2. Review of Literature
2.1 Economic significance of whitefly (*Bemisia tabaci* Gennadius)

Whiteflies and its biotypes are poly-phagous pests of great significance in agriculture worldwide (Kontsedalov et al., 2008), hardly exceeding 1.0 mm in length. It belongs to family Aleyrodidae from the suborder Homoptera of order Hemiptera having 1,556 extant species in 161 genera (Martin & Mound, 2007) and associated with 160 host plant species from 42 families of 113 plant genera of field and fruit crops, ornamentals, and forest trees including weeds (Brown and Bird, 1992). Adults are of snow-white in color attributed to the secretion of wax on its body and wings. Adult as well as immature stages inhabit and feed on the lower surface of leaves reducing plant vigor by depletion of plant sap (Khan et al., 2011). Foliage is contaminated with eliminated honeydew on which black sooty mould grows, which reduces the photosynthetic area and lowers the aesthetic appearance of ornamentals. Adults of a small number of species, most notably *Bemisia tabaci* (Gennadius) are important as vectors of many virus diseases than as direct pests.

Under severe infestation of yellow mosaic virus on black gram, the harvest was resulted with blank yield (Gupta and Pathak, 2009). An excessive use of pesticides failed to control the whitefly (Roditakis et al., 2005) and led to serious problems of resistance (Prabhakar et al., 1992). This escalation of problems had prompted many researchers to get involved in management studies of whiteflies, so as to check the spread of the viruses they are capable of transmitting. Use of action threshold based on monitoring of insect pests are the basic practice for decision making in integrated pest management and the nature of efforts to do so are greatly affected by the flight behavior and size of the concerned insect pest. Monitoring can be performed very easily on weak flying and large size insects as compared to minute and fast flying insect’s viz., whiteflies and hoppers.

Information on biological attributes and population dynamics of whiteflies is an important key for its successful control; it involves collection and handling as a very first step. The small size of whiteflies and attraction towards yellow color and orientation behavior toward light (positive photo-taxis) has however made the counting a hectic and troublesome task (Holmer et al., 1998 and Ahmad et al., 2010). Many researchers have tried and are still working on various ecological and management aspects viz., natural population fluctuation, dynamics and bio-assay of different pesticide molecules for this
specific pest. Some attempts had been made by different workers on quantitative studies of whitefly population employing various methods on different host (Table 1).

Table 1: Literature available on whitefly counting methods

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Author</th>
<th>Host</th>
<th>Method of observation</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Alicai (1999)</td>
<td>Sweet potato</td>
<td>NDM</td>
</tr>
<tr>
<td>3</td>
<td>Zabel et al., (2001)</td>
<td>Tomato</td>
<td>NDM</td>
</tr>
<tr>
<td>4</td>
<td>Nombela et al., (2001)</td>
<td>Tomato</td>
<td>Counting on all leaves of each plant</td>
</tr>
<tr>
<td>5</td>
<td>Mallah et al., (2001)</td>
<td>Cotton</td>
<td>TMB (Leaf turn method)</td>
</tr>
<tr>
<td>6</td>
<td>Muniz et al., (2002)</td>
<td>Tomato and Pepper</td>
<td>TMB (Leaf turn method)</td>
</tr>
<tr>
<td>7</td>
<td>Leite et al., (2003)</td>
<td>Brinjal</td>
<td>TMB (Leaf turn method)</td>
</tr>
<tr>
<td>11</td>
<td>Sanchez-Pena et al., (2006)</td>
<td>Brinjal</td>
<td>NDM</td>
</tr>
<tr>
<td>13</td>
<td>Sequeira and Naranjo (2008)</td>
<td>Cotton</td>
<td>Abaxial side of single leaf (Leaf turn method)</td>
</tr>
<tr>
<td>14</td>
<td>Muqit et al., (2008)</td>
<td>Tomato</td>
<td>NDM</td>
</tr>
<tr>
<td>15</td>
<td>Dharne and Kabre (2009)</td>
<td>Chilli</td>
<td>TMB (Leaf turn method)</td>
</tr>
<tr>
<td>16</td>
<td>Gupta and Pathak (2009)</td>
<td>Black Gram</td>
<td>NDM</td>
</tr>
<tr>
<td>17</td>
<td>Castle et al., (2009)</td>
<td>Melon vine</td>
<td>Fifth terminal leaf (Leaf turn method)</td>
</tr>
<tr>
<td>18</td>
<td>Byrne (2010)</td>
<td>Poinsettia</td>
<td>Leaf turn method</td>
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</tbody>
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TMB = Top, middle and bottom; NDM = No defined method
2.2 Population dynamics of whitefly under field condition:

The *Bemisia tabaci* appears on cotton during Mid-May and its population increases gradually until it peaks at the end of July (Ali *et al.*, 2004). The population decreases from the first week of August and can no longer be observed by the end of September, while contrary to this, Farman-Ullah *et al.*, (2006) suggested that, the infestation get commenced from last week of July and continue up to December with the maximum population during October. On the other hand, Sharma and Rishi (2004) observed the appearance of *B. tabaci* on cotton from the first week of June to end of September being high between Mid-August and end of September.

Change in population level is largely attributed to temperature and rainfall (Rashid *et al.*, 2003), whereas Hirano *et al.*, (1995), opined that climatic factors did not have a major role to play in population fluctuations. The population always tended to increase along with quantity of food resources; hence the changes of the quantity of food resources seemed to influence the population fluctuations. The operation of regulatory processes in population density is influenced largely by both the distance between habitat patches and the amplitude of temporal fluctuations of the quantity of food resources. According to Nayak *et al.*, (2004), of all abiotic factors contributing the population fluctuation, the relative humidity and sunshine hours are major components responsible for population build up of the whitefly while maximum temperature, rainfall and wind velocity are negatively associated whitefly population. Kharif season sown crop of green gram and black gram bean are more vulnerable to the attack of whitefly than zaid season (Kumar *et al.*, 2004).

The physico-morphic characters of the leaves viz., leaf lamina thickness and gossypol glands play a significant role in *B. tabaci* population regulation (Khan *et al.*, 2010). Leaf area and trichome length also impart a resistance against whitefly in black gram (Taggar and Gill, 2012). Similar findings have also been reported by De *et al.*, (2005), Pun *et al.*, (2010) and Magar and Nirmal, (2010). Different genotypes, moisture contents of leaves, gossypol glands, hair density and length of hair on midrib, leaf veins of cotton have the direct bearing on population change of whitefly (Parvez *et al.*, 1997).

Foda, (2000) in a study opined that, the host preferred for feeding is not chosen again for oviposition. The different strata of the host plant canopy (upper, middle and
lower leaves) are also reported to influence the population and the highest population can be seen on upper leaves approximately 40% of total population, followed by middle and lower leaves on cotton (Razaq et al., 2004). On the other hand, on brinjal plants, whitefly colonizes all over the plant strata except upper stratum and the total number of whitefly larvae were found to be most abundant on middle stratum (Rasdi et al., 2009). Leite et al., (2005) also reported similar observations in case of okra.

The horizontal distribution of adult tobacco whiteflies exhibits an aggregation pattern both in aubergine and soybeans, and so did their vertical distribution on the aubergine leaves (Hong et al., 2008). Emergence of whitefly starts right from initiation of first true leaf of soybean and green gram during June, but remains low in count in comparison to cotton. Cotton also enjoys more egg deposition of silver leaf whitefly than on soybean and green gram bean. Moreover, nymphs colonized with large population on cotton plants, followed by soybean. Similarly, a comparative more colonization of whitefly on black gram bean than on green gram is practically apparent (Kumar et al., 2004). In choice test among collard (Brasslike oleracea L. var. acephala D.C.), soybean (G. max (L.) Merr.) and tomato (L. esculentum Mill.), whitefly preferred collard for shortest nymphal development and tomato for longest. The hatching percentage was also found higher on collard and lower on tomato (Takahashi et al., 2008).

The intercropping of cowpea has also a good role to play in whitefly population build up on cotton. The host plant resistance of genetically engineered cotton genotypes, Gossypium hirsutum L., known as Bt-cotton against the whitefly (Bemisia tabaci Genn.) is of unstable nature. Some genotypes are highly susceptible to B. tabaci attack while few are registered as moderately or highly resistant one (Ashfaq et al., 2010).

Magar and NirmaI (2010) suggested the first occurrence of whitefly population and disease incidence might get influenced by cultivars and months of sowing. Spring vegetables such as Citrullus spp., Cucumis spp. Solanum spp. and pulse, Glycine max, mainly help in the pre-cotton season build-up of whitefly populations in addition to early sown cotton (Rafiq et al., 2008).

The crop age has an apparent impact on colonization of whitefly. The B. tabaci prefers 30 days old tomato plant for colonization (Toscano et al., 2002) and 60 days old crop of okra (Hasan et al., 2008). As far as leaf age is concerned, the Parabemisia
myricae (Kuwana) prefers incompletely expanded growing leaves of lemon however; \textit{Dialeyrodes citri} (Ashmead) and \textit{Aleurothrixus flloccosus} (Maskell) exhibit a greater fondness for young and completely expanded leaves (Walker and Zareh, 1990). It seems that the age preference of whitefly species also varies with respect to host plants.

The whitefly prefers external perimeter of greenhouses compared to open field crops or uncultivated areas which may be a reason behind significant \textit{T. vaporariorum} adult movement between indoor and outdoor patches (Nannini \textit{et al.}, 2009).

In okra, a lower whitefly population can be recorded from the crops sown in December-April followed by an increased and maintained at the higher level up to November. A high migration from one to another plantation is another important phenomenon in spatial and temporal population dynamics of \textit{B. tabaci} biotype B on two successive okra crops (Leite \textit{et al.}, 2005).

Agronomic practices like excessive use of nitrogen and irrigation also play a significant role in population build-up of whitefly, whereas alteration in sowing date did not exhibit any significant influence on the same (Dhawan and Simwat, 1998). Both adult and immature whitefly responds positively to application of nitrogen on cotton (Bi \textit{et al.}, 2003). The levels of glucose and fructose were also found positively correlated with whitefly densities particularly in June-planted cotton (Bi \textit{et al.}, 2005). High potassium content in leaves of cucumber has a negative influence on whitefly population growth (Lu \textit{et al.}, 2007). Sattar \textit{et al.}, (2005) observed a negative correlation between the incidence of whitefly with increasing nitrogen and protein contents in the leaf extracts of the cucurbits.

Leaf infection of Gemini viruses transmitted by whitefly itself has a negative influence whitefly development and longevity (Sidhu \textit{et al.}, 2009). Cotton leaf curl virus infection reduces the fecundity and longevity of \textit{B. tabaci} compared with non-viruliferous whiteflies. Female whiteflies survived longer than the male irrespective of their being viruliferous or non-viruliferous. In contrast, no significant difference in the reproductive rate per generation between those released on infected and healthy tomato plants was observed by Matsuura and Hoshino (2009).

\textbf{2.2.1 Impact of abiotic factors:}
A number of workers have studied the biological aspects of whitefly species under different set of environment viz., temperature (Han et al., 2013; El-Helaly et al., 1971; Butler, 1983; Zalom et al., 1987) and host plants (Sharaf, 1985; Cherry, 1980; Coudriet et al., 1985 & 1986). Pervasive effects of temperature on biochemical and physiological processes are thought to play a fundamental role in shaping the distribution and abundance of organisms (Yu et al., 2012). The effect of temperature on the development of *Bemisia tabaci* has been studied extensively in both laboratory as well as under field condition on many host plants viz., green gram (*Vigna radiata*), black gram (*Vigna mungo*), tomato (*Lycopersicon esculentum*), chili (*Capsicum annum*), okra (*Abelmoscus esculentus*), brinjal (*Solanum melongena*), cotton (*Gossypium hirsutum*) cucurbits, crucifers and ornamentals etc. Females of both *B. tabaci* and *T. vaporariorum* are heat tolerant specifically the females of *B. tabaci* in comparison to *T. vaporariorum* (Liu et al., 2007; Hu et al., 2011). Sudden rise in temperature also reported to reduce the fecundity of *T. vaporariorum*. The survival of *T. vaporariorum* decreased faster than *B. tabaci* (Cui et al., 2007). Moreover, Zalom et al., (1987); Verma et al., (1990); Wang and Tsai (1996); Bosco and Casiagli (1998); Gupta et al., (1998); Sengonca and Liu (1999); Muniz (2000); Bao-li (2003); Fekrat and Shishhebor, (2004); Lin et al., (2004); Yang and Chi (2006); Bonato et al., (2007); Manzano and Lenteren, (2009); Guo et al., (2012) and Albergaria-Nuno and Cividanes, (2002) are some of the pioneer studies on effect of temperature and humidity on whitefly development.

2.2.2 Impact of Host Plants:

The preference of host plants is also reported to vary in accordance with available heterogeneity of crop plants. For example, Coudriet et al., (1985) in a study suggested that the time required by *Bemisia tabaci* (Gennadius) to complete development from egg to adult was affected by the host plant to which it was confined. Further, when the whitefly (*Bemisia tabaci* Genn.) was reared on cucumber, eggplant, squash, tomato plants, showed a varying development response. In a follow up study, Costa et al., (1991) also observed similar findings however all the parameters are not different each time. They reported insignificant difference between oviposition rates on lettuce (*Lactuca sativa* L.) and cantaloupe (*Cucumis melo* L.). However, a greater offspring survival was
recorded on cantaloupe than on lettuce. In case of female longevity, a minor difference among populations reared on the same host plant or within populations reared on different hosts has been observed by Bethke et al., (1991). Moreover, the females originating from poinsettia produced significantly more eggs if reared on either poinsettia or cotton than did females from the cotton population.

Under cooler outdoor conditions, whiteflies developed significantly slow from egg to adult on alfalfa plants than on to cotton and the percentage of adult eclosion on alfalfa was significantly lower on alfalfa than on cotton. The percentage of whitefly survival from egg to adult on alfalfa, broccoli, cotton, and zucchini however, did not differ significantly in the greenhouse study. The egg hatching rates on different plants also did not vary greatly along with mean developmental time from egg to adult on the host plants such as alfalfa, broccoli, cantaloupe, cotton and zucchini in a greenhouse (Yee and Toscano, 1996).

Developmental time from egg to adult is influenced by the host plant and ranges from 17.3 days on eggplant to 20.9 days on garden bean as reported by Tsai and Wang, (1996). The highest average number of eggs laid per female and the female longevity can be observed on eggplant followed by tomato in addition, the maximum intrinsic rate of natural increase (r_m) for B. argentifolii was apparent on eggplant. The eggplant was the most suitable host for B. argentifolii whereas garden-bean was the least suitable among five tested commercial vegetables (Kakimoto et al., 2007). In the absence of egg plant, the order of preference among five host species was tomato > cabbage > pepper > tobacco > cotton. The egg laying order was cabbage > tomato > cotton, and tobacco > pepper (Cao et al., 2008). However, in the presence of cucumber, eggplant, pepper, cotton, and sweet potato, the highest selectivity of B. tabaci was apparent on cucumber and the lowest selectivity on pepper (Zhao et al., 2009).

In the absence of cultivated host plants the whitefly species may find weeds as suitable hosts where they can survive and reproduce. Among the 18 weed species studied, B. argentifolii showed a colonization preference for Sonchus oleraceus L. and Solanum nigrum L. followed by Conyza canadensis L. (Cronq.), Euphorbia elioscopia L., E. peplus L., and spontaneous clover, Trifolium repens L. The life table statistics also corresponds to the ranking of host preference as colonization does (Calvitti and Remotti,
Among, Ageratum houstonianum Mill., Bidens pilosa L. var. radiata Sch. Bip.; Crassocephalum crepidioides (Benth.) S. Moore; Eclipta prostrata L.; Emilia sonchifolia var. javanica, and Solanum nigrum L., the S. nigrum was the most suitable wild host and E. sonchifolia the poorest for B. argentifolii moving from crops to a transient habitat (Shun and Nan, 2002). In the presence of Amaranthus retroflexus, Chromolaena odorata, Desmodium tortuosum, Euphorbia heterophylla and Malvastrum coromandelianum, the Amaranthus retroflexus and M. coromandelianum were considered poor hosts for both populations, due to the low fecundity and survival of eggs, pupae and adults. It was estimated that B. tabaci could achieve 13–22 generations per year (Gachoka et al., 2005). Even though, the reason of host preference among weed plants is not known yet similar pattern of host plant preference among whitefly species has been reported.

As far as the superiority among the biotypes is concerned, the Q biotype of Bemisia tabaci has the ability to displace B biotype (Xu et al., 2006; Hu et al., 2011; Junbo et al., 2012; Chu et al., 2012). The development of Q-biotype was recorded faster than the B-biotype on S. nigrum and D. stramonium and most of the reproductive parameters of Q-biotype was found greater than those for the B-biotype (Muniz, 2000). In the midst of cotton, tomato and poinsettia, the species of B. tabaci (B and Q) prefers to settle on nutritionally superior tomato, but at the same time it prefers nutritionally inferior poinsettia for egg laying, favoring optimal oviposition theory for host plant preference. However, the nymph survivorship of B and Q species is reduced and immature developmental duration from egg to adult markedly prolongs on poinsettia as compared to cotton and tomato and hence, supporting the optimal foraging theory. Females of B and Q putative species of B. tabaci preferentially ovipositing on poinsettia may be a trade-off between nymph performance and the avoidance of natural enemy (Jiao et al., 2012). Both the biotypes (B and Q) exhibit a clear variation in their traits (Iida et al., 2009). The B-biotype successfully develops to become adult on only one of five tested cultivars of kidney bean, whereas the Q-biotype could utilize all the test plants including beans and vegetables as hosts regardless of the cultivar. This finding suggests that the determination of host plants in B. tabaci is greatly influenced both by plant species and cultivar. In addition, there is a high possibility that the Q-biotype has the ability to adapt.
to a wider range of plant species and cultivars compared with the B-biotype (Hu et al., 2011).

Soybean is the other crop that also exhibits a varying development response probably due to its attractiveness to adults and oviposition preference (Etoro do Valle et al., 2012). Among soybean, adzukibean and green gram, the development from egg to adult took longer time on adzukibean and the shorter on soybean. The female longevity differ significantly from each other, while the male survived for longer periods on soybean compared to green gram. The female fecundity, net reproductive rate and the intrinsic rate of increase \( r_m \) was highest on soybean (Chen et al., 2003) as also reported by others (Mansaray and Sundufu, 2000; Musa and Ren, 2005). In the presence of soybean, adzukibean and green gram, silver leaf whitefly (B. argentifolii) preferred soybean taking less time to develop from egg to adult and to double its population.

Among cucumber, *Cucumis sativus* L., cauliflower, *Brassica oleracea* L., rape, *Brassica campestris* L. and lettuce, *B. tabaci* preferred cauliflower most, followed by cucumber, cole and lettuce (Yang et al., 2004). However, in a study comprising 21 vegetables belonging cucurbitaceous, cruciferous and solanaceous taxonomic groups along with heading fennel, *B. tabaci* exhibited maximum fondness to watermelon under field conditions (Wu et al., 2004). Whitefly did not exhibit a marked variation between cucurbits like *Citrullus lanatus*, *Citrullus vulgaris* var. *fistulosus* and *Cucumis melo* (Sattar et al., 2004) while, cucumber in between hairy black gram, bitter cucumber and sponge black gram had a maximum fondness for the *B. tabaci* (Xu et al., 2008).

Even the variation has been observed among the plant originated biotypes of cassava and okra biotypes of *B. tabaci*. Cassava was preferred for whitefly landing and oviposition but did not oviposit on okra. The biotype of whitefly collected from okra preferred okra, oviposited on eggplant, tomato, garden egg and cowpea but did not oviposit on cassava. The okra biotype developed on all hosts except cassava, but survived only marginally on cabbage and pepper, while the cassava biotype did not develop on okra, cabbage and pepper (Omondi et al., 2005). On chili, the whitefly density and oviposition rate had a positive correlation with trichome density and negative relation with cuticle thickness of leaves. The *Capsicum annuum* showed a maximum resistance against whitefly than *C. frutescens*, *C. chinense*, *C. baccatum* on the basis of adult
survival and oviposition rate (Firdaus et al., 2011). A distinct variation between host plants showing difference in gross fecundity rate, gross fertility rate, mean age gross fecundity and fertility, mean egg hatch, parameters of *Bemisia tabaci* and *B. argentifolii* on cotton and rapeseed was recorded but the differences were non-significant with respect to gross hatch rate, net fecundity rate, net fertility rate, mean age net fecundity and fertility, number of eggs female/day and daily reproductive rate in both species (Samih and Izadi, 2006).

The combinations of host plants along with influence of abiotic factors like temperature have also been analyzed and it is apparent from the literature that influence was further categorized when other factors included. The cucumber, among rest of the tested plants *viz.*, cucumber, cantaloupe, squash, and watermelon, exhibited preference for 'B' biotype of *Bemisia tabaci* at three constant temperatures (Bayhan et al., 2006). Similarly, the oriental melon revealed a favor for whitefly among bell pepper, oriental melon, and eggplant (Han et al., 2012).

On the other hand whitefly did not exhibit any marked variation in development and demographical attributes on infested leaves collected from the field of cucumber (*Cucumis sativus* L.) zucchini (*Cucurbita pepo* L.) eggplant (*Solanum melongena* L.) and cotton (*Gossypium hirsutum* L.) under confined condition (Samih, 2005).

Polyploidization has played an essential role in the diversification of seed plants and often has profound effects on plant physiology and morphology. Yet, little is known about how plant polyploidization has shaped the ecology and evolution of interactions between phytophagous insects and their hosts. Polyploidization could either facilitate or impede colonization of new hosts. *Greya politella* (Lepidoptera: Prodoxidae) is highly specialized on plants in the genus *Lithophragma* (Saxifragaceae) throughout most of its geographic range. In central Idaho, some populations have shifted to the related *Heuchera grossularifolia*, a plant that has repeatedly undergone autopolyploidization. Previous studies have shown that populations feeding natively on *H. grossularifolia* prefer tetraploids to diploids in naturally mixed stands. Here it was further to see whether this difference is caused by an inherent preference for tetraploids, or if the preference in present Heuchera-feeding populations has evolved over time. Moths from a strictly *Lithophragma* feeding population were tested for preference of diploid or tetraploid *H.*
grossulariifolia, using a combination of field experiments and caged choice trials. In all trials, attack rates on these non-hosts were very low, with no observable difference between ploidies. In addition, there was little evidence that females manipulated their clutch sizes when ovipositing into different plant species or ploidy levels. Hence, the local shift from Lithophragma to Heuchera in central Idaho is not due to failure of the moths to discriminate between these plant species. Furthermore, the higher attack rates on tetraploids in native H. grossulariifolia-feeding populations cannot be caused by a higher initial preference for these plants, but must instead be a result of differences in plant phenology and/or selection acting on local populations.

The high diversity of phytophagous insects has been explained by the tendency of the group towards specialization; however, generalism may be advantageous in some environments. The cerambycid, Apagomerella versicolor exhibits intra-specific geographical variation in host use. In northern Argentina it is highly specialized on the herb Pluchea sagittalis (Asteraceae), while in central and southern areas it uses seven Asteraceae species. Host specific geographical variation from ecological and evolutionary perspectives were investigated field host availability and use across a wide latitudinal range, and performed laboratory studies on insect oviposition preference and larval performance and mitochondrial DNA (mt DNA) variation in a phylo-geographical framework. Geographic variation in host use was unrelated to host availability but was highly associated with laboratory oviposition preference, larval performance, and mtDNA variation. Genetic studies revealed three geographic races of A. versicolor with gene flow restriction and recent geographic expansion. Trophic generalism and oligophagy within A. versicolor seem to have evolved as adaptations to seasonal and spatial unavailability of the preferred host P. sagittalis in cooler areas of the species' geographic range. No single genotype is successful in all environments; specialization may be advantageous in environments with uniform temporal and spatial host availability, while being a trophic generalist may provide an adaptive advantage in host-constrained environments.

To test the hypothesis that natural enemy populations differ in their behavioural responses to plants or to plant allelochemicals, Kester and Barbosa (1994) compared the populations of gregarious endoparasitoid, Cotesia congregata (Say) Hymenoptera:
Braconidae) that differed in their historical and present exposure to tobacco. The major hosts for both populations were *Munduca sexta* L., and *M. quinquemaculata* (Haworth) (Lepidoptera: Sphingidae), but these hosts were typically encountered on tobacco by parasitoids in one population (Upper Marlboro) and tomato by parasitoids in another population (Wye). Early in season, Wye parasitoids preferred to oviposit in *M. sexta* on tomato rather than on tobacco and upper Marlboro parasitoid showed no preference; neither of the strains originating from the two populations showed a landing preference for tobacco or tomato in flight chamber trials, but upper Marlboro parasitoids search longer on tomato. When nicotine solutions were applied to tobacco leaf, searching response of upper Marlboro parasitoids were enhanced by 0.001-1.0% nicotine, and searching responses of wye parasitoids were decreased by 0.001-1.0% nicotine.

Myres *et al.* (1981) in a study suggested that a contagious egg distribution causes overcrowding of larvae on some plants but insures low levels or no attack other plants in parallel. This prevents extinction of plants and insects. An experiment on Cactoblastis moth revealed the selection of plants with characteristics which may increase the success of their larvae. Field observations and cage experiments indicate that large, green cactuses near previously attacked cactuses receive more eggs. Plants which are actively photosynthesizing are also more attractive as oviposition sites. These oviposition preferences contribute to the observed contagious egg distribution.

2.3 Chemical control

Among number of pest control options, only chemical control method responds quickly and rapidly and is a primary strategy for the management of whitefly but sustaining it for a long time is difficult (Palumbo *et al.*, 2001). Conventional management of whitefly with old active ingredients depends on spray coverage and deposition (Sharaf, 1986). According to Palumbo *et al.*, (2001), the repeated applications of these chemicals are important which results sometime in the development of resistance among whitefly. Recently numerous molecules have been introduced in to the market to combat the whitefly menace. A considerable amount of research has been conducted over the past 30 years on the role of chemicals to control whiteflies (Sharaf, 1986; Dittrich *et al.*, 1990).
Some new molecules such as insect growth regulators (IGRs) are getting more attention of scientists as a good substitute (Ali et al., 2005). IGRs (buprofezin and pyriproxyfen) were used as key factor in the resistant management, integrated management of whitefly in USA (Ellsworth and Martinez-Carrillo, 2001), and reducing the number of insecticides treatments applied for whitefly control in the coming years in Arizona, USA (Ali et al., 2005; Simmons et al., 1997). Buprofezin prevents the adult emergence from the pseudopupa of Bemisia tabaci (Valle et al., 2002). The neonicotinoid insecticides (imidacloprid) interfere with the nicotinic acetylcholine receptor of the insect nervous system (Ali et al., 2005; Yamamoto, 1996).

Pyriproxyfen and buprofezin are most prominent members of insect growth regulators group (IGR) (Palumbo et al., 2001), however, buprofezin was the first selective IGR. Both the compounds are effective against the immature stage of whitefly by inhibiting the incorporation of N-acetyl-glucosamine into chitin and interfering with cuticle formation (Kanno et al., 1981) resulting into failure of ecdysis. On the other hand pyriproxyfen disrupts normal juvenile hormonal balance (Dhadialla et al., 1998) resulting into suppression of embryogenesis, metamorphosis, and adult formation (Ascher and Eliyahu, 1988; Ishaaya and Horowitz, 1992, 1995). It is not effective against adult stage. Pyriproxyfen is reported to affect all immature stages while buprofezin is particularly first and second instar stage (Beevi and Balasubramanian, 1991). To improve compatibility between chemical and biological controls, the use of selective insecticides such as insect growth regulators is crucial (Qureshi et al., 2009). In cucurbits, the use of pyriproxyfen has been shown by others to be an effective method of reducing the number of sap-sucking insects, especially silverleaf whitefly, B. tabaci (Gennadius) Biotype B. A comparison between pyriproxyfen and buprofezin was made on bitter melon crop for the control of populations of silverleaf whitefly and for their effects on fruit production. Pyriproxyfen controlled silverleaf whitefly and tended to have heavier fruits than the control treatment and reduced the abundance of nymphs and exuvia. Buprofezin showed no evidence in controlling silverleaf whitefly compared with the pyriproxyfen and control treatments. Neither pyriproxyfen nor buprofezin had any effect on the number of harvested fruit or overall fruit yield, but the average weight per fruit was higher than the control treatment. Pyriproxyfen was effective in controlling whitefly populations in bitter
melons, and both pyriproxyfen and buprofezin may have the potential to increase yield. Their longer-term use may increase predation by natural enemies as they are species-specific and could favour build up of natural enemies of silverleaf whitefly. Thus, the judicious use of pyriproxyfen may provide an effective alternative to broad-spectrum insecticides in small-scale cucurbit production. In a similar study, Ishaaya and Horowitz (1995) observed an apparent inhibition of egg-hatch of *T. vaporaria* on the lower surface of cotton leaves when their upper surface was treated with pyriproxyfen, indicating a pronounced translaminar effect. In a comparative study of pyriproxyfen and thiamethoxam on *B. tabaci* biotype B, ovicidal effect of pyriproxyfen was found eight times higher than that of thiamethoxam at the recommended concentration. The nymphal mortalities of both insecticides treated on the third instar stage were over 85% however, thiamethoxam was very effective against adults, but the activity of pyriproxyfen was relatively low. It exhibited root up-take systemic effect on nymphs and adults of *B. tabaci*. Marked residual impact of pyriproxyfen and thiamethoxam was also seen, particularly thiamethoxam maintained high control effect with over 90% up to 7 days after treatment (Lee et al., 2002).

Studies on chemo-sterilant impact of pyriproxyfen were conducted on greenhouse whitefly by using yellow fabric lures coated with one mg of pyriproxyfen per cm². A drastic suppression of whitefly populations was recorded on bean plants in laboratory and glasshouse experiments. Numbers of eggs and larvae were reduced practically to zero over a period of several weeks (Oouchi and Langley, 2005). A rapid development of resistance in whitefly was recorded against these growth regulators (Crowder et al., 2006). It was suggested that growers may be able to prolong the usefulness of pyriproxyfen by applying lower toxin concentrations and promoting susceptible populations in refuges because, the resistance evolved faster when susceptibility to pyriproxyfen was greater in susceptible males than susceptible females. In contrast, resistance evolved slower when susceptibility to pyriproxyfen was greater in resistant males than resistant females.

Pyriproxyfen is practically non-toxic to bees. In this context, De Wael et al., (1995) found that bumblebee *Bombus terrestris* colonies developed normally after feeding on pyriproxyfen-sucrose solution. Effects of pyriproxyfen were evaluated in the
laboratory on larvae, pupae, and adults of the endoparasitoids *Enarsia pergandiella* Howard, *E. transvena* (Timberlake), and *E. formosa* Gahan, as well as on their host, *Bemisia argentifolii* Bellows & Perring and was found effective in controlling *B. argellitifolii*, safer to *E. pergandiella*, and relatively safe to *E. transvella*, but relatively toxic to *E. formosa*, especially pupae (Liu and Stansly, 1997).

The use of pyriproxyfen under row covers controls whitefly, reduces fruit damage and increases the size, weight, and quality of fruit, and may also control other sap-sucking insects (Qureshi et al., 2007).

Masao et al., (2007) utilized the whitefly attraction to the yellow color and an excellent un-hatching activity of pyriproxyfen against whitefly using yellow tape. The combination suppressed the whitefly when it was applied as a preventive measure. Additionally, the tape formulation reduced the worker's exposure and environmental impact by avoiding direct spraying.

Crowder et al., (2007) sprayed pyriproxyfen on sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (B biotype) and measured survival for males and females from a susceptible strain and a laboratory-selected resistant strain, as well as for hybrid female progeny from crosses between the strains. In all tests, survival was higher for the resistant strain than the susceptible strain, but did not differ between sexes in each strain. Survival to the adult stage did not differ between eggs and nymphs directly exposed to sprays. For susceptible and hybrid individuals, survival was lower on leaves collected the day of spraying than on leaves collected two weeks after spraying. In contrast, survival of resistant individuals did not differ based on the timing of exposure. Dominance of resistance to pyriproxyfen depended on the type of exposure. Resistance was partially or completely dominant in direct exposure bioassays and on leaves collected two weeks after spraying. Conclusively he opined that intensive use of pyriproxyfen will help in developing resistance in whitefly. On the other hand, Satoshi et al., (2007) exposed the whitefly adults to a tape formulation of pyriproxyfen for 5 minutes in a plastic cylinder (7 cm dia x 18 cm) and allowed them lay eggs for 24 hours on a bean leaf which bore eggs laid by untreated adults. In reciprocal experiments, untreated adults were allowed to lay eggs on a bean leaf which bore eggs laid by treated adults. The mortality of eggs laid by untreated adults exposed to treated adults was significantly higher than that of control
eggs. These findings showed that pyriproxyfen was transported by \( B. \) \textit{tabaci} adults which were exposed to the tape formulation.

Another novel insecticide, spirornesifen belonging to the new chemical class of spirocyclic phenyl-substituted tetronic acids, with a unique mode of action was tested against the greenhouse whitefly, \textit{Trialeurodes vaporariorum} Westwood (Homoptera: Aleyrodidae) on strawberry, \textit{Fragaria} \textit{ananassa} (L.). Egg hatching inhibition by 80\% and 100\%, respectively was observed at 0.5 and 1.0 mg /liter, whereas at concentrations of 3.1, 3.0, and 10.0 mg /liter, respectively, it killed 100\% of the first, second, and third instar nymphs. It was found less toxic to adults as compared to nymphs. Comparatively, the toxicity was recorded higher to pyriproxyfen and lower to buprofezin (Bi and Toscano, 2007).

Basit \textit{et al.}, (2013) investigated the effects of various mixtures of neonicotinoid and insect growth regulator against a susceptible and a resistant strain of whitefly and recorded potentiation ratio (PR) greater than 1 suggesting synergistic interactions between insecticides. From this study it was suggested that, the mixtures of neonicotinoids with buprofezin or pyriproxyfen at a 1:1 ratio could be used to restore the efficacy of these neonicotinoids against \( B. \) \textit{tabaci}.

Of all the conventional insecticides, synthetic pyrithroids are reported to be most effective in bringing down the whitefly population (Ellsworth and Watson, 1996; Prabhaker \textit{et al.}, 1998) and are primarily effective against the whitefly adults (Palumbo \textit{et al.}, 2001). The efficacy against nymphs is however difficult to achieve, because of their immobility and feeding on lower surface of leaves. If adults are continually moving into fields, frequent applications of foliar sprays are be required to prevent \( B. \) \textit{tabaci} populations from causing direct crop damage or transmitting whitefly borne viruses (Berlinger \textit{et al.}, 1993; Schuster \textit{et al.}, 1996). The nicotinoids are referred as nitroquanidines, nitromethylenes and chloronicotinyls, and most commonly as the neonicotinoids (Yamamoto \textit{et al.}, 1995), causing irreversible blockage of postsynaptic nicotinergic acetylcholine receptors (Bai \textit{et al.}, 1991; Liu and Casida, 1993). Imidacloprid was the first neonicotinoids used to control whitefly (Plaumbo \textit{et al.}, 2001; Mullins and Engle, 1993). It is a stomach poison and also absorbed by the roots and transported mainly in the xylem where it is distributed evenly throughout young, growing
plant tissues (Mullins, 1993). Application of imidacloprid through drip irrigation can efficiently deliver the compound directly to the active root system where it remains in an aqueous solution for extended periods of time (Palumbo et al., 2001). Due to its rapid plant uptake and systemic translocation within newly emerging plants, prophylactic applications of imidacloprid have been reported to reduce the incidence of aphid-borne viruses (Boiteau and Singh, 1999; Gourmet et al., 1996). Neonicotinoid insecticides (imidacloprid, acetamiprid and dimethoate) interfere with the nicotinic acetylcholine receptor of the insect nervous system (Ali et al., 2005; Yamamoto, 1996). Ahmad et al., (2001) reported a very high resistance to dimethoate and deltamethrin, and a moderate resistance to monochrotophos. Concurrently, whitefly resistance acephate, fenpropathrin, lamdacyhalothrin and bifenthrin mostly remained still low.

Acetamiprid is broader spectrum and safer to pollinators than other members in second generation group (Palumbo et al., 2001; Yamada et al., 1999). Soil application is comparatively more effective than imidacloprid (Takahashi et al., 1992). Thioclorpid is the most recent introduction in second generation group of neonicotinoids. Khan et al., (2000) recorded no significant difference among the products viz., Deltaphos 10+350EC (Deltamethrin + Triazophos), Azocord 44 EC (Cypermethrin + Monocrotophos), Azofas 42 EC, (Alphamethrin + Monocrotophos) Cytac 24 EC (Cypermethrin + Amitraz), Laser 25 EC (Cypermethrin + Dimethoate) and Polytrin-C 440 EC (Cypermethrin + Profenofos) applied four times for controlling sucking insect pests and bollworms. Mortality up to 96.67-100.00% and 91.02-95.57% of thrips, jassid and whitefly with above pesticides was found, respectively.

The efficacy of new insecticides against sucking insect pests for example dimethoate 30 EC, triazophos 40 EC, fenpropathrin 30EC, imidacloprid 17.8 SL, spinosad 45 SC, Eco neem 3% and standard check acetamiprid 20 SP, one day after spraying Fenpropathrin showed superior efficacy in bringing down all the sucking pest population followed by Dimethoate, imidacloprid and standard check acetamiprid. dimethoate and imidacloprid were most effective against aphid and dimethoate alone was most effective on leafhopper, whitefly and thrips at three days after spraying which were found to be superior over other treatments followed by imidacloprid, acetamiprid,
triazophos, fenpropathrin, eco-neem and spinosad. The similar trend was also observed even at seven days after spray (Shivana et al., 2011).

According to Borah et al., (1996), among dimethoate and malathion, best impact was found with dimethoate at 15 and 30 days after germination followed by dimethoate 0.03 percent at 15 days after germination + malathion at 30 days after germination. The use of cotton as trap crop, sown one month ahead in between the green gram rows with single spray of dimethoate at 15 days after germination of green gram controls whiteflies as well as yellow mosaic virus effectively. An experiment conducted by Khattak et al., (2004) to evaluate the efficacy of acetamiprid 20 SP, thiomethaxam 25 WG, difenthuran 500 EC, methamidophos 60 SI and imidacloprid 200 SL revealed a significant reduction in population of whiteflies even at 240 hours after spray. On the other hand, Awan and Saleem (2012) when applied four insecticides alone and in combinations like cypermethrin 10 EC, deltaphos 360 EC (deltamathrin with triazophos), deltaphos 360 EC + confidor 200 SL (deltamathrin with triazophos and imidacloprid), cypermathrin 10 EC with confidor 200 SL (imidacloprid) found none of the insecticides or combinations effective for the control of *B. tabaci*.

Among acetamiprid, imidacloprid and thiomethaxam, the highest rate of reduction against adult (87.5%) and nymphs (82.4%) after three sprays was observed with thiomethaxam. In autumn plantation acetamiprid was found least effective causing 67.3 and 60.1% reduction of adults and nymphs. However, it was also less toxic to coccinellids (Al-Kherb, 2011).

Haggag and Farghaly (2007) investigated the impact of metalaxyl (Ridomil plus 50% WP) and chlorpyrifos-methyl (Reldan 50% EC) alone or as mixture against *A. solani* and *Bemisia tabaci* (Genn.). The chlorpyrifos-methyl (125 ppm) and metalaxyl + chlorpyrifos-methyl (75 + 125 ppm, respectively) treatments were found effective in reducing the population of immature stages of *B. tabaci* by 65.7 and 84.0% on tomato and eggplant respectively. In field applications, the tested pesticides reduced the early blight disease severity on tomato and eggplant after foliar sprays. The chlorpyrifos-methyl and metalaxyl + chlorpyrifos-methyl mixture were found more effective against *B. tabaci*, while the metalaxyl was ineffective. Whereas Elenkov et al., (1980), reported
about 80% reduction in fecundity of *Trialeurodes vaporariorum* (Westw.) with the application of same fungicide.

He et al., (2013) assessed the effects of sublethal and low-lethal concentrations of four widely used insecticides on the fecundity, honeydew excretion and feeding behavior of *B. tabaci* adults. The probing activity of the whiteflies feeding on treated cotton seedlings was recorded by an Electrical Penetration Graph (EPG). The results showed that imidacloprid and bifenthrin caused a reduction in phloem feeding even at sublethal concentrations. In addition, the honeydew excretions and fecundity levels of adults feeding on leaf discs treated with these concentrations were significantly lower than the untreated ones. While, sublethal concentrations of chlorpyrifos and carbosulfan did not affect feeding behavior, honeydew excretion and fecundity of the whitefly. An antifeedant effect of the imidacloprid and bifenthrin on *B. tabaci* was clearly apparent, whereas behavioral changes in adults feeding on leaves treated with chlorpyrifos and carbosulfan were more likely caused by the direct effects of the insecticides on the insects’ nervous system itself. Besides the lethal effect, the sublethal concentration of imidacloprid and bifenthrin impairs the phloem feeding, i.e. the most important feeding trait in a plant protection perspective.

Qureshi et al., (2009) tested the efficacy of pyriproxyfen and buprofezin for their impact on crop yield, predation and efficacy to control the whitefly in bitter melons and found pyriproxyfen to be effective in controlling whitefly populations. Their potential to increase the yield was also noted and it was opined that their longer-term use may increase predation by natural enemies as they are species-specific and could favor build up of natural enemies of whitefly. Ma et al., (2010) has also reported the juvenile hormones to be safe for vertebrates.

Apart from development of resistance, the destruction of beneficial insects is another drawback of pesticide indiscriminate uses. It is therefore, mandatory to evaluate the suitable products to be used in plant protection strategy. In an integrated control program, it has become important to utilize insecticides with minimal toxicity to natural enemies of pests. Such practice might help to alleviate the problems of pest resurgence, which is frequently associated with greater use of insecticide in plant protection strategies (Yadav, 1989).
The ladybird beetle *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) mainly free-living predatory species that consumes a large number of prey during lifetime. Therefore, it is considered to be beneficial to agricultural crops, and contributes to the regulation of population of insect pests on which it feeds. Among others the 7-spotted ladybird beetle, *Coccinella septempunctata* L. has attracted considerable attention as biological control agent because of its potential to control many soft-bodied insect pests particularly the aphid on which it feeds voraciously in the immature as well as mature stages (Samal and Misra, 1982). The fourth instar larvae of this predator are more voracious than larvae of other instars (Rizvi *et al.*, 1994). Vostrel (1991) stated that most of times tested fungicide, acaricides, insecticides (carbamates & synthetic pyrethroids), exerted negative effects to varying degrees on all stages of *Coccinella septempunctata*. Average mortality was lowest for acaricides, while fungicides were slightly more toxic. Insecticides nearly always caused comparatively higher mortality of all development stages, but adults were more resistant in many cases.

Solangi *et al.*, (2007) studied the comparative toxicity of different insecticides *viz.* confidor, talstar, sumialpha, polo, danitol, steward, tracer and proclaim against 4th instar grub of seven spotted beetle *Coccinella septempunctata* L. It was observed that denitol was comparatively more toxic with 72% and 90% mortality at 96 hours and one week intervals respectively. While Tracer was less toxic with 30% and 38% mortality at 96 hours and one week intervals respectively.