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Review Article

Management of Climatic Factors for Successful Silkworm (*Bombyx mori* L.) Crop and Higher Silk Production: A Review

V. K. Rahmathulla

P3 Basic Seed Farm, National Silkworm Seed Organization, Central Silk Board, Ring Road, Srirampura, Mysore, Karnataka 570 008, India

Correspondence should be addressed to V. K. Rahmathulla, rahmathullavk@yahoo.co.in

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The seasonal differences in the environmental components considerably affect the genotypic expression in the form of phenotypic output of silkworm crop such as cocoon weight, shell weight, and cocoon shell ratio. The variations in the environmental conditions day to day and season to season emphasize the need of management of temperature and relative humidity for sustainable cocoon production. The present review paper discuss in details about the role of temperature and humidity on growth and development of silkworm including recent studies on heat shock protein. Study also discusses the influence of air and light on silkworm development. In addition to this study emphasis on the role of various environmental factors on embryonic development of silkworm egg, nutritional indices of silkworm larva and reproductive potential of silkworm moth. The study also highlights about the care to be required during silkworm spinning and influence of temperature and humidity on post cocoon parameters of silkworm. The study included future strategies to be taken for the management climatic condition for successful cocoon crop. The paper covers 140 references connected with the topic.

1. Introduction

Sericulture is the science that deals with the production of silk by rearing of silkworm. Silk is called the queen of textiles due to its glittering luster, softness, elegance, durability, and tensile properties and is discovered in China between 2600 and 2700 BC. Silk originating in the spittle of an insect is a natural fibrous substance and is obtained from pupal nests or cocoons spun by larvae known as silkworm. The silk is preferred over all other types of fibres due to its remarkable properties like water absorbency, heat resistance, dyeing efficiency, and luster. Factors mainly influence the physiology of insects are temperature and humidity. Despite wide fluctuations in their surroundings, insects show a remarkable range of adaptations to fluctuating environmental conditions and maintain their internal temperature and water content within tolerable limits. Adaptation is a complex and dynamic state that widely differs from species to species. Surviving under changing environment in insects depends on dispersal, habitat selection, habitat modification, relationship with water, resistance to cold, diapause and developmental rate, sensitivity to environmental signals, and syntheses of variety of cryoprotectant molecules. The mulberry silkworm (*Bombyx mori* L.) is very delicate, highly sensitive to environmental fluctuations, and unable to survive extreme natural fluctuation in temperature and humidity because of their long years of domestication since 5000 years. Thus, the adaptability to environmental conditions in the silkworm is quite different from those of wild silkworm and other insects. Temperature, humidity, air circulation, gases, light, and so forth, show a significant interaction in their effect on the physiology of silkworm depending upon the combination of factors and developmental stages affecting growth, development, productivity, and quality of silk.

Silkworm is one of the most important domesticated insects, which produces luxuriant silk thread in the form of cocoon by consuming mulberry leaves during larval period. The growth and development of silkworm is greatly influenced by environmental conditions. The biological as well as cocoon-related characters are influenced by ambient temperature, rearing seasons, quality mulberry leaf, and genetic constitution of silkworm strains. Different seasons affect the performance of *Bombyx mori* L. The seasonal differences in the environmental components considerably affect the genotypic expression in the form of phenotypic output such as cocoon weight, shell weight, and cocoon shell ratio. The variations in the environmental conditions during the last decade emphasize the need of management of the temperature and relative humidity for sustainable cocoon production. India enjoys the comfortable second position for the production of silk in the world next only to China. Traditionally sericulture in India is practiced in tropical environmental regions such as Karnataka, Tamil Nadu, Andhra Pradesh, and West Bengal and to a limited extent in temperate region of Jammu and Kashmir. The existing tropical condition provides scope for exploiting the multivoltine × bivoltine hybrid at commercial venture as they are very hardy and have tremendous capacity to survive and reproduce under fluctuating environmental climatic conditions. Bulk share of the silk production (95%) is accounting from multivoltine hybrids. The researchers [1] evaluated the genetic potential of the multivoltine silkworm and identified suitable parents for breeding programmes. However, the silk quality produced from multivoltine strain is at low level when compared to the existing international standards. China account for over 80% of the world silk production while India, which is the second largest producer, accounts for about 15-16% of the total production. China silk is of superior quality as they are of the bivoltine strain. Considering these drawbacks, adoption of bivoltine sericulture became imperative and imminent considering its potentiality even under Indian tropical conditions. In this line, many productive and qualitatively superior bivoltine hybrids have been developed by utilizing Japanese commercial hybrids as a breeding resource material. However, the hot climatic conditions prevailing particularly in summer are not conducive to rear these high yielding bivoltine hybrids throughout the year. It is a well-established fact that under tropical condition, unlike polyvoltines, bivoltines are more vulnerable to various stresses like hot climatic conditions of tropics, poor leaf quality, and improper management of silkworm crop during summer that is not conducive for bivoltine rearing for technologically and economically poor farmers of India [2–4]. This paper discusses the role of different environmental factors affecting the growth, survivability, productivity, and disease incidence in silkworm. The paper also discusses the optimum conditions of environmental factors required for higher productivity in sericulture and, further, the paper also reviews the results and findings of various researchers who studied the effect of environmental factors on growth, development, feed conversion, reproductive potential, and postcocoon parameters of silkworm.

2. Role of Temperature on Growth of Silkworm

Temperature plays a vital role on the growth of the silkworms. As silkworms are cold-blooded animals, temperature will have a direct effect on various physiological activities. In general, the early instar larvae are resistant to high temperature which also helps in improving survival rate and cocoon characters. The temperature has a direct correlation with the growth of silkworms; wide fluctuation of temperature is harmful to the development of silkworm. Rise in temperature increases various physiological functions and with a fall in temperature, the physiological activities are decreases. Increased temperature during silkworm rearing particularly in late instars accelerates larval growth and shortens the larval period. On the other hand, at low temperature, the growth is slow and larval period is prolonged. The optimum temperature for normal growth of silkworms is between 20°C and 28°C and the desirable temperature for maximum productivity ranges from 23°C to 28°C. Temperature above 30°C directly affects the health of the worm. If the temperature is below 20°C all the physiological activities are retarded, especially in early instars; as a result, worms become too weak and susceptible to various diseases. The temperature requirements during the early instars (I, II, III) are high and the worms feed actively, grow very vigorously, and lead to high growth rate. Such vigorous worms can withstand better even at adverse conditions in later instars. The optimum temperature required for rearing silkworms of different early instars are as described in Table 1.

Generally, the room temperature is low during winter and rainy season, which should be regulated by heating the room with electric heaters or charcoal fires. Thermoregulator-fitted electrical heaters are best since they do not emit any injurious gases. When electricity becomes costly and not available in many rural areas of sericulture belt, properly dried charcoal can be used. However, the carbon dioxide and other gases emitted in this burning process are injurious to silkworms and they can be regulated by providing more ventilation particularly in daytime. Besides this, the doors and windows should be kept closed particularly during night. Late in the day, as the outside temperature goes up, doors and windows should be opened to allow warm air to the room. During summer season when day temperature is high, all the windows should be kept open. Simultaneously, windows and doors are covered with wet gunny cloth during hot days to reduce the temperature and increase humidity [5, 6]. Otherwise, suitable air coolers can be used for this purpose.

The success of the sericulture industry depends upon several variables, but environmental conditions such as biotic and abiotic factors are of particular importance. Among the abiotic factors, temperature plays a major role on growth and productivity of silkworms [7, 8]. There is ample literature stating that good quality cocoons are produced within a temperature range of 22–27°C and that cocoon quality is poorer above these levels [9, 10]. However, polyvoltine breeds reared in tropical countries are known to tolerate slightly higher temperature and adjust with tropical climatic conditions [11]. In order to use bivoltine races in a tropical country like India, it is necessary to have a stable cocoon crop in a high temperature environment. High temperature adversely affects nearly all biological processes including the rates of biochemical and physiological reactions [12], and can eventually affect the quality or quantity of cocoon crops in the silkworm and subsequently silk produced. Several studies [13–15] demonstrated that silkworms were more sensitive to high temperature during the fourth and fifth stages. It is well

Table 1: Optimum temperature and humidity requirements of silkworm during various stages.

Environmental factors	Incubation	I instar	II instar	III instar	IV instar	V instar	Spinning	Cocoon preservation
Temperature	25°C	28°C	27°C	26°C	25°C	24°C	25°C	25°C
Relative humidity	75–80%	85–90%	85%	80%	70–75%	65–70%	70%	80%

understood that the majority of the economically important genetic traits of silkworms are qualitative in nature and that phenotypic expression is greatly influenced by environmental factors such as temperature, relative humidity, light, and nutrition [16–23]. The Figures 1(a), 1(b), 1(c), 1(d), and 1(e) describe the contribution of various factors such as environmental, racial, and other factors on important cocoon traits. The figures illustrate that cocoon yield and reelability are the most affected traits due to the adverse environmental factors. The length of 1st instar period of silkworm larvae was increased by decreasing the temperature for 10 days [24]. Similarly, researchers [25] found that temperature and RH exert synergistic impact regarding silkworm larval period. These results are in conformity with those of earlier workers [26] and reported that change in temperature along with RH has pronounced effect on moulting period. Similarly, the reports of different researchers [27, 28] recorded that decrease in temperature enhances the moulting duration in silkworm. Table 2 shows the effect of different temperature during late instars on various cocoon traits of silkworm. In a serious of experiments, researchers [29] observed that resistance to high temperature is a heritable character and it may be possible to breed silkworm races tolerant to high temperature. Several studies of different workers [30–32] reported that the quantitative characters of silkworms in a known environment are of utmost importance in sericulture. The effect of low temperature during rearing on some characters of breeding line races were studied [33]. Similarly, studies of silkworm breeders [34, 35] found that low temperature is always better than higher temperature with reference to productivity of silkworm and larval duration for different instars. Another studies reported that the F1 bivoltine hybrids is more adjustable for high temperature and high humidity when compared with their parents [36]. In an important review, work scientists [37] also reported that temperature and relative humidity were among the various factors that influence growth, behavior, and instar larval periods in silkworm and discussed the adaptation of insects to varying environmental conditions. The acclimatization of silkworm races with environmental condition especially temperature was studied in detail [38]. Seasonal effect on silkworm under Kashmir and subtropical conditions were studied [39]. Different workers demonstrated the influence of humidity during rearing time and its role on disease incidence [40]. Suitable hardy bivoltine races evolved and were tested in the field for summer and, rainy seasons of Uttarpradesh, India [41]. Recently the influence of various seasons such as summer, rainy, and winter on cocoon and grainage traits of popular bivoltine races of India were studied and concluded that temperature and humidity affect all characters of these races [42]. High temperature affects nearly all biological processes including the rates of biochemical and physiological reactions [43] ultimately affecting the quality and quantity of cocoon crops.

Table 2: Effect of temperature during late-age rearing on cocoon traits of silkworm.

Traits	Temperature °C				Control (24°C)
	36–22	36–22	32–22	32–26	
Pupation (%)	86.00	66.10	92.50	91.40	95.0
Cocoon weight [g]	1.58	1.62	1.96	1.84	2.10
Shell weight [g]	0.316	0.337	0.470	0.441	0.480

Source, Suresh Kumar et al. [45]

The silk cocoon production is determined by various factors including environment and genotype of the silkworm. Figure 2 describes the contribution of genetic and environmental factors on growth and development of silkworm and its important economic traits.

3. Studies on Heat Shock Protein

The tropical Indian multivoltine races of *Bombyx mori* (Pure Mysore, C. Nichi, and Nistari) are more tolerant to high temperature, as against the exotic bivoltine races of temperate origin. Unlike multivoltine, bivoltine races have better yield potential and produce superior quality of silk but do not survive under extreme climatic conditions prevailing in India. It is known that when subjected to high temperature, the cells display a heat shock response by synthesizing a novel set of protein, called heat shock protein (HSP) and it is interesting to note that thermotolerant always accompanied by the presence of HSPs [46]. An eminent scientist [47] attempted to understand the difference of thermotolerance in a multivoltine (C.Nichi) and bivoltine race (NB18). The heat shock response in mulberry silkworm races with different thermotolerances were also studied [48–50]. Many quantitative characters decline sharply at higher temperatures and, therefore, one of the key considerations in developing bivoltine hybrids for tropics could be the need for thermotolerant bivoltine strains. The recent advances in silkworm breeding and those in stress-induced protein synthesis have opened up a new avenues to evolve robust productive silkworm hybrids [45, 51–57]. On thermal treatment, all genetic traits of silkworms showed a decline with the increase of temperature above standard level. Workers [58] reported similar results and they found that biological molecules like DNA, RNA, lipids, and so forth were vulnerable to heat stress. Temperature stress causes a number of abnormalities at the cellular level as the normal pattern of protein synthesis halts. However, a brief exposure of cells to sublethal high temperature was found to render protection to the organism of subsequent and more severe temperature changes [59, 60].

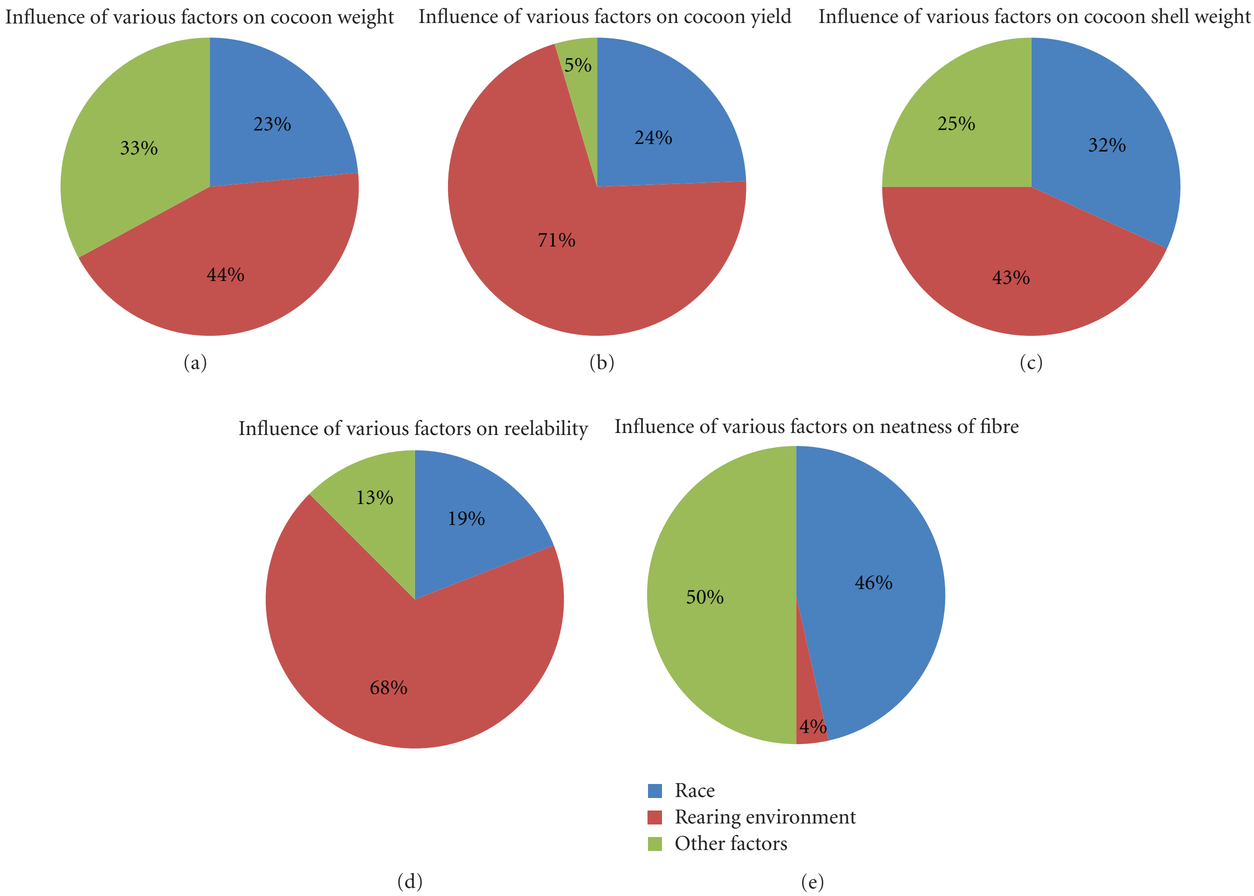

Figure 1: Influence of various factors on cocoon yield, weight, shell weight, reelability, and neatness source: [44].

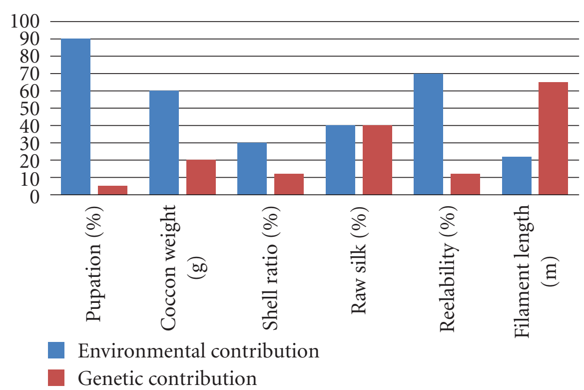

Figure 2: Environmental and genetic contribution to various economic traits of silkworm, *Bomby mori* L. (percentage).

Therefore, it is very much essential to gauge the degree of phenotypic difference of the economical traits to understand the genetic steadiness under the varied environmental conditions and the productivity of different breed under various environmental conditions. Intensive and careful domestication over centuries has apparently deprived the insect of opportunities to acquire thermotolerance. Among many factors responsible for poor performance of the bivoltine strains under tropical conditions, the main culprit is temperature. Indeed, many quantitative characters decline sharply when temperature is higher than 28°C. Researchers, especially silkworm breeders in the sericulture field, always agree that it is a difficult task to breed such a bivoltine breeds that are suitable to the high temperature and fluctuating climatic conditions of India.

4. Role of Humidity on Growth of Silkworm

Humidity plays a vital role in silkworm rearing and its role is both direct and indirect. The combined effect of both temperature and humidity largely determines the satisfactory growth of the silkworms and production of good-quality cocoons. It directly influences the physiological functions of the silkworm. The young-age silkworms can withstand to high humidity conditions than later-age worms and under such condition, the growth of worm is vigorous. The optimum humidity conditions required for different early-age worms and late-age worms are as described in Table 1.

Humidity also indirectly influences the rate of withering of the leaves in the silkworms rearing beds. Under dry conditions especially winter and summer the leaves wither very fast and consumption by larvae will be less. This affects growth of the larvae and results in wastage of leaf in the rearing bed. Retarded growth of young larvae makes them weak and susceptible to diseases. At a humidity of 90 percent or higher, if temperature is maintained at 26°C–28°C, they can grow without being greatly affected. Like temperature, humidity also fluctuates widely not only from season to season but also within the day itself. Therefore, it is necessary for the silkworm rearers to regulate it for their successful crop. For this purpose, wax coated (paraffin) paper is used to cover the rearing beds during young-age rearing to raise humidity and to avoid leaf dryness. Otherwise, wet foam rubber pads or paper pads soaked in water can also be used to increase humidity in the rearing beds. Rich famers can use humidifier with humidistat to regulate humidity in the rearing room. However, it is important to lower humidity to 70 percent or below during the moulting time in each instar to facilitates uniform and good moulting. Water forms a large proportion of insect tissues and survival depends on the ability to maintain and to balance water in the body. There is no limiting range of humidity and most insects can develop at any humidity provided they are able to control their water balance [61]. The effect of high humidity on weight of larva of silkworm was studied [62]. 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 [63–65]. The environmental factors, in particular temperature and humidity at the time of rearing and moisture content of mulberry leaf, affect growth of the silkworm [66, 67]. The role of water and humidity in sericulture were well studied by workers [68]. The seasonal effect and role of humidity on growth and nutritional efficiency of silkworm were also studied [69]. Researchers evolved a suitable race particularly to spring and autumn rearing [70]. The role of humidity on seed production parameters were well-studied by different workers [71]. Researchers [72] also listed out the phenotypic and genotypic characters during different season. The performances of polyvoltine races under dry climatic condition of Rayala seema areas of Andhra Pradesh, India [73], were also studied. Abiotic factor that has significant impact on the performance of insects in terrestrial environments is humidity. Humidity interacts with the availability of free water and with the water content of the food and it mostly shows indirect effect on growth and development. Demands in humidity vary depending on the biological circle. The effect of adverse climatic conditions for successful bivoltine cocoon crop was studied [74, 75]. In Italy, researchers studied the effect of various environmental factors on growth of silkworm larva [76]. The seasonal changes, atmospheric humidity, and soil moisture percentage have profound effect on the growth and quality of mulberry leaves, which in turn influence the silkworm health and cocoon crop production and, therefore, suggest the importance of leaf moisture both in palatability and assimilation of nutritive components of the leaf.

5. Role of Air and Light on Growth of Silkworm

Like other animals, silkworms also require fresh air. By respiration of silkworms, carbon dioxide gas is released in the rearing bed. The freshness of air can be determined by its CO_2 contents. Although atmospheric CO_2 content is generally 0.03-0.04% in the rearing room, carbon monoxide, ammonia, sulphur dioxide, and so forth are also released in the rearing room when farmers burn charcoal to raise temperature. These gases are injurious to silkworms; therefore, care should be taken to allow fresh air through proper ventilation to keep the toxic gases at a low level. If CO_2 exceeds above 2 percent concentration, the growth of silkworm is retarded. Insecticides and disinfectants are also avoided in the rearing room. Young silkworm larvae are more susceptible to the poisonous gases and hence artificial circulation of air is extremely useful in bringing down the contaminated air. The air current of 1.0 m/sec during 5th-age rearing reduces the larval mortality and improves ingestion, digestibility, larval weight, cocoon weight, and pupation rate compared to those recorded under zero ventilation condition [77].

Silkworms are photosensitive and they have a tendency to crawl towards dim light. They do not like either strong light or complete darkness. Rearing of silkworms in continuous light delays the growth. Further, it causes pentamoulters and reduces both larval and cocoon weights. Silkworms are fond of dim light of 15 to 20 lux and avoid strong light and darkness. Late-age worms survive better in 16-hour light and 8-hour dark periods. However, young-age worm prefers 16 hr darkness and 8 hr light period. Larvae of silkworm do not prefer either strong light or complete darkness but usually light phase, in contrast to the dark phase, activates the larvae. Silkworm is an insect of small lifespan with positive phototactism [78]; the silkworm larvae are fed in complete darkness during the life cycle, their larval duration is longer, and cocoon quality becomes poor [79]. Rearing in either complete darkness or in bright light leads to irregularity in growth and moulting. Light phase usually makes larval duration longer than the dark phase. The influence of light and temperature on growth of silkworm was studied in detail [80].

6. Role of Environmental Factors on Embryonic Development

The effect of temperature on the growth and development of silkworm has been studied extensively; however, much attention has not been paid on the effect of temperature on embryonic development. It has been reported that in exothermic organisms, when rate of development is plotted against temperature, a sigmoidal curve is obtained with an almost linear correlation in central temperature range. Temperature is a parameter in developmental cycle, which can be manipulated experimentally, but its effect is very complex for interpretation. The physiological explanation for embryonic death after exposure to lethal temperature is likely to be highly complex and probably species specific. Improper egg incubation results in various problems during the hatching and rearing period. If silkworm egg is subjected to incubation at high temperature and low humidity the hatching of larvae severely affected. It is well known that the environmental conditions during embryonic development not only affect the diapauses nature of eggs but also larval/pupal duration, cocoon weight, and egg production [81]. Among the development stage of silkworm, *Bombyx mori,* the egg stage has the lowest tolerance to high temperature. Temperature during incubation also affects voltinism character, as the embryonic stage is the most sensitive to temperature [82]. Bivoltine eggs incubated at a temperature above 25°C produce moths that lay hibernating eggs, while those incubated at lower temperature (below 25°C) produce moths that lay mixed and fully nonhibernating eggs. Development rate is directly influenced by temperature and is modified by humidity. At high temperature the embryo grows faster up to the setae formation stage and succumbs to death as the yolk cannot be utilized in pace with the high rate of development and comes in way of normal development [83]. Kittlans [84] stated that temperature above 33°C and abnormal cold treatment of embryos might also cause embryonic death or abnormal development. Cold treatment of silkworm *(Bombyx mori)* eggs leads to formation of tetraploid individuals, which lay large eggs [85].

During silkworm 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, the hatching invariably is low. A number of factors complicate the effect of humidity on respiration; most important of which is the water content of the insect. The effects of humidity are very closely associated with temperature, that is, water loss by desiccation, spiracular diffusion, retention of ingested water, and production of metabolic water [63]. Humidity less than 60% results in loss of water from silkworm eggs and high humidity of 90% and above leads to retention of physiological waste water inside the egg resulting in poisoning of embryos. The effect of light on incubation and growth of embryo, requirement of black boxing at pinhead stage, and exposure to light on 10 or 11 day was studied in detail for bivoltine silkworm [78]. Humidity in combination with temperature has a very strong effect on physiology of the egg [86]. However, the ideal temperature is 25°C and coupled with 75–80% relative humidity for both bivoltine and multivoltine eggs (Table 1). The occurrence of unfertilized eggs in silkworm and its reason were studied in detail [87]. Workers also studied the effect of refrigeration of multivoltine eggs at blue stage and its effects on hatching and rearing parameters [88].

7. Influence of Environmental Factors on Nutritional Indices

Variation in the fluctuations of temperature prevents insects from attaining their physiological potential performance and they achieve it only if placed in an ideal and favorable environment. Because of natural selection imposed by less ideal environmental conditions, insects have evolved certain abilities to evaluate their environment and to make decisions involving physiological, behavioral, and genetic responses. These responses frequently involve changes in the consumption and utilization of food, rate, and time of feeding behavior, metabolism, enzyme synthesis, nutrient storages, flight behavior, and other physiological and behavioral processes. Natural environments exhibit large amount of variation in abiotic components (temperature, humidity, etc.) which play an important role on the consumption and utilization of food. Variation in environmental factors away from the conditions that allow insects to achieve their ideal performance may reduce their performance unless compensated for changes in their physiology and behavior. Variable temperature regimes may influence performance differently compared to constant temperature; growth performance is often stimulated in fluctuating temperature regime [89]. Insects have also evolved various enzymatic and metabolic adaptations that allow them to survive and develop in a broad range of temperatures. Temperature acclimation and physiological and behavioral thermoregulation allow individual insects to compensate to various degrees of changes in ambient temperature [90]. The silkworm growth is manifested by the accumulation of organic matter resulting from the balance between anabolic and catabolic reactions fuelled by the nutritive substances absorbed after digestion of food. The silkworms from the same genetic stock responded variedly when fed on the leaves of different nutritional quality, which is an indicator of efficient utilization and conversion of food into silk substance. When a temperature exceeds 30°C, metabolic functions become erratic and result in poor health. At the same time when temperatures fall below 20°C, metabolic functions becomes inactive again leading to irregular growth and health becomes poor [91].

Variation of the ingesta and digesta values among the different breeds and same breed in different seasons has been reported [92, 93]. The rate of food consumption and leaf quality significant influences on larval growth, weight, and survival were studied [94]. Analysis of the nutritional indices like the rates of ingestion, digestion, assimilation, and conversion in the growing larvae would be useful in understanding the racial differences in the digestive and assimilation abilities of the silkworm. The evaluation of the strains must be made based on food utilization efficiency

Table 3: Combined effect of humidity and air current during spinning time on cocoon reelabilty of silkworm.

Temperature (°C)	Humidity (%)	Air current (cm/sec)	Reelability (%)
20°C	65	0	75
		50	90
	90	0	78
		50	92
25°C	65	0	92
		50	96
	90	0	55
		50	90
30°C	65	0	85
		50	93
	90	0	30
		50	80

at different feeding amounts under favorable conditions for each sex [95]. Researchers [44] reported that with the increase in temperature (20–30°C) leaf-silk conversion rate decreases. The physiological activities, food intake, and economic parameters are influenced by body temperature of the silkworm. An increase in intake of mulberry leaves during late age with decrease in rearing temperature was reported [96]. Effects of various environmental factors on nutritional and water requirements of insects were studied [97–105]. The effect of temperature on leaf-silk conversion in silkworm reported that low temperature (26°C) throughout the rearing period favoured higher silk conversion with better survival in bivoltine silkworm [106]. A high efficiency of conversion in larvae reared at low temperature was reported [107]. Workers analyzed the nutritional indices and nutritional efficiency parameters of 5th instar larvae of popular India bivoltine races under different environmental conditions [108]. They demonstrated that the nutritional indices parameters like ingesta, digesta, approximate digestibility, and reference ratio were superior under optimum temperature (23–25°C) and humidity conditions (65–70%). Different authors [109–111] studied the effect of leaf moisture on nutritional parameters and development of silk gland of silkworm. However, the efficiency parameters like ECI cocoon were higher for higher-temperature-maintained silkworm batches and this might be because of less choice of feed that leads to some physiological adoptions to overcome nutritional stress (Table 4).

8. Influence of Temperature on Reproductive Potential of Silkworm Moth

The reproductive performance of silkworm varies with impertinent climatic factors in addition to physiological status of the parent. The commercial viability of silkworm is dependent on correlation between cocoons, moths, and reproductive potential of the strains. The cocoon weight and reproductive characters were greatly influenced by different temperature regimes [112]. The rate of egg production varies with temperature, accelerated up to a point of optimum temperature and humidity conditions. In the silkworm, *Bombyx mori*, maximum ovulation and fecundity with minimum retention were observed at temperature 25.36 ± 0.17°C and any fluctuation from this level decreased ovulation, oviposition fecundity and increased retention of eggs [113]. Reports are available on temperature-induced sterility in silkworm. Male silkworm moths almost became sterile when kept at 32°C for 4 days after spinning even though pupae were preserved at moderate temperature of 23°C throughout the remaining period [114]. Workers [115] reported that male silkworm become sterile at high temperature (above 33°C) during spinning and demonstrated that 19 hr continuous exposure to high temperature induces sterility in male silkworm [116]. The Induction of sterility at high temperature in different Indian races was studied [117, 118]. The quality of seed cocoon and that of egg yield are directly related and the number of dead pupae varies from race to race in different seasons [119]. The effect of temperature on reproductive potential of Bulgarian races was studied [120]. The effect of different temperature and humidity on preservation of seed cocoon and pupae of the new bivoltine hybrids (CSR races) was also studied [121]. The role of humidity on preservation of seed cocoon and potentiality of egg production was studied [122] and researchers studied [123] the refrigeration of cocoon and its effects on grainage parameters and egg production.

9. Environmental Care during Silkworm Spinning

If the temperature rises beyond 22°–25°C during spinning, the shell becomes very loose and folded with wrinkles and knots. It also changes the properties of sericin. This induces cohesion of silk filaments and causes difficulties in reeling. Low temperature slows down the secretion of silk thread and resulting in large-sized cocoons. Further, it takes very longtime for spinning. Relative humidity (60–70%) induces good health, good reelability, and good-quality cocoon. When it rises above optimum level the larvae and pupae cease to death. Low humidity causes double-layered cocoons and loose cocoons. Excessive moisture and harmful gases are released from the faeces and urine of silkworms during spinning. Air current speed should be less than one meter per second and fast or strong air current causes crowding of mature silkworms resulting in more number of double cocoons. Mounting room requires moderate, even illumination and strong light causes crowding of silkworms at one side and finally results in double cocoons or uneven-thickness cocoons. Complete darkness will slow down the spinning process resulting in low-quality cocoons. The effect of temperature and humidity on spinning behavior of silkworm was studied [124, 125]. Table 3 describes the combined effect of humidity and air current during spinning time of silkworm and the results show that low humidity (65%) and air current of 50 cm/sec are adequate for obtaining a good reelability of above 95%.

10. Influence of Temperature on Postcocoon Parameters

Cocoon quality parameters play an important role on the quality of the raw silk reeled. A large number of parameters, some of which are important for the parent cocoon race maintenance, define the cocoon properties and some are important for cocoon reeling. For a reeler, the technological parameters of the cocoon are significantly important, since they determine the quality, quantity, and efficiency of the reeling process. Significant variation in cocoon shape and cocoon size in hybrids results in variation in filament size as well as the quality of the reeled thread [126]. It was also mentioned that when reeling is carried out with irregular and nonuniform cocoons it results in thread breakage, hindrance due to slugs, poor reelability, poor cooking, decreased raw silk recovery, variation in raw silk denier, and poor neatness [127]. To obtain uniform filament size in auto and semiautomatic reeling units, cocoon size uniformity is very important

Table 4: Effect of different temperature and humidity conditions on nutritional indices of silkworm.

Environmental condition	Ingesta (g)	Digesta (g)	Approximate digestibility (%)	ECI cocoon (%)	ECI shell (%)
Temp 36°C and humidity 40%	3.04	0.850	27.99	18.27	8.94
Temp 20°C and humidity 90%	4.45	1.340	30.11	16.91	8.60
Temp 25°C and humidity 70%	4.41	1.430	32.44	16.86	9.17

Source [108].

[128]. Extensive studies have been carried out on cocoon shape variation in parental silkworm breeds and their hybrids [129–135]. Limited information is available on the combined effect of different temperature and humidity on various cocoon characters and reeling parameters at different stages during rearing and spinning of silkworm larvae which in turn will provide valuable information to the technology developers who are engaged in the improvement of quality and quantity of silk acceptable to the level of international standard [136]. The different temperature during spinning period and its effects on cocoon and reeling parameters of new bivoltine hybrids were studied [137]. The researchers evaluated the influence of various nutritional and environmental stress factors on silk fibre characters of bivoltine silkworm [138]. Researchers also [139] have shown that a relation exists between water content of cocoon layers during the spinning stage and reelability of cocoons and recommended that water content of the cocoon layer should be below 20% in order to obtain good-quality cocoons with better reelability. It is to be noted that when the humidity of ambient conditions is high during cocoon spinning, water present in the spinning solution, silkworm urine, and faeces is evaporated slowly influencing the structure of sericin. Various workers also described care to be taken after cocooning and before harvesting the cocoon [140].

11. Future Strategies

India enjoys the patronage of second position for the production of silk in the world next only to China. Sericulture in India is practiced predominantly in tropical environmental regions. Though, the introduction of robust and thermotolerant races in the field during summer months had considerable impact on the productivity level and returns in some selected areas, later planners realized this does not match to that of other productive bivoltine hybrids. Therefore, the acceptance level of this hybrid with the farmers was not up to the expected level because of the low productivity traits. This has necessitated the development of a more suitable temperature tolerant hybrid with better productivity traits than existing races. Mulberry and silkworm improvement programmes are continuous processes for evolving newer and high-yielding genotypes, which can sustain productivity under biotic and abiotic stresses. Genetic transformation techniques need to be further fine-tuned for developing transgenic silkworm with stable expression of cloned genes of commercial importance.

Some of the earlier studies addressed the selection of silkworm breeds in respect of thermotolerance by identifying thermotolerant silkworm breeds. However, a clear understanding of the genetic basis and variability in the expression of quantitative and qualitative genetic traits during exposure to high temperatures is an important step for the selection of potential thermotolerance parental resources for breeding programmes. To achieve greater success, there is a necessity of understanding the molecular mechanism of temperature tolerance in silkworm, identification of various groups of heat shocking proteins (HSPs), understanding of different expression pattern of various HSPs, in polyvoltine and bivoltine races to locate the genes responsible for the heat inducible HSPs, and subsequent steps to introduce the same into the silkworm genome.

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