection in phytophagous insects. *Ann. Rev. Entomol.*, **5**: 193-218.
- Timmins W. A., Bellward K., Stamp A. J. and Reynolds S. E. (1988) Food intake, conversion efficiency and feeding behaviour of tobacco hornworm caterpillars given artificial diet of varying nutrient and water content. *Physiol. Entomol.*, **13**: 303-314.
- Trager W. (1953) Nutrition. In: *Insect Physiology* Roeder K. D. (Ed.), John Wiley & Sons, Inc. New York, pp. 350-386.
- Tripathi A. K., Sinha D. P. and Singh S. B. (1988) Rearing of *Antheraea mylitta* (Saturniidae: Lepidoptera) larvae on nine species of host plants. *Environ. Ecol.*, **6**: 331-334.

- Ueda S., Kimura R. and Suzuki K. (1971) Studies on the growth of silkworm *Bombyx mori* L: III Relative increase in body weight and silk gland weight in fifth instar. *Bull. Seric. Exp. Stn.*, **25**: 1-20.
- Ullal S. R. and Narasimhanna M. N. (1987) *Hand Book of Practical Sericulture*. Central Silk Board, Bangalore, pp. 1-166.
- Umbarihowar J. and Hastings A. (2002) The impact of resource limitation and the phenology of parasitoid attack on the duration of insect herbivore outbreaks. *Theor. Popul. Biol.*, **62**: 259-269.
- Uvarov B. P. (1928) Nutrition and metabolism. *Trans. Ent. Soc. Lond.*, **76**: 255-343.
- Venkataramu B. V. (1986) Nutrient status of different mulberry varieties and its effect on growth and development of *Bombyx mori* L. *M. Sc. (Agriculture) Thesis*, University of Agricultural Sciences, Bangalore, p. 88.
- Venugopal P. and Krishnaswami S. (1987) Adoptability of silkworm *Bombyx mori* L. to tropical condition. *Indian J. Seric.*, **26** (2): 63-71.
- Waldbauer G. P. (1968) Consumption and utilisation of food by insects. In: *Advances in Insect Physiology*, Beatment J. W. L., Trecherne J. W. and Wigglesworth V. B. (Ed.), Academic Press, London, pp. 229-288.
- Waldbauer G. (1996) *Insects through the seasons*. Harvard University Press, USA, p. 289.
- Waldbauer G. (2003) *What Good Are Bugs? Insects in the Web of Life*. Harvard University Press, USA, p. 345.
- Waldbauer G. P. (1964) Quantitative relationship between the number of fecal pellets, fecal weights and the weight of food eaten by tobacco hornworms. *Entomol. Exp. Appl.*, **7**: 310-314.
- Wellington W. G., Johnson D. L. and Lactin D. J. (1999) Weather and insects. In: *Ecological Entomology*, Huffaker C. B. and Gutierrez A. P. (Ed.), John Wiley and Sons, New York, p. 756.
- Xue M., Pang Y. H., Wang H. T., Li Q. L. and Liu T. X. (2009) Effects of four host plants on biology and food utilization of the cutworm, *Spodoptera litura*. *J. Insect Sci.*, **10**: 1-14.
- Yadav G. S., and Mahobia G. P. (2009) Exploitation of Sidha (*Lagerstroemia parviflora*) for rearing of tropical tasar silkworm in Bastar Plateau of Chhattisgarh, India. *J. Ecobiology*, **25** (1): 85-90.
- Yokoyama T. (1963) Sericulture. *Annu. Rev. Entomol.*, **8**: 287-306.

Revue

IMPACT DE LA SAISON D'ELEVAGE, DES PLANTES HOTES ET DE LEURS INTERACTIONS SUR LES CARACTERES ECONOMIQUES DE *ANTHERAEA MYLITTA*

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RÉSUMÉ

Le ver à soie tropical tasar, *Antheraea mylitta* (Lépidoptère: Saturnidé) est polyphage, insecte forestier producteur de soie ayant une importance commerciale en Inde. Les peuples dépendants de la forêt élèvent sa larve sur différentes plantes hôtes deux ou trois fois par an pour un faible revenu. Les larves de *A. mylitta* se nourrissent de beaucoup d'espèces d'arbres mais dans tous les cas montrent une grande sélectivité de comportement en fonction des aspects physiques et chimiques des plantes hôtes. La récolte de cocons de *A. mylitta*, est influencée par l'hétérogénéité des plantes hôtes et des conditions climatiques. Le rôle des plantes, de la température, de l'humidité, de la pluviométrie, de la photopériode et d'autres variables climatiques sur la croissance et le développement des insectes a été clairement démontré. Cet article fournit une analyse en profondeur des implications des diverses plantes hôtes, des facteurs écologiques et des éléments nutritionnels de *A. mylitta* ce qui donne des informations sélectives pour les chercheurs, les populations associées à l'élevage du tasar tropical et les gestionnaires de la forêt qui sont particulièrement concernés par l'amélioration de la vie de la forêt pour ceux qui en dépendent.

Mots clés: Facteurs biotiques et abiotiques, utilisation de l'alimentation, ver à soie de la forêt, croissance et développement, tasar indien, nutrition du ver à soie.



GENETIC ASSESSMENT OF RESISTANCE TO GRASSERIE IN SILKWORM (*BOMBYX MORI* L.) THROUGH GENERATION MEANS ANALYSIS

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ABSTRACT

Grasserie, known as a destructive and fatal disease in silkworm, is caused by infection of nuclear polyhedrosis virus. In the current study, in order to evaluate genetic resistance of silkworm (lines 154 and 104) to grasserie, virus inoculation in various generations [*i.e.*, parental (P1 and P2), first filial (F1), second filial (F2), direct and reverse back crosses (BC1, BC2, RBC1 and RBC2 generations)] was performed. Collected data were analyzed through generation mean analysis method and by applying joint scaling test. Results indicated that besides additive and dominant gene effects, additive-additive epistatic gene effect influences the genetic resistance of silkworms to grasserie. Dominance ratio of the studied trait indicated that resistance to grasserie is controlled by over dominance gene action. Heritability of the trait, resistance to grasserie, was variable from a low to medium degree. Also, the minimum effective gene number was estimated from 0.8 to 6.5, for this trait. The results indicate the importance of dominance gene effects and therefore, suggests the prospects of applying cross breeding strategy for genetic improvement of resistance to nuclear polyhedrosis virus in silkworm.

Key words: Generation mean analysis, grasserie, resistance, silkworm.

INTRODUCTION

Silkworm rearing in tropics is prone to diseases and necessitates an extra care and suitable management practice. Among silkworm diseases, grasserie poses a major threat for crops in sericulture industry especially in tropical regions. The disease is caused by infection of silkworm larvae by the nuclear polyhedrosis virus (NPV) (Samson, 1992; Watanabe, 2002; Seidavi *et al.*, 2008).

Earlier studies have shown that pure and hybrid varieties of silkworm do not show similar resistance to NPV (Watanabe, 2002; Seidavi *et al.*, 2007). Resistance to grasserie in silkworm is controlled by polygenes (Watanabe, 2002; Kiran Kumar and Sankar Naik, 2011). As a result, proper selection and breeding strategy could improve the resistance of silkworm to grasserie (Nagaraju, 2002). To select and implement an effective

breeding program for a trait, genetic diversity and sufficient knowledge about the inheritance of that trait is essential. Generation mean analysis, as a biometric method, can investigate appropriate genetic model for inheritance of the studied quantitative trait, utilizing phenotypic performance of various generations (including parental generations, F1, F2, backcrosses, *etc.*) (Mather and Jinks, 1982; Kearsey and Pooni, 1996; Hinkelmann, 2012). This method is effective to understand the performance of the parents and their importance in the creation of heterosis in crossbreeding or selection of pedigree. Also in this method, the role of epistatic effects on genetic and phenotypic performance of the studied trait could be specified. The advantage of this method is increasing the sensitivity of the model by reducing errors compared with the other methods, such as Diallel cross (Hallauer and Miranda, 1988). Studies have shown that ignoring epistatic effects, in the case of its presence, would

lead to biased estimation of the genetic parameters and misleading results in prediction of the genetic improvement (Templeton, 2000). In generation mean analysis procedure, the presence of epistatic effects in the genetic model of the studied traits could be investigated using scaling test. This method has been used widely in farm plants (Fotokian *et al.*, 2009; Iqbal *et al.*, 2010; Yousefi and Babaian Jolodar, 2012; Magda and El-Rahman, 2013; Soltanlou *et al.*, 2013; Dorri *et al.*, 2014). However, in farm animals, it has not been adequately used due to long generation time and the lack of access to the required basic generation. Limited studies have been performed in silkworm for estimating genetic model of traits utilizing this method. Duan and Zhu (1994) and Zhao *et al.* (2001) investigated cocoon characteristics using generation mean analysis and expressed that epistatic effects should not be ignored while studying the inheritance of the cocoon characteristics. Zhang *et al.* (1998) analyzed gene effects on the amount of silkworm eggs laid, using this method and concluded that the additive gene effects are the most important genetic parameters influencing this trait and dominance effects are not significant. Also, Xian *et al.* (2006) examined feed efficiency of Chinese oak silkworm using the generation mean analysis and found that the studied trait was influenced by additive, dominance and epistatic gene effects. In another study, Zhaojun *et al.* (2001) investigated silkworm resistance to fluoride and reported simple additive-dominance model and incomplete dominance in the inheritance of this trait.

The genetic model for resistance to grasserie in silkworm has not been analysed in any of the previous investigations. Hence, in the current study, biometrical approach using the generation mean analysis was taken up to understand the genetic factors conferring resistance to grasserie in two Chinese silkworm lines. After determining the appropriate model, genetic parameters, such as heritability and number of genes affecting the studied trait were predicted.

MATERIALS AND METHODS

The study was performed on the Chinese origin lines of

154 and 104 of *Bombyx mori* L. in the Research Institute of Silkworm situated at Pasikhan Some'esara, Gilan, Iran. Rearing was performed under the standard condition (relative humidity of 75 % and temperature of 24-26 °C). To evaluate the genetic parameters imparting resistance of silkworms to NPV, virus inoculation was conducted on fourth instar larvae at a concentration of 10^7 viral particles per milliliter, on parental lines (P_1 and P_2), the first and the second filial generations (F_1 and F_2), and direct and reverse backcross generations (BC_1 , RBC_1 , BC_2 , and RBC_2). The resistance of families to NPV was determined as the rate of survival to virus inoculation. For the virus inoculation, mulberry leaves were smeared with viral particles at the mentioned concentration and fed to the larvae. The resistance of families to NPV in each generation was scored as the rate of survived larvae after virus inoculation to the whole population at the beginning of inoculation.

GLM procedure of SAS 9.2 was utilized for comparing the resistance of families to NPV. Furthermore, the Tukey method was used in order to compare the least square means of resistance of silkworms to NPV over various generations.

Generation mean analysis was performed utilizing weighted least squares mean and joint scaling test was used to determine the appropriate genetic model affecting resistance to grasserie (Mather and Jinks, 1982; Kearsy and Pooni, 1996). The genetic components were evaluated using the following model:

$$Y = m + \alpha[a] + \beta[d] + \alpha^2[aa] + \alpha\beta[ad] + \beta^2[dd]$$

Where, Y is the average performance of each generation, m is the mean of over all generations in each cross, [a]: sum of additive gene effects, [d]: sum of dominance gene effects, [aa]: sum of additive by additive interaction gene effect, [ad]: sum of additive by dominance interaction gene effect, and [dd]: sum of dominance by dominance interaction gene effect. Values of α , β , α^2 , $\alpha\beta$, and β^2 are the prediction coefficients for the parameters of model.

All existing generations were evaluated using two, three,

four, five and six parameter models in order to determine the model that best describes the observed means. Chi-square test was used to fit different models. It should be noted that model testing will be suitable for the interpretation of the effects on the model if chi-square test is not significant (Kearsy and Pooni, 1996; Gusmini *et al.*, 2007).

After determining the appropriate model, the parameters of the selected model were investigated using t-test. Dominance ratio was estimated as $\frac{d}{a}$.

Heritability in broad sense (h_b^2) and heritability in narrow sense (h_n^2) were predicted following the established methods as shown below:

$$h_{b1}^2 = \frac{V_{F2} - \sqrt{V_{P1} \times V_{P2}}}{V_{F2}} \quad (\text{Mahmud and Kramer, 1951})$$

$$h_{b2}^2 = \frac{V_{F2} - \frac{V_{P1} + V_{P2} + V_{F1}}{3}}{V_{F2}} \quad (\text{Allard, 1960})$$

$$h_{b3}^2 = \frac{V_{F2} - \sqrt[3]{V_{P1} \times V_{P2} \times V_{F1}}}{V_{F2}} \quad (\text{Warnner, 1952})$$

$$h_{b4}^2 = \frac{V_{F2} - \frac{V_{P1} + V_{P2}}{2}}{V_{F2}} \quad (\text{Allard, 1960})$$

$$h_{b5}^2 = \frac{V_{F2} - \frac{V_{P1} + V_{P2} + 2V_{F1}}{4}}{V_{F2}} \quad (\text{Mather and Jinks, 1982})$$

$$h_{n1}^2 = \frac{2V_{F2} - (V_{BC1} + V_{BC2})}{V_{F2}} \quad (\text{Warnner, 1952})$$

$$h_{n2}^2 = \frac{V_{F2} - 0.5(V_{BC1} + V_{BC2})}{V_{F2}} \quad (\text{Dorri *et al.*, 2014})$$

The number of effective genes (n and EF) was calculated using the following methods:

$$n_1 = \frac{(\mu_{P2} - \mu_{P1})^2}{8(V_{F2} - V_{F1})} \quad (\text{Castle, 1921})$$

$$n_2 = \frac{(\mu_{P2} - \mu_{P1})^2}{8[V_{F2} - (0.5V_{F1} + 0.25V_{P1} + 0.25V_{P2})]} \quad (\text{Castle, 1921})$$

$$n_3 = \frac{(\mu_{P2} - \mu_{P1})^2}{8[(V_{BC1} + V_{BC2}) - (V_{F1} + 0.5V_{P1} + 0.5V_{P2})]} \quad (\text{Castle, 1921; Lande, 1981})$$

$$n_4 = \frac{(\mu_{F1} - \mu_{P1})^2}{4[V_{BC1} - 0.5(V_{F1} + V_{P1})]} \quad (\text{Chen and Line, 1995})$$

$$n_5 = \frac{(\mu_{P2} - \mu_{P1})^2}{8[2V_{F2} - (V_{BC1} + V_{BC2})]} \quad (\text{Castle, 1921; Lande, 1981})$$

$$EF_1 = \frac{(\mu_{P2} - \mu_{P1})^2 (1.5 - 2h(1-h))}{8[V_{F2} - 0.25(V_{P1} + V_{P2} + 2V_{F1})]}, \quad h = \frac{\mu_{F1} - \mu_{P1}}{\mu_{P2} - \mu_{P1}} \quad (\text{Wright, 1968})$$

$$EF_2 = \frac{[0.5(\mu_{P2} - \mu_{P1})]^2}{[2V_{F2} - (V_{BC1} + V_{BC2})]} \quad (\text{Mather and Jinks, 1982})$$

$$EF_3 = \frac{(\mu_{P2} - \mu_{P1})^2}{8[2V_{F2} - 0.25(V_{P1} + V_{P2} + 2V_{F1})]} \quad (\text{Lande, 1981})$$

In these equations, subscripts P1, P2, F1, F2, BC1 and BC2 refer to the related generations. V and μ refer to the variance and the observed mean in the related generation, respectively.

Weighted least square means analysis, joint scaling tests and estimation of genetic parameters were carried out in MATLAB R2008b.

RESULTS AND DISCUSSION

The results of analysis of variance for resistance to grasserie for 154 and 104 Chinese lines crosses indicated significant differences among various studied generations ($p < 0.0001$) (Table 1). This difference represents the possibility of genetic analysis of this trait using generation mean analysis method. The least square means of various generations in addition to their standard deviations are presented in Table 2.

Table 1: Analysis of Variance result for resistance to NPV in various studied generations

Source of Variation	df	SS	MS	F	p
Generation	7	12079.70	1725.70	11.79	<0.0001
Error	73	10680.57	146.31		
Total	80	22760.47			

In this study, investigation of two, three, four, five and six

Table 2: Least square means of resistance to nuclear polyhedrosis virus in various studied generations after virus inoculation of the fourth instar larvae

Generation	Number of investigated families	Least Square Means $\pm$ Standard Error*
P ₁	7	56.29 $\pm$ 4.59 ^b
P ₂	6	33.58 $\pm$ 4.95 ^c
F ₁	8	79.29 $\pm$ 4.29 ^a
F ₂	16	67.93 $\pm$ 3.03 ^{ab}
BC ₁	9	70.45 $\pm$ 4.04 ^{ab}
RBC ₁	11	80.42 $\pm$ 3.65 ^a
BC ₂	12	70.92 $\pm$ 3.50 ^{ab}
RBC ₂	12	78.48 $\pm$ 3.50 ^a

*Various letters indicate significant differences among least square means ($p < 0.05$)

parameter models by weighted least squares method indicated that the simple additive-dominance genetic model cannot effectively explain the variation of resistance to grasserie in silkworm. In turn, the six parameter model including the mean, additive, dominance and the epistatic genetic effects was the best one for describing the variation of resistance to grasserie in silkworm. This result indicates the complex polygenic inheritance of resistance to grasserie in silkworm, as it was reported in previous studies (Watanabe, 2002; Kiran Kumar and Sankar Naik, 2011). The estimated genetic effects of the six parameter model are summarized in Table 3. Testing the individual effects of the fitted model by t-test showed that the mean effect and the additive-dominance and the dominance-dominance epistatic gene effects did not have significant effect on genetic variation of resistance to grasserie in silkworm. Greater dominance effect (d) compared with additive effect (a) in the fitted model refers to the greater role of dominance compared with additive effects in the studied trait.

Considering the dominance ratio (d/a) of the studied trait (which was larger than unity), it could be stated that the relationship among alleles influencing resistance to grasserie is under the control of over-dominance. Due to the significant dominance effect of resistance to grasserie, crossbreeding would be an efficient way for the creation of heterosis and improvement of genetic and phenotypic performance of the evaluated trait. Other studies also

Table 3: Joint scaling test for resistance to NPV in silkworm

Effect type in the genetic model	t Value	Mean $\pm$ Standard Error
m (Mean)	0.46 ns	6.97 $\pm$ 1.31
a (additive)	3.09**	11.35 $\pm$ 3.67
d (dominance)	4.96**	171.50 $\pm$ 34.59
aa (epistasis)	2.55**	37.96 $\pm$ 14.86
ad (epistasis)	-1.74 ns	-16.47 $\pm$ 9.49
dd (epistasis)	-4.79 ns	-99.19 $\pm$ 20.70
Chi-square test results	$p > 0.05$	
d/a	15.11	

ns - Non-significant; ** - Significant at 0.01 level.

suggest the importance of crossbreeding in improving the resistance to grasserie in silkworm (Mirhosseini *et al.*, 2008; Seidavi *et al.*, 2008).

Estimation of heritability in broad and narrow sense and the number of effective genes of the studied trait evaluated by various methods are summarized in Table 4. The estimation of broad and narrow sense heritability for resistance to NPV by utilizing different methods varied from low to moderate range. This result indicates the greater role of environmental effects on the expression of resistance to grasserie in silkworm. The minimum number of effective genes must be considered with caution because the number of segregating genes may differ from the actual number. Factors such as incomplete linkage of similar alleles and inequality of gene effects could lead to estimation of the minimum number of genes affecting a trait less than its actual value (Soltanlou *et al.*, 2013). Probably, genes affecting resistance to grasserie in silkworm are linked together and are segregated as a group or effective factors. In the present case, the formulae used

Table 4: Heritability and the effective gene number affecting resistance to grasserie in silkworm

Heritability	Value	Effective gene number	Value
h^2_{b1}	0.20	n_1	0.68
h^2_{b2}	0.23	n_2	1.16
h^2_{b3}	0.32	n_3	0.32
h^2_{b4}	0.09	n_4	1.06
h^2_{b5}	0.30	n_5	1.14
h^2_{n1}	0.31	EF_1	6.5
h^2_{n2}	0.15	EF_2	4.54
		EF_3	1.16

for estimation of the number of effective genes, predict the number of effective factors and the number of single genes could be more than the number of estimated values in Table 4.

Conclusion

The results of this study indicate that the inheritance of the resistance to grasserie in silkworm larvae is a trait with over-dominance effects. In traits with large dominance degree, crossbreeding leads to fast genetic improvement of the trait through creation of increased hybrid vigor. Further, results suggested that the epistatic effects are also important in expression of NPV resistance and interpretation of this trait is a difficult task due to its complex and polygenic inheritance. However, considering the over-dominance gene action of the studied trait and the advantages of short generation interval in silkworm with the possibility of obtaining various generations quickly from this organism, the results show the prospects of control of grasserie disease in susceptible silkworm lines by applying crossbreeding strategy with resistant lines.

REFERENCES

- Allard R.W. (1960) *Principles of plant breeding*. John Wiley and Sons, New York.
- Castle W. E. (1921) An improved method of estimating the number of genetic factors concerned in cases of blending inheritance. *Sci.*, **54**: 223.
- Chen X. M. and Line R. F. (1995) Gene number and heritability of wheat cultivators with double high temperature adult plant (HTAP) resistance and interaction of HTAP and race-specific seedling resistance to *Puccinia striiformis*. *Phytopathol.*, **85**: 573-578.
- Dorri P., Khavari Khorasani S. and Shahrokhi M. (2014) Generation Mean Analysis: A Case study of variance components in KSC 500 generations of maize (*Zea mays* L.). *Int. Res. J. App. Basic Sci.*, **8**(2): 194-200.
- Duan J. L. and Zhu J. (1994) Analysis of gene effects on some cocoon characters in silkworm *Bombyx mori* L. *J. Biomath.*, **9**(4): 10-17. [Full text: in Chinese]
- Fotokian M. H., Ahmadi J. and Fabriki Orang S. (2009) Study of the genetic traits of wheat under drought stress conditions using generation mean analysis. *Iran. J. Biol.*, **22** (3): 431-441.
- Gusmini G., Wehner T. C. and Donaghy S. B. (2007) SAS Quant: a sas software program to estimate genetic effects and heritabilities of quantitative traits in population consisting of 6 related generations. *J. Hered.*, **98** (4): 345-350.
- Hallauer A. R. and Miranda Fo J. B. (1988) *Quantitative genetics in maize breeding*. 2nd edition, Iowa State University Press, Ames, IA.
- Hinkelmann K. (2012) Design and analysis of experiments. Vol 3: *Special designs and applications*, Wiley & Sons, INC., p. 582.
- Iqbal M., Khan K., Rahman H. and Sher H. (2010) Detection of epistasis for plant height and leaf area per plant in maize (*Zea Mays* L.) from generation mean analysis. *Maydica*, **55**: 33-39.
- Kearsey M. J. and Pooni H. S. (1996) *The genetic analysis of quantitative traits*. Chapman & Hall.
- Kiran Kumar K. P. and Sankar Naik S. (2011) Development of Polyvoltine×Bivoltine hybrids of mulberry silkworm, *Bombyx mori* L. tolerant to BmNPV. *Int. J. Zool. Res.*, **7** (4): 300-309.
- Lande R. (1981) The minimum number of genes contributing to quantitative variation between and within populations. *Genet.*, **99**: 541-553.
- Magda E. A. E. and El Rahman (2013) Estimation of some genetic parameters through generation mean analysis in three bread wheat crosses. *Alexander J. Agric. Res.*, **58** (3): 183-195.
- Mahmud I. and Kramer H. H. (1951) Segregation for yield, height and maturity following a soybean cross. *Agron. J.*, **43**: 605-609.
- Mather K. and Jinks J. L. (1982) *Biometrical genetics, the study of continuous variation*. Chapman & Hall.
- Mirhosseini S. Z., Seidavi A. R., Ghanipoor M. and Bizhannia A. R. (2008) Phenotypical improvement for resistance of Iranian silkworm lines against grasserie disease through one

- generation of selection. *Agric. Sci.*, **18** (2): 151-159 [in Persian].
- Nagaraju J. (2002) Application of genetic principles for improving silk production. *Curr. Sci.*, **83** (4): 409-414.
- Samson M.V. (1992) Silkworm crop protection. *Proceedings of the National Conference on Mulberry Sericulture Research*, Central Sericultural Research and Training Institute, Mysore, India, pp. 24-34.
- Seidavi A. R., Mirhosseini S. Z., Ghanipour M. and Bizhannia A. R. (2008) Comparison of resistance to grasserie disease and performance in some genetic combination of silkworm in Iran. *Mod. Genet.*, **3** (2): 21-28 (In Persian).
- Seidavi A. R., Mirhosseini S. Z. and Ghanipour M. (2007) Investigation on pathogenesis and oral LD50 concentration inoculation of nuclear polyhedrosis virus in 36 Iranian silkworm varieties, *Bombyx mori* L. *Pajouhesh Sazandegi*, **74**:167-174 (In Persian).
- Soltanlou H., Heydari F., Ramzanpour S. S., Kalate Arabi M. and Kia Sh. (2013) Genetic analysis of resistance to septoria in wheat seedling stage. *Mod. Genet.*, **8** (3): 289-298.
- Templeton A. R. (2000) Epistasis and complex traits. In: *Epistasis and the evolutionary process*, J. B. Wolf *et al.* (Ed.), Oxford University Press, New York, pp. 41-57.
- Warnner J. N. (1952) A method for estimating heritability. *Agron. J.*, **44**:427-430.
- Watanabe H. (2002) Genetic resistance of the silkworm, *Bombyx mori* to viral diseases. *Curr. Sci.*, **83** (4): 439-446.
- Wright S. (1968) The genetics of quantitative variability. In: *Evolution and genetics of populations, Vol I. Genetic and biometric foundations*, S. Wright (Ed.), University of Chicago press, Chicago IL.
- Xian X. L. W. Y. M., Xian M. L. F. Y. H. and Li M. Q. (2006) Genetic Model and Estimates of Gene Effect of Dietary Efficiency for Chinese Oak Silkworms, *Antheraea pernyi*. *Sci. Seric.*, **3**: 23. [Full text: in Chinese].
- Yousefi Z. and Babaian Jolodar N. (2012) Genetic assessment of siliques length in rapeseed (*Brassica napus* L.) using generation mean analysis and RAPD markers. *Iran. J. Crop Sci.*, **4** (1): 72-82.
- Zhang Z., Lu C., Li F. and Xiang Z. (1998) Estimation of gene effect parameters for the amount of laid eggs in silkworm (*Bombyx mori* L.). *Acta Seric. Sinica*, **24** (1): 19-22 [Full text: in Chinese].
- Zhao Y., Wei Z., Qian H. and He S. (2001) Analysis of Gene Effects of Cocoon Characters in Silkworm (*Bombyx mori* L.). *Acta Seric. Sinica*, **27** (4): 257-260 [Full text: in Chinese].
- Zhaojun W., Zhang W. and Zhifan Z. (2001) Analysis on Gene Effects of Fluoride-Resistance in Silkworm (*Bombyx mori* L.). *Acta Seric. Sinica*, **27** (2): 158-161 [Full text: in Chinese].

Article scientifique

EVALUATION GENETIQUE DE LA RESISTANCE A LA GRASSERIE CHEZ LE VER A SOIE (*BOMBYX MORI* L.) PAR L'ANALYSE DES MOYENNES DES GENERATIONS

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RESUME

La grasserie est une maladie destructive et fatale chez le ver à soie, cause par l'infection par le virus de la polyédrose. Dans notre étude, afin d'évaluer la résistance génétique du ver à soie à la grasserie (lignées 154 et 104) Une inoculation du virus à différentes générations [parentale (P1 et P2), F1 et F2) ainsi que dans les croisements de retour directs et inverses (BC1, BC2, RBC1 et RBC2). a été effectuée. Les résultats ont été analysés par la méthode de la moyenne de génération ainsi que par un test d'échelle. A côté des effets de gènes dominants et additifs, nous trouvons des influences d'effet épistatique additif-additif. Le taux de dominance des caractères étudiés indiquent que la résistance à la grasserie est contrôlée l'action de surdominance génétique. L'héritabilité est variable de degré faible à moyen. Le nombre minimum de gènes efficaces a été estimé de 0,8 à 6,5 pour ce caractère. Ces résultats montrent l'importance des effets de gènes dominants et suggèrent l'application de la stratégie de croisements pour l'amélioration de la résistance au virus de la polyédrose nucléaire chez le ver à soie.

Mots clés: Analyse par moyenne de génération, grasserie, résistance, ver à soie.



CORRELATION BETWEEN VITELLOGENIN RECEPTOR GENE EXPRESSION AND FECUNDITY IN SILKWORM, *BOMBYX MORI*

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ABSTRACT

Insect vitellogenin receptor (VgR) belongs to the low-density lipoprotein receptor (LDLR) gene superfamily and plays a critical role in oocyte development by mediating the endocytosis of the major yolk protein, vitellogenin (Vg). However, the extent of *VgR* expression level playing a role in determining the fecundity among various genotypes is less known. Herein, we show the transcriptional expression of *Bombyx mori VgR* in various developmental stages of ovary by RT-PCR and *in situ* hybridization. The *VgR* expression levels were found to be high in pre- and vitellogenic phases of the ovary and declined in the post-vitellogenic phase. Further, using TaqMan Real Time PCR, we determined the mRNA expression levels of *VgR* gene among different strains of silkworm. The *VgR* gene expression levels were measured among 17 silkworm genotypes, in which high transcript levels were observed in BBE0213, BB10255, BBE0244, BBI0293, BBI291, BBE0247, BBI0325, and BBI0290 among bivoltine strains and in a multivoltine strain, BMI0007. These breeds are high yielders in terms of fecundity (≥ 500) whereas, the rest 7 low yielders (< 500) showed lower *VgR* expression levels. The highest expression level was seen in BBE0213 with correspondingly high fecundity of 590 followed by BBI0255 whose fecundity was 572. Overall, the differential expression levels of *VgR* in silkworm strains were found to be correlated with that of fecundity; a high *VgR* transcript level leads to high fecundity. In addition, comparative expression levels of *VgR* transcripts had revealed better manifestation in bivoltine silkworm strains than multivoltine strains indicating their importance in egg production. Our results clearly indicate that the *VgR* gene is a potential target for better egg production strategies in sericulture.

Key words: *Bombyx mori*, fecundity, gene expression, vitellogenin receptor.

INTRODUCTION

The vitellogenin (Vg) and lipophorin (Lp) are major yolk protein precursors in insects and are incorporated into the growing oocytes through vitellogenin (VgR) and lipophorin receptors (VgR and LpR) - mediated endocytosis (Van der Horst *et al.*, 1993; Sappington and Raikbel, 1998). These receptors belong to the well characterized vertebrate low-density lipoprotein receptor

(LDLR) superfamily and play a crucial role in oocyte development to sustain reproduction (Swevers *et al.*, 2005). Yolk protein receptors are characterized in a number of insects (Tufail and Takeda, 2009) including the silkworms, *Bombyx mori* (Ravikumar *et al.*, 2006; Lin *et al.*, 2013), *Samia ricini* (Bala *et al.*, 2016), *Antheraea pernyi* (Liu *et al.*, 2011), and honey bee, *Apis mellifera* (Guidugli-Lazzarini *et al.*, 2008). Vg, the abundant yolk protein, is synthesized in the fat body and released into the

hemolymph and taken up by the VgR and stored as vitellin (Vn) in the ovary. It provides nutrition in oogenesis and is vital for egg maturation and embryonic development (Swevers *et al.*, 2005). In *Drosophila melanogaster* and *B. mori*, deceptive VgR cause yolk proteins fail to accumulate in the oocytes (Perrimon *et al.*, 1986; Lin *et al.*, 2013). Though the relationship between expression level of VgR and ovarian development has been extensively studied in a variety of insects, information on correlation between VgR transcript levels and fecundity is lacking. Considering the importance of VgR gene expression which is not only of scientific interest but also of potential economic impact in sericulture, as it is directly related to viable egg production, the present study was undertaken. We intended to examine whether there is any correlation between the amount of VgR transcripts and fecundity among silkworm, *B. mori* strains. Here we show that VgR can be used as a functional molecular marker in screening promising silkworm strains for high yield.

MATERIALS AND METHODS

Silkworms

The *B. mori* germplasm strains of Central Sericultural Germplasm Resources Centre (CSGRC), Central Silk Board, Hosur, Tamil Nadu, India were used for the study. The following silkworm accessions were employed: Bivoltines - BBE-0213, BBI-0255, BBI-0293, BBI-0290, BBE-0244, BBI-0291, BBI-0247, BBI-0325, BBI-0105, BBI-0106, BBE-0015, BBI-0063, BBE-0230, BBE-0229, BBI-0292; Multivoltines - BMI-0007 and BMI-0062.

RNA isolation and cDNA synthesis

RNA was extracted from ovaries of fifth instar larva, pupa (Day 1-9) and adult moth of each silkworm strain using RNeasy Mini Kit (Qiagen) according to manufacturer's protocols. RNA was quantified by Nanospectrophotometer (Thermo Corporation) and analysed on a 1 % agarose gel and by ethidium bromide

staining. Two µg of total RNA was used for reverse transcription using oligo dT primers (PrimeScript, Takara). The resultant first strand cDNA was used for semi-quantitative and real time PCR assays.

Semi-quantitative PCR

Initially, for detecting the VgR expression levels at different developmental stages, RT-PCR was performed using the first strand cDNA as template. The following primer sets from *B. mori* VgR (Accession No. HM172611) and cytoplasmic actin 3 (Accession No. U49854) genes were used: VgR - Forward: 5'-AGTGCCTTGGACCTCCTCCACG-3' and VgR-Reverse: 5'-CTTCTGATCGATTGTTGCCACAC-3'; Cyto3 - Forward 5' - CCCATCGAACACGGAATCGTCAC-3' and Cyto3-Reverse 5'-; GTTCGAAACATTCAACACGCCCG-3'. The PCR program included a denaturation step of 1 min at 94 °C followed by 30 cycles of 30 s at 94 °C, 30 s annealing at 62 °C and 30 s extension at 72 °C, and a final extension step of 5 min at 72 °C. The RT-PCR products were analyzed by electrophoresis on 2 % agarose gel, stained with ethidium bromide and band intensity viewed under ultraviolet light. Care was taken to avoid genomic DNA contamination. Each RT-PCR product was verified by sequencing.

Whole-mount *in-situ* hybridization (ISH)

RNA probes (sense and antisense) were generated by *in vitro* transcription from the T7 promoter using the DIG RNA Labelling Kit (SP6/T7 Roche) according to manufacturer's protocol. The primers used for the amplification of VgR fragment were: Forward 1: 5'-T A A T A C G A C T C A C T A T A G G G A G A A G T G C C T T G G A C C T C C T C C A C G -3' and Reverse 1: 5'-CTTCTGATCGATTGTTGCCACAC-3'; Forward 2: AGTGCCTTGGACCTCCTCCACG and Reverse 2: TCTCCCTATAGTGAGTCGTATTACTTCTGATCGATTGTTGCCACAC, for sense and antisense riboprobes, respectively. Ovaries of different developmental stages were fixed in 4 % formaldehyde in PBS, dehydrated,

digested with Proteinase K and transferred to hybridization buffer at 52 °C for 2 h. Ovaries were replaced with hybridization buffer containing DIG-labeled probes and incubated overnight at 52 °C. After series of washing, detection was carried out with anti-DIG-alkaline phosphatase antibodies and visualized using nitro blue tetrazolium (NBT)/5-bromo-4-chloro-3-indolylphosphate (BCIP) solution and observed under a microscope (Motic).

TaqMan Real Time PCR

TaqMan Gene Expression Assays (ABI/Invitrogen) were carried out using custom made primers and probes from *B. mori* *VgR* and cytoplasmic actin 3 genes. The expression analysis was performed in three biological replicates. Relative quantification using comparative $\Delta\Delta C_t$ method was used for gene expression analysis in a Step One Plus Real Time PCR Machine (ABI). *VgR* expression was normalized using cytoplasmic actin gene and then related to a calibrated sample. Student's t-test was employed for statistical analyses. The primers and probes for *VgR* and cytoplasmic actin 3 were: 5'-GCTCCCAGGTCTGCGT-3'; 5'-GAGAGCAGAGGCATTATAGCTGTA-3'; 5'-CCGACCCATTCCCC-3'; 5'-GCCCATCTACGAGGGATACG-3'; 5'-AGGATCTTCATGAGGTAGTCTG-3'; 5'-CCTGCGTCTGGACTTG-3', respectively. The PCR program consisted of 95 °C for 10 min, 40 cycles of 95 °C for 15 s, 68 °C for 30 s, and 72 °C for 30 s.

RESULTS

First, we have carried out a semi-quantitative PCR to determine the expression levels of *VgR* at larval, pupal and adult stages using a representative silkworm strain, Pure Mysore. The results are presented in Figure 1. The *VgR* expressions levels were observed low from V instar larvae to early day pupae and then dramatically increased before full vitellogenic phase with the highest level observed on Day 5-7, and decreased thereafter through the post-vitellogenic phase. Minimal transcript levels were seen in adult eggs. This observation was supported

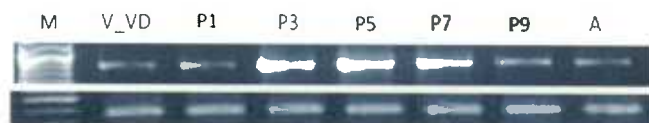


Figure 1: Transcription profiles of *BmVgR* gene in the ovary at different developmental stages. V_VD: fifth instar larva, day 5; P1, P3, P5, P7, P9: pupae of day 1, 3, 5, 7 and 9, respectively; A: adult; lower panel- *Bm* cytoplasmic actin 3 expression levels were used as a reference; M: DNA size marker.

by RNA *in situ* hybridization analysis of ovaries using *VgR*-specific antisense riboprobe. It showed that *VgR* mRNA expression levels were restricted to oocytes and were low in the early stage of ovarian development and increased mRNA levels were observed on 6th day of pupation which declined afterwards (Figure 2). These data clearly indicated that the maximum *VgR* expression levels were restricted between 5 and 7 days after pupation. Hence, day 6 pupae were chosen further to examine the comparative expression levels of *VgR* transcripts in 17 silkworm genetic stocks which have varied fecundity, ranging from 231 to 590.

To get an accurate level of *VgR* mRNA expression levels

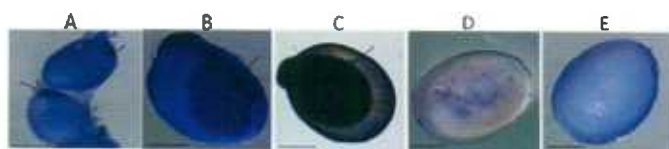


Figure 2: Whole-mount *in situ* hybridisation, showing ovarioles hybridised with *BmVgR* anti sense (A-D), and sense riboprobes (E- control). Arrows indicate the accumulation of *BmVgR* mRNA (dense blue/brown colour) in oocytes. A- 4th Day ovarioles with low level of transcripts confined to the anterior end of the ovarioles, B & C- 6th Day ovariole with high levels of transcripts, D- 8th Day ovariole with trace amount of transcripts, Scale bars: 350 µm.

among silkworm strains, TaqMan Real Time PCRs were carried out. Results are presented in Figure 3. High levels of *VgR* mRNA were measured in BBE0213, BB10255, BBE0293, BB10290, BBE0244, BB0291, BBE0247 and BBI0325 among bivoltine high yielders whereas, in low

yielders (BBI0105, BBI0106, BBE0015, BBE0230, BBE0229, BBI0292 and BBI0063), the *VgR* expression levels were low. Similar results were observed in multivoltine strains. These results clearly indicate an apparent correlation between the *VgR* mRNA levels and fecundity. The highest level of *VgR* expression was observed in BBE0213 ($P < 0.05$) and the lowest in BBI0105 among bivoltine strains. The relative expression level of *VgR* mRNA in BBE0213 strain was though higher than that in the BBI0255 strain, the two high yielders, the difference was not statistically significant. However, the variation was highly significant ($P < 0.05$) when compared to the high yielder in the multivoltine strain, BMI0007. Significant differences ($P < 0.05$) were also found between the multivoltine low yielder (BMI0062) and bivoltine low yielder strains. The study has thus revealed differences in *VgR* expression levels between silkworm strains and a strong correlation of the parameter with fecundity. The *VgR* transcript level has direct correlation with the prolificacy of the strains. The differential *VgR* expression levels also indicate the involvement of voltinism in the quantum of eggs produced.

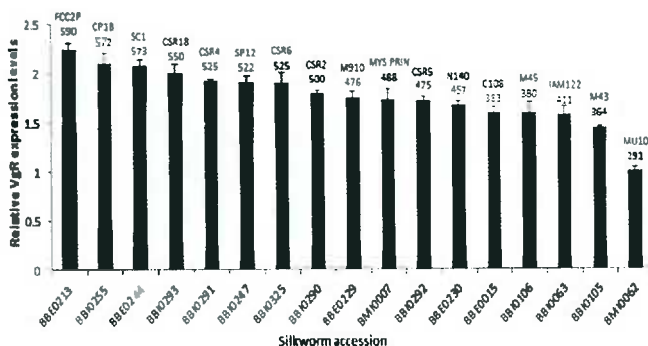


Figure 3: TaqMan Real Time PCR analysis of *BmVgR* gene expression in different silkworm strains. The silkworm accession no. (lower), its common name and fecundity (upper) are indicated in each histogram. Values represent mean $\pm$ SE.

DISCUSSION

The relationship between the level of *Vg* and *VgR* transcripts and ovarian development is unequivocal and has been shown in a number of insects, using RNA interference (Ciudad *et al.*, 2006; Lu *et al.*, 2009; Tufail

and Takeda, 2009; Shu *et al.*, 2011; Lin *et al.*, 2013; Lu *et al.*, 2015). However, the report on connection between the expression levels of *VgR* and fecundity in insects is scarce. Our results clearly showed that increased transcript levels directly correlate to the fecundity among silkworm strains; an increased level of *VgR* transcripts leads to high fecundity. It also revealed a better manifestation of *VgR* expression in bivoltine silkworm strains than multivoltine strains. Similar observations were reported with *Vg* expression levels and fecundity in silkworm, *B. mori* (Paul and Keshan, 2016). In *Tetranychus cinnabarinus*, the fecundity and the expression of *Vg* and *VgR* were significantly higher in fenpropathrin resistant strain than that in susceptible strain, both at transcriptional and translational levels (Liu *et al.*, 2016). In *Helicoverpa armigera*, silencing of *VgR* gene inhibited the yolk protein deposition in the ovaries, led to the dramatic accumulation of *Vg* in hemolymph, and eventually resulted in a declined fecundity (Zhang *et al.*, 2016).

The fecundity values among silkworm strains in this study was ranging from 291- 590 and the average hatching percentage of the larvae was about 98 % (data not shown) in all strains. Though the fecundity and fertility are influenced by other factors also, the accumulation of sufficient amount of yolk determined the viability of eggs. The *Vg* accumulation into the developing oocytes was mediated through the *VgR* on the cell surface of the oocytes which resulted in the ovarian development and oviposition. It is of special importance in *B. mori* and other silkworms where viable eggs contribute to increased silk production. Although the silkworms with high content of *VgR* showed increased fecundity, the underlying mechanism is not clear. Comparatively more mRNA levels may support yolk uptake by a large number of ovarian follicles, while lower levels might support only a few follicles. It may be possible that the *VgR* transcript levels can alter the oocytes' intrinsic ability to develop into mature eggs.

Conclusion

This is the first report stating that a strong correlation exists between *VgR* expression levels and fecundity in

silkworm. Further, our results suggest that expression level of the *VgR* gene can be used as a molecular marker in reproduction in silkworms and it is a potential target for better egg production strategies in sericulture.

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REFERENCES

- Bala R., Sabu U., Varma M., Thomas D. S., Sinha D. K., Rao G. P., Trivedy K., Vijayan K. and Ravikumar G. (2016) Cloning and functional characterization of a vertebrate low-density lipoprotein receptor homolog from eri silkworm, *Samia ricini*. *J. Mol. Biochem.*, **5**: 87.
- Ciudad L., Piulachs M. D. and Bellés X. (2006) Systemic RNAi of the cockroach vitellogenin receptor results in a phenotype similar to that of the *Drosophila* yolkless mutant. *FEBS J.*, **273**: 325.
- Guidugli-Lazzarini K. R., do Nascimento A. M., Tanaka E. D., Piulachs M. D., Hartfelder K., Bitondi M. G. and Simoes Z. L. (2008) Expression analysis of putative vitellogenin and lipophorin receptors in honey bee (*Apis mellifera*) queens and workers. *J. Insect Physiol.*, **154**: 1138.
- Lin Y., Meng Y., Wang Y. X., Luo J., Katsuma S., Yang C. W., Banoo Y., Kusakabe T., Shimada T. and Xia Q. Y. (2013) Vitellogenin receptor mutation leads to the oogenesis mutant phenotype "scanty vitellin" of the silkworm, *Bombyx mori*. *J. Biol. Chem.*, **288**: 13345.
- Liu Q. N., Zhu B. J., Liu C. L., Wei G. Q. and Wang Z. G. (2011) Characterization of vitellogenin receptor (VgR) from the Chinese oak silkworm, *Antheraea pernyi*. *Bull. Insectol.*, **64**: 167.
- Liu X., Shen G., Xu H. and He L. (2016) The fenprothrin resistant *Tetranychus cinnabarinus* showed increased fecundity with high content of vitellogenin and vitellogenin receptor. *Pesticide Biochem. Physiol.*, **134**: 31.
- Lu H. L., Vinson S. B. and Pietrantonio P. V. (2009) Oocyte membrane localization of vitellogenin receptor coincides with queen flying age, and receptor silencing by RNAi disrupts egg formation in fire ant virgin queens. *FEBS J.*, **276**: 3110.
- Lu K., Shu Y., Zhou J., Zhang X., Zhang X., Chen M., Yao Q., Zhou Q. and Zhang W. (2015) Molecular characterization and RNA interference analysis of vitellogenin receptor from *Nilaparvata lugens*. *J. Insect Physiol.*, **73**: 20.
- Paul S. and Keshan B. (2016) Ovarian development and vitellogenin gene expression under heat stress in silkworm, *Bombyx mori*. *Psyche*, **1** (<http://dx.doi.org/10.1155/2016/4242317>)
- Perrimon N., Mohler D., Engstrom L. and Mahowald A. P. (1986) X-linked female sterile loci in *Drosophila melanogaster*. *Genetics*, **113**: 695.
- Ravikumar G., Okuda K., Tsuchida K., Yamamoto K., Nohata J., Ajimura M. and Mita K. (2006) Lipophorin receptor from the silkworm, *Bombyx mori*: cDNA cloning, genomic structure, alternative splicing and isolation of a new isoform. *J. Lipid Res.*, **47**: 1005.
- Sappington T. W. and Raikhel A. S. (1998) Molecular characteristics of insect vitellogenins and vitellogenin receptors. *Insect Biochem. Mol. Biol.*, **28**: 277.
- Shu Y., Wang Y., Lu K. and Zhang G. (2011) The first vitellogenin receptor from a Lepidopteran insect: Molecular characterization, expression patterns and RNA interference analysis. *Insect Mol. Biol.*, **20**: 61.
- Swevers L., Raikhel A. S., Sappington T. W., Shirk P. and Iatrou K. (2005) Vitellogenesis and Post-vitellogenic maturation of the insect ovarian follicle. In: *Comprehensive molecular insect science*, Volume 1, Gilbert L. I., Iatrou K. and Gill S. S. (Ed.), Amsterdam: Elsevier Pergamon, p. 87.
- Tufail M. and Takeda M. (2009) Insect vitellogenin/lipophorin receptors: molecular structures, role in oogenesis, and regulatory mechanisms. *J. Insect Physiol.*, **55**: 87.
- Van der Horst D., Weers J. P. M. and Van Marrewijk W. J. A. (1993) Lipoproteins and Lipid Transport. In: *Insect Lipids*:

Chemistry, Biochemistry and Biology, D. W. Stanley-Samuleson and D. R. Nelson (Ed.), University of Nebraska Press, Lincoln, NE, p. 1.

Ling G. (2016) Molecular characterization and function analysis of the vitellogenin receptor from the cotton bollworm, *Helicoverpa armigera*. *PLoS ONE*, 11: e0155785.

Zhang W., Ma L., Xiao H., Xie B., Smagghe G., Guo Y. and

Article scientifique

CORRELATION ENTRE L'EXPRESSION DU RECEPTEUR, DU GENE DE LA VITELLOGENINE ET LA FECONDITE CHEZ *BOMBYX MORI*

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RESUME

Le récepteur de la vitellogénine des insectes (VgR) appartient à la superfamille des gènes récepteurs de lipoprotéines de faible densité (LDLR) et jouent un rôle critique dans le développement de l'ovocyte par l'intermédiaire de l'endocytose de la protéine majeure du vitellus, la vitellogénine. Cependant, le niveau d'expression de *VgR* qui joue un rôle dans la fécondité parmi d'autres génotypes est peu connu. Ici, nous montrons l'expression transcriptionnelle du *VgR* de *Bombyx mori* à différents stades de développement de l'ovaire par RT-PCR et hybridation *in situ*. Le niveau d'expression de *VgR* est élevé pendant les phases pré- et vitellogéniques de l'ovaire et décline dans la phase post-vitellogénique. En utilisant la PCR en temps réel TaqMan nous avons déterminé les niveaux d'expression de l'ARMm du gène *VgR* chez différentes lignées de vers à soie. Les niveaux d'expression du gène *VgR* ont été mesurés chez 17 génotypes chez lesquels des niveaux élevés de transcrits ont été observés chez BBE0213, BB10255, BBE0293, BB10291, BBE0244, BB1291, BBE0247, BBI0325 et BB10190 lignées bivoltines et chez la lignée polyvoltine BM1007. Ces lignées ont une fécondité élevée (>500) alors que les 8 autres ont une faible fécondité (<500). L'expression la plus élevée est observée chez BBE213 chez la quelle la fécondité est de 590 suivie par BB10255 qui présente une fécondité de 572. L'expression différentielle de *VgR* chez le ver à soie est fortement corrélée avec la fécondité ; un niveau de transcrits de *VgR* élevé conduit à une fécondité élevée. Notre analyse révèle également une manifestation meilleure de la transcription chez les vers à soie bivoltins comparée aux polyvoltins. Nos résultats indiquent que le gène *VgR* est une cible potentielle pour les stratégies d'amélioration de la production d'œufs en sériciculture..

Mots clés: *Bombyx mori*, fécondité, expression des gènes, récepteur de la vitellogénine



IMPACT ASSESSMENT OF LESS FRICTION JACQUARD IN SILK HANDLOOM WEAVING

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ABSTRACT

Silk handloom weaving is one of the important textile activities in Tamilnadu province of India providing large scale employment to the rural people. In order to reduce drudgery that has been encountered in this sector and simultaneously to improve the quality and productivity of silk saree weaving, less friction jacquard was developed by Central Silk Technological Research Institute, Bengaluru. Its performance was tested in terms of pulling load required to operate the jacquard for shed opening that invariably results in drudgery during weaving. The laboratory trial results revealed that the pulling load of 240 hooks capacity less friction jacquard was significantly less than that of conventional jacquard by 38 %. Moreover, 3356 less friction jacquards of varying hooks capacities were provided to the weavers to address the drudgery issue and the impact assessment of the equipment was carried out after one year of its installation through a survey, by randomly selecting, thirty weavers who were provided with 240 hooks capacity less friction jacquard and the paired *t*-test for the productivity of less friction jacquard gadget *vis-à-vis* conventional jacquard was worked out. Based on the questionnaire survey data, it is found that the less friction jacquard has the advantages of ease of maintenance, better saree quality, longer card life and less noise level. When compared with conventional jacquard, the silk saree production of less friction jacquard has increased by 19 %, pulling load that results in drudgery decreased by 25 % and daily earnings has increased by 25 %.

Key words: Earnings, less friction jacquard, production performance, pulling load, silk productivity.

INTRODUCTION

As per the statistics of 2010, only 43 lakhs handlooms exist in the country including 1.89 lakhs in Tamilnadu (Ministry of Textiles, 2010) and afterwards, it has been observed that the handloom industry suffered a crunch particularly the silk handlooms which were in doldrums. The total number of handlooms working in the co-operative fold is 75,600 out of which, 40,000 handlooms are working on silk. The average annual manufacture of various handloom products, through the handloom weavers is around ₹500 crore (100 million US dollars), out of which, 35 % production is being procured by Co-op. Tex., a state level Handloom Cooperative Marketing Organization, through its various showrooms in the country and the rest of about 65 % is being sold by

weavers' co-operative societies through other means. It is certain that the handloom industry in Tamilnadu province has created ample opportunities for the weavers in the rural areas, next to Agriculture. The handloom industry particularly the silk handloom is of late, in deep crisis due to (1) shortage of manual skilled labourer who is exposed to drudgery, (2) lack of additional family labourer without whom it is seldom possible to produce saree on handloom, (3) low productivity and low income when compared to other occupation that requires semi or un-skilled labour and (4) lack of modernization / technology up-gradation / modification in tune with the requirement that deterred the second generation weavers as well as the younger generation.

With this backdrop, it was envisaged to study the existing

conventional jacquards (Chandrashekar, 2005) adopted in the silk handloom weaving industry and document the disadvantages associated with it. Thus the details in respect of twenty-five weavers, chosen randomly were documented, wherein it revealed the main drawbacks of conventional jacquards as (1) use of rivet to join parts which does not allow free movement but, may cause damage to the moving parts, (2) use of bolts and nuts that get damaged often, to link thread rod and lifting rod, (3) lack of zinc coating on the iron parts of jacquard box, which may bring about rusting due to oxidation during weaving that is always carried out under humid condition, (4) fixing of the cylinder with bolts and nuts, wherein the continuous rotation of the cylinder wears them out easily and (5) very less gap (one inch) provided between the eight line pin-board hooks (240 & 480 hooks Jacquard Box) which often results in bending of straight hooks.

Central Silk Technological Research Institute (CSTRI), Bengaluru had attempted to improve the conventional jacquard used in the silk handloom weaving by incorporating ball bearings at the appropriate places where frictional forces are hampering the movement that in turn increase the load required for shedding operation through jacquard box. Thus, 20 ball bearings were incorporated in the less friction jacquard to reduce the friction of the moving parts and improve the free movement of jacquard box as well. The gap between the hook lines was increased from 1 to 1 1/8 inches, in an effort to prevent bending of straight hooks and any such damage to the jacquard box.

Thus, the improved, less friction jacquard box for silk handloom was designed with the objectives, such as to provide smooth weaving experience, speed up weaving process, avoid damage of parts in jacquard box and increase the production as well as the earning capacity of weavers in order to develop an interest in weaving for both men and women, particularly the senior weavers who left the field due to drudgery related issues. The new device was tested for its performance through a series of laboratory trials. In an attempt to address the drudgery

issues involved in silk handloom weaving, CSTRI, Central Silk Board in co-ordination with the Department of Sericulture under the Secretariat of Handloom, Handicraft, Textiles & Kadhi, Government of Tamilnadu has provided less friction jacquards to the weavers of the co-operative societies. During the year 2013-2014, 3356 less friction jacquards were provided to the weavers engaged in silk handloom weaving. The impact assessment of this technological intervention was carried out after one year through a survey, by randomly selecting the weavers from different areas. The impact assessment was conducted during a span of three months by meticulously observing their occupation and documenting the features of the gadget vis-à-vis conventional jacquard used in silk handloom weaving in order to assess the advantage derived out of the equipment with an aim to plan future strategy for en-mass transfer of technology in a phased manner.

MATERIALS AND METHODS

Salient features of less friction jacquard

A sectional view of the modified less friction jacquard is depicted in Figures 1 and 2, the first one refers to one side of the jacquard wherein 10 ball bearings are fitted. Two types of bearings are used; 6 medium sized ball bearings labeled as X and 4 small sized ball bearings labeled as Y fitted on each side of the jacquard. There are two types of attachment labeled as U and L fitted on to the solid shaft A, that is lifted using the conventional lifting mechanism for the formation of the shedding. The attachments U and L carry 4 ball bearings each. The attachment L consists of 2 medium sized ball bearings, X1 and X2 that are fitted on the front side of the attachment and 2 small sized ball bearings, Y1 and Y2 on the rear side of the attachment in order to grip the solid shaft A at the lower part of the Jacquard.

Similarly, the attachment U consists of 2 medium sized ball bearings, X3 and X4 that are fitted on the rear side of the attachment and 2 small size ball bearings, Y3 and Y4 on the front side of the attachment so as to grip the solid

shaft A at the upper part of the jacquard as shown in Figure 2. Thus, the upward and downward movement of the solid shaft A is made very smooth without any distortion resulting in proper formation of shed with less wear and tear to the rubbing metallic parts. The ball bearing reduces the friction of the moving part and accordingly, reduces the resultant load required for lifting the hooks for the formation of the shedding.

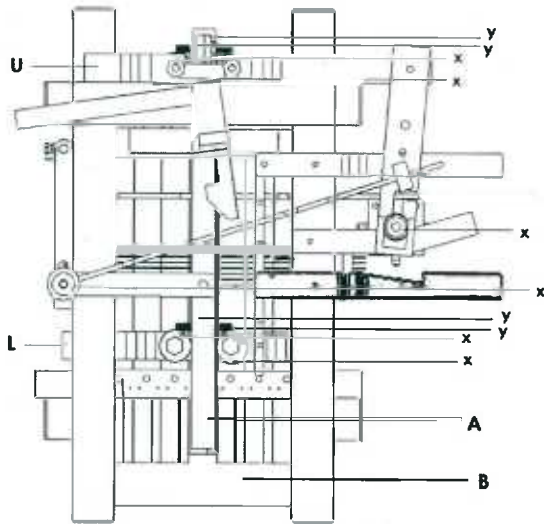


Figure 1: Sectional view of Jacquard

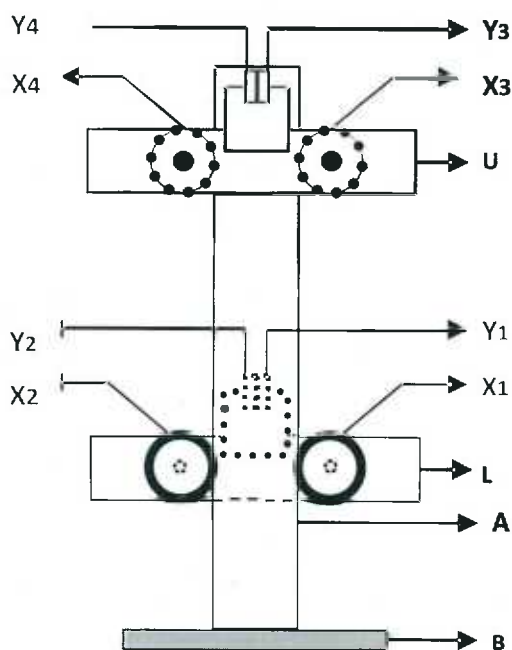


Figure 2: Solid shaft with ball bearings

Data source

The laboratory trials' data on the highest pulling load required to operate the 240 hooks less friction jacquard vis-à-vis conventional jacquard were measured using spring scale called rattle. The impact assessment survey results of the technological intervention through less friction jacquard in respect of thirty weavers selected randomly, conducted during January to March 2016, were considered for the study.

Data analysis

The test results data in respect of the highest pulling load required to operate the 240 hooks less friction jacquard and conventional jacquard were tested for statistical significance using *t*-test through Minitab software. The survey results data in respect of thirty weavers were segregated as general and technical information. The general information viz., age, sex, experience, quality of gadget, handling & usage, maintenance & repair, noise level and pulling speed were meant for subjective analysis and the technical information of both conventional and less friction jacquard viz., pulling load, productivity and revenue generation were meant for objective analysis. The descriptive statistics for each technical quality parameter was generated using the Minitab software for the survey results of the technological intervention. The paired *t*-test that is appropriate for testing the difference between two means when data are paired (Garrett and Woodworth, 1965; Akhnazarova and Kafarov, 1982), for each technical quality parameter was carried out to ascertain the qualitative improvement in order to probe the impact made in the handloom industry to enable planning of en-mass transfer of technology.

RESULTS AND DISCUSSION

Laboratory trials

The findings of the paired *t*-test of data on pulling load of less friction jacquard gadget vis-à-vis conventional jacquard are given in Table 1. It is evident from the *P* value that the pulling load in kg has significantly decreased

($t=28.95$, $P=0$) when compared to the conventional jacquard which could be attributed to the ball bearings incorporated in the appropriate contact places to reduce the friction between metal parts.

Table 1: Comparative analysis of the conventional vs less friction jacquard

Parameter	Statistics	Conventional jacquard	Less friction jacquard
	n	30	30
	$\bar{x}$ (kg)	15.73	9.77
	s	1.51	1.14
Pulling load	Average standard error	0.2751	0.207
	t value	28.95	
	P value	0	

Field trials

General information on less friction jacquard intervention

The weavers under survey generally belonged to the age group of 29 to 67 years, out of which, 60 % have fallen under the class of 36-55 years. Women constituted around 37 %, who availed the gadget and have effectively been utilizing the equipment. The experience of the weaver counts from 5 to 45 years, out of which 90 % had more than 10 years of experience. All the weavers opined that (1) the quality of gadget provided to them was very good, (2) handling and usage of the equipment including its maintenance and repair were very easy and (3) the noise level has reduced. They also informed that the quality of the silk saree produced was better and fabric defects aroused due to Jacquard malfunctioning were completely eliminated.

Descriptive statistics of the technical parameters related to less friction jacquard intervention

The descriptive statistics of the technical parameters of less friction jacquard are presented in Table 2.

The results of the paired t -test of all three technical parameters of less friction jacquard gadget vis-à-vis

Table 2: Descriptive statistics of conventional vs less friction jacquard intervention

Parameter	Statistics	Conventional jacquard	Less friction jacquard
Production (inch·d ⁻¹)	$\bar{x} \pm s$ ($n = 30$)	37.47 $\pm$ 2.03	44.50 $\pm$ 2.01
	Minimal value	30	35
	Maximal value	38	45
Pulling load (kg)	$\bar{x} \pm s$ ($n = 30$)	12.07 $\pm$ 0.37	9.03 $\pm$ 0.18
	Minimal value	12	9
	Maximal value	14	10
Revenue (₹d ⁻¹)	$\bar{x} \pm s$ ($n = 30$)	437 $\pm$ 112	546 $\pm$ 129
	Minimal value	300	375
	Maximal value	700	800

conventional jacquard are provided in Table 3.

It is evident from the P value (Montgomery, 2010; Kadhar *et al.*, 2017) that the production per day in inches in respect of less friction jacquard was significantly higher when compared with that of conventional jacquard ($t = -57.61$, $P = 0$). The pulling load in kg has also significantly

Table 3: Paired t -test of quality parameters of conventional and less friction jacquard

Parameter	Statistics	Conventional jacquard	Less friction jacquard
Silk saree production	n	30	30
	$\bar{x}$ (inch·d ⁻¹)	37.47	44.50
	s	2.03	2.01
	Average standard error	0.371	0.368
	t value	-57.61	
	P value	0	
	n	30	30
Pulling load	$\bar{x}$ (kg)	12.07	9.03
	s	0.37	0.18
	Average standard error	0.067	0.033
	t value	91.00	
	P value	0	
Revenue	n	30	30
	$\bar{x}$ (₹d ⁻¹)	437	546
	s	112	129
	Average standard error	20.50	23.60
	t value	-11.04	
	P value	0	

decreased ($t = 91$, $P = 0$) and revenue generated by the weaver using less friction jacquard was significantly higher when compared to the conventional jacquard ($t = -11.04$, $P = 0$).

Conclusion

The intervention made through less friction jacquard has made a tremendous positive impact on the livelihood of the weavers in terms of better working atmosphere, substantial improvement in productivity and significant reduction in drudgery besides considerable increase in the earnings of the weaver winder. The gadget has to be made available to other weavers of the Tamilnadu province in the years to come for which the concerned department has agreed in principle to initiate the necessary action.

REFERENCES

- Akhnazarova S. and Kafarov V. (1982) *Experiment optimization in chemistry and chemical engineering*. Mir Publishers, Moscow, pp. 24-41.
- Chandrashekar S. (2005) Kanchipuram silk saree GI 15. *Geographical Indications Journal*, 4: 1-12.
- Garrett H. E. and Woodworth R. S. (1965) *Statistics in psychology and education*. 3rd Edn., Vakils, Feffer and Simons Pvt. Ltd., Bombay, pp. 212-231.
- Kadhar K. M. A., Rameshbabu V. K. and Naik S. V. (2017) Production performance impact assessment of motorized two bobbin weft winding machine. *Acta Sericol. Sin.*, 43 (1): 0102-0105.
- Ministry of Textiles, Government of India (2010) *Third national handloom census of weavers and allied workers*. National Council of Applied Economic Research, New Delhi, pp. 30-42.
- Montgomery D. C. (2010) *Design and analysis of experiment*. 7th Edn., Wiley India (P) Ltd., Delhi, pp. 36-45.

Article scientifique

EVALUATION DE L'IMPACT DU JACQUARD FAIBLE FRICTION DANS LE TISSAGE ARTISANAL DE LA SOIE

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RESUME

Le tissage manuel est l'une des activités textiles importantes dans la province du Tamilnadu en Inde fournissant un emploi à une large population rurale. Afin de réduire ce qui est perçu comme une corvée et d'améliorer la qualité et la productivité du tissage des saris en soie, le jacquard à faible friction a été développé par le Central Silk Technological Research Institute à Bangalore. Sa performance a été testée par la charge requise pour opérer l'ouverture qui résulte en une corvée pendant le tissage. Les résultats des essais en laboratoire révèlent que la charge d'une capacité de 240 crochets de charge sur jacquard à faible friction est significativement plus faible de 38 % qu'avec le jacquard conventionnel. De plus, 3356 jacquards faible friction de diverses capacités de crochets ont été fournis aux tisseurs pour évaluer la corvée et l'évaluation de l'impact de l'équipement a été réalisée après une année d'installation par sélection aléatoire chez trente tisseurs à qui on avait fourni des jacquard sans friction de 240 crochets et nous avons réalisé le test t entre jacquard conventionnel et sans friction. Selon les résultats d'un questionnaire le jacquard sans friction demande une maintenance moindre, donne une meilleure qualité de saris, prolonge la vie de la carte et est

moins bruyant. La production de saris avec le jacquard sans friction est supérieure de 19 % à celle du jacquard conventionnel et la charge qui entraîne le sentiment de corvée décroît de 25 %, le revenu quotidien augmentant de 25 %.

Mots clés: Revenus, jacquard sans friction, performance de production, charge de tirage, productivité de la soie.



DEVELOPMENT OF MUGA SILKWORM, *ANTHERAEA ASSAMENSIS* (HELPER) EGG PRESERVATION SCHEDULE BASED ON EMBRYONIC GROWTH STUDIES

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ABSTRACT

In muga culture, during summer (June – July), Aherua pre-seed crop and early Bhodia seed crop (August) are adversely affected with high temperature and humidity and as a result, late Bhodia seed crop (September) and commercial crop of Kotia (October-November) are negatively impacted with inadequate quantity of superior quality eggs for muga silk production. With this backdrop, an experiment was designed to formulate a viable seed preservation schedule to tide over the adverse seasons. In the present investigation, distinct morphological features of the embryo were used as growth markers to identify specific embryonic stages. Muga silkworm eggs of 24, 36, 48, 60, 72 and 84 h age were subjected to single step refrigeration method (SSRM) and distinguished the cold tolerant embryonic stages as of 36 and 72 h. SSRM results indicated that 24 and 36 h age eggs preserved at 10 °C for 10 days required 5/6 days to complete incubation ($10 + 5/6 = 15/16$ days) resulting in above 75 % hatching. Sixty, 72 and 84 h age eggs preserved at 10°C for 10 days displayed 2-3 days of incubation ($10 + 2/3 = 12/13$ days) with more than 80 % hatching. SSRM studies unraveled the mystery of developmental response under preservation and provides scope for developing new preservation schedules by ascertaining cold tolerance limits of 24, 36, 48, 60, 72 and 84 h age eggs at 2.5, 5, 10, 15 and 20 °C temperature regimes.

Key words: *Antheraea assamensis* (Helper), hatching %, muga embryonic age, preservation, single step refrigeration method (SSRM).

INTRODUCTION

Long lasting and alluring golden hue of muga silk accounts for its unique supremacy among all natural silks and high demand in textile industry. In muga culture, there are six crops consisting of two pre-seed crops viz., Aherua (June-July) and Jarua or Aghenua (December-January), two seed crops viz., Chotua (February-March) and Bhodia (August-September), and two commercial crops viz., Jethua (April-May) and Kotia (October-November). Commercial crops, Kotia and Jethua generate reeling cocoons, whereas, seed crops, Bhodia and Chotua are

intended for stock maintenance and seed multiplication (Figure 1) (Singh *et al.*, 2013). The two commercial crops are linked with two different cycles of pre-seed and seed crops conducted during adverse climatic conditions characterized by very high temperature and humidity during summer and very low temperature and humidity during winter, respectively in addition to silkworms often being exposed to other vagaries of nature, attack of pests /predators and diseases leading to crop failure (Chakravorty *et al.*, 2007).

Monimala Saikia *et al.* (2016) reported that, among

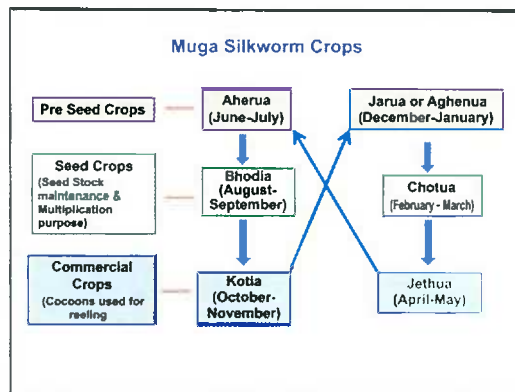


Figure 1: Schematic representation of muga silkworm crops: the commercial crops are linked with two different cycles of pre-seed and seed crops

various constraints encountered while raising commercial crops, non-availability of adequate quantity of healthy seed stands first. Out of the muga DFL (disease free layings) production target of 8.07 lakh set for 2017-18, 5.57 lakh was achieved (Anonymous, 2018). Hence, to minimize the ever persisting gap that exist between demand and supply of muga silkworm seed, development of an efficient seed preservation technology was felt inevitable. Singh and Goswami (2012) reported that late Bhodia crop that prevails during September to October has more silk content and hence, has more economic value in the market. So, supply of healthy seed during this demanding commercial crop season is the most essential. Seed cocoons procured at the Jethua crop (April-May) needed to be preserved up to the beginning of Bhodia crop (August-September) by skipping Aherua (June-July) crop

season. For this purpose, seed / cocoon preservation schedule of 70 days is required but this was impractical with muga seed due to its non-diapause and multivoltine nature. Considering the pupal diapause nature of *Antheraea* species, several researchers (Sengupta and Singh, 1974; Choudhury *et al.*, 1987; Khanikor and Dutta, 1997, 2000) attempted to preserve the muga seed cocoons for longer durations but the moth emergence percentage and fecundity were not satisfactory. Later, Rajkhowa *et al.* (2011) revealed that muga seed cocoons could be preserved for a maximum of up to 42 days; but the needed duration of preservation is for 70 days to overcome the harsh climatic condition. In this context, Silkworm Seed Technology Laboratory, Bengaluru, along with Central Muga Eri Research and Training Institute (CMERTI), Lahdoigarh came up with a unique idea of developing a seed preservation schedule for 25 days along with seed cocoon preservation of 42 days that would serve the purpose (Figure 4). In the present study, embryological growth features of muga silkworm were recorded and considered as morphological markers and initial attempts were made to identify the cold tolerant embryonic stages through single step refrigeration method (SSRM).

MATERIALS AND METHODS

Muga seed cocoons were procured from CMERTI, Lahdoigarh and kept under optimum temperature of 25°C and relative humidity of 85 % for grainage operations. The emerged moths were allowed for pairing up to 12 h and after depairing, female moths were tied on khari kas for egg

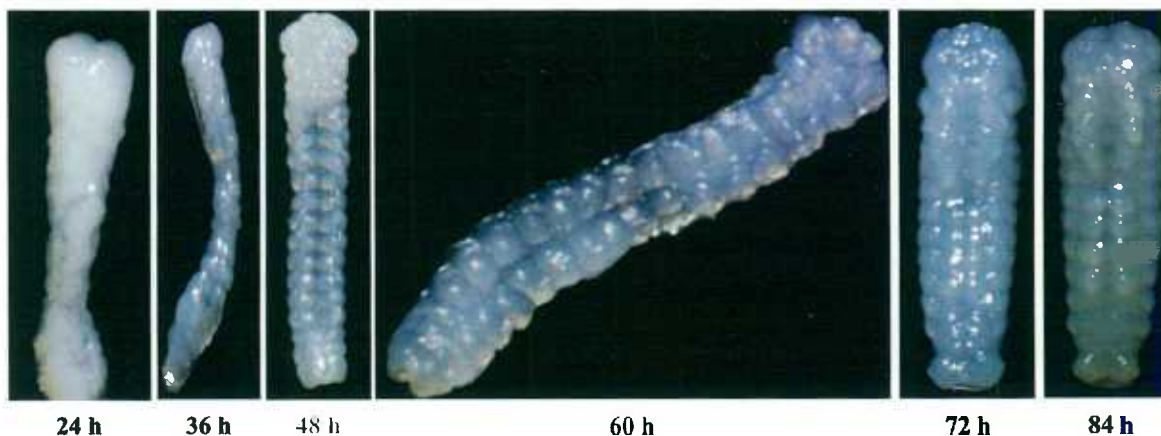


Figure 2: Muga silkworm embryonic stages subjected to single step refrigeration method (SSRM)

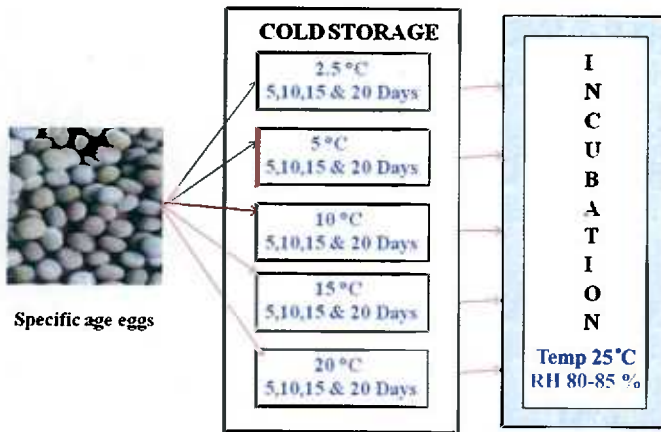


Figure 3: Single step refrigeration method (SSRM) designed to determine the cold tolerant embryonic stages of muga silkworm eggs

laying. After commencement of egg laying, the zero hour was recorded. Eggs were collected after 24, 36, 48, 60, 72 and 84 h for further experimentation. Through embryo isolation technology (Vemananda Reddy *et al.*, 2003), morphological growth features pertaining to 24, 36, 48, 60, 72 and 84 h embryonic stages were recorded and utilised as standard growth markers to identify the age of the eggs.

Muga eggs of 24 (spoon shaped embryo), 36 (the longest embryonic stage), 48 (prominent neural groove), 60 (formation of appendages in gnathal region), 72 (declined embryonic length) and 84 h (appearance of appendages as a pair of buds in abdominal region) age were collected

(Figure 2) and done surface sterilization with 2 % formalin and subsequently subjected to 2.5, 5, 10, 15 and 20 °C temperature for 5, 10, 15 and 20 days under SSRM to identify the cold tolerant stages of embryos based on their hatchability (Figure 3).

The eggs incubated at 25 °C temperature and 85 % relative humidity served as control. The results pertaining to different treatments were analyzed statistically.

RESULTS AND DISCUSSION

Muga silkworm eggs of various age viz., 24, 36, 48, 60, 72 and 84 h were preserved at various temperature regimes for different durations under SSRM and the results obtained are presented in Tables 1-5. At 2.5 °C, significantly high hatching performance of 75 % was recorded for 72 h eggs preserved for 5 days. All the remaining stages exhibited less than 65 % hatching (Table 1). At 5 °C, the hatching performance of 24, 36, 48, 60, 72 and 84 h age eggs preserved for 5 days, were recorded above 75 %, similarly, for 10 days duration also, the hatching performance was significantly high i.e., above 74 % for both 36 and 72 h age eggs (Table 2). The eggs preserved at 10 °C, for 5 and 10 days also revealed above 75 % hatching (Table 3). The hatching performance of 24, 36, 48, 60, 72 and 84 h eggs kept at 15 °C, for 5 and 10 days were comparatively better than that of 5 and 10 °C, with

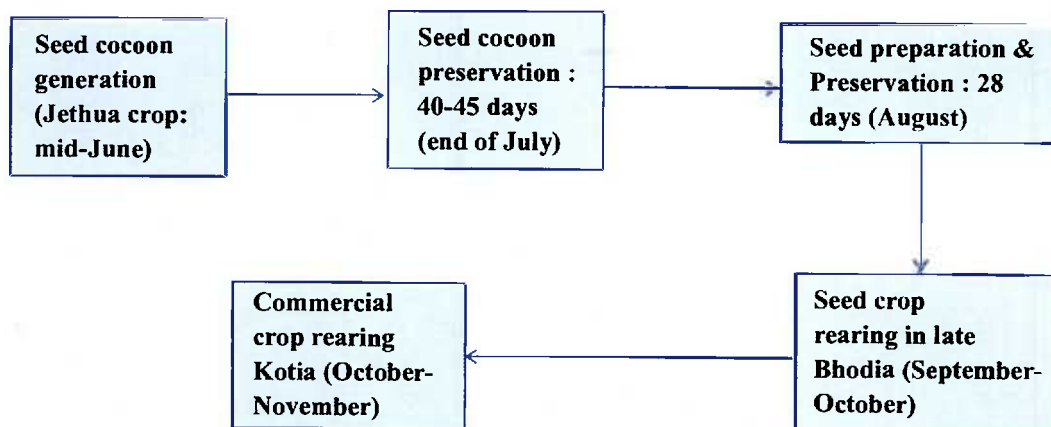


Figure 4: Tentative plan for utilization of developed technologies for enhancing muga silk production

Table 1: Hatching performance (%) of different age embryos preserved at 2.5 °C

Duration of preservation (Days)	Embryonic age					
	24 h	36 h	48 h	60 h	72 h	84 h
5	62.23 (5P+7I)	51.00 (5P+6/7I)	49.16 (5P+5/6I)	51.11 (5P+5I)	75.00 (5P+5I)	46.19 (5P+4I)
10	35.11 (10P+7I)	16.77 (10P+6I)	28.11 (10P+5I)	4.80 (10P+4I)	0.00 (10P+3I)	1.64 (10P+2I)
15	0.00	13.60 (15P+1I)	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00
F -Test	*	*	*	*	*	*
S. Em ±	3.759	3.629	5.564	1.092	1.768	3.093
CD @ 5 %	11.268	10.881	16.680	3.273	5.300	9.272

* Significant @ 5 %; (P+I) = Preservation + Incubation duration in days.

Table 2: Hatching performance (%) of different age embryos preserved at 5 °C

Duration of preservation (Days)	Embryonic age					
	24 h	36 h	48 h	60 h	72 h	84 h
5	77.94 (5P+6/7I)	80.65 (5P+6/7I)	81.46 (5P+5I)	81.01 (5P+4/5I)	83.91 (5P+4/5I)	86.19 (5P+3/4I)
10	67.42 (10P+5/6I)	74.34 (10P+4/5I)	30.88 (10P+4/5I)	32.91 (10P+3/4I)	80.37 (10P+2I)	73.19 (10P+2I)
15	5.18 (15P+6I)	8.62 (15P+4I)	0.00	0.00	0.00	3.60 (15P+1I)
20	0.00	0.00	0.00	0.00	0.00	0.00
F -Test	*	*	*	*	*	*
S. Em ±	2.378	2.542	2.895	4.789	2.718	2.064
CD @ 5 %	7.130	7.621	8.680	14.359	8.148	6.187

* Significant @ 5 %; (P+I) = Preservation + Incubation duration in days.

above 79 %. At 15 °C, preservation duration of 15 days successfully worked out for 36 h age eggs with above 75% hatching but in the case of 60, 72 and 84 h eggs, prior hatching occurred on 13th day itself and were unable to continue up to the targeted period of 15 days. Similarly, when the different embryonic age eggs were preserved for 20 days duration at 15 °C, 24, 36 and 48 h eggs showed very less hatching % beyond 15 days, whereas, 60, 72 and 84 h eggs showed prior hatching on 13th day itself in cold storage (Table 4). Somewhat similar trend was exhibited in the case of preservation under 20 °C too. The 24, 36, 48, 60, 72 and 84 h eggs preserved at 20 °C, for 5 and 10 days showed above 80 % hatching. At 20 °C, the lower embryonic age eggs (24 and 36 h) preserved for 15 days recorded above 70 % hatching with incubation duration of one day but less hatching when extended beyond 15 days. Eggs of 48, 60, 72 and 84 h, preserved at 20 °C and intended for 15 and 20 days showed prior hatching on 12th, 13th and 14th day itself and hence, couldn't be continued to be preserved up to the targeted period of 15 and 20 days (Table 5).

From these results, we found that 24 and 36 h age muga eggs preserved at 10 °C for 10 days followed by an incubation period of 5-6 days, recorded above 75 % hatching. Similarly, 24 and 36 h age muga eggs preserved at 15 and 20 °C for 10 days followed by incubation of 4-5 days, showed 80 % hatching. But 60, 72 and 84 h age muga eggs preserved at 10 °C for 10 days followed incubation of 2-3 days, and recorded above 80 % hatching. 36 h age muga eggs were able to withstand 5

Table 3: Hatching performance (%) of different age embryos preserved at 10 °C

Duration of preservation (Days)	Embryonic age					
	24 h	36 h	48 h	60 h	72 h	84 h
5	81.12 (5P+6/7I)	87.05 (5P+6/7I)	80.01 (5P+5/6I)	80.22 (5P+4/5I)	84.20 (5P+4/5I)	82.30 (5P+3/4I)
10	77.44 (10P+5/6I)	78.05 (10P+5/6I)	76.60 (10P+3/4I)	83.28 (10P+2/3I)	83.30 (10P+2I)	84.15 (10P+2I)
15	4.91 (15P+5I)	36.37 (15P+4/5I)	32.80 (15P+4I)	57.17 (15P+4I)	29.09 (15P+4I)	32.27 (15P+3I)
20	7.60 (20P+5I)	15.92 (20P+5/6I)	8.60 (20P+4I)	14.24 (20P+3I)	14.55 (20P+3I)	15.11 (20P+2I)
F -Test	*	*	*	*	*	*
S. Em ±	2.685	0.967	0.625	2.941	4.026	4.209
CD @ 5 %	8.048	2.900	1.872	8.818	12.069	12.169

* Significant @ 5 %; (P+I) = Preservation + Incubation duration in days.

and 10 °C for 10 days and also showed sustainable hatching % when preserved at 15 and 20 °C up to 15 days. 72 h age eggs were able to withstand lower temperature of 2.5 °C for five days. 72 h age eggs also showed better hatching % after preserving at 5, 10, 15 and 20 °C for ten days. Control muga eggs subjected to 25 °C temperature and 80-85 % RH with proper aeration showed 89 % of hatching after 9 days of incubation.

Singha *et al.* (1998) revealed that 36 hours old eggs during May and 114-126 hours old embryos during November corresponding to stage 15 as per normal table of *Bombyx mori* were ideal for preservation as these stages were found to be cold resistant. In this study, based on SSRM results, it was identified that 36 and 72 h eggs were able to withstand wide range of temperature for longer duration and recorded sustainable hatching % when compared to

Table 4: Hatching performance (%) of different age embryos preserved at 15 °C

Duration of preservation (Days)	Embryonic age					
	24 h	36 h	48 h	60 h	72 h	84 h
5	80.05 (5P+5/6I)	88.24 (5P+5/6I)	87.40 (5P+5I)	82.24 (5P+5I)	89.34 (5P+5I)	81.07 (5P+4/5I)
10	81.12 (10P+4/5I)	88.00 (10P+4/5I)	85.60 (10P+3/2I)	83.54 (10P+2I)	82.11 (10P+2I)	79.04 (10P+1I)
15	28.43 (15P+1I)	78.07 (15P+1I)	56.00 (15P+0I)	65.09 [#]	90.04 [#]	75.03 [#]
20	43.59	15.09	21.20	77.27 [#]	74.45 [#]	72.04 [#]
F -Test	*	*	*	*	*	*
S. Em ±	1.902	3.052	0.700	1.613	1.018	1.944
CD @ 5 %	5.703	2.099	2.099	4.835	3.053	5.827

* Significant @ 5 %; (P + I) = Preservation + Incubation duration in days;
[#] Prior hatching.

those of 24, 48, 60 and 84 h.

Generally, the incubation duration of muga eggs varies season-wise *i.e.*, around 10 days during winter and a day less during summer. When specific embryonic age eggs (24, 36, 48, 60, 72 and 84 h) preserved in cold storage for certain period were released from cold storage for incubation at 25 °C temperature and 85 % relative humidity, the incubation period varied in all SSRM treatments in comparison with the normal incubation period of 9 days (Table 1-5). This unraveled the mystery of developmental pattern of Muga eggs and is evident that, by inducing hibernation through temperature management, the non-diapause muga eggs chronological development (Circadian cycle of embryonic growth) can be made slow so that the hatching point may be prolonged through preservation. This phenomenon is very unique in muga silkworm when compared to *B. mori* L. Multivoltine pure races / breeds of *B. mori* L. belonging to Bombycidae can be preserved up to 35 days in cold storage with an incubation of 9/10 days (Vijaya Kumari *et al.*, 2016). In the case of 24, 36, 48, 60, 72 and 84 h muga eggs belonging to Saturniidae, preserved for 5, 10 and 15 days in cold storage, the incubation duration decreased and ranged from 1 to 7 days (Table 1-5) from the general range of 9 / 10 days. Yaginuma *et al.* (1990) revealed that young age of multivoltine eggs can tolerate cold but not advanced stage embryos since sorbitol, the cryoprotective agent appears only during former stage but not in the latter. In these preliminary studies, maximum preservation period found possible with 36 h muga eggs

Table 5: Hatching performance (%) of different age embryos preserved at 20 °C

Duration of preservation (Days)	Embryonic age					
	24 h	36 h	48 h	60 h	72 h	84 h
5	81.05 (5P+5I)	85.84 (5P+5I)	80.01 (5P+5I)	87.12 (10P+4I)	81.62 (10P+4I)	87.35 (10P+3I)
10	81.98 (10P+4I)	84.63 (10P+3/2I)	85.64 (10P+2I)	86.39 (10P+1/2I)	81.05 (10P+1I)	85.15 (10P+1I)
15	72.80 (15P+1I)	74.52 (15P+1/0I)	68.39 [#]	65.82 [#]	42.28 [#]	45.59 [#]
20	25.40	35.60	40.00 [#]	67.09 [#]	47.58 [#]	43.13 [#]
F -Test	*	*	*	*	*	*
S. Em ±	3.747	2.189	4.396	1.783	5.075	3.544
CD @ 5 %	11.234	6.561	13.179	5.346	15.216	10.624

* Significant @ 5 %; (P + I) = Preservation + Incubation duration in days;
[#] Prior hatching.

was 10 days along with 5/6 days of incubation. This gives a clue for further studies and opens up a challenging task providing scope to develop new preservation schedules for muga silkworm eggs. Future studies are required to develop 20 days preservation schedule for different age eggs by considering the variable embryonic age cold tolerance limits at different temperature schedules under SSRM.

Conclusion

It is concluded that, by developing seed cocoon and seed preservation technologies together as depicted in Figure 4, supply of sufficient Muga seed can be ensured in future to late Bhodia and Kotia commercial crops.

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REFERENCES

- Anonymous (2018) *Functioning Of Central Silk Board & Performance of Indian Silk Industry as on 1st January*, Central Silk Board, Ministry of textiles, Govt. of India, Bengaluru, p.13.
- Chakravorty R., Das R., Neog K., Das K. and Sahu M. (2007) *A diagnostic manual for diseases and pest of muga silkworms and their host plants*. CMERTI, CSB, Lahdoigarh, Jorhat, Assam, pp. 1-47.
- Choudhury C. C., Dubey O. P., Choudhury A. and Sengupta K. (1987) Effect of refrigeration and preservation of muga seed cocoons *Antheraea assamensis* Ww. *Sericologia*, **27** (3): 547-552.
- Khanikor D. P. and Dutta S. K. (1997) Induction of pupal diapause in muga silkworm (*Antheraea assama* Westwood) (Lepidoptera: Saturniidae). *J. Assam Sci. Soc.*, **39**: 40-44.
- Khanikor D. P. and Dutta S. K. (2000) Low temperature preservation of seed cocoons for delaying moth emergence in muga silkworm (*Antheraea assama* Westwood). *Int. J. Wild Silkworm Silk*, **5**: 216-220.
- Monimala Saikia, Kumud Ghosh and Richard S. Peigler (2016) Factors affecting on quality muga silkworm, *Antheraea assamensis* (Helfer) seed crop production: A review. *J. Entomol. Zool. Stud.*, **4** (6): 806-810.
- Rajkhowa G., Kumar R. and Rajan R. K. (2011) Studies on the long-term preservation method of Muga Cocoon (*Antheraea assamensis* Helfer) at low temperature. *Munis. Entomol. Zool.*, **6** (2): 815-818.
- Sengupta K. and Singh K. (1974) Some studies on the effect of refrigeration of muga *A. assamensis* cocoons on moth emergence, egg laying and hatching of eggs. *First International Seminar on non-mulberry silks*, 3-4 October 1974, CTRTI, Ranchi, 1974, p. 174.
- Singh N. I. and Goswami D. (2012) Food plant varietal effect on the rearing and grainage of Muga silkworm, *Antheraea assamensis* Helfer. *Mun. Ent. Zool.*, **7**: 1023-1027.
- Singh R. N., Bajpeyi C. M., Tikader A. and Saratchandra B. (2013) *Muga Culture*, Published by S. B Nangia, A. P. H. Publishing Corporation, New Delhi, India, pp.1- 422.
- Singha B. B., Sahu A. K. and Das P. K. (1998) Identification of low temperature resistant embryonic stage(s) in muga silkworm, *Antheraea assama* Ww. *The 3rd International Conference on Wild Silkworm*, Bhubaneswar, Orissa, 11-14 November, p. 50.
- Vemananda Reddy G., Vijaya Lakshmi Rao and Kamble C. K. (2003) Silkworm seed preservation schedules and embryo isolation techniques. In: *Fundamentals of Silkworm egg Bombyx mori L.*, Kamble C. K. (Ed.), Silkworm Seed Technology Laboratory, Central Silk Board, Bangalore, pp. 48-77.
- Vijaya Kumari K. M., Jaya Prakash P., Vemananda Reddy G. and Jayappa T. (2016) Studies on Double refrigeration of polyvoltine eggs for long term preservation in Silkworm, *Bombyx mori* L., for tropics. *Indian J. Seric.*, **55** (1-2): 38-42.
- Yaginuma T., Kobayashi M. and Yamashita O. (1990) Distinct effects of different low temperatures on the induction of NAD-Sorbitol dehydrogenase activity in diapause eggs of the silkworm, *Bombyx mori* L. *J. Comp. Physiol.*, **B160**: 277-285.

Article scientifique

DEVELOPPEMENT DU VER A SOIE MUGA *ANTHRAEA ASSAMENSIS* (HELPER). PROCEDURE DE CONSERVATION DES ŒUFS BASEE SUR L'ETUDE DU DEVELOPPEMENT EMBRYONNAIRE

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RESUME

Dans la culture muga, pendant l'été (Juin-Juillet) la récolte de pré grainage Aherua et celle du grainage précoce Bhodia (Août) sont affectées par les fortes températures et humidité ce qui entraîne un impact négatif sur la période Bhodia tardive (Septembre) et la récolte commerciale de Kotia (Octobre-Novembre). Dans cette étude, des efforts ont été faits pour développer un protocole de conservation des œufs allant jusqu'à 20 jours afin de réduire les effets néfastes du climat sur la culture muga. Des éléments morphologiques de l'embryon ont été utilisés comme marqueurs de croissance pour identifier les étapes spécifiques de l'embryogenèse. Des œufs muga de 24, 36, 48, 60, 72 et 84 h ont été soumis à une seule étape de réfrigération (SSRM) et nous avons distingué des âges embryonnaires tolérant au froid de 36 et 72 h. Les résultats indiquent que les œufs de 24 et 36 h conservés à 10 °C pendant 10 jours demandent 7 jours pour achever l'incubation ($10+7=17$ jours) avec un taux d'éclosion de 75 %, alors que les œufs de 60, 72 et 84 h conservés à 10 °C pendant 10 jours demandent 3-4 jours d'incubation ($10+3/4=13/14$ jours) avec un taux d'éclosion de plus de 80%. Le SSRM ouvre la voie à une nouvelle méthode de conservation avec des œufs de 36 et 72 h tolérant au froid acquérant une durée de conservation de 25 et 21 jours respectivement.

Mots clés: *Antheraea assamensis* (Helper), % d'éclosion, stade embryonnaire muga, durée de conservation, méthode de réfrigération en une seule étape (SSRM).



USE OF CHEMICALS DURING COCOON COOKING FOR BETTER REELING PERFORMANCE AND SUPERIOR QUALITY SILK

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ABSTRACT

For a given sample of cocoons, the ease of unwinding of the filaments during reeling process depends upon the quality of cocoon as well as processing techniques. The studies conducted at Central Silk Technological Research Institute (CSTRI), Bengaluru, have proven that the cocoons produced under unfavorable climatic conditions (particularly monsoon season) have lower reelability and are characterized with an average of 0.5~1.0 unit more renditta than the cocoons produced during favourable climatic conditions. Series of studies conducted on this issue attribute it to the high crystalline nature of sericin due to more gelatinisation caused while spinning by silkworms under high humid conditions. Therefore, it is not possible to achieve desired results from these cocoons if we adopt the same reeling technology as set for good quality cocoons. It is well known that sericin is highly sensitive to alkaline media and many efforts have also been made by the researchers to cook the cocoons using chemicals so that softening and swelling of sericin is achieved during cocoon cooking to result in better reelability of the cocoons. There is a lot of scope to continue the work in this area as a desired chemical recipe is not yet attained, and controlling the waste generation being another challenge associated with this procedure. In this line, Silk plus, a formulation of Na_2CO_3 and NaHCO_3 , developed at Central Muga Eri Research and Training Institute, Central Silk Board, Lahdoigarh, Assam, India has been successful in achieving higher reelability and lower renditta from muga cocoons. The present study aimed to ascertain the efficacy of the use of chemicals while cooking the mulberry cocoons particularly those produced under unfavourable conditions, to improve the reelability and quality of raw silk. Based on the findings, Silk plus and the wetting agent, Ethylene oxide condensate based surfactant are recommended for enhancing the reeling performance.

Key words: Alkaline, reelability, sericin, Silk plus, unfavorable climatic conditions.

INTRODUCTION

Cocoon cooking is a very important process of silk reeling that influences directly the raw silk recovery, productivity and quality of silk and hence, plays a role in the economics of the filature. Improper cocoon cooking results in poor recovery, low productivity, poor quality and higher conversion cost. The studies conducted at Central Silk Technological Research Institute (CSTRI), Bengaluru, have revealed that the cocoons produced under unfavorable climatic conditions (particularly monsoon season) have lower reelability resulting in an average of

0.5~1.0 unit more of renditta than the cocoons produced in favourable climatic conditions (Subhas and Somashekar, 2004, 2008). Quite a number of studies conducted on this aspect attributed this to the high crystalline nature of sericin in the cocoon due to more gelatinisation when the silkworm spin it under high humid conditions.

Provision of appropriate temperature and duration for cocoon cooking is vital in determining the quality of raw silk and its optimum productivity in reeling process. Moreover, uniform and proper softening and swelling of sericin depend upon the sericin characteristics, cocoon

drying and cooking conditions (Omura, 1981). Many aspects of cocoon cooking have been investigated (Shimazaki and Sekijima, 1961; Shimazaki and Yamamoto, 1962; Hariraj *et al.*, 2005). The well established fact that sericin is highly sensitive to alkaline media, has prompted researchers to incorporate the use of suitable chemicals in cocoon cooking so that proper softening and swelling of sericin is attained leading to better reelability of the cocoons. The best recipe for this purpose is yet to be worked out. Therefore, the present study was proposed.

MATERIALS AND METHODS

Raw material

Indian bivoltine hybrid silk cocoons were used for the study.

Drying conditions

The cocoons were dried using a batch type hot air dryer under a temperature profile of 115 °C - 100 °C - 85 °C - 70 °C - 55 °C, for a period of 5 hours. The degree of drying attained was 42 %.

Cocoon cooking

Open pan cooking method was employed for cooking the cocoons. After preparation of recipe, chemicals were directly added to the pan at 50-60 °C. Cocoons were cooked at boiling temperature. The following chemicals were used for the experiments.

- i) Sodium carbonate (Na_2CO_3)
- ii) Sodium Bi-carbonate (NaHCO_3)
- iii) Silk Plus: (Physical mixture of Na_2CO_3 & NaHCO_3 formed on Molar basis)
- iv) Trisodium phosphate (Na_3PO_4)
- v) Wetting agents (Mild silk specific surfactant and Ethylene oxide condensate based surfactant)

While selecting the chemicals, care was taken to see that they are harmless to the operatives in silk reeling, cost effective and commonly available as well. Moreover, it was ensured that very small quantities of chemicals in a diluted form were used.

Brushing condition

The cooked cocoons were brushed at 80 °C in a manual brushing unit and then taken for reeling.

Reeling

The cooked cocoons were reeled on CSTR Multi end reeling machine. The reeling parameters were as mentioned below.

Reeling speed: 100 m/min
Basin water temperature: 40 °C

Investigated parameters

The following parameters were investigated to study the influence of chemicals on cocoon cooking to achieve better reeling performance and quality characteristics of raw silk.

1. Reelability (%)
2. Average filament length (m)
3. Non-broken filament length (m)
4. Raw silk recovery (%)
5. Renditta
6. Cleanness %
7. Neatness (%)
8. Tenacity (g/d)
9. Elongation %
10. Cohesion (strokes)

RESULTS AND DISCUSSION

Three trials using different lots of cocoons were conducted under the study. Results of reeling performance and quality of raw silk tested are given in Tables 1, 2 and 3.

Table 1: Reeling performance and quality of raw silk (Experiment 1)

Control / Treatment	Reela-bility %	FL (m)	NBFL (m)	RSR %	Renditta	Cleanness %	Neatness %	Tenacity (g/d)	Elongation %	Cohesion (strokes)
Control	76.0	992	744	79.6	5.97	97	93	3.62	17.4	71
Na ₂ CO ₃ (0.25 gpl)	77.5	1000	762	81.0	5.88	98	94	3.52	17.2	70
Na ₂ CO ₃ (0.50 gpl)	80.4	941	739	73.3	6.55	97	94	3.54	15.8	58
Na ₂ CO ₃ (1 gpl)	87.9	957	823	69.7	6.62	90	92	3.43	16.2	44
Silk plus (0.25 gpl)	79.5	989	782	83.1	5.67	99	96	3.59	18.3	76
Silk plus (0.50 gpl)	80.4	980	776	78.8	5.86	98	96	3.64	17.5	67
Silk plus (0.75 gpl)	82.5	964	788	76.7	6.02	98	95	3.56	16.2	85
Na ₃ PO ₄ (0.25 gpl)	76.5	976	736	79.5	6.04	95	87	3.43	17.3	74
Na ₃ PO ₄ (0.50 gpl)	79.8	986	774	76.7	6.01	100	95	3.60	16.0	45
Na ₃ PO ₄ (0.75 gpl)	76.6	964	735	80.2	6.01	99	92	3.47	17.1	56
WT1 (0.25 gpl)	82.2	976	798	79.1	5.83	98	90	3.44	15.3	75
WT1 (0.50 gpl)	87.6	936	815	75.8	6.08	96	93	3.57	17.0	61
WT1 (1.0 gpl)	88.0	944	827	76.3	6.04	94	88	3.58	18.3	54
Na ₂ CO ₃ (0.25 gpl) + WT2 (0.25 gpl)	75.3	951	714	90.5	5.53	99	93	3.29	21.1	61
WT2 (0.5 gpl)	76.0	937	716	89.4	5.60	100	95	3.49	19.2	59
F-Value	3.761**			4.29**	8.010	0.52 ^{ns}	4.156**	2.822**		

** Significant; FL- Filament length; NBFL - Non-breakable filament length; RSR- Raw silk recovery; WT-Wetting agent; WT1- Mild silk specific surfactant; WT2-. Ethylene oxide condensate based surfactant

With respect to the test parameters viz., reelability, silk recovery, neatness, elongation and renditta, the differences in results are significant between the treated and controlled samples. Cocoon samples treated with Silk plus and wetting agents 1 & 2 during cooking have yielded lower renditta and better silk recovery % and hence, are promising.

Wider range of concentrations of the better performing chemicals were tested further. The results of second experiment also clearly reveal the prominent and

Table 2: Reeling performance and quality of raw silk (Experiment 2)

Control / Treatment	Reela-bility (%)	FL (m)	NBFL (m)	RSR (%)	Renditta
Control (Open pan cooking)	74.9	990	740	79	5.7
Silk Plus (0.475 gpl)	69	995	673	80.2	5.7
Silk Plus (0.95 gpl)	68.7	1041	707	77.9	5.8
WT2 (0.50 gpl)	65.2	1031	663	81.4	5.6
WT2 (1.0 gpl)	69.4	1037	707	79.1	5.7
WT2 (2.0 gpl)	70.5	1064	740	81.4	5.6
Na ₂ Co ₃ (0.25 gpl) + WT2 (0.25 gpl)	71.7	1023	722	79.1	5.7
F-Value	15.861**	9.119**	12.554**	35.327**	24.287**

Table 3: Reeling performance and quality of raw silk (Experiment 3)

Control / Treatment	Reelability %	FL	NBFL	Silk recovery %	Renditta	Cleanness %	Neatness %	Tenacity (g/d)	Elongation (%)	Cohesion (Strokes)
Control (Open pan cooking)	76.6	946	716	84.9	5.9	97	97	3.44	17	37
Silk Plus (0.475 gpl)	85.1	890	751	87.5	5.73	100	93	3.34	19.2	85
Silk Plus (0.95 gpl)	89.3	891	781	84.6	5.93	100	92	3.48	17.2	156
Silk Plus (1.9 gpl)	95	728	679	70.0	7.2	97	90	3.67	18.6	98

significant impact of the treated chemicals over the control in respect of characteristics, such as reelability, silk recovery and renditta. Although there observed a

decrease in reelability in samples, renditta has improved significantly without affecting the quality characteristics, on use of wetting agent 2.

Table 4: Cost of chemicals used and its economics

Chemical	Price/ kg (₹)	Cost of treatment/ kg of silk produced (₹)			Quantity required / 8 h & cost			Expected qty. of cocoons to be saved per 8 h in a 10 basin unit (kg)	Net gain / day (₹)
		0.25 gpl	0.50 gpl	1.00 gpl	0.25 gpl	0.50 gpl	1.00 gpl		
Trisodium Phosphate	100	0.84	1.68	2.52	100 g, Rs. 10	200 g, Rs. 20	400 g, Rs. 40	2	600
Sodium Carbonate	70	0.6	1.2	2.4	100 g, Rs. 7	200 g, Rs. 14	400 g, Rs. 28	2	600
Sodium Bi-Carbonate	60	0.52	1.04	1.56	100 g, Rs. 6	200 g, Rs. 12	400 g, Rs. 24	2	600
Wetting agent 2	365	3.04	6.08	3.04	100 g, Rs. 36	100 g, Rs. 72	400 g, Rs. 144	2	600

Assumptions: 1. Water in cooking vessel is changed 10 times per day; 2. Cooking vessel capacity: 10 litres; 3. 80 kg cocoons / 8 h in 10 - Basin MRM.

Post cocoon parameters assessed for the third consecutive experiment involving a still higher concentration of Silk plus also revealed a significant difference in respect of reelability in all the treated samples as compared to control sample out of which silk plus at 0.475 gpl has given good results in terms of lower renditta, better silk recovery % and comparatively better quality characteristics.

Cost analysis of the use of chemicals

Cost analysis of chemical treatment while cocoon cooking of cocoons was done and it is observed that cost is negligible, whereas, benefits are highly significant. Results of cost analysis are shown in Table 4.

From the above results, the following conclusions could be drawn for the benefit of silk reeling industry.

1. When the reeling performance particularly reelability of cocoons is inferior, significantly better results can be achieved by the use of recommended chemicals in cocoon cooking.
2. Based on the results of the present work, the following chemicals have been identified for use during cocoon cooking for achieving significantly better reeling performance and raw silk quality. Any one of them, as recommended can be employed in cocoon cooking to enhance the reeling performance.

1) Silk plus - 0.25~0.50 gpl

(Physical mixture of Na_2CO_3 and NaHCO_3 taken on

molarity basis)

2) Wetting agent 2 - 0.5~1.0 gpl
(Ethylene oxide condensate based surfactant)

Conclusion

Results clearly indicate that reeling performance and quality of silk can be significantly improved by using chemicals particularly when the reelability is moderate to poor. The output of the study as anticipated resulted in deriving effective methods / techniques for better cooking of cocoons particularly produced under unfavourable conditions. This will help the reelers to realise significantly better silk recovery (*i.e.*, lower renditta), achieve better quality of silk and productivity as compared to existing conventional cooking methods. Further, the cost analysis data also substantiate their usage since the cost stands negligible as against the highly significant benefits.

REFERENCES

- Akahane (1994)
- Hariraj G., Haruo Kinoshita and Somashekar T. H. (2005) Studies on bivoltine cocoon cooking - Part II - Influence of permeation treatments in cooking process on reeling characteristics of Japanese Bivoltine cocoons. *Sericologia*, 45 (2): 189-199.
- Omura T. (1981) *Silk Reeling Techniques in Tropics*, Japan International Co-operation Agency, Tokyo, Japan, pp. 61, 125.
- Shimazaki A. and Sekijima M. (1961) Studies on pretreatment

- of cocoon cooking: Part I. *J. Sci. Tech. Japan*, **11**: 1-8.
- Shimazaki A. and Yamamoto A. (1962) Studies on pretreatment of cocoon cooking: Part II. *J. Sci. Tech. Japan*, **12**: 4-7.
- Subhas V. N. and Somashekar T. H. (2004) Influence of cocoon spinning conditions in reeling performance and quality of raw silk of multi-bivoltine cocoons. *Indian J. . Fibre Text. Res.*, **29**: 324-332.
- Subhas V. N. and Somashekar T. H. (2008) Influence of temperature and humidity maintained during cocoon spinning in reeling performance and quality of raw silk of Indian bivoltine hybrid cocoons. *Sericologia*, **48** (4): 379-389.

Article scientifique

UTILISATION DE PRODUITS CHIMIQUES PENDANT LA CUISSON DES COCONS POUR OBTENIR UNE MEILLEURE FILATURE ET UNE QUALITE SUPERIEURE DE SOIE

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RESUME

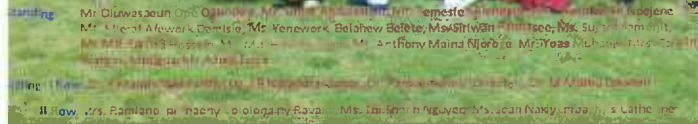
Pour un échantillon donné de cocons, la facilité du dévidage des filaments pendant la filature dépend de la qualité des cocons ainsi que des techniques. Les études conduites au Central Silk Technological Institute (CSTRI) de Bangalore a établi que les cocons produits dans des conditions climatiques défavorables (en particulier durant la mousson) présentent une faible dévidabilité, avec en moyenne 0,5 à 1,0 unité de plus de perte que les cocons produits dans de bonnes conditions climatiques. Des études réalisées ici attribuent cela à la nature cristalline de la séricine due à une gélification au cours du filage par les vers à soie dans des conditions humides. Il n'est donc pas possible d'obtenir des résultats souhaités de ces cocons avec les mêmes techniques de filature utilisées pour les cocons de bonne qualité. La séricine est sensible aux milieux alcalins et de nombreux efforts ont été réalisés pour cuire les cocons avec des produits chimiques afin d'assouplir et de gonfler la séricine pour obtenir une meilleure dévidabilité des cocons. Il y a beaucoup de visions pour continuer ce travail alors qu'aucune recette chimique n'a été obtenue et le contrôle des déchets reste un défi associé à ces procédés. Dans ce domaine, Silk Plus, une formule de Na_2CO_3 et de NaHCO_3 développée au CMERTI (CSB) de Lahdoigarh en Assam (Inde) a permis un succès pour obtenir une meilleure dévidabilité et un faible renditta à partir de cocons muga. Nous présentons ici une tentative d'amélioration de la dévidabilité et de la qualité de la soie grège par l'utilisation de produits chimiques pendant la cuisson des cocons de vers à soie mûrier produits dans des conditions défavorables. Selon ces découvertes, Silk Plus et l'agent de mouillage. Surfactant basé sur la condensation d'oxyde d'éthylène sont recommandés pour améliorer les performances en filature.

Mots clés: Alcalin, dévidabilité, séricine, silk plus, conditions climatiques défavorables.

Training on Sericulture and Silk Industry

A four weeks training on "Sericulture and Silk Industry" was held at Central Sericultural Research and Training Institute, Mysore during 2-29 September, 2019. The training was fully sponsored under the Indian Technical and Economic Cooperation (ITEC) programme of Ministry of External Affairs, Govt. of India. Nineteen officials from 9 countries participated in the training. Apart from the class room lectures on different aspects of sericulture and silk industry, the trainees were also exposed to the successful model of commercial sericulture practice through practical classes and extensive field visits to the sericulture areas and facilities of Karnataka province.





Visit of Bangladesh Delegation

ISC facilitated the visit of a nine member delegation from Bangladesh led by Mr. Abdul Hakim, Director General, Bangladesh Sericulture Development Board. They visited the sericulture areas and facilities during 2nd to 12th September, 2019. As part of this visit, the delegation visited the Office of the ISC on 10th September, 2019 and discussed about taking up a mega sericulture project in Bangladesh. Based on this, ISC facilitated a meeting between the delegation and Central Silk Board for sourcing technical and logistical support from India for the development of sericulture industry in Bangladesh. As a follow up of this visit, ISC in consultation with Central Silk Board has developed a MoU for collaboration between both the countries.







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Dollo M., Samal P. K., Sundriyal R. C. and Kumar K. (2009) Environmentally sustainable traditional natural resource management and conservation in Ziro Valley, Arunachal Himalaya, India. *J. Am. Sci.*, 5: 41–52.

Ceci S. J., Williams W. M. and Barnett S. M. (2009) Women's underrepresentation in science: Sociocultural and biological considerations. *Psychol. Bull.*, 135: 218–261.

Russell E. W. (1961) Soil conditions and plant growth. (9th edition), John Wiley and Sons, New York.

Power J. F. (1990) Fertility management and nutrient cycling. In: *Dry land agriculture, strategies for sustainability. Advances in soil science*, Singh R. P., Parr J. F. and Stewart B. A. (Eds.), Springer Verlag, New York.

Fagoonee I., Schmuterer R. and Ascher K. R. S. (1987) Use of neem in vegetable crop protection in Mauritius. *Proceedings of the 3rd International Neem Conference*, Nairobi, Kenya, 10-15 July, 1986, pp. 419-429.

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