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Status of *Bemisia tabaci* (Gennadius) in Context of its Biology and Ecology in Cotton Agroecosystem

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***Abstract*:** Cotton is an important cash crop and extensively cultivated in different parts of the world. Many factors are responsible for its low productivity and production but the magnitude of insect pests that damage cotton crop from sowing to maturity, is most important. Introduction of Bt cotton lead to drastic reduction in bollworms incidence but sucking insect pests such as whitefly, mealybug, jassid and thrips aphids has increased. Among these, whitefly, *Bemisia tabaci* is most serious pest of cotton. At present, it is globally distributed and known to infest several plant species. It causes damage to cotton crop by direct feeding and contamination of lint by honey dew and sooty mould. It transmits a deadly cotton leaf curl virus. *B. tabaci* has strong relationship with abiotic factors like temperature, humidity and precipitation. Temperature has positive correlation and relative humidity has negative correlation with whitefly. A combination of temperature and relative humidity is highly important for its multiplication in cotton. For a multi-voltine and multi-crop pest like *B. tabaci* estimating rates of mortality in the field is extremely complex and difficult. So, life table studies are important to predict pest outbreaks and to develop pest management strategies.

***Keywords*:** *B. tabaci*, Cotton, Biology, Ecology, Life tables

Cotton is a premier cash crop of India cultivated on an area of 11.3 million hectare, with an annual production of 37.0 million bales and average lint yield of 541 kg per hectare during 2017-18 (Anonymous, 2019). Among the various factors responsible for low production and productivity of cotton, the magnitude of insect pests that damage cotton crop from sowing to maturity is most important. Cotton is a sensitive/complex crop, on which pest attacks periodically and harboured 1,326 species of insects from sowing to maturity in different cotton growing areas of the world (Hargreaves 1948) and 162 species have been reported on the crop in India (Sundramurthy and Chitra 1992). Insect pest complex of cotton crop is broadly divided into four categories namely sucking insect pests, foliage feeders, bollworms and lint stainers. Among these, nine are considered as key pests in different zones resulting in 50-60 per cent loss in seed cotton yield (Dhawan 2004). Due to various reasons, the incidence of insect pests has increased tremendously resulting into failure of cotton crop in the past in Punjab, Haryana, Rajasthan, Andhra Pradesh and Gujarat states of India (Dhawan 2000). With the introduction of Bt cotton in 2002 in India and particularly in Northern states in 2005, lead to drastic reduction in bollworms incidence but sucking insect pests such as whitefly, mealybug, jassid and thrips aphids has increased.

Among the sucking insect pests, whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) has assumed the status of a serious pest of cotton in the recent past and during *kharif* 2015, it appeared in epidemic form in Punjab and Haryana. It is a polyphagous pest and feeds on about 600 plant species including many ornamental and greenhouse crops (Li et al 2011). Improved transportation technology and increased frequency of international transport of plant material has contributed to the extension of the geographical range of the *B. tabaci* complex. At present, it is globally distributed and occurs on all continents except Antarctica. It was first recorded on tobacco in Greece in 1889 and on cotton at Pusa, Bihar (India) during 1905 (Misra and Lambda 1929) and assumed the status of a serious pest on cotton in undivided Punjab in the 1930s. Subsequently, outbreaks of this pest were noticed in different cotton growing states in India, Andhra Pradesh (1984-87), Tamil Nadu, Maharashtra and Karnataka (1985-87), Gujarat (1986-87) and Punjab (1996). Up to 1995, it was a minor pest in Punjab, but became a major pest 1996 onwards (Dhawan et al 2007). It became a major pest on cotton in India after 1984 (Patil et al 1990). The use of synthetic pyrethroid on non-Bt cotton to control bollworms in early 1980s favoured whitefly multiplication (Dhawan et al 2007). Over the years, whitefly has created a niche in agroecosystem and has almost become a pest of regular occurrence in all the cotton growing areas of North-West India. Losses from the species complex in worldwide agricultural systems have been extensive and its emergence as a major threat in agricultural production systems has been characterized by outbreaks in many parts of the world (Gerling and Henneberry 2001).

Whitefly can cause damage to the cotton crop directly by the sucking the sap from the leaves of cotton plants resulting in leaf yellowing, leaf wilting, leaf drop and overall decline in seed cotton yield and indirectly by the excretion of honeydew by nymphs and adults on which sooty mold (black fungus) grows. The presence of sooty mold on leaves interferes with photosynthesis and affects the overall health and growth of the plant as well as lint quality. The third type of damage is caused by transmitting cotton leaf curl virus and the infected plants exhibit leaf curling, crumpling, vein thickening, cupping and plant stunting causing a loss of 10.5-92.2 per cent seed cotton yield in Punjab (Singh et al 1994). Sukhija et al (1986) reported 8-31 per cent loss in seed cotton yield due to the attack of whitefly, whereas Natarajan et al (1986) estimated losses to the tune of 15-20 per cent in South India. About 30-80 per cent loss in cotton was reported in Pakistan by Hameed *et al* (1994). Bedford and Mackham (1993) reported monetary losses of $ 500 m in cotton and vegetables. It also acts as a sole vector of more than 100 plant viruses, which cause diseases to many commercial crops in different parts of the world (Jones 2003). For the management of whitefly, insecticides are mainly used by the farmers. The repeated use and excessive doses had resulted in toxicity to natural enemies, insect resistance especially organophosphates, cyclodienes, synthetic pyrethroids and even for neconicotinoids (imidacloprid, thiamethoxam and acetamprid) and insect growth regulators like pyriproxyfen (Cahill et al 1995 and Byrne *et al* 2003). Although, most control efforts are insecticide based, but the most successful management is facilitated by an understanding of the biology and ecology of the species and melding of chemical, biological, cultural and other control tactics. In this paper, biology and ecology of *B. tabaci* have been reviewed for its proper management on cotton.

Life stages of *Bemisia tabaci:* Whitefly is generally a misnomer as it is not a true fly. In fact, it is closely related to scale insects, mealybugs and aphids in the order Hemiptera. Both adult and nymphal stages produce extracuticular wax that soils their body. The wax is nothing but the tightly curled threads of about 1 mm in diameter. Females normally possess two pairs of wax plates while males are provided with four pairs of wax plates. The hind and forelegs are generally instrumental in spreading the waxy material over the entire body except the eyes.

Egg: Females firmly embed the eggs in leaf tissue with a vertical orientation (Buckner et al 2001). Eggs are laid either singly or in scattered groups usually in circular groups, on the underside of leaves, with the broad end touching the surface and the long axis perpendicular to the leaf. Eggs are whitish when first laid but gradually turn brown. A glue like substance is deposited at the base of the pedicel to cement the eggs in place. Eggs draw water through their pedicels from the leaf, thereby preventing the desiccation before hatching. Hatching occurs after 5-9 days at 30°C but, this depends on host species, temperature and humidity. On smooth leaf varieties of cotton, the adults usually deposit eggs in semicircle. The eggs could be spindle shaped (Rao and Reddy 1989) and sub elliptical (Hussain and Trehan 1933). Under field and insectary conditions on cotton, females have been reported to lay 28 to 43 eggs (Husain and Trehan 1933). Egg laying under controlled temperature laboratory conditions has been highly variable, ranging from 32 to 257 eggs per female over a temperature range of 25.5 to 32.6°C (Butler et al 1983, Horowitz 1983, Bethke et al 1991 and Powell and Bellows 1992).

Crawler: First instar nymphs generally called crawlers, are flat, oval, transparent, light green and scale-like. This first instar is the only stage of this insect which is mobile. It moves from the egg site to a suitable feeding location on the lower surface of the leaf where its legs are lost in the ensuing moult and the larva becomes sessile. During hot summer, the crawlers walk quickly in search of suitable sites for settling on the same leaf (Hussain and Trehan 1933). The crawler may walk for few hours to cover a distance of a few millimeters before settling down on the leaf. Soon after settling, crawler inserts its mouthparts into leaf tissues and the stylet follows an intracellular path until the phloem is penetrated and sap extraction begins.

Nymph: The crawlers turn into sedentary stage. Both the subsequent stages, viz. second and third instar nymphs are sedentary and creamy white to yellow in colour, pointed at the rear end and possess oval shape. After the completion of nymphal stage, these insects turn into pseudopupal stage (Reddy and Rao 1989).

Pupa: The last nymphal stage (fourth instar) is often referred to as pseudo-pupa or puparium and is about 0.7 mm long and lasts about 6 days. It is within the latter period of this stage that the metamorphosis to adult occurs. It possesses two red eye spots, oval in shape and devoid of long waxy spines. Like the second and the third instar nymphs, it is again immobile.

Adult: The adult of whitefly is white, about one mm long with a pale yellow body which remains covered with pairs of tent like white wings of uniform size. Males are slightly smaller than the females. The body and both pairs of wings are covered with a powdery, white to slightly yellowish, waxy secretion. Adult emergence usually takes place in the morning. Compound eyes of the adult are red. Adults start to copulate as early as 2-6 hours post-emergence and females become fertilized on day they emerge (Luan et al 2008). Maximum emergence takes place between 8.00 a.m. to 1.00

p.m. (Hussain and Trehan 1933). Adults often remain near the pupal case for 10 to 20 minutes following emergence to spread and dry their wings. Males and females are sexually immature at emergence (Li et al 1989). The period of egg laying may range from 1-22 days depending on temperature under field and insectary conditions and 2-5 days under laboratory conditions. Female usually lays about 100 pear shaped eggs on the lower surface (Reddy and Rao 1989). Sharaf and Batta (1985) reported the adult longevity between 7.6-11.7 days.

Biology of *B. tabaci:* It has been studied by several workers. Adults begin feeding immediately after emergence and mate within 1-2 days. At 24.5 to 28°C, the average pre-oviposition period is 1.6 days (Ohnesorge et al 1981). Gameel (1978) reported that eggs on cotton hatched in 20.5 and 5.2 days, respectively at 15 and 40°C. The egg hatching reduced to 62 per cent at 15°C and 59 per cent at 40°C, but it ranged from 92 to 98 per cent at 25 to 35°C. In the field, the first, second, third, and fourth nymphal instars period completed in 2-4, 4-8, 4-8, and 4-8 days, respectively. Adult males were shorter lived (13.0 days) than females (61.5 days) on cotton from September to December in Sudan. Being polyphagous, it remains active throughout the year on a variety of hosts. However, on cotton, it is active during May-October in North, Central and South Zone of India (Dhawan et al 2007). The detailed investigations on the biology of the whitefly were first made in undivided Punjab by Hussain and Trehan (1933), whereas in South India, the extensive study on biology was carried out in Andhra Pradesh during the mid-eighties at the time of its outbreak on cotton (Anonymous 1989). In North India, eggs hatch in 3-5 days during active cotton season (April-September) but hatching extends to 5-17 days in October-March at low temperature conditions. The nymphal stage is about 9-14 days during March-April and 17-73 days during October-March (Hussain and Trehan 1933). Duration of egg stage varied from 4.35-5.9 days during different seasons viz. pre-monsoon, monsoon and post-monsoon (Aneja 2000). However, the studies carried out in Punjab demonstrated the total nymphal period of 7-13 days during the active cotton season on different cotton varieties (Butter and Vir 1991). Pupal period is generally 2-8 days (Hussain and Trehan 1933). In another study, under Punjab conditions, Aneja (2000) reported that duration of first, second, third nymphal instars and pupal stage varied from 3.90 to 6.40, 4.85 to 6.80, 2.75 to 6.65 and 4.60 to 5.65 days, respectively.

The total life cycle takes about 14-27 days in April-September, 36 days in October-November and 92-107 days in November-February and 30 days in March. The total duration of life cycle at Pusa and New Delhi been recorded as 12-17 days in August-September (Misra and Lamba 1929). In another study, the life cycle took 13-16 days in April-October and 33-47 days in November-February at Delhi on different hosts (Mohanty and Basu 1987). Study carried out in Punjab reported the total life cycle of 26-44 days during active cotton season (Aneja 2000). There are about 10-12 generations of the pest in a year. The adult longevity is normally 2-5 days in summer and may go up to 24 days in November (Hussain and Trehan 1933). In South India, life cycle is the shortest (13 days) in September and the longest (20.5 days) in December (Rao and Reddy 1989). The complete development period from egg to adult stage takes 15-70 days depending upon the weather conditions. In south, the female laid 28-300 eggs depending on the host and temperature conditions. The average fecundity of female is 43 eggs. The total fecundity between 18.1-26.8 eggs was reported in another study by Aneja (2000). However, Butter and Vir (1991) observed an average fecundity between 12-43 eggs. The sex ratio (Male: female) is usually 1: 1. The proportion of male and female is generally high in March-August, while it is low during September-February (Pruthi and Samuel 1942). The sex ratio is dependent on temperature, being 1: 1.8 at 30^{0}C and changed to 1: 3.1 at 14^{0}C (Sharaf and Batta 1985). However, Broad and Puri (1993) did not record range in the sex ratio on various crops during different months and ruled out the effect of temperature on sex ratio.

The studies carried out on the biology of whitefly on resistant and susceptible cultivars in South India indicated no difference in incubation, nymphal and pupal periods and duration of life cycle. However, the average egg load on resistant varieties was 8.8-15.1 eggs per leaf against 41.5-53.9 eggs per leaf on susceptible cultivars. The average fecundity was 12.53 and 48.53 eggs per leaf on resistant and susceptible varieties, respectively. The survival of different stages, viz. nymph, pupa and adult was 75.1, 81.8 and 89.3 per cent on resistant varieties against 87.0, 90.5 and 95.8 per cent on susceptible varieties, respectively (Anonymous 1989). Egg density can be as high as 1,200 eggs per square inch. The egg, nymphal and total development period of *B. tabaci* varied from 6.02-7.48 days, 15.87-19.87 days and 19.00-23.30 days, respectively on different genotypes during June-July whereas the respective durations in August-September were 5.60-7.60, 16.00-18.23 and 17.77-21.67 days, respectively. The egg survival varied from 53.33-86.67 per cent during June-July. Nymphal survival ranged from 42.83 per cent on PA 183 genotype to 70.67 per cent on F 846 genotype (Jindal 2004). In a similar study Ashfaq et al (2010) observed that maximum population of the *B. tabaci* on transgenic genotypes VH-255 and I-2086 while, the lowest population was recorded on non-transgenic genotype CIM-496. Chandi and Kular (2014, 2015) reported that during post-monsoon season duration of egg, first, second and third nymphal instar and pupal stage varied from 4.87 to 5.90, 4.81 to 5.02, 4.50 to 4.92, 4.52 to 5.30 and 3.95 to 4.45 days, respectively on different cultivars, however during monsoon season respective durations varied from 4.20 to 5.30, 4.67 to 4.93, 3.73 to 4.30, 4.37 to 4.93, 3.60 to 4.32 and 4.82 to 5.35 days, respectively on different Bt and non-Bt cultivars.

Ecology of *B. tabaci:* It has strong relationship with abiotic factors like temperature, humidity and precipitation. Upper temperature thresholds for growth and development are probably greater than 35^{0}C (Butler et al 1983). But a definite combination of temperature (27^{0}C) and relative humidity (71%) is highly important for the multiplication of whitefly in cotton system (Singh and Butter 1985). Effect of temperature on life functions is well documented under laboratory conditions. Time to complete immature stage development varies with change in temperature and can also be affected by the host plant. Total development times of eggs and the four nymphal stages in the field may vary greatly (14 to 107 days). Egg development in the laboratory takes five days at 34.7°C and 23 days at 15.4°C (Butler *et al* 1983, Wagner 1995). Nymph development times in the laboratory varied from 10.7 days at 27.5°C to 36.3 days at 17.7°C (Enkegaard 1993 and Wagner 1995). Differences in development times of as much as 10 days have been observed on different hosts at similar temperatures (Coudriet et al 1985 and Tsai and Wang 1996).

The duration of the egg stage varied from 22.5 days at 16.7°C to five days at 32.5°C, whereas eggs failed to hatch at 36.0°C. The total development time from egg to adult varied from 65.1 days at 14.9°C to 16.6 days at 30.0°C. Development took longer, and there was evidence of aestivation at temperatures fluctuating between 27 and 43°C. Peak emergence of adults occurred between 6 and 9 a.m. The average number of eggs laid per female was 81 at 26.7°C and 72 at 32.2°C. Males lived an average of 7.6 and 11.7 days, and females lived an average of 8.0 and 10.4 days, at 26.7 and 32.2°C, respectively (Butler *et al* 1983). Verma et al (1990) observed that eggs did not develop properly below 10^{0}C and above 36^{0}C. Optimum development of eggs was found between 25 and 30^{0}C and the optimum rate of adult development between 20 and 30^{0}C. Bishnoi et al (1996) reported that optimum temperature of 25-30^{0}C and humidity range of 40-58 per cent for build-up of cotton whitefly. Adult males in the laboratory have been observed to live 8-10 days at 16-32 °C and females 10-35 days at 14-32^{0}C (Butler et al 1983 and Enkegaard 1993).

Temperature is the major contributing factor in determining the density of whitefly. Whitefly population density generally begins to increase, coinciding with the closing of the crop canopy of cotton and repeated irrigations. With the receding of monsoon season, the whitefly population tends to remain high on cotton and responsible for creating conditions like development of sooty mould, blackening and stickiness of seed cotton. Dhawan and Simwat (1999) recorded significant negative relationship of whitefly with minimum temperature and evening relative humidity. The correlation of whitefly with sunshine and rainfall, however, was inconsistent. A significant negative correlation was found between whitefly catch and maximum/minimum temperatures and a significant positive correlation with mean morning relative humidity. The studies carried out in Karnataka showed that all the weather parameters collectively influence the whitefly population (Naik and Lingappa 1992). Besides, the changes in quantity of food resources seemed to influence the population fluctuations in this pest species. In Central India, temperature 28-36^{0}C and 60-92 per cent relative humidity during the period of scanty rainfall between August to January favour the build-up of this pest (Jayaswal 1989). However, in North India (Punjab), the population build of the pest is negatively correlated with temperature and rainfall.

Ashfaq et al (2010) showed that temperature had a positive effect on the population of whitefly whereas relative humidity was negatively correlated with whitefly. Darwish et al (2000) determined that 25 and 30^{0}C were found to be the most favourable for the development of egg and nymphal stages. Threshold temperatures of 10.52, 4.59 and 7.06^{0}C were calculated for the development of egg, nymph and from egg to adult stages, respectively. Based on the thresholds, these stages needed about 81.5, 371.7 and 426.7 day-degrees, respectively to complete their development. Chandi (2014) reported that net reproductive rate, finite rate of increase and intrinsic rate of increase was more at 32^{o}C in combination with 65 per cent RH.

Life table studies: Multiple abiotic and biotic mortality factors act on insect populations. These forces may be naturally occurring, as in case of predators, parasitoids, pathogens, host-plant effects and weather or manmade such as cultural manipulations and the use of insecticides. Understanding of the timing, spatial distribution and magnitude of these mortality factors is central to the study of population dynamics. It is also central to predicting pest outbreaks and in developing better pest management systems that take advantage of, and build upon, existing mortality forces (Naranjo and Ellsworth 2005). The construction of life tables is a robust method for describing and quantifying mortality in a population (Deevey 1947). Analysis of life tables developed for many insects have provided knowledge about population dynamics and their regulation in many ecological systems. The construction of life tables is vital to the description and understanding of the mortality factors in a population. Such analyses are not only of considerable theoretical interest, but also provide a rational and predictive basis for pest control.

Many biotic and abiotic mortality factors impact the population dynamics of *B. tabaci* in agricultural ecosystems, yet we have a poor understanding of the rates of these mortality factors and how they may be involved in overall population regulations. For a multi-voltine and multi-crop pest like *B. tabaci,* estimating rates of mortality in the field is extremely complex and difficult. The effect of various conventional insecticides is generally well known; however, studying the effect of such factors as predation and parasitism is much more difficult. Life table studies categorize the sources of mortality and provide a means to quantify rates of death from various factors over the course of a generation (Naranjo and Ellsworth 1999).

Comparative study on the life table parameters of whitefly was carried out in growth chamber under 24±2^{o}C, 55±3% RH and 16:8 (L: D) photoperiod in Iran by Samih et al (2003). The results revealed that age specific mortality (qx) began at the 22nd day and reached the highest value at the 49th day. Life expectancy (ex) was 26.9 at the initiation of development which was reduced to zero at the 28th day. Life table studies of *B. tabaci* by Naranjo and Ellsworth (1999) revealed that predation and dislodgment were major sources of egg and nymphal mortality, and overall survival from egg to adult ranged from 0-18.2 per cent. The major sources of mortality were predation (17%) and missing (18%). A very small fraction of the eggs were inviable (0.5%) and nearly 65 per cent of the eggs hatched. In another study, Naranjo and Ellsworth (2005) observed that median rates of mortality were in ranked order: predation (0.532), dislodgment (0.453), unknown factors (0.369), egg inviability (0.109), and parasitism (0.100). When pooled over all factors, the highest median marginal rates observed were during the egg stage (0.531) and the 4th nymphal stadium (0.687) and rates during the first three nymphal stadia ranged from 0.167 to 0.226. Naranjo (2007) used a combination cohort-based life table studies to measure egg mortality and recruitment studies to measure egg to settled first instar mortality in the cotton fields of Phoenix and Arizona and noted that crawler survival was 89.2 per cent.

Age specific reproduction parameters of whitefly on cotton were studied by Samih and Izadi (2006) in Iran. At 24±2ºC, 55±3% RH and 16:8 h (L: D) photoperiod, gross fecundity rate and gross fertility rate was 66.38 and 45.57, respectively. Cohort-based, partial life tables were constructed by Karut and Naranjo (2009) to determine the mortality, parasitism, predation sources and rates of mortality factors affecting *B. tabaci* on cotton in the eastern Mediterranean region of Turkey over a two year period. Across 10 independent cohorts, the highest median rate of marginal mortality pooled over all stages was attributed to parasitism (0.69) followed by predation (0.67). The greatest amount of marginal immature mortality occurred during the fourth nymphal stadium (median=0.77) and mortality during this stage was also most predictive of variation in total mortality. Pooled over all developmental stages, the highest rates of irreplaceable mortality were associated with parasitism (median: 0.112), followed by predation (0.088), dislodgement (0.020) and unknown (0.017). Field estimates of mortality from life table studies in cotton indicate that both eggs and nymphs are subject to mortality from many factors, with total surviva1 of immatures averaging just over 6 per cent (Naranjo 2001).

Life table of *B. tabaci* under natural conditions were constructed at vegetative and flowering stage of Bt cotton by Chandi (2014). Rainfall and natural enemies were responsible for reduction in *B. tabaci* population under natural conditions. Egg inviability was also responsible for mortality in egg stage. The net reproductive rate, intrinsic rate of increase and finite rate of increase were higher at vegetative stage than at flowering stage but the mean length of generation was more at flowering stage than at vegetative stage.

CONCLUSION

B. tabaci is most serious pest of cotton and is known to infest more than 600 plant species globally. High reproductive rate and multiple host sequences provide optimal conditions for its development. Temperature has positive correlation and relative humidity has negative correlation with whitefly. However, multi-voltine and multi-crop pest like *B. tabaci*, estimating the rates of mortality in the field is extremely complex and difficult. Therefore, life table studies are important to predict whitefly outbreaks and by understanding biology and ecology, we can properly manage this pest in cotton.

REFERENCES

Aneja AK 2000. *Biology of whitefly, Bemisia tabaci (Gennadius) on American Cotton.* M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India.

Anonymous 1989. *Management of Whitefly, Bemisia tabaci (Genn.) on Cotton.* Pp 55. Andra Pardesh Agricultural University, Hyderabad.

Anonymous 2019. http:// www.cotcrop.gov.in/statisticis.asp

Ashfaq M, Ane M, Zia K, Naseem A and Hasan M 2010. The correlation of abiotic factors andphysico-morphic characteristics of (*Bacillus thuringiensis*) Bt transgenic cotton with whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae) and jassid, *Amrasca devastans* (Homoptera: Jassidae) populations. *African Journal of Agricultural Research* **5**: 3102-2107.

Bedford LD and Mackham PJ 1993. A new strain of whitefly threatens crops worldwide. *Grower* (April 8, 1993): 11-13.

Bethke JA, Paine TD and Nussly GS 1991. Comparative biology, morphometrics and development of two populations of *Bemisia tabaci* (Homoptera: Aleyrodidae) on cotton and poinsettia. *Annals of the Entomological Society of America* **84**: 407-411.

Bishnoi OP, Singh M, Rao V, Niwas R and Sharma P 1996. Population dynamics of cotton pests in relation to weather parameters. *Indian Journal of Entomology* **58**: 103-107.

Broad VK and Puri SN 1993. Some studies on the behaviour of whitefly. *Journal of Maharashtra University* **18**: 101-103.

Buckner JS, Freeman TP, Ruud RL, Chu CC and Henneberry TJ 2001. Characterization and functions of the whitefly egg pedicel. *Archives of Insect Biochemistry and Physiology* **49**: 22-33.

Butler GD, Henneberry TJ and Clayton TE 1983. *Bemisia tabaci* (Homoptera: Aleyrodidae): development, oviposition and longevity in relation to temperature. *Annals of the Entomological Society of America* **76**: 310-313.

Butter NS and Vir BK 1991. Response of whitefly, *Bemisia tabaci* (Genn.) to different cotton genotypes under screen house conditions. *Indian Journal of Entomology* **53**(1): 115-119.

Byrne FJ, Castle S, Prabhaker N and Toscano NC 2003. Biochemical study of resistance to imidacloprid in B biotype *Bemisia tabaci* from Guatemala. *Pest Management Science* **59**: 347-352.

Cahill M, Byrne FJ, Gorman K, Denholm L and Devonshire AL 1995, Pyrethroid and organophosphate resistance in the tobacco whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae). *Bulletin of Entomological Research* **85**: 181-187.

Chandi RS 2014. *Ecological studies on whitefly, Bemisia tabaci (Gennadius) in Bt cotton.* Ph.D. Dissertation, Punjab Agricultural University, Ludhiana, India.

Chandi RS and Kular JS 2014. Biological parameters of whitefly, *Bemisia tabaci* (Gennadius) on Bt and non-Bt cotton under Punjab conditions. *Journal of Experimental Zoology India* **17**(2): 555-561.

Chandi RS and Kular JS 2015. Comparative biology of whitefly, *Bemisia tabaci* (Gennadius) on Bt cotton hybrids in Punjab. *Indian Journal of Ecology* **42**(1): 40-43.

Coudriet DL, Prabhakar N, Kishba AN and Meyerdirk DE 1985. Variation in development rate on different hosts and overwintering of the sweetpotato whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae). *Environmental Entomology* **14**: 516-519.

Darwish YA, Mannaa SH, Abdel Rahman MAA 2000. Effect of constant temperatures on the development of egg and nymphal stages of the cotton whitefly, *Bemisia tabaci* Genn.) (Homoptera: Aleyrodidae), and use of thermal requirements in determining its annual generation numbers. *Assiut Journal of Agricultural Sciences* **31**(1): 207-216.

Deevey ES 1947. Life table for natural populations of animal. *Quarterly Review of Biology* **22**: 283-314.

Dhawan AK 2000. Cotton pest scenario in India: Current status of insecticides and future perspective. *Agrolook* **1**(1): 9-26.

Dhawan AK 2004. Insect resistance in cotton: Achievements and challenges. In: Dhaliwal GS and Singh R (eds). *Host Plant Resistance to Insects: Concepts and Applications.* Pp 263-314. Panima Publishing Corporation, New Delhi.

Dhawan AK, Butter NS and Narula AM 2007. *The cotton whitefly, Bemisia tabaci (Gennadius).* Department of Entomology, Punjab Agricultural University, Ludhiana, pp 1-96.

Dhawan AK and Simwat GS 1999. Population dynamics of whitefly *Bemisia tabaci* (Genn.) on cotton-An ecological approach. In: Dhaliwal GS, Randhawa NS, Arora R and Dhawan AK (eds). *Ecological Agriculture and Sustainable Development* Vol. I. Pp 335-448. IES & CRID, Chandigarh.

Enkegaard A 1993. The poinsettia strain of the cotton whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae), biological and demographic parameters on poinsettia *(Euphorbia pulcherrima)* in relation to temperature. *Bulletin of Entomological Research* **13**: 55-60.

Gameel OI 1978. The cotton whitefly, *Bemisia tabaci* (Genn.), in the Sudan Gezira. In Third Seminar on the *Strategy for Cotton Pest Control,* May 8-10, 1978, p. 111-131. CIBA-Geigy, Basel, Switzerland.

Gerling D and Henneberry TJ 2001. The status of *Bemisia* as a cotton pest: Trens and future possibilities VII. In FM Gillham, ed., *Proc of the worldwide cotton research conference 2, New frontiers in cotton research*, pp 639-43 Athens, Greece. September 6-12, 1998, International cotton advisory committee, Washington, DC.

Hameed S, Khalid S, Ehsanrut HE and Hashmi AA 1994. Cotton leaf curl in Pakistan caused by a whitefly transmitted geminivirus. *Plant Disease* **78**: 529.

Hargreaves H 1948. *List of Recorded Cotton Insects of the World*. Pp 50. Commonwealth Institute of Entomology, London.

Horowitz AR 1983. *Population dynamics of the tobacco whitefly (Bemisia tabaci Gennadius) on cotton*. Ph.D. Thesis. Tel Aviv University, Tel Aviv, Israel.

Hussain HS and Trehan KN 1933. Observations on the life history, bionomics and control of whitefly of cotton, *Bemisia gossypiperda* (M & L). *Indian Journal of Agricultural Sciences* **6**(4): 701-53.

Jayaswal AP 1989. Whitefly on cotton and its management: A review. *Journal of Cotton Research and Development* **3**(1): 10-22.

Jindal V 2004. *Studies on mechanisms of resistance to whitefly Bemisia tabaci (Gennadius), in cotton, Gossypium hirsutum Linnaeus.* Ph.D. Dissertation, Punjab Agricultural University, Ludhiana, India.

Jones DR 2003. Plant viruses transmitted by whiteflies. *European Journal of Plant Pathology* **109**: 195-219.

Karut K and Naranjo SE 2009. Mortality factors affecting *Bemisia tabaci* populations on cotton in Turkey. *Journal of Applied Entomology* **133**: 367-374.

Li T, Vinson SB and Gerling D 1989. Courtship and mating behavior of *Bemisia tabaci* (Homoptera: Aleyrodidae). *Environmental Entomology* **18**: 800-806.

Li SJ, Xue X, Ahmed MZ, Ren SX, Du YZ, Wu JH, Cuthbertson AGS and Qiu BL 2011. Host plants and natural enemies of *Bemisia tabaci* (Hemiptera: Aleyrodidae) in China. *Insect Science* **18**: 101-120.

Luan JB, Ruan YM, Zhang L and Liu SS 2008. Pre-copulation intervals, copulation frequencies, and initial progeny sex ratios in two biotypes of whitefly, *Bemisia tabaci*. *Entomologia Experimentalis et Applicata* **129**(3): 316-324.

Misra CS and Lamba KS 1929. The cotton whitefly (*Bemisia gossypiperda* n. sp.). *Bulletin of Agricultural Research* **96**: 7.

Mohanty AN and Basu AK 1987. Biology of whitefly vector *Bemisia tabaci* Genn. on four host plants throughout the year. *Journal of Entomological Research* **1**: 15-18.

Naik LK and Lingappa S 1992. Distribution pattern of *B. tabaci* (Gennadius) in cotton. *Insect Science and its Applications* **13**(3): 277-279.

Naranjo SE 2001. Conservation and evaluation of natural enemies in IPM systems for *Bemisia tabaci. Crop Protection* **20**: 835-852.

Naranjo SE 2007. Survival and movement of *Bemisia tabaci* (Homoptera: Aleyrodidae) crawlers on cotton. *Southwestern Entomologist* **32**(1): 17-23.

Naranjo SE and Ellsworth PC 1999. *Mortality factors affecting whitefly population in Arizona cotton management systems: Life table analysis.* Arizona cotton report, The University of Arizona College of Agriculture.

Naranjo SE and Ellsworth PC 2005. Mortality dynamics and population regulation in *Bemisia tabaci*. *Entomologia Experimentalis et Applicata* **116**: 93-108.

Natarajan K, Sundramurthy VT and Basu AK 1986. Meet the menace of whitefly to cotton. *Indian Farming* **36**: 37-44.

Ohnesorge BN, Sharaf N and Allawi T 1981. Population studies on the tobacco whitefly *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae) during the winter season. II. Some mortality factors of the Immature stages. *Zeltschrift Angewandte Entomologie* **92**: 127-136.

Patil BV, Nandhihalli BS and Hugar P 1990. Effect of synthetic pyrethroids on the population build- up of cotton whitefly, *Bemisia tabaci* (Gennadius). *Pestology* **14**: 17-21.

Powell DA and Bellows TS Jr. 1992. Preimaginal development and survival of *Bemisia tabaci* on cotton and cucumber. *Environmental Entomology* **21**: 359-363.

Pruthi HS and Samuel CK 1942. Entomological investigations on the leaf curl disease of tobacco in northern India. V. Biology and population of whitefly vector (*Bemisia tabaci* Genn.) in relation to incidence of disease. *Indian Journal of Agricultural Sciences* **54**: 35-37.

Rao NV and Reddy AS 1989. Seasonal influence on the development duration of whitefly (*Bemisia tabaci*) in upland cotton (*Gossypium hirsutum*). *Indian Journal of Agricultural Sciences* **59**: 283-285.

Samih MA and Izadi H 2006. Age specific reproduction parameters of cotton whitefly (*Bemisia tabaci*) and silverleaf whitefly (*B. argentifolii*) on cotton and rapeseed. *International Journal of Agriculture and Biology* **8**(3): 302-305.

Samih MA, Kamali K, Talebi AA and Jalali JM 2003. Comparative study on the life table parameters of local populations of cotton whitefly *Bemisia tabaci* in Iran. *Journal of Entomological Society Iran* **23**(1): 1-19.

Sharaf N and Batta Y 1985. Effect of some factors on the relationship between the whitefly, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) and the parasitoid *Eretomocerus mundus* Mecret (Hymenoptera: Aphelinidae). *Zeitschrift für Angewandte Entomologie* **99**: 267-276.

Singh J and Butter NS 1985. Influence of weather factors on the build up of whitefly, *Bemisia tabaci* Genn. on cotton. *Indian Journal of Entomology* (Special issue) **2**: 363-366.

Singh J, Sohi AS, Mann HS and Kapur SP 1994. Studies on whitefly, *Bemisia tabaci* (Genn.) transmitted cotton leaf curl disease in Punjab. *Journal of Insect Science* **7**(2): 194-198.

Sukhija HS, Butter NS and Singh J 1986. Determination of the economic threshold of whitefly, *Bemisia tabaci* (Genn.) on American cotton in the Punjab. *Crop Pest Management* **32**(2): 134-136.

Sundramurthy VT and Chitra K 1992. Integrated pest management in cotton. *Indian Journal of Plant Protection* **20**: 1-17.

Tsai JH and Wang K 1996. Development and reproduction of *Bemisia argentifolii* (Homoptera: Aleyrodidae) on five host plants. *Environmental Entomology* **25**: 810-816.

Verma AK, Ghatak SS and Mukhopadhyay S 1990. Effect of temperature on development of whitefly (*Bemisia tabaci*) (Homoptera: Aleyrodidae) in West Bengal. *Indian Journal of Agricultural Sciences* **60**: 332-336.

Wagner TL 1995. Temperature-dependent development, mortality, and adult size of sweetpotato whitefly biotype B on cotton. *Environmental Entomology* **24**: 1179-1188.

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