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Breeding Perspective for Silk Yield and Quality in Indian Tropical Tasar Silkworm, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae)

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Abstract: Though, India enjoys the availability and practice of mulberry, tasar (tropical/temperate), eri and muga silks, the utilization of tropical tasar seri-biodiversity, however requires appropriate breeding methods so to exploit the global demand of this vanya silk, besides reforming tribals, weaker sections and landless rural populace on economic front. Among the existing forty four ecoraces of *Antheraea mylitta* Drury, only Daba and Sukinda are commercially applied for cocoon production and want is *in situ* conservation and *ex situ* stabilization of additional ecoraces, particularly the *Shorea robusta* (sal) based, as amenable parental base for hybridization and silk production. The breeding for disease and adversity resistance, correlation among the trait(s) of commercial value as the tasar silkworm being an eco-insect reared outdoor and exploring the biotechnological tools for transgenic application appears pragmatic and worth. The management of genotype and environment interaction through multilocational breeding stations irrespective of rearing seasons applying compatible ecorace; breed or line(s) and involving the beneficiaries for their indigenous knowledge along with trained breeders is the indispensable strategy to achieve the tasar raw silk productivity and quality. The review has dealt with feasible breeding scenario of tasar silkworm in attaining the qualitative yield for the commercial sustenance of tropical tasarculture.

Key words: *Antheraea mylitta*, breeding perspective, seri-biodiversity, tasarculture, Vanya silk

INTRODUCTION

India stood second largest producer of silk, after China, with 15610, 2038, 603 and 119 MTs of mulberry, eri, tasar and muga raw silk respectively during 2008-09, provided employment for 2.50 lakh Below Poverty Line (BPL) families and annual foreign exchange of Rs 3165 crores to the country (Anonymous, 2009). Among silks, the tropical tasar, an important vanya silk is produced by the wild silkworm of *Antheraea mylitta* Drury of order Lepidoptera and family Saturniidae (Jolly *et al*., 1974; Suryanarayana and Srivastava, 2005). It is polyphagous and feeds primarily on sal (*Shorea robusta*), asan (*Terminalia tomentosa*) and arjun (*Terminalia arjuna*) and secondarily on *Zizyphus mauritiana*, *Terminalia paniculata*, *Anogeissus latifolia*, *Syzigium cumini*, *Careya arborea*, *Lagerstroemia parviflora* and *Hardwickia binata* (Suryanarayana *et al*., 2005). The tasarculture is a base livelihood for the tribals of Jharkhand, Chhattisgarh, Orissa, Madhya Pradesh, Uttar Pradesh, West Bengal, Bihar, Maharashtra and Andhra Pradesh states either through the collection of nature grown cocoons or by rearing in forests or on raised economic plantation (Thangavelu *et al*., 2002; Ojha *et al*., 2009). The objective of this activity is to utilize economic wild life, conserving the associated environment for sustainable rural and tribal development (Raffi and Ramanujam, 2001; Gill and Lal, 2002; Mahapatra, 2009).

Though, the tasar silk insect has forty four ecoraces, only the semi-domesticated Daba and Sukinda are contributing for country's tasar raw silk, besides few other wild ecoraces like Raily from Chhattisgarh; Modal and Jata from Orissa; Sarihan and Laria from Jharkhand; Bhandara from Maharashtra and Andhra from Andhra Pradesh (Rao *et al*., 2004; Suryanarayana *et al*., 2005; Hansda *et al*., 2008; Ojha *et al*., 2009; Reddy, 2010). The varied voltinism and higher interference of environment on crop performance with tentative returns made the industry unreliable over the alternative agro based enterprises (Thangavelu, 2002). Though, the tasarculture is an important co-discipline of applied forest biology, needs special understanding and addressing towards breeding perspective to promote the sustainable utilization of this precious natural resource (Mahapatra, 2009; Reddy *et al*., 2010a). The basic information on ecology, environmental factors, climatology, flora, fauna

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and their inter-relationship, the life cycle, diapause, reproductive biology and voltinism and population dynamics of tasar insect reveal its critical requirements to handle for breeding. The commercial attributes of tasar insect, viability in the offered eco-climatic condition suggests their biotic and economic potential and the commercial feasibility of ecorace/ breed/ line. Hence, the coordinating of adoptable breeding strategies for tasar silk yield and quality found vital for its indispensible role in generating rural livelihood, employment and foreign revenue.

APPROACH FOR SUSTAINABLE YIELDS

The utilization of biodiversity either by choice or by suitability must match with yields and quality of end produce for commercial sustenance. The process of applying insects in a generation to become parents of next progeny is selection, either to upgrade genetic configuration or to construct an end product in the desired direction was reported by Basavaraja *et al*. (2005), Reddy *et al*. (2008, 2009a). The selection, though in simple is just choosing parents based on ideal phenotypic character; the extent of genetic or end product improvement, however depends on their variability, level of selection, heritability rate, correlation among the traits chosen; as artificial selection acts only an added force on natural selection (Yamaguchi, 2001; Miller, 2005; Chandrasekhar and Basavaraja, 2008; Reddy *et al*., 2010a). As the availability of basic parental material being the constraint in tropical tasar silkworm, the focus priority should be on ecorace domestication for amenability and application. Further, the role of environment on genotype was proven evident, the productive potential of progeny on the chosen commercial trait(s) need compatibility of crop season. The wider selection with more number of traits reduces clarity of phenotype on the targeted trait of economic importance. The limited availability of domesticated ecoraces and their pupal diapause need a different and coherent approach, while exploiting parental variation for qualitative output as was reported by Hansda *et al*. (2008), Ojha *et al*. (2009) and Reddy *et al*. (2009a-c, 2010c). The *in situ* conservation, *ex situ* stabilization, basic stock maintenance based on the magnitude of commercial trait(s) and their combine for heterobeltiosis, evolving disease and adversity resistant breeds, backcrossing for traits of qualitative advantage and utilization of compatibility of genotype x environment (G x E) relations for optimal commercial trait expressivity for rearing season(s) are the explorable breeding avenues for sustainable and qualitative silk yields of tasar silkworm, *A. mylitta*.

ORGANIZING ADDITIONAL ECORACES

Basically, the conservation and management of any wildlife should encompass whole spectrum of biota and activities ranging from ecosystems at macro level (*in situ* conservation) to micro level (*ex situ* conservation), yet, the conservation priority of tasar insect must be *in situ*, as thereby protection is accorded not only to the insect species and their productivity but also the habitats, ecosystems and biodiversity. However, Hansda *et al*. (2008), Rajnarian *et al*. (2008), Ojha *et al*. (2009) and Reddy *et al*. (2010b) view that the tasar insect wildlife must be conserved *ex situ* as valuable genetic resource and promising livelihood of tasar cultivators. The performance of ecoraces vary with their origin, genetic diversity and habitat as their distinction reflects through phonotypical trait was reported by Yamaguchi (2001), Nagaraju (2002), Miller (2005) and Reddy *et al*. (2009a, d). The tasar races of each ecozone needs systematic classification to utilize their diversity for commercial efficiency in terms of silk yield and quality as the individual variety can be a potential resource in building up variation among new population through hybridization. The trivial deviation of any character from *in situ* under *ex situ* is said to be stabilized, which vary among tasar ecoraces or within the ecorace population. The positive inclination of wild ecorace under captivity with human interference ranks the feasibility and enhances its utility either for breeding or for commercial application aiming silk productivity and quality.

The healthy genetic resource of tasar silkworm with 44 ecoraces and the available genotypic and phenotypic variations in their natural population can very well serve the fundamental needs in evolving breeds/lines/varieties of better commercial value (Thangavelu, 2002). The better fecundity, egg fertility and amenability during rearing and grainage activities, improved effective rate of rearing (ERR), cocoon yield, larval survivability and disease resistance with wider adaptability to growing areas indicates the status of tasar ecorace on domestication and economic utilization was reported by Hansda *et al*. (2008), Ojha *et al*. (2009), Reddy *et al*. (2010c). In contrary, the wild ecoraces posses better fecundity, higher cocoon and shell weights, longer and finer silk filaments, but, their low egg fertility, hatching, cocoon yields and mainly non-amenability and non-adaptability to *ex situ* environments are the inadequacies for their commercial application. However, in-depth study on ecoraces under various zones and attempts for *in situ* conservation and *ex situ* stabilization can widen the parental base for their commercial use under various tasar practicing locations. The choice of amenable ecoraces provides advantage to mix feasible characters (available with wild and semi-domesticated) through hybridization, either to enhance productivity or quality and even both collectively (Reddy *et al.*, 2008, 2009d). Further, the mid parent heterosis itself can elevate silk yield, filament length and refines filament denier at F_1 level (Reddy *et al.*, 2010c) and intercrossing among parents of same ecorace generated under different ecozones can yield better in terms of quantity and quality. The conservation and utilization of ecoraces to produce viable basic and commercial seed to contribute for qualitative silk yields was reported by Hansda *et al.* (2008), Rajnarain *et al.* (2008) and Reddy *et al.* (2009c). In spite of vast availability of *S. robusta* flora and its based ecoraces compared to *T. arjuna* and *T. tomentosa*, they are yet to be explored commercially. However, these ecoraces are contributing for country's raw silk as nature grown cocoons and few of them are known for the silk filament of very fine denier (Suryanarayana and Srivastava, 2005), though they show heavy mortality during late larval stages and do not permit human handling either during rearing or seed production. Their conservation not only generates the amenable tasar genetic resource for breeding but also saves them from extinction, as their current level of decline is alarming with deforestation and over exploitation (Mahapatra, 2009). Thus, the strategic approach of conserving the tasar silk insect *in situ* and *ex situ* is must to retain the bio-variability (both inter and intra-population) for current and future utilization.

MULTILOCATIONAL BREEDING STATIONS

The reproductive potential of different forms of tasar ecoraces has the influence of environmental factors and physiological status of parents involved as the parental moth correlation and their origin is vital to make them commercially viable (Reddy *et al.*, 2008, 2009c, 2010b). The reports of Rajnarain *et al.* (2008) and Reddy *et al.* (2009c, e) reveal that the quality of tasar silkworm seed and optimal vigor of ecorace are mainly depends on the parental stocks used, the system of basic stock maintenance (breeder's stock) and their replenishment periodicity. The breed should not undergo inbreeding depression, genetic drift with un-scientific selection methods and not to lessen the adoptability tolerance to meet the quality needs of commercial silkworm seed (Yamaguchi, 2001). The performance of tasar ecorace is comparatively inferior under *ex situ* (commercial rearings) than its *in situ* habitat (natural rearings) and hence, it requires the orderly maintenance of basic stock (during multiplication) to retain its level of vigour for sustainable commercial performance.

The potential of a race can be seen mostly in its native position as the phenotypical expression being a collective outcome of genotype in a given environment and this holds very true for tasar ecoraces (Hansda *et al.*, 2008; Ojha *et al.*, 2009). Unlike the domesticated silk insect *Bombyx mori*, which reared indoor with controlled conditions of environment and feed to regulate its potential (Yamaguchi, 2001; Basavaraja *et al.*, 2005; Chandrasekhar and Basavaraja, 2008), the performance of the wild tasar insect *A. mylitta*, depends on its growing surroundings (*in situ* or *ex situ*) and variety and status of its food plant. Further, the altitude and photoperiod of the ecological niche of a particular ecorace can influence its phenotype and voltinism. Though, the inherent potential of any tasar ecorace in respect of fecundity, cocoon weight, shell weight and silk ratio traits can be expressed superior under its *in situ* habitat, they can be retained or improved by applying selective parents (based on pupal or shell weights) at basic seed stock level was reported by Reddy *et al.* (2009c, e). Further, the basic stock if maintained under *in situ* conditions can exhibit optimal potential on commercial trait(s), mostly true to breed vigour, which can contributes subsequently to improve the commercial seed. The approach of maintaining individual ecorace and basic stock under its native areas (multilocational basic seed breeding stations) will lead to true to type ecorace stocks to utilize the original potential and vigour of tasar ecoraces even on their commercial application. This approach for semi-domesticated and commercially exploited Daba and Sukinda ecoraces can further enhances their potential because of better inherent performance levels under *in situ* (Suryanarayana and Srivastava, 2005) over the current basic and commercial stocks maintained *ex situ*.

APPROPRIATE BREEDING METHODS

Heterobeltiosis in commercial trait(s): The commercial utilization of heterosis is based on excess over middle parent i.e., relative heterosis and excess over better parent i.e., heterobeltiosis. The potential of response in chosen character can be seen in offspring generation as heterotic effect; however it depends on genetic variation and selection accuracy among parents (Basavaraja *et al.*, 2005). The selection of commercial character must based on breeding value and is essential for productivity improvement as like female moth emerges from heavier pupae lay more eggs and male moth of particular ecorace show higher mating potency as was observed by Reddy *et al.* (2008, 2009a, b, 2010c). The parental nativity, phenotypic variability and genetic diversity are imperative reasons for better heterobeltiosis either in fecundity, egg hatching, shell weight and silk ratios or collectively in more traits, might be with trait specific combining ability. Such parents of any hybrid can certainly express character wise heterobeltiosis with prospect of productivity and quality of silk. The objective of improving either fecundity and fertility or shell weight and silk ratio is only to attain overall gain in total silk yield, which is important for commercial sustenance (Yamaguchi, 2001; Nagaraju, 2002). Though, the positive heterosis in shell weight can attain gain in silk yield, the fecundity, egg fertility, Effective Rate of Rearing (ERR) and cocoon yields are the other associated factors responsible for overall improvement in silk yield. Also, the heterobeltiosis in reciprocal hybrids can augment productivity with an additional scope of applying parental material in full for seed production with reduced cost of production.

Correlation of productive trait(s): Though, the sustenance of tasarculture depends mainly on the silk production, the quality of raw silk is also equally important and both of them are normally influenced by the breed, feed and growing environment. The tasar rearing being an outdoor practice mostly on the nature grown food-plants, the success of tasar silk production go with the race or breed applied for commercial rearing (Rao *et al*., 2004; Hansda *et al*., 2008; Reddy *et al*., 2009a, b, 2010c). The generation of raw silk mainly took place under commercial crop rearing season (September-December), where the environmental conditions and quality of the feed are superior and hence the role of breed is paramount in achieving the higher quantity (yield) with better quality (denier) of silk. The tasar silkworm is destined to undergo diapause after commercial rearing season and it develops thicker cocoon shell to combat the environmental adversities ahead with severe winter and summer while completing its life cycle. Hence, by nature the silk insect produce more silk during the commercial crop season than seed crop (July-August). The reports of Petkov *et al*. (2000), Radhakrishna *et al*. (2001), Davidowitz *et al*. (2004), Zhao *et al*. (2007) and Reddy *et al*. (2009c, e) indicates that the production of higher silk yield during commercial crop rearing season was with better genotype and environment (G x E) interaction. Hence, correlating the productive trait(s) appropriate to crop seasons and their response to heterosis or heterobeltiosis and survival of the breed as ERR or cocoon yield over the existing race option(s) amounts to yield elevation and commercial prospective (Sekharappa *et al*., 1999; Petkov *et al*., 2003; Reddy *et al*., 2009c; Seshagiri *et al*., 2009). The influence of hybridization as positive heterosis in F_1 hybrids though indicates the commercial advantage, it may suite for productivity and not quality as the positive heterosis leads to thicker silk filament with high denier. Further, the denier of filament is more of racial character and attaining higher silk yield with filament of lower denier looks intricate as the productivity and quality are negatively correlated as observed by Sekharappa *et al*. (1999), Petkov *et al*. (2000), Verma *et al*. (2003) and Reddy *et al*. (2009d, 2010a). However, the breeding approach for attaining better productivity together with quality over the existing options looks rational and hence attaining silk productivity keeping silk quality either marginally changed either way or unchanged or vice versa must be a success and commercial advantage in tropical tasarculture.

Disease and adversity tolerant breeds: The induction of resistance to disease is an important objective in silkworm breeding as it complements both yield and quality of the end produce. The health is the most vital character and it besets with quantitative and qualitative characters and if a breed fails to tolerate the diseases resulting poor cocoon, it cannot be considered as promising (Watanabe, 2002; Basavaraja *et al*., 2005). The healthiness might be due to resistance to diseases in which the disease cannot infest it, while the other is adaptability against pathogens and changed rearing environment. However, these two aspects are controlled by genetical, physiological and pathological apart their rearing environment and the rate of disease prevalence, yet, vary among disease resistant and susceptible. The resistance to disease is strain specific by gene action, while the tolerance is strain un-specific by minor gene or polygenic action, which is biologically common. The disease resistance to a particular strain of pathogen is vertical, while the other is horizontal, which universally resists all strains of pathogens. The reports of Nagaraju (2002) and Basavaraja *et al*. (2005) reveal that the disease resistance mainly revolves around the immune response, which in general very poor in insects and more specifically in silkworm. The knowledge on the principles of disease tolerance and resistance through interactions of host and pathogen are vital to evolve a breed survives against the pathogenic action for a disease. The defense systems through haemocytes, humoral immunity and anti-viral activity of digestive juice needs exploitation besides the hypothetical genetics and biotechnological advancements in linking host pathogen interaction (Zhang *et al*., 2008; Lie *et al*., 2010).

Backcrossing for quality trait(s): The selection of breeding method is to develop a breed with stability and productivity in terms of silk quantity, the method of repeated backcrossing among appropriate donor and recipient parents looks apt for attaining the quality of commercial traits was reported by Petkov *et al.* (2000), Nagaraju (2002), Verma *et al.* (2003) and Reddy *et al.* (2010a). The parental selection is always crucial in commercial trait precision and hence silk yield and filament quality variation apart from varied shell weight, silk ratio and filament length are important while selecting parents, even if they are divergent ecoraces (Verma *et al.*, 2003; Basavaraja *et al.*, 2005). To introgress the quality associated commercial trait like filament denier, the repeated backcrossing found significant, if the parental selection is based on quantitative in recipient and qualitative in donor (Reddy *et al.*, 2009d). In general, domestication and acclimatization of tasar ecoraces to new environment (*ex situ*) decline their performance in commercial traits and are not effective as donors to introgress economic trait(s). In view of this, selection of wild ecorace with superior traits as recipient parent and infusion of compatible trait(s) from domesticated with continued selection for desired trait(s) in following generations appears rational. At times, the opposite trend in silk yield, filament length illustrates the correlation among quantity and quality. However, the interaction of high heterogenousity and introgressive hybridization of parents involved can influence silk yield positively. The introgression of finer filament denier with retained or improved silk yield through application of suitable parental ecoraces applying the backcross breeding proven prospective to promote silk quality at least with the retained levels of silk yield. In the same way, Watanabe (2002) and Basavaraja *et al.* (2005) have suggested that the application of backcross method using parental resource of disease resistance are of helpful to evolve the breed survives better against the pathogens.

Biotechnology application: The silkworm genetic resources with reference to the tropical tasar need to be characterized using molecular tools to identify and understand the border line among the ecoraces and their populations (Petkov *et al.*, 2000; Nagaraju, 2002; Moghaddam *et al.*, 2005). This knowledge on population structure can provide the basic clues for evolving appropriate conservation and management strategies of tasar genetic resource. Zhang *et al.* (2008) and Lie *et al.* (2010) have observed that the quantitative trait loci (QTLs) linked with the trait(s) of yield, quality and disease resistance can establish the linkages either to manage productivity or quality. This may provide insight for a very important aspect of regulating the diapause either to make the tasar insect multivoltine or to budget higher food allocation for qualitative silk productivity.

Exploitation of rearing seasons: The tropical tasar silkworm, *A. mylitta,* with limited annual life cycles needs exploitation of compatibility with all possible rearing season(s), to augment silk yield. The inadequacy of tasar breeds for a season or region also being the constraint in utilizing the existing tasar flora, the critical need is to specify ecorace options for regional and seasonal compatibility. Yamaguchi (2001), Nagaraju (2002), Moghaddam *et al.* (2005), Rajnarain *et al.* (2008) and Reddy *et al.* (2009e) have observed that the maintenance of breed vigor is essential through parental recombine to regain the race potential and compatibility for seasons. The compatibility classification of parents or their combinations to crop seasons specifying the silk yield and quality is essential in view of the vast availability of nature grown tasar flora (Hansda *et al.*, 2008; Ojha *et al.*, 2009; Reddy *et al.*, 2010a). The current approach of applying cocoons of seed crop (with less silk content) for commercial seed production and cocoons of commercial crop (with more silk content) for basic seed or silk production, needs management for parent season compatibility to attain silk productivity and quality. The highly organized sensory and neuro-motor systems of insect (more comparable to those of vertebrates) and their response and persistence against environmental change as was earlier reported by Davidowitz *et al.* (2004), Miller (2005), Zhao *et al.* (2007), Chandrasekhar and Basavaraja (2008) and Reddy *et al.* (2009c, 2010b) which found advantageous in exploiting qualitative yields in wild silk moths. However, during commercial crop season the selection of quantitative traits like silk yield and filament length should be stressed because of congenial weather and feed quality in addition to longer feeding period. While in seed crop season, the fluctuations in temperature, humidity, rainfall and feed quality are high and hence priority should be on fecundity and hatching to have more population to compensate larval loss and to attain the qualitative silk productivity.

HUMAN RESOURCE APPLICATION

As like the specific application need of breeding material and methods, the human resource application is also significant in attaining the potential of silk yields in tasarculture. The cause and impacts on extensive collection of wildlife from core habitats, disease out breaks and control, management of predators attack, besides the species suitability is worth sharing with native beneficiaries for effective *ex situ* conservation was suggested by Madhu (2001), Kler *et al.* (2002) and Carlsson and Berkes (2005). The wild nature of tasar insect and the mechanism of its adaptation as ecorace to different ecological niches can suggest indication in attaining better silk output. In view of inadequate information on such lines, the participation of native tasar rearers becomes vital for their close association with this insect wildlife in *in situ* for very long. However, the involvement of landless rural people, self help groups and the Non Government Organizations (NGOs) in tasarculture is because they understood its potential for rural and tribal upliftment (Balaji, 2001; Sethi and Singh, 2001; Pande *et al*., 2002; Dhirendra, 2009; Satyanarayana *et al*., 2009; Sinha *et al*., 2009). Further, the requirement of precise breeding approach for handling unique nature of tasar insect (though, the genetic principles remain same) unlike other known silkworm varieties, demands the trained breeders. Hence, the human resource participation as native tasar cultivars and trained tasar breeders and their coordinated efforts can yield qualitative silk for the sustainable tropical tasarculture

CONCLUSIONS

The acceptance of well-proven genetic principles, use of competent parent material, testing procedures and genetic correlations, though complement tasar silk productivity; such application and amalgamation needs wider parental base, which is possible only on organizing additional ecoraces. The yield exploitation by heterobeltiosis and commercial trait correlation, breeding for adversity and disease resistance, quality advancement through backcrossing and yield targeting biotechnological tools, integration of physiological and ecological basics through multilocational breeding stations with compatibility of breed and season looks realistic for the sustainable silk yields. The involvement of aboriginals for native knowledge and trained breeders for methodical handling of the material are indispensable in achieving the task. It is the time for combining the conventional and modern techniques to address the breeding needs in commercial tropical tasarculture to bring the mandatory change towards sustainability.

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