Host Plant Resistance to Insect Pests in Horticultural Crops

M. Mani, N. Natarajan, R. Dinesh Hegde, and M. Kishan Tej

Abstract One of the major elements in any Integrated Pest management (IPM) programme is the use of resistant cultivars to insect pests. Host plant resistance (HPR) has offered the simple solution for insect pests and insect vector transmissible disease management on several agricultural and horticultural crops from time to time. Host plant resistance, tolerance and susceptibility to insect pests in fruit crops, namely mango, citrus, guava, sapota, banana, pomegranate, ber, custard apple, aonla, jackfruit, bael, date palm and apple, vegetables, namely tomato, brinjal, okra, chillies, onion, snake gourd, pumpkin, bitter gourd, bottle gourd, sponge gourd, ridge gourd, musk melon, watermelon, cowpea, cabbage and drumstick, tuber crops, namely potato, cassava, dioscorea, taro, elephant and elephant foot yam, ornamentals, namely rose, carnation, chrysanthemum and gerbera, spices, namely black pepper, turmeric, cardamom, cumin, coriander, fennel and fenugreek, plantation crops like tea, coffee and cashew, are discussed. These resistant varieties can be cultivated without much change in normal practice of cultivation, and tolerant and less susceptible varieties can also be incorporated into insect pest management practices.

1 Introduction

Plant resistance is defined as 'the consequence of heritable plant qualities that result in a plant being relatively less damaged than a plant without the qualities'. Host plant resistance (HPR) along with natural enemies and cultural practices is central component of any pest management strategy. One of the earliest documentation of plant resistance against insect can be traced back to 1785 during which wheat variety 'Underhill' was found to be resistant against *Mayetiola destructor* (Say) (Havens,

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1792) in California. Later, Lindley (1831) reported that the apple variety 'Winter Majetin' and 'Siberian Bittersweet' were resistant to the wooly apple z*Eriosoma lanigerum* (Hausm). Reginald Henry Painter is regarded as 'Father of Host Plant Resistance'. The control of grape phylloxera, *Phylloxera vitifoliae* (Fitch), by using North American rootstocks (*Vitis labrusca*) stood as the classical example in use of host plant resistance for economic benefit during 1900s which rescued entire French vine industries from devastation (Painter, 1951). The classical book 'Insect Resistance in Crop Plants' by R.H. Painter had created greater interest in the field of host plant resistance since 1951. Selection of crop plants was started as early as 10,000 years ago during which many wild ancestor species were transformed into elite cultivars, the process was referred as crop domestication. Wild relatives, shown high level of resistance, were exploited to diversify the basis and increase the level of resistance to insect pests in different crops. Modern breeding approaches and advanced research in molecular biotechnology enabled added advantage in the development of host plant resistant research (Sharma, 2007). Wilde (2002) lists 25 major crops to which resistant varieties have been developed, and Smith and Clement (2012) figured out resistant genes observed in 23 crops. The role of host plant resistance in pest management has been discussed by Painter (1951, 1958) followed by Stanley (1965), Kennedy (1978), Maxwell and Jennings (1980), Smith (1989), Panda and Khush (1995), Clement and Quisenberry (1999), Sharma and Rodomiro (2002), Smith (2005), Sharma et al. (2007), Smith and Clement (2012) and Stout (2013). With the development of insect resistance to insecticides which are commonly used for insect control, there is an urgent need to develop more resistant varieties, since several genotypes resistant to insect pests have been identified in several horticultural crops.

2 Definition of Plant Resistance

Painter (1951) described plant resistance as relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage done by the insect. According to Smith (1989), resistance of plants to insects enables a plant to avoid or inhibit host selection, oviposition and feeding, reduce insect survival and development, and tolerate or recover from injury from insect population that would cause greater damage to other plants of the same species under similar environmental conditions. In the broadest sense, plant resistance is defined as 'the consequence of heritable plant qualities that result in a plant being relatively less damaged than a plant without the qualities'. In practical agricultural terms, an insect-resistant crop cultivar is one that yields more than a susceptible cultivar when confronted with insect pest invasion. Resistance of plants is relative and is based on comparison with plants

lacking the resistance characters, i.e. susceptible plants. Several definitions have been used to convey the relative level of resistance in a plant. However, the problem of quantifying resistance continues to be a problem influencing farmer acceptance of insect-resistant cultivars. A better

way to define resistance levels in agronomically improved resistant cultivars is through quantified comparisons of insect pest damage or plant yield loss of susceptible cultivars.

3 Mechanism of Plant Resistance

Painter (1951), in his classical book, 'Insect Resistance in Crop Plants' proposed basic triad of mechanism of resistance, namely non-preference (antixenosis), antibiosis and tolerance.

Painter, in his classical book 'Insect Resistance in Crop Plants', proposed basic triad of mechanism of resistance, namely non-preference, antibiosis and tolerance. Kogman and Ortman (1978) proposed the term antixenosis as the term non-preference pertains to the insect and not to the host plant.

i. **Non-preference (Antixenosis)**: The term non-preference refers to the response of the insect to the plant characters that discourage its uses for oviposition, food and shelter (Painter, 1951). Kogman and Ortman (1978) proposed the term antixenosis as the term Non-preference pertains to the insect and not to the host plant. Antixenosis refers to the plant characteristics that affect herbivore behaviour in ways that disturbs the acceptance of the host by an herbivore. Antixenosis is a type of resistance may be due to the presence of certain chemicals in the plant which act as feeding or ovipositional deterrents, while a few others may act as insect repellents. Besides chemicals, morphological features of plants, especially the presence of trichomes, epicuticular waxes, silica content, colour and posture can impart antixenosis. Hairy varieties of soyabean and cotton are not preferred for oviposition. Wax bloom on crucifers deters diamond back moth *Plutella xylostella.*
ii. **Antibiosis**: Antibiosis refers to the adverse effects of the host plant on the insect pest due to the presence of some toxic substance or absence of required nutritional compounds. In other words, antibiosis denotes obnoxious effects of resistant plants on insect physiology and on the life stages such as reduced growth, survival and fecundity, failure of larva to pupate or failure of adult emergence and increased mortality. Long life cycle due to antibiosis effect results to increased exposure of immature stages of the insect to the natural enemies.
iii. **Tolerance**: The word tolerance symbolizes the ability of a plant to withstand herbivore injury with no significant economic damage/loss. A few plants withstand the injury by producing more number of tillers, roots, leaves etc. of damaged plants parts. Such plants are said to be tolerant to that particular pest. Tolerance usually results from one or more of the following characters, namely general vigour of the plant, re-growth of damaged tissues, strength of stems and

resistant to lodging, production of additional branches, efficient utilization of non-vital plant parts by the insect and compensation by growth of neighbouring plants (Emmanuel et al., 2015). Plant tolerance traits are classically grouped into those that alter (i) physiological processes such as photosynthetic activity and growth, (ii) phenology and (iii) use of stored nutrients.

However, there is confusion over calling these as 'Mechanism' of resistance. Since it is obvious that a resistant phenomenon contains combination of these characteristics frequently and also there exists an ambiguity in terms such as antixenosis and antibiosis, it is preferable to consider them as types or categories of resistance (Smith, 2005).

4 Terms *U*sed in *H*ost *P*lant *R*esistance

Ecological Resistance/Pseudo resistance: Certain crop varieties may overcome the most susceptible stage rapidly and thus avoid damage. Early maturing crop cultivars have been used as an effective pest management strategy. Pseudo resistance includes host evasion, induced resistance and host escape.

i. **Host evasion:** A host plant may pass through the most susceptible stage quickly or at a time when insects are less in number. Early sowing or planting of crops helps to overcome the pests damage.
ii. **Induced resistance:** It is form of temporarily increased resistance as resulting from some conditions of the plant or its environment such as changes in the amount of nutrients or water applied to the crop. Application of potassium fertilizers induces the resistance in the plants to insect pest attack.
iii. **Host escape:** A host plant escapes from the insect attack due to the lower insect population or no infestation.

Genetic resistance: The factors that determine the resistance of the host plant to insect establishment include the presence of structural barriers, allelochemicals and nutritional imbalance. These resistance qualities are heritable and operate in a concerted manner, and tend to render the plant unsuitable for insect utilization.

Monogenic resistance: Resistance is controlled by a single gene.

Oligogenic resistance: Resistance is governed by a few genes.

Polygenic resistance: It is governed by many genes.

Vertical resistance: If a series of different cultivars of crop show different reactions when infested with different insect biotypes, it is also referred to as a qualitative biotypic resistance. Vertical resistance is generally but not always of a high level and it is controlled by a major gene or oligogene. It is considered as less stable.

Horizontal plant resistance: Horizontal resistance describes the situation where a series of different cultivars of a crop show no differential interaction when infested with different biotypes of an insect. Generally, horizontal resistance is controlled by several poly genes or minor genes each with a small contribution to the resistance trait. Horizontal resistance is moderate, does not exert a high selection pressure on the insect, and is thus more durable and stable.

Immunity: An immune variety is one which a specific insect will never consume or injure under any known conditions. Cultivars are immune to the attack of specific insects which are otherwise known to attack the other cultivars of the same plant species.

High resistance: A variety with high resistance is the one which possesses qualities resulting in small damage by a specific insect under a given set of conditions.

Low resistance: A low resistance indicates the possession of qualities which cause a variety to show lesser damage or infestation by an insect than the average damage.

Moderate resistance: An intermediate level of resistance is sometimes referred to as moderate resistance.

Susceptibility: A susceptible variety is the one which shows average damage or more than average damage caused by an insect.

Highly susceptible: A variety shows high susceptibility when much more damage than the average damage is done by the insect under consideration.

Moderate susceptibility: An intermediate level of susceptibility is also referred to as moderate susceptibility.

5 Advantages of HPR

The role of plant resistance to insects in IPM has been well defined. Use of insect-resistant crop varieties is economically, ecologically and environmentally advantageous. Even partial resistance to insects will bring significant benefits, particularly when it is combined with other IPM components. Plant resistance can be an important component of any pest management programme/system because of the following advantages.

i. Economic benefits occur because crop yields are saved from loss to insect pests, and money is saved by not applying insecticides that would have been applied to susceptible varieties.
ii. In most cases, seed of insect-resistant cultivars costs no more, or little more, than for susceptible cultivars.
iii. Ecological and environmental benefits arise from increases in species diversity in the agro ecosystem, in part because of reduced use of insecticides.
iv. Increases in species diversity increase ecosystem stability which promotes a more sustainable system, far less polluted and detrimental to natural resources.
v. Use of plant resistance method of control is not pest density dependent, whereas the other methods like biological control are pest dependent.

vi. Specificity: Plant resistance is specific, only affecting the target pest. It is the target pest or a group of pests, and generally has no adverse effects on the non-target organisms.
vii. Cumulative: Effects of plant resistance on the insect population density are cumulative over the successive generations of the target pest because of reduced survival, delayed development and reduced fecundity.
viii. Persistence: Usually the effectiveness of resistant cultivars is long-lasting. Most of the insect-resistant varieties express moderate to high levels of resistance to the target insect pests throughout crop growing season except certain environmental conditions or occasional occurrence of the new biotypes/high pest densities. In contrast, pesticides have to be applied frequently to achieve satisfactory control of the pest populations. Even partial resistance to insects will bring significant benefits, particularly when it is combined with other IPM components. In fact, when durability of resistance is considered, partial resistance is preferable to total resistance.
ix. **Compatibility:** The impact of the resistant cultivar on standard cultural, biological and insecticidal control methods is well defined. Use of Plant resistant cultivars is compatible with the above other methods of pest control. Deployment of insect-resistant cultivars should be aimed at conservation of the natural enemies, thereby minimizing the number of applications. Insect-resistant cultivars synergize the effects of natural, biological and cultural insect pest-suppression tactics. The compatible and complementary role plant resistance to insect pests plays with other direct control tactics is in concert with the objectives of IPM.
x. **Compatibility of host plant resistance with natural enemies:**

   Varieties with moderate levels of resistance that allow the pest densities to remain below economic threshold levels (ETLs), are best suited for use in IPM in combination with natural enemies. Restless behaviour and prolonged developmental period of the immature stages on the resistant varieties increases the susceptibility of target pests to the natural enemies. The use of insect-resistant varieties and biological control brings together two unrelated mortality factors, which reduce the pest population's genetic response to selection pressure from plant resistance and the natural enemies. Acting in concert, they provide a density-independent mortality at times of low pest density, and density-dependent mortality at times of high pest density. Physico-chemical characteristics of the host plants also play an important role in host specificity of both the insect hosts and their parasitoids. Host plant exercises a tremendous effect on the activity and abundance of natural enemies, e.g. average rates of parasitism of *H. armigera* eggs (mainly by *Trichogramma* spp.) have been found to be 33% on sorghum, 15% on groundnut and 0.3% on pigeon pea, while little or no parasitism was observed on chickpea. Therefore, due care should be taken to select host plants and the parasitoid species while planning for biological control of insect pests. HPR and biological control: Plant-resistant varieties to insects in general are compatible with the natural enemies for pest management. Varieties with moderate level of resistance that allow the pest population to remain economic threshold are best suited for use in pest management in combination with natural enemies. Insect-resistant varieties also increase the effectiveness of natural enemies because of favourable ratio between the density of target pest and its natural enemies. The use of host plant resistance and biological control bring together unrelated mortality factors and thus reduce the pest population.

xi. **Environmental safety:** There are no harmful effects of HPR on non-target organisms, humans and the environment.

xii. **Ease of adoption:** It does not involve any costs to the farmers. Also, the farmers need not have any special knowledge of application technique.

6 Approaches for Developing Resistance to Insect Pests

6.1 Conventional Approaches in Breeding for Resistance to Insect Pests

Considerable progress has been made in identification and utilization of germplasm for resistance to insects. Wild relatives of crops are important sources of genes for resistance to insects. Wild relatives have shown high level of resistance, and also have different mechanisms/genes conferring resistance to insect pests and also can be exploited to diversify the basis and increase the level of resistance to insect pests in different crops. Expert is needed on identification of sources of resistance; knowledge of the genetics of resistance; development of effective selection and breeding schemes for resistance; and widespread evaluation of new lines along with controls in production areas to determine merit for release. Many wild ancestor species were transformed into elite cultivars, and the process was referred to as crop domestication. By the conventional approaches, the wheat variety 'Underhill' was found to be resistant against *Mayetiola destructor* (Say) in California (Havens, 1792). The apple varieties 'Winter Majetin' and 'Siberian Bitter Sweet' were found resistant to the wooly apple aphid *Eriosoma lanigerum* (Hausm) (Lindley (1831). The control of grape phylloxera, *Phylloxera vitifoliae* (Fitch) by using North American rootstocks (*Vitis labrusca*), stood as the classical example in use of host plant resistance for economic benefit during 1900s which rescued entire French vine industries from devastation (Painter, 1951). Wilde (2002) lists 25 major crops to which resistant varieties have been developed, and Smith and Clement (2012) figured out resistant genes observed in 23 crops. However, resistance breeding programmes are underway for a few crop pests only due to one reason or other. Cultivars with multiple resistances to insect pests are in greater demand for sustainable crop production, and this required a concerted effort from scientists involved in the crop improvement programme.

6.2 Modern Approaches for Developing Resistance to Insect Pests

The new tools need to become a part of the total plant breeding programme. At this stage, breeders need to combine molecular and classical approaches in enhancing germplasm and developing crop varieties with desirable horticultural traits along with insect resistance. In some cases, sufficiently high levels of resistance to some insect pests of many crops have not been secured through classical breeding. Molecular approaches alone, or in combination with classical breeding, may be the most useful approach to attain a desired resistance level. Modern approaches include (i) Genetic engineering, (ii) Inducible resistance (Gene switches), (iii) Marker-assisted selection (MAS), (iv) Gene sequence and function and (v) Metabolic pathways.

i. **Genetic engineering in crop plants for insect resistance:** Significant progress has been made over the past three decades in handling and introduction of exotic insecticidal genes into crop plants. Transgenic plants with high levels of resistance to some insect pests have been developed in recent years through insertion of a gene controlling the virus coat protein into a host genome. Genes from bacteria such as *Bacillus thuringiensis* have been successfully used for insect control through transgenic crops. Trypsin inhibitors, lectins, ribosomes inactivating proteins, secondary metabolites, vegetative insecticidal proteins and small RNA viruses can be used alone or in combination with Bt genes to impart resistance to insect pests (Sharma & Rodomiro, 2002).
ii. **Inducible resistance (Gene switches):** There is also some other type of mechanism that can neither be allotted to any of these categories, i.e. herbivore-induced plant volatiles (HIPVs) and so in this case it is aptly called induced resistance (Stout, 2013). Chemically induced expression systems or gene switches enable temporal, spatial and quantitative control of genes introduced into plants or those that are already present in plants to impart resistance to insects. A number of inducible genes have been identified in plants based on endogenous chemical signals such as phytohormones response to insect attack. Effectiveness of the chemical injury inducer Actigard in providing resistance to various insect pests in tomato has been demonstrated by Inbar et al. (1998).
iii. **Markar-assisted selection (MAS):** Marker-assisted selection can be used to accelerate the pace and accuracy of transferring insect resistance genes into improved cultivars. Narvel et al. (2001) used microsatellite markers to identify soybean QTLs (quantitative trait loci) for resistance to foliar feeding lepidopteran insects, to determine the degree to which different QTLs have been transferred into soyabean cultivars.
iv. **Gene sequence and function:** A routine large-scale approach can be commonly followed by generating and sequencing a library of expressed genes. A large number of ESTs are now available in the public databases for several crops such

as maize, sorghum and soybean. This technology offers powerful new uses for the gene discovered through sequencing (Hunt & Livesey, 2000).

v. **Metabolic pathways:** Genetic engineering can be used to change the metabolic pathways to increase the amounts of secondary metabolites, which play an important role in host plant resistance to insect pests, e.g. medicarpin & sativan in alfalfa and cajanol & stilbene in chickpea (Sharma et al., 2002).

7 Application of Host Plant Resistance in Horticulture Crops

Plant resistance work as mentioned earlier has been started in horticulture crops such as apple and grapes. A greater progress has been made in identifying resistance sources, and understanding the genetics and mechanism of resistance to important pests of horticultural crops. Despite several works published on later part of nineteenth century and early twentieth century followed by release of number of resistant varieties, the work is still lagging in horticultural crops. The resistant varieties can be cultivated without much change in normal practice of cultivation and these can also be incorporated into insect pest management practices. As far as published works on plant resistance to arthropods are concerned, Kennedy (1978) gave the overall work of HPR in fruits and vegetables during 1966–1977 wherein he reported that over 200 papers were published in North America. It included 9 fruit crops with 19 crop insect interactions and 21 vegetable crops with 70 crop insect pest associations. Host plant resistance, tolerance and susceptibility to insect pests in fruit crops, namely mango, citrus, guava, sapota, banana, pomegranate, ber, custard apple, aonla, jackfruit, bael, date palm and apple, vegetables, namely tomato, brinjal, okra, chillies, onion, snake gourd, pumpkin, bitter gourd, bottle gourd, sponge gourd, ridge gourd, musk melon, watermelon, cowpea, cabbage and drumstick, tuber crops, namely potato, cassava, dioscorea, taro, elephant and elephant foot yam, ornamentals, namely rose, carnation, chrysanthemum and gerbera, spices, namely black pepper, turmeric, cardamom, cumin, coriander, fennel and fenugreek, plantation crops like tea, coffee and cashew, are discussed.

7.1 Mango

The population density of mango hoppers (*Amritodus atkinsoni*, *Idioscopus clypealis* & *I. niveosparsus*) was lower on *Dashehari* and 'Anwar Retaul' (less than 4 hoppers/inflorescence) and higher on variety 'Fajri Klan' (more than 60 hoppers/inflorescence). At Hyderabad, Bangalora and Chinnarasam have recorded less than 10 hoppers (*A. atkinsoni*) per panicle. In Haryana, Lazzat Bhakshi and Khader are also found to be less susceptible to mango hoppers. Mango cultivars Rajmanu and Vanraj are less susceptible to mango hopper *Amritodus atkinsoni* Lethierry while Dashahari and Totapari are the most affected by the hoppers. At Junagadh, varieties, namely Mallika and Jumbo Kesar were found less susceptible to *A. atkinsoni*. The varieties, namely Kesar, Nilphanso, Nileshan, Malgoa, Langro, Payari, Begam palli, Rajapuri and Jamadar proved to be moderately resistant to *A. atkinsoni.* At Bilaspur, Chhattisgarh, minimum hopper population was recorded for the variety Sundarja followed by Himsagar (about one hopper/twig/panicle). Mango hybrids Nedgoa, A.U. Rumani, Mehmood Bahar, Neleshan-Gujarat, Arka Punit, Sindhu, Manjira, Sangam, HY-165 and Neeluddin have shown resistance to hoppers (*Amritodes atkinsoni*, *Idioscopus clypealis* & *I. niveosparsus*), thrips (*Scirtothrips mangiferae*, *S. dorsalis* & *Rhipiphorothrips cruentatus)*, leaf miner *Acrocercops syngramma*, leaf gall midge *Procontarinia matteiana*, shoot borer *Chlumetia transversa* and fruit flies (*Bactrocera dorsalis & B. correctu*s). GMH-1 (a promising hybrid from Gujarat) and Neleshan (except hoppers) showed moderate to susceptible reaction to most of the insect pests. Neeleshwari was less susceptible to these insect pests (Kumar et al., 2002). Mango varieties resistant to hoppers such as Baneshan, Totapuri and Chinnarasam had less nitrogen, more phosphorus, potassium, calcium, total phenol and orthodihydroxy (OD) phenols and less of reducing sugars (Nachiappan & Baskaran, 1983). Magnesium and non-reducing sugar content were not related to resistance. Mallika with the highest basal and induced antioxidant enzyme activities is indicated as the most tolerant hybrid to mango hoppers whereas Ratna having the lowest is reported as the most sensitive hybrid to leafhopper infestation. Results implicated that peroxidase, polyphenol oxidase, glutathione reductase and phenols played an important role in integrated defence response of mango to leafhopper infestation and the hybrids with higher levels of tolerance exhibited higher capacity for upregulation of defensive enzyme (Anusha et al., 2016).

Phenolics was lower, i.e. 6–13 mg/g in peels of susceptible varieties Banganapalli, Totapuri and Alphonso whereas in fruit fly-resistant varieties Langra & EC 95862 it was higher 42–53 mg/g of peel (Abraham Verghese et al., 2012). Mango varieties Langra, *Dashehari,* EC-95862, Mylepellian and Bombay Green are less susceptible to fruit fly. The presence of high tannin content in mango peel at critical stages of infestation played an important role in deterring or preventing fruit fly damage in mango. The main factors of resistance in mango to fruit flies are in the fruit peel and not in the fruit pulp. The polyembryonic varieties, namely EC 95862 and Mylupilian were less preferred by *B. dorsalis* in both choice and no-choice bioassays showing ovipositional non-preference resistance type in both the tests. Also, it was found that maggot survival was lowest in these varieties and the maggots eventually died within the pulp indicating influence of some mechanical and chemical barriers against *B. dorsalis*. Polyembryonic varieties contain abundant fibre in the pulp compared to other cultivars. These studies on the low susceptibility of these polyembryonic varieties to *B. dorsalis* throw light on the quantum of influence exerted individually by the fruit rind and the pulp. Therefore, the low susceptibility of these varieties may be due to combined influence of rind as well as pulp (Kamala Jayanthi & Verghese, 2008). An extra early maturing (15 March to

15 April) mango variety, Arka Neelachal Kesari, with attractive fruit colour and shape was identified for cultivation in eastern coastal regions of India. It escapes from fruit fly damage and yields 70–110 kg fruits /tree.

Most cultivars grown in India are susceptible to mango nut weevil *Sternochetus mangiferae*. Sundara Babu (1969) reported the incidence of nut weevil ranging from 28% in Jehangir to 100% in Totapuri and Neelam. The character of rough and tough fruit skin and age of the hybrids had a bearing on the incidence of the nut weevil. Out of 33 varieties of mango tested in India for resistance of mango nut weevil, 'Kalepad' and 'Hybrid 11/15' were most resistance to the weevil (Singh, 1989). Godse and Bhole (2003) screened 92 cultivars for resistance to mango nut weevil and no infestation was found in cultivars 'Sindhu', 'Bombay Green', 'FirangiLudua', 'Pulihora', 'Jahangir', 'Sabja', 'Salgadino', 'Hatizool', 'Dodamia' and 'Fazri'. Potential mechanisms of resistance are cultivars that produce no seed, those that form seeds with ahardorinsect-toxic covering early or those that fruit off season (Hansen, 1993). In Hawaii, the cultivar 'Itamaraca' had shown some resistance (Balock & Kozuma, 1964), perhaps because it induced off-season flowering and therefore produced weevil free fruits. Larval penetration of the seed of the variety Itamaraca is reported to be impossible.

Varietal preference of stem borer *Batocera rufomaculata* is evident with Alphonso, Langra and Jehangir being the most susceptible (25–50% damage) and Himayuddin and Banganapalli are less susceptible ones. Mango varieties, namely Neelam and Humayudin, are found tolerant to stem borer (Reddy et al., 2015).

Off-season bearing mango trees (June to November bearing) were found to escape from mango fruit borer *Autocharis* (Noorda) *albizonalis (=Deanolis albizonalis).* All other varieties grown in Andhra Pradesh, India are found to be susceptible to mango fruit borer attack. The fruit borer attack is in peak when the acid content of the fruit is at low level and the infestation is continuously decreased with the increased level of acid content of the fruit.

Mango varieties Makaram, Chinnaswarnareka, Mulgoa, Delhi and KO 11 are tolerant varieties to mango shoot gall psylla *Apsylla cistellata*.

In Punjab (Pakistan), mango cultivar Chaunsa was highly susceptible to giant scale insect and Tukhmiless susceptible to giant mealy scale *Drosicha mangiferae* Green. Carbohydrates were significantly higher in leaves of highly susceptible Chaunsa cultivar, i.e. 66.16% while less susceptible Tukhmi had significantly lower contents, i.e. 43.80% of carbohydrates. So it was concluded that special attention on Chaunsa (summer bahisht) cultivar of mango should be given when devising IPM programme for the control of mango giant scale (Karar et al., 2015).

Mango hybrids Nedgoa, A.U. Rumani, Mehmood Bahar, Neleshan-Gujarat, Arka Punit, Sindhu, Manjira, Sangam, HY-165 and Neeluddin have shown resistance to hoppers (*Amritodes atkinsoni*, *Idioscopus clypealis* & *I. niveosparsus*), thrips (*Scirtothrips mangiferae*, *S. dorsalis* & *Rhipiphorothrips cruentatus)*, leaf miner *Acrocercops syngramma*, leaf gall midge *Procontarinia matteiana*, shoot borer *Chlumetia transversa* and fruit flies (*Bactrocera dorsalis* & *B. correctu*s). GMH-1 (a promising hybrid from Gujarat) and Neleshan (except hoppers) showed moderate to susceptible reaction to most of the insect pests. Neeleshwari was less susceptible to these insect pests (Kumar et al., 2002).

7.2 Citrus

At Nagpur, citrus genotypes, namely Willits citrange, Trifolia, Rich 16-6, Flying dragon, Trifoliate Orange (Chethali, Gonicoppal), Carizzo Citrange (Chethali), Troyer Citrange (Gonicoppal), showed resistance to the psyllid *Diaphorina citri*. In North Eastern Hill region of India, Gal Gal (*Citrus pseudolimon*), Kagzi lime (*C. aurantifolia*) and Karna Kata (*C. karna*) are relatively more tolerant to psyllid *Diaphorina citri* Kuwayama, and very low psyllid population is recorded on Carrizo Citron, Soh Shyrkhoit (*C. latipes*), Gandharaj Citron, Karun Jamir (*C. aurantium*), Pommelo (*C. grandis*), Soh Nariange (*C. sinensis*) and Sweet lime (*C. limmettioide*s) (Rao et al., 1999). In Andhra Pradesh, Sour oranges, Sangtra mandarin, rough lemon and Citranges are found to be moderately resistant to *D. citri* while the varieties of sweet oranges and acid limes are found to be susceptible to the psyllid (Chakravarthi et al., 1998). Cultivars of citrus Cleopatra and Rubidoux are found to be resistant (0–10% damage) to *Diaphorina citri* while Minneola, Frost Marsh, Troyer, Citrumela and Karna Khatta are highly susceptible (40–100% damage) to the psyllid in Punjab (Batra et al., 1970).

At North Eastern Hilly region of India, Assam lemon (*C. limon*), Satkara (*C. macroptera*) and Pommelo (*C. grandis*) and Kharna Khatta are found to be highly tolerant to the citrus leaf miner *Phyllocnistis citrella* Stainton. The oviposition by the citrus leaf miner was the highest on Rangpur Lime and slightly lower on Jatti Khatti and Karna Khatta. Cleopatra and Troyer were moderately preferred. Highest larval prolonged duration and the minimum survival observed in Troyer might be possibly due to antibiosis. The pupal period was prolonged on Troyer as compared to other hosts. At PAU, Ludhiana, the larval and pupal duration of the leaf miner was highest and larval survival was minimum in Troyer, indicating possibility of antibiosis (Batra & Sandhu, 1983). The presence of higher phenolic compounds in the six rough lemon strains (Jatti Khatti, Miri, *Volkameriana*, South Africa I and South Africa II) seems to contribute towards the tolerance to leaf miner (Kaur et al., 1994).

In Meghalaya, micro propagated varieties, namely Assam lemon (*Citrus limon*), Satkara (*C. macroptera*) and Pommelo (*C. grandis*) are found to be highly tolerant to the citrus mealybug *Planococcus citri*, which can be used as rootstock in multiplication programmes (Pathak & Rao, 1999). The lines like Assam lemon, Satkara and Pummello are found to be resistant to the citrus mealybug (2.95–17.72% damage). At Nagpur, Rich 16-6, Flying dragon, Trifoliate orange, Troyer citrange, Carrizo citrange are found least susceptible to blackfly, psylla and leaf miner. Further, Sun-chu-sha mandarin and Trifoliate hybrid, Cleopatra mandarin and Troyer citrange are found least susceptible to thrips and mites.

Mandarin, Clementine, Santra Baladi and rough lemon are found more resistant to California red scale *Aonidiella aurantii* (Maskell) while lemon Baladi, sour orange and grapefruit are highly susceptible to the red scale. Susceptibility has decreased with increase oil glands of leaves and fruits in *Citrus* spp. (Habib et al., 1972). At Petlur, Nellore, Andhra Pradesh, Selections 21, 1 and Vikram were found to be resistant against *Scirtothrips* sp. Selection 1 showed combined resistance against thrips and mites (Sreedevi & Rajulu, 2008).

7.3 Grapevine

The control of grape phylloxera, *Phylloxera vitifoliae* (Fitch) by using North American rootstocks (*Vitis labrusca*) stood as the classical example in use of host plant resistance for economic benefit, which rescued entire French vine industries from devastation (Painter, 1951). The grape variety Jaishi has been reported to be immune to the attack of thrips on account of its thick leaves and heavy pubescence on the underside. Very low incidence of *S. dorsalis* (3–4% scabbing) was observed on Karachi and Fakdi (Thirumurthi et al., 1972). Perlette are less susceptible to thrips than Thompson Seedless. Himrod is rated as least susceptible variety (Batra et al., 1992). Significantly lowest thrips population was recorded in Red Globe while the highest population of thrips was recorded in Fantasy Seedless, followed by Kishmish Rozavis white. Among the genotypes, significantly lowest sugar and amino acid contents and highest phenol and tannin contents were recorded in Red Globe which supported lowest pest populations (Choudhury & Nadaf, 2018).

There is the existence of potential mealybug resistance in Vitis spp. In California (USA), significant differences were detected among cultivars and rootstocks in the recorded number of *P. ficus* juveniles, adults and egg sacs. Cabernet Sauvignon and Chardonnay were two of the most favourable grape cultivars for mealybug population growth. Rootstocks IAC 572, 10-17A and RS-3 have shown some level of resistance, and therefore identified as useful rootstocks for breeding. Using resistant rootstocks with scion cultivars that have reduced susceptibility to mealybug could help reduce mealybug populations living under the bark or overwintering on roots that systemic insecticides have trouble targeting (Naegele et al., 2020). Similarly, antiobiosis resistance was described for a grape rootstock to the citrus mealybug, *Planococcus citri* (Risso), that had a reduction in the number of viable offspring compared to susceptible cultivars (Filho et al., 2008).

7.4 Sapota

Sapota cultivars Pilipatti, Bhuripatti, PKM-5 and Mohangootee are less susceptible to the bud borer *Anarsia achrasella* Bradley, while the higher bud damage is observed in DHS-1, Kalipatti and DHS-2 during March to June. Sapota variety

PKM 1 is resistant to the leaf webber *Nephopteryx eugraphella* Ragonot (Sandhu & Scran, 1983). There is less damage by *N. eugraphella* and *Anarsia epotias* Meyrick in PKM-I, Kirthabarthi, Cricket Ball, Guthi and Oval. However, CO-1 was highly susceptible attributed to the spreading nature of large and evergreen leaves. In case of chiku moth, *N. eugraphella*, the less damage was noticed in Bhuripatti, Singapore and Mohangoottee, whereas the higher infestation on Pilipatti, DHS-1, Murabba and Paria Collection during April, May and December. Sapota seed borer *Trymalitis margarias* Meyrick causes less fruit loss in PKM-5, DSH-1, PKM-2, Bhuripatti and PKM-1, however the higher fruit infestation in Kalipatti, Cricket ball and CO-2 during November-December (Bisane & Naik, 2016). Sapota varieties, namely PKM-1, PKM-2, DHS-1, DHS-2, Bhuripatti, Pilipatti and Singapore are found least susceptible to the fruit fly, *Bactrocera dorsalis*. However, Zumakhiya, CO-2 and Kirthibarthi are found to be moderately susceptible to the fruit fly. Kalipatti, Cricket Ball, Paria Collection, Murabba and Mohangoote are found highly susceptible to *B. dorsalis*. The fruit fly infestation had significant positive correlation with total soluble solids (TSS) and total sugars whereas it had negative correlation with acidity. Physical characters, namely fruit shape and skin pulp ratio had no significant impact on fruit fly incidence. Sapota genotypes with thin fruit skin are susceptible to fruit fly damage as compared to those with thick fruit skin (Amol & Abhishek, 2013).

7.5 Banana

Banana weevil, *Cosmopolites sordidus* Germar is a major limiting factor in the cultivation of plantains and bananas in many countries. In Uganda, a number of Musa L. cultivars and hybrids have displayed high levels of resistance to banana weevil, while most highland banana cultivars are found to be susceptible to weevil attack. Antibiosis mechanisms offer the primary avenues of resistance. Development of the weevil was slower on some resistant cultivars. Sap appeared to play a minor role in reducing egg eclosion rates on some resistant cultivars. Methanol extracts from Kayinja, a resistant cultivar, inhibited larval development on corms of susceptible cultivars in the laboratory (Kiggundu et al., 2007). In sub-Saharan Africa, all plantains were equally susceptible to the banana weevil, while a wild banana accession and some cooking and dessert banana cultivars showed high levels of resistance. Differential genotypic responses were observed in euploid plantain-banana hybrids. Segregation results suggest that host plant response to weevil in *Musa* is controlled by gene(s) exhibiting partial dominance towards the resistant parent and modifier genes with additive and dosage effects for susceptibility in the plantain parent. In natural banana germplasm, resistant clones showed increased corm hardness, as measured by a penetrometer in longitudinal and cross sections of outer and central corm tissues. This might suggest a non-preference mechanism for weevil resistance. However, the lack of correlation between corm hardness with PCI and CS scores in the segregating progenies suggested that other mechanisms may be more important in conferring resistance to banana weevil (Ortiz et al., 1995). In India, Locatan was the least susceptible to the weevil attack while Muduranga was the most susceptible to the rhizome weevil, and the resistance level was in the order of *Musa balbisina* > Cavendish (D) > Cavendish (R) > Poovan > Virupakshi > Rasabale > *M. acuminata* > Sirumali > Nendran > Neypoovan > Nallabontha > Budubale. The reaction of 28 clones of banana on the basis of bunch weight, number of hands, number of fingers, duration and total soluble solids indicated that Chakkia had the highest stability and adaptability as it had resistance to rhizome weevil. Kostha and Bontha was free from damage while Malaimonthan, Peapeykunnan, Locatan, Chakkia and Jamani possessed a moderate level of multiple-resistance to rhizome weevil.

Banana cultivars Jurmony, Thatillakunnan, Malakali, Padathi, Ageneswar, Krishnavazhai and Kali are found to be resistant to lacewing bug *Stephanitis typicus* Distant on the basis of number of bugs/leaf and eggs/unit area while Klueyteparod and Manoranjitham are highly susceptible. The varieties Malbhog and Chenichampa have proved to be highly susceptible, both in terms of damage and in number of insects present, while Bhimkal is completely free, Kaskal highly resistant and Jahajee resistant. Resistance in these last three varieties appears to be contributed with their broad, thick and compact leaf-sheaths and pseudostems, and antibiosis was also suggested as one of the contributory factors (Mohanasundaram, 1987).

Vennon, Klue taperod and Peyan are found to be less susceptible to banana thrips.

Among the cultivars, Palayankodan and Kodappanillakunnan are completely devoid of root mealybugs *Geococcus coffeae* Green and *Geococcus citrinus* Kuwana infestation. Nendran is the most susceptible one with highest number of root mealybug colonies (4.38) followed by Njalipoovan (2.55) (Smitha & Maicykutty Mathew, 2010). Irrespective of the seasons, two cultivars, namely Palayankodan and Kodappanillakunnan, are completely free from root mealybug. The number of colonies of the root mealybug was significantly highest (4.38 colonies/sample) in Nendran. The cultivar, Njalipoovan also recorded more number of colonies (2.55). The least number of colonies (0.42) is observed in the cultivar, Poovan (Rasthali). There was a significant positive correlation between root mealybug population and phenol content ($r = 0.981$) in different varieties. Highest total phenol content is in the variety Palayankodan (176.90 g 100 g^{-1}) followed by Kodappanillakunnan (μ g 100 g^{-1}). The lowest phenol is found in Nendran variety. The phenol content in the roots might be the reason for offering resistance to plants against mealybug.

Vennon, Klue taperod and Peyan are found be less susceptible to banana thrips.

7.6 Guava

Fruit characters of guava cultivars are found to have influenced the damage by fruit fly, *Bactrocera dorsalis*. Fruits of red flesh and seedless guava with rough and wrinkled skin had very low infestation. Guava varieties, namely Pink flesh, Red flesh and strawberry cultivars with rough gritty skin, have exhibited low infestation while Bramasi and Guinea varieties with intermediate mellow skin had moderate infestation as against smooth skinned Allahabad Safeda, Apple colour and Lucknow 49 suffering severe infestation. Fruits with red flesh and rough skin had less damage compared to those with white flesh and smooth skin. However, fruit shape did not show any effect on the incidence (Reddy & Vasugi, 2002). High levels of vitamin C, total soluble solids and total phenols in the fruits of different guava cultivars are found to contribute for the resistance to *B. correcta* (Bezzi) (Jalaluddin et al., 2001). The per cent infestation of *B. dorsalis* is positively correlated to totals sugars, TSS and total proteins but was negatively correlated to total phenols, orthodihydroxy phenols and flavonols. Acidity and vitamin C in fruits showed a very weak but negative impact on fruit fly incidence. Endogenous metabolites were reported to play a significant role in fruit fly resistance (Kaur et al., 1994). In Himachal Pradesh, smooth skinned varieties, namely Red Flesh, Allahabad Safeda and Local are found to be highly susceptible to the fruit fly attack (65–80.4% infestation), whereas rough skinned pear-shaped variety is least susceptible (35%) as compared to other varieties Lucknow-49, SeedLess, Behat Coconut and Local where the infestation ranged between 45. 7 and 56.5% (Rajpal Singh, 2008). Wild species of Psidium, namely *Psidium chinensis* and *P. quadrangularis* were found to be resistant to *B. dorsalis* (less than 10% damage), while *Psidium molle* and *P. cattleianum* were resistant to tea mosquito bug *Helopeltis antonii* (Sign.) (Reddy & Vasugi, 2008).

The total soluble solids (TSS) and total sugars were positively correlated with fruit fly infestation, while acidity was negatively correlated. The tea mosquito bug incidence did not exhibit significant correlation with any of these parameters (Reddy & Vasugi, 2004a). Guava varieties Red flesh, Sardar Guava, Dharar and Annu Ishkwala are moderately resistant to the guava shoot borer *Microcolona technographa* Meyrick (Sharma et al., 2004). Dudhkhaja, Arka kiran, Lalit and Hisar Surkha are found to be less susceptible to the guava fruit borers.

At Bangalore, the mean number of bore holes by *Inderbala tetraonis* per tree varies from 0 in Spear Acid to 11 in EC147036 (7-12). Accessions, namely Banagalore Local, Lalit, Portugal, Superior Sour Lucidum were resistant less than 2 holes/tree while three collections, namely Seedless, Hafsi and exotic EC147036 (7-12) are highly susceptible recording more than 10 holes/tree. Popular cultivars like Allahabad Safeda, Arka Miridula, Chittidar and Benara are moderately resistant (less than 2 holes/tree) (Reddy & Vasugi, 2004b).

At ICAR-Central Institute for Subtropical Horticulture, Lucknow, 19 guava genotypes were evaluated against the fruit borer, *Deudorix isiocrates* F. infestation under field conditions to identify the less susceptible germplasm. Based on the level of infestation genotype Florida Seedling was categorized as less susceptible whereas Hong Kong White and CISH-G1 were categorized as highly susceptible germplasm.

7.7 Pomegranate

There was less fruit damage by *Deudorix* (*Virachola*) *isocrates* (Fabricius) (6.5%) in the cultivar Jyothi had followed by Bedano Bosco (10.30%) while the maximum fruit damage was observed in the cultivar Coimbatore (30.40%) while Ganesh and Yercaud 1 suffered 23.80 and 18.20% fruit damage respectively, exhibiting a negative correlation between fruit damage and rind thickness of the fruit. The rind thickness of Jyothi was 3.58 mm whereas the rind thickness of Ganesh and Yercaud-1 was 2.15 and 2.19 mm respectively. Phenol and tannin contents of the flowers and fruits had negative correlations as the resistant varieties Jyothi and Bedano Bosco possessed a higher tannin content (6.70 and 6.92 g/100 g) and total phenolics (8.03 and 8.20 g/100 g) as compared to the susceptible variety 'Coimbatore' (4.88 and 5.47 g/100 g of tannin and phenol respectively) (Karuppuchamy, 1995). Speen Sakar and G-137 are found to be resistant varieties to *D. isocrates*. Debano Bosco is also found less susceptible to the fruit borer. Dholka and Kashmiri local cultivars were moderately susceptible to infestation by *D. epijarbas*. Less borer incidence was recorded in Pomegranate variety Dholka (13.72%), Kashmiri local (14.62%) and Bedana (15.27%), and the highest mean incidence was recorded in variety Kandhari (25.97%) (Sajad et al., 2016).

7.8 Ber

The early ripening cultivars of ber are more prone to the attack of fruit fly *Carpomyia vesuviana* Costa. Late ripening cultivars like Sanaur-1, Chinese, Safeda Selected, Iliachi, Mirchia, ZB-3 and Umran have resisted to the fruit fly attack (Mann & Bindra, 1976). The ber cultivar Seb (3.75% fruit damage) is the most tolerant followed by Jogia (7.68%), Gola (16.60%) and Mundia-Murchera (15.60%) (Sachan, 1984). F1 of the cultivar Seb crossed with a local cultivar, Tikadi (resistance to *C. vesuviana)* showed 90% resistance but with poor fruit quality (Faroda, 1996) while backcrossing to Seb, the BC_1 line had 87–90% resistance with desirable fruit characters and high level of antibiosis. According to Singh and Vashishta (1984), Ilaichi is moderately resistant and Tikadi is resistant to fruit fly. Growers can adopt the potential fruit fly-resistant cultivars of ber (Tikadi, Katha and Illaichi cultivars) with minimal financial investment to obtain higher yields. The phenol, tannin and flavonoid contents had significant negative correlations with per cent fruit infestation. Flavinod and phenol content were responsible for 89 % of the total variation in the fruitfly infestation. Sharma et al. (1998) had reported that the ber cultivars Tikadi and Ilaichi were highly resistant (1–10%), and the cultivars Umran, Tas Bataso, Deshi Alwar, Kishmis, were resistant (11–20%) or moderately resistant (21–30%) to this pest. There was a positive correlation with fruit weight, pulp stone ratio, total soluble solids and total sugars, while negative correlation with acidity, vitamin C and total phenols. Ber lines B.S.75-3 and B.S.75-1 were identified as fruit fly-resistant lines in Haryana, India (Godhara et al., 2002a, 2002b).

Ber cultivars Banarsi Pewandi, Ajmeri, Gola Gurgaon and Jhajjar Selection have been found to be resistant to the fruit borer, *Meridarchis scyrodes* Meyrick. Sanaur-2, Umran, Kadaka, Sanaur-6, Gola, Chhuhara and Seb are found to be susceptible to the fruit borer. Illaichi could be declared as moderately resistant; Sanaur-2 (36.85%) suffered the highest infestation on par with Umran (Azam-Ali et al., 2006). The cultivars Ilaichi and Chuhara fruits recorded lowest pest infestation of 1 larva/fruit (Nandihalli et al., 1996). Growing of resistant cultivars like Gola Gurgaon, Jhajjar Special, Kadaka, Ajmeri, Banarsi Pewandi and Derakhi, Danda, Seb, Elachi, Jogia and Manuki (<10% damage) is useful to get less fruit borer damage.

The varieties Umran and Seb are attracted more for the egg laying of ber fruit weevil *Aubeus himalayanus* Voss. The mean damage is 23.63% in Gola and 43.28% in Seb, and higher fruit dropping is observed in Seb (73.48%) than the Gola (48.52%) (Karuppaiah et al., 2010). The damage in the cultivar Umran is up to 5–10% (Balikai, 1999). The ber cultivars such as Rothak Gola, Laddu Glory, Chuhara and Desi Alwar are found to be tolerant to bark eating caterpillar. Ber cultivar Cultivar Gola was found to be the most susceptible cultivar to the attack of lac insect *Kerria lacca* Kerr. and *K. sindica* followed by 'Kaithli' and 'Umran' (Lakra & Kher, 1990).

7.9 Custard Apple

Red Sitaphal and Pink Mammoth are found to be less susceptible to the fruit fly *Bactrocera dorsalis*. Custard apple hybrid Arka Sahan was found to be highly susceptible to the fruit fly attack. Cultivars, namely Arka Sahan, Red Sitaphal and Washington-98797, all belonging to species *Annona squamosa*, were free from infestation by *Helopeltis antonii* (Sign.). Ramphal of species *A. reticulata* (78.95%) and Cherimoya of *A. cherimola* (60.86%) were the severely affected varieties while Mammoth and Pink Mammoth of *A. squamosa* had moderate incidence of 37.63 and 21.62%, respectively. Balanagarí and Local Sitaphal, other two varieties of *A. Squamosa,* suffered the lowest fruit infestation (13–15%). Among the species, *A. reticulata* and *A. cherimoya* were most preferred by *H. antonii* compared to *A. squamosa* (Reddy, 2009).

7.10 Indian Goose Berry (Amla/Aonla)

Aonla varieties, namely NA-7 (43.70%) and Chakaiya (33.60%), are susceptible to the

fruit borer *Deudorix* (*Virachola) iisocrates* (Fab.). NA-10 and Chakaiya are less susceptible to the fruit borer attack. There is minimum incidence of aonla aphid

Schoutedonia (=*Cerciaphis*) *emblica* (Patel & Kulkarny) on Amla varieties Chakaiya and Francis. Aphid population was maximum (6.62/ twig) on variety Krishna Chakaiya and Francis (Bharpoda et al., 2009; Devi & Rajasekaran, 2011). Aonla variety NA-10 (Narendra-10) followed by Kanchan was found to be least preferred by gall forming insect *Betousa stylophora* Swinhoe, leaf roller *Garcillaria acidula* Forster, bark eating caterpillar *Indarbela quadrinotata* Walker in clonal seed orchards (CSO) (Meshram & Soni, 2011). According to Neelesh (2016), none of the variety was found free from the attack of cow bug *Oxyrhachts tarandus* (F.)] and shoot gall maker *B. stylophora*. However, on the basis of number of bug and gall and branch infestation due to cow bug and shoot gall maker, varieties Chakaiya, Kanchan and Krishna were found to be relatively less susceptible and varieties N. A.-10, N.A.-6, N.A.-7 and Local are to be relatively more susceptible. Kishore (2009) reported that the aonla variety N.A.-6 was found to be less susceptible recording less cowbug population, and level of infestation Chakaiya was found to be highly susceptible recording highest pest population and level of infestation. Variety N.A.-6 was found less susceptible to the aphids recording minimum population.

*7.11 Indian Cherry/Lasora (***Cordia myxa***)*

Three genotypes, namely AHCM-22-1, AHCM-25 and AHCM-34 are found to be resistant to the tingid bug *Dictyla cheriani* while AHCM-14, AHCM-30 and AHCM-31 are moderately resistant in lasora crop. Free amino acid had positive correlation with infestation, whereas phenols, tannin, alkaloid and flavonoid contents had significant negative correlation with infestation. Phenols and flavinoid contents explained (96.9 and 96.1%, respectively) of the total variation in bug infestation and bug density per leaf. The one principal component was extracted explaining cumulative variation of 90.07% in infestation. The flavonoid, alkaloid, tannins, phenols content, roughness and hairiness were the novel antibiosis and antixenotic characters found in Indian cherry accessions, which were resistant to *D. cheriani*. Thus reduction in tingid bug infestations on resistant accessions could be due to phenotypic (biophysical) characters and antibiosis (allelochemicals). Indian cherry accessions AHCM-22-1 (12.22%), AHCM-25 (14.17%) and AHCM-34 (17.57%) were classified as resistant to *D. cheriani* and these could be used in future breeding programme (Haldhar et al., 2019).

7.12 Jackfruit

Jack cultivars G-1, G-2, G-9 and ACC G-65 are less susceptible to the shoot and fruit borer *Diaphania caesalis.*

7.13 Bael

Bael varieties CISHB 2 and Pant Sujata are free from incidence of the fruit borer *Cryptophlebia ombrodelta* (Lower) (Singh, 2014).

7.14 Date Palm

Date palm varieties Mishrig and Gondaila were found to be most susceptible to date white scale *Parlatoria blanchardii* Targioni-Tozzetti whereas varieties Brakawi and Jaw were moderate, and Tamoda were found as tolerant to the scale insect (Mohamed, 1991).

7.15 Apple

Malling-Merton-9 rootstock was reported to be used in Himachal Pradesh owing to its inherent resistance to woolly apple aphid *Eriosoma lanigerum* (Hausmann). Some degree of resistance was observed in Golden Delicious to this pest in Kulu. Some of the tolerant/resistant varieties to woolly aphid are Stocks M-21, M 778, M 779, M-793, MM 104, MM 110, MM-111, MM 112, MM 113, MM 114, MM 115 and crab apple (*Malus baccata* var. *himalica*) (Chauhan, 1987). Rootstocks free from aphid infestation were M-9, M-16, MM-101 and MM 108-115 (Thakur & Gupta, 1998). Interestingly mechanism of resistance was also attempted. The resistance characteristics of the apple resistance genes (Er1, Er2 and Er3) to the woolly apple aphid were studied according to the performance measured on apple cultivars containing these resistance genes (Sandanayaka & Hale, 2003). The resistance characteristics of Northern Spy (Er1), Robusta 5 (Er2) and Aotea (Er3) were compared to the susceptible cultivar Royal Gala, by measuring the aphid settlement, development and survival rates correlated with electronically monitored probing behaviour. The results showed that Er1 and Er2 had a higher level of resistance with a significantly shorter period of phloem feeding, suggesting that the resistance factors were present in the phloem tissue. Phenological measurements indicated that the aphids showed poor settlement, development and survival on Er2. Er1 also showed low settlement and survival, although not as low as Er2.

The resistant varieties to San Jose Scale, *Quadraspidiotus perniciosus* (Comstock) (below 3%) include Benoni, Green Sweet, Pecks Pleasant, Jonathan, Buckingham, Winter Banana, Rymer, Cox's Orange, Pippin, summer Golden Pippin, Tompkins, Red Astrachan, King David, Cortlant and Mcintosh. Heavy infestation of *Q. perniciosus* was recorded on Royal Delicious, Golden Delicious and Early Shanbury.

In Budapest, Hungary, high resistance was in traditional apple cultivar Sóvári to the green apple aphid *Aphis pomi*; and High resistance to rosy leaf-curling aphid (*Dysaphis devecta*) in traditional apple cultivars Batul & Pónyik), high resistance and/or moderate resistance for spotted tentiform leaf miner (*Phyllonorycter blancardella* in all old cultivars) and for codling moth *Cydia pomonella* in Starkrimson, Batul and Pónyik. Golden Delicious and Starkrimson are moderately resistant to *Eriosoma lanigerum* while Batul, Pónyik and Sóvári are highly resistant to *E. lanigerum.* Old apple cultivars sustained in their original regions could be a significant source of genes for apple breeding programmes (Bálint et al., 2013).

7.16 Brinjal

Pusa Purple Long, Pusa Purple Cluster, Junagadh Long, Pusa Krante were reported to be resistant to the fruit borer. Varieties such as Pusa Purple Long, Pusa Purple Cluster, Pusa Purple Round, H-128, H-129, Aushey, H- 165, Shyamla, Arka Kesav, Arka Kusmakar, Punjab Barsati, Kalyanpur-2 and Gote-2 have also been reported to be tolerant to brinjal fruit borer. Brinjal cultivars, namely PPC-2, Aushey, H165, Thorn, Pendy, Punjab Barsati, Pusa Purple Cluster, Arka Kusmak, Doli-5, H 407, HLB-12, JC-1, GBH-1, JC-2, Pant Brinjal Hybrid 1 and PPI 1 are found less susceptible to brinjal shoot and fruit borer. In Himachal Pradesh, the brinjal cultivar SM- 202 was found highly resistant and SM 17-4 and PBR 129-5 were fairly resistant to *L. orbanalis.* One accession, namely IC136347 was found to be resistant which had the lowest fruit damage of 5.62% as against 74.33% fruit damage in highly susceptible genotype (IC136564) (Ramesh et al., 2015). Brinjal genotypes IC-090050 and IC-090199 have shown lowest infestation fruit and shoot borer while Irapaduguda-W showed highest fruit damage. Based on per cent fruit damage, twelve genotypes, namely IC090050, IC-090199, EC-169084, EC-316742, EC-316309, IC-089955, EC-316273, Bhagyamathi, IC090674, EC-169089, IC-110949 and IC-111392 were found to be moderately resistant to borer damage. The lowest per cent fruit damage was observed in the genotype IC-090050 (10.26%) followed by IC-090199 (12.75%), EC-169084 (13.03%) and the lowest per cent shoot damage was observed in the genotype IC-090050 (4.11%) followed by IC-090199 (4.21%) and EC-169084 (4.32%) (Leela et al., 2018). In Kerala, Hybrids Wardha local × Palakurthi local, Swetha × Vellayani local and Neelima recorded minimum infestation of shoot and fruit borer during both kharif and summer seasons (Kavishetti & Lekha Rani, 2018). In Punjab, minimum infestation in fruits was found in genotype IGB-92 (20.83%) while maximum infestation in fruits was recorded in IGB-89 (79.30%). At Akola (Maharashtra), the genotypes Arka Mahima, Arka Sanjivani and wild species *Solanum incanum* have exhibited total resistance to *L. orbonalis*. Brinjal cultivars Pusa Purple cluster, Pusa Kranti, Pusa purple long, Chu Chu, Black Beauty are tolerant to the fruit borer while Kalia F1 hybrid, Ravaiya Hybrid, Aruna are moderately tolerant to the fruit borer. Varieties SM 17-4, PBr 129-5 Punjab Barsati, ARV 2-C, Pusa Purple Round, Punjab Neelam, Kalyanpur-2, Punjab Chamkila, Gote-2, PBR-91, GB-1, GB-6 are resistant/tolerant to shoot and fruit borer *L. orbonalis*, aphids, jassids, thrips and whitefly at IIVR Varanasi. Accessions, S-34 and S-258 were reported resistant to both the borers and leafhopper. Non-preference and antibiosis are the major mechanisms of resistance to shoot and fruit borer *Leucinodes orbonalis* Guenee. The resistance to shoot and fruit borer can be attributed to fruit characters like firmly arranged seeds in the mesocarp and skin thickness (Mishra et al., 1988). In the long fruited varieties, thick fruit skin, narrow pericarp, oblong or extra long fruits with green or light purple colour and closely packed vascular bundles in the pulp were proposed as possible causes of resistance. Spherical fruits are more preferred than long and narrow fruits (Mote, 1981). Resistance to fruit borer might be due to smooth surface of fruit and possibly due to fruit colour and leaf. The tight and semi tight fruit calyx was also important to prevent the initial borer penetration into fruits. Similarly, hard fruit rind, compact sclerenchymous shoots and compact seed in mesocarp were recorded as attributes of resistance varieties. In addition to fruit characters, the hairs on leaves were considered as criteria for ovipositional preference as fewer eggs were laid on the densely pubescent leaves which also hindered the movement of newly hatched larva. Biochemical factors like low amounts of N, K and Zn and high amounts of P, Ca, Mg, Fe, Mn, Cu, total carbohydrates and phenols in leaves and fruits were found to be resistant factors. The varietal variation in terms of free reducing sugars, ascorbic acid, minerals and high ash: silica ratio, contributed for resistance through decrease in ovipositional preference, growth and survival of the insect. Greater amount of crude fibre, fat, total sugars, serine, phenols and alcohol and less lysine were noted as susceptibility factors. Similarly, total phenols, polyphenol oxidase activity and glycoalkloid content also had negative effect on infestation. Dhankar (1988) achieved resistance in HE-12, a progeny of cross between resistant PPC-2 and commercial cultivar possessing good quality fruits coupled with resistance. Punjab Agricultural University has released 'Punjab Barsati' variety possessing moderate resistance to fruit borer. *Solanum gilo* was found to be most resistant to borer and crossable with *S. melongena.* A cross with Aruna × CO_2 cross was found to be tolerant to the fruit borer. The varieties reported as resistant in one place have been found to be susceptible at other places. For example, Pusa Purple Long and Pusa Purple Cluster though reported resistant in North India was found to be highly susceptible to fruit borer damage at Bangalore (>30%). Punjab Chamkila is also reported found to be resistant to the fruit borer in 1979. CO1 reported as resistant at Rahuri but found to be susceptible at Coimbatore. In Nauni Solan, Himachal Pradesh, the per cent fruit damage varied from 6.66 to 46.63% recording the minimum fruit infestation in 'DS-407' and Ganesh while the maximum fruit infestation was observed in Prapti which was at par with Pusa Purple Long and Neelkanth. The total phenol content was the maximum in DS-407 cultivar followed by Ganesh, Brinjal Long (F1), Long Green, Pusa Purple Cluster, Pusa Purple Long and Neelkanth, while it was minimum on Prapti cultivar (Sharma et al., 2017).

In Bangladesh, the brinjal varieties Jumki-1 and Jumki-2 were highly resistant (HR) against brinjal shoot and fruit borer (BSFB), *Leucinodes orbonalis* Guen. Islampuri-3, BL-34 and Muktakeshi were fairly resistant (FR), Singnath long and

Singnath-4 were tolerant to brinjal shoot and fruit borer (Mannan et al., 2003). In Mymensingh, Bangladesh, in case of shoot infestation, the varieties/lines Katabegun WS and Marich begun S were found to be tolerant while the varieties/lines Amjuri, Borka, Dharola, Deembegun, ISD 006, Kajla, Khatkhatia BAU, Laffa S, Singnath, Thamba and Uttara were found to be moderately tolerant. In case of fruit infestation, the varieties/lines Thamba (3.07% damage) and Katabegun WS were found to be tolerant. The variations in the level of infestation could be explained due to the presence of thin stem, more branches, lower third leaf length and width, more spines, rough leaf surface area, heavily lignified thick cuticle, broad and thick hypodermis, closely packed vascular bundle and small pith area which might have contributed for lower infestation and vice versa in case of higher infestation (Ahmad et al., 2008). Some of the wild *Solanum* species such as *anomalum*, *gilo*, *incanum*, *indicum*, *integriifolium*, *khasianum*, *sisymbriifolium* and *xanthocarpum*. were reported to possess high resistance to EFSB. However, the resistance in these wild species should carefully be evaluated and confirmed before attempting to transfer the resistance to cultivated eggplant. In addition, the crossability and hybridization of cultivated eggplant with its wild relatives generally pose difficulties due to breeding incompatibilities and in several cases, crosses were only successful if in vitro embryo rescue was employed. The attempts to transfer the resistance from the wild species to the cultivated *Solanum melongena* were not successful. At AVRDC, Taiwan, an eggplant accession (EG058) that consistently suffered less damage to shoot and fruits is considered as an important source of resistance. Turbo, a commercial F1 hybrid grown in Thailand, also exhibited significant resistance to EFSB in Thailand and Taiwan. In addition, two Bangladesh accessions, namely BL009 and ISD006, possess appreciable levels of resistance in Taiwan. Further research on these resistant sources indicated neither the trichomes nor the antibiosis as the basis of resistance. Instead, the anatomical characters may probably contribute to the resistance as explained by Mishra et al. (1988) in some resistant accessions, which needs to be confirmed in further studies. Currently, genetically transformed brinjal resistant to brinjal shoot and fruit borer is being tested in many places in India.

Brinjal Varieties such as Arka Shirish, Hissar Selection 14 and Shankar Vijay are found to be tolerant to *Henosepilachna vigintioctopunctata* (Fab.). Pusa Purple Round and Apple Green Flesh were reported to have moderate resistance to this pest. *Solanum mammosum* and *Solanum viarum* are less susceptible to *H. vigintioctopunctata.* Density, length and position of hairs were the factors attributed for resistance in *S. mammosum*. The resistant species had multicellular, unbranched, non-glandular hairs, whereas the susceptible *S. melongena* had stellar hairs. The surface cuticular components of wild accessions have suppressed feeding of beetles and reduced their body weight. Trichome density and trichome length were used to establish the antixenosis mechanism in resistant/moderately resistant brinjal varieties besides orthodihydroxy phenol content.

The genotypes EC316309 and IC-111448 are found resistant to leaf hopper *Amrasca biguttula biguttula* Ishida. Resistance to leafhopper was contributed by long and dense hairs present on the leaves. Brinjal cultivars KB 9, Pusa Purple Long, KP 10, L 13 and BB1 are reported as tolerant to the leaf hopper (Gaikwad et al., 1991). IC-090050 with 9.90% hopper burn intensity was considered as highly resistant to the leaf hopper which recorded 1.41 and 2.74 times lesser than the cultivars Bhagyamathi and Dommeru local respectively in per cent jassid infestation. Chaklasi Doli, Doli 5 and Pusa Purple are tolerant to the leaf hopper *A. biguttula biguttula.*

Brinjal cultivars PKM-1, KKM-1, Pootheri Local and Soorakundu Local are found to be less susceptible to *Bemisia tabaci* Gennadius (Gaikwad et al., 1991). Entries EP 55, EP 78 and EP 52 are reported to resistant to *B. tabaci* (Shunmugaraj, 1995). The reasons attributed to the less susceptibility of above entries to sucking pests of brinjal are due to the poor quality of host plants with purple coloured leaves, as reported by Kalra (2004). The biochemical factors, namely, reducing and non-reducing sugars, solanine and phenols were found to contribute to antibiosis mechanism of resistance against whitefly which could be measured by considering the ratio between 4th instar nymphs to adults in green house and by multiple tests. Pusa Purple is tolerant to *B. tabaci.*

Plant height and total sugars had positive correlation with incidence of *Aphis gossypii.*

Sugars at low concentration act as phagostimulants but are toxic at higher concentration. High glucose and fructose level and low sucrose and maltose were present in resistant varieties of bhendi while vice versa in the susceptible varieties. High organic acid, namely malic and oxalic acid content found in highly susceptible varieties acted as feeding stimulant. The resistant factors include low nitrogen, high sugar: nitrogen ratio, low free amino acid content and total phenol while high content of minerals like phosphorous, potassium, calcium and magnesium favoured aphid infestation. Annamalai Brinjal variety is found less susceptible to the *Aphis gossypii.* In assessing the resistance or susceptibility of a variety, the population level of aphid was considered as main criteria.

Five aubergine lines/varieties were screened for resistance to brinjal mealybug *Coccidohystrix insolita*. An accession PI-381272-2 was found to be resistant to *C. insolita.*

7.17 Tomato

At Varanasi, the lowest fruit borer population *Helicoverpa armigera* was observed on IIVR Sel-1, JKTH-3064 and Mani Khamenu at 0.86, 0.86 and 0.88 larvae/plant, respectively. Tomato varieties, namely Arka Vikash, Pusa Gaurav, Pusa Early Dwarf, Punjab Keshri, Punjab Chhuhara, Pant Bahar, Azad, Avinash-2, Hemsona, Krishna, Sartaj are tolerant to the fruit borer *Helicoverpa armigera*. Cultivars, namely T 27 and T 32 are also found less susceptible than the fruit borer. At Anand, Tomato 3 (AT 3) was found resistant to *Helicoverpa armigera.* Among the various morphological characters, number of branches/plant as well as number of trichomes/cm^2 on leaf and calyx showed significant positive relationships. Similarly, significant positive association was observed between number of trichomes/cm^2 of corolla and fruit damage.

Whitefly population *Bemisia tabaci* was lowest on IIVR Sel-1, ZTH 1039, TH 017, TH 317, Rishi 7, NTH 960 and JKTH 3064 (0.70 flies/10 cm plant twig). *Lycopersicon hirsutum f. glabaratum, Solanum pennellii,* Avinash-1, Avinash-2, Mruthyunjaya-1, Mruthyunjaya-2 and Mruthyunjaya-3 are less susceptible to the whitefly *B. tabaci.*

The lowest leaf miner population was observed on Pusa Ruby, Jawahar Acc 99 and IIVR Sel-1 (5.93, 7.82 and 9.46% mean leaf infestation *Liriomyza trifolii*, respectively). The tomato pinworm *Tuta absoluta* (Meyrick) is one of the major pests attacking the commercial tomato. The antixenosis, including resilience as an example of this mechanism, is given by a set of features, colour, odour, taste of the plant, which cultivar is less preferred for the herbivore to the process of oviposition and food. Mechanisms may be physical (presence of trichomes, waxy surfaces, tissue hardness) or chemicals as repellent (terpenes, oils) or dissuasive (alkaloids, flavonoids, lectonas, phenols, tannins). The inheritance of antixenosis resistance of genotype BGH1497 is ruled by a gene of greater effect and polygenes in epistatic interactions, with a phenotypic proportion of 13:3 between susceptible and resistant genotypes, respectively (Antônio et al., 2011).

The *Lycopersicon hirsutum* accession LA 1777 and the *L. hirsutum* f. *glabratum* accession LA 407 were found to be highly resistant to all four insect pests *Spodoptera littoralis* (Boisd.), *Plusia chalcites* (Esp.), *Heliothis armigera* (Hbn.), and *Phthorimaea operculella* (Zeu.). The possible mechanisms of resistance, i.e. the physical entrapment of larvae and the toxic action of phytochemicals in the various accessions, are discussed (Juvik et al., 1982)

7.18 Okra

At Coimbatore, the most infested or preferred genotypes by *Amrasca biguttula biguttula* were AE 10, Pusa Sawani and AE 15 with pooled damage grade index being 3.23, 3.15 and 3.18, respectively. The least mean numbers of leafhopper and damage grade index were observed with the genotypes AE 65 and AE 23, with differences among the genotypes evaluated being statistically significant. Okra cultivar A.E.22 was rated as highly resistant to the leaf hopper *Amrasca biguttula biguttula.* Resistance in okra varieties to leafhopper was governed by non-preference and antibiosis mechanisms. The variety A.E. 22 was less preferred for oviposition and feeding compared to the susceptible variety, Pusa Sawani. Antixenosis (hairs in the midrib and lamina) and antibiosis (imbalance in the chemical composition) constituted the resistance mechanism in the leafhopper resistant line AE 22. In addition, the rate of multiplication of the insects on resistant variety was low compared to the susceptible variety. High moisture content of leaves has facilitated easy penetration of stylets by leafhopper inflicting hopper burn. Accumulation of total nitrogen in susceptible varieties was supposed to weaken the plant cells for easy stylet penetration and ovipositor. Relatively high quantity of total and orthohydroxy phenols was present in resistant bhendi varieties besides calcium and magnesium content while potassium and phosphorous were high in susceptible varieties (Uthamasamy & Subramaniam, 1980). The resistant variety had five times less eggs on its leaves as compared to the susceptible line. Only 42.9% of the nymphs were able to complete the life cycle on AE-22 as compared to 87.6% in the susceptible cultivar Pusa sawani. The plant characters like plant height and stem thickness were positively correlated with leafhopper infestation. The resistant varieties had more number of long hairs on the midrib and lamina which interfere with movement and oviposition. The leaf hoppers preferred low sugar and high nitrogen content which were observed in susceptible varieties as against excessive carbohydrate and low nitrogen content in resistant variety A.E.30. There was positive correlation of leafhopper incidence with plant height and stem thickness (Uthamasamy et al., 1973). It was observed that the okra varieties having more and longer hairs on the mid-rib and leaf lamina were resistant to leafhopper, rather than those having more hair density. Jassid-resistant varieties had higher total sugar, non-reducing sugars, tannins and silica in the leaves (Singh & Agarwal, 1988). Okra lines, namely IC-7194, IC-13999 New Selection and Punjab Padmini are found tolerant to the leaf hopper. According to Srinivasa and Sugeetha (2001), Okra cultivar KS 410 was least preferred while Parbhani Kranti, Line 199 and GOH 1 were the most preferred by hoppers during the kharif season. The varieties VRO 3 and kasha Pragti were found to be resistant to jassid infestation (Raut et al., 2013). During rainy season, the least leaf hopper population was recorded with variety V3 (Gujarat Okra-2) 10.13 leaf hopper/3 leaves at 30 DAS which was inferior to the varieties V7 (Parbhani Kranti), V6 (Gujarat Okra- 1), V4 (Arka Abhay) and V5 (Perkins Long Green), respectively, whereas least leaf hopper population was recorded in variety V3 (Gujarat Okra-2) 5.90 leaf hopper/3 leaves during summer season which was at par with variety V1 (Arka Anamika), respectively (Pawar & Varma, 2014). At Rahuri (Maharashtra), White Velvet, Clemson Spineless, Early Long Green, AE 27 and IC 75 shown less susceptibility to the hoppers (Teli & Dalaya, 1981). At Hisar (Haryana), HB-45, HB-39 and HB-43 are found to be resistant to the leaf hopper (Kishore et al., 1983). Both Arka Anamika and Parbhani Kranti have shown moderate resistance against aphids, jassids and whitefly (Ghosh et al., 1999). Okra cultivar KS 410 has registered the lowest number of hoppers, while GOH- 1 was the most preferred by the hoppers (Srinivasa & Sugeetha, 2001). Minimum hopper population (2.15/leaf) was recorded on Shreya which was at par with Viraj, Swati and Kashi pargati (Dawar, 2017). Wild species *Abelmoschus manihot, A. moschatus* (IW 1502) and *A. tuberculatus* (IW 495) were identified as resistant lines to the leaf hopper.

The okra variety Pusa Sawani showed moderate resistance to aphid damage. Presence of high glucose and fructose level and low sucrose and maltose was in resistant varieties of bhendi while vice versa in the susceptible varieties. High organic acid, namely malic and oxalic acid content found in highly susceptible varieties acted as feeding stimulant. The resistant factors include low nitrogen, high sugar: nitrogen ratio, low free amino acid content and total phenol while high content of minerals like phosphorous, potassium, calcium and magnesium favoured aphid infestation.

Okra varieties less susceptible to fruit borer *Earias* spp. had more lignified tissues with compact vascular bundles and narrow shoot pith. Significant negative correlation was observed between silica content and degree of shoot damage. Borer preferred less the dark green coloured fruits. They also confirmed that the varieties having medium long, less smooth, more trichomes and minimum seeded fruits were less infested. The biochemical characters such as total sugar and crude protein were positively correlated with fruit borer infestation, whereas total phenols had negative correlation.

The minimum infestation on shoots of okra was observed on Arka Anamika (13.1%) and the maximum was on Parbhani Kranti (27.7%) (Sharma & Jat, 2009). There was lowest fruit infestation in EMS-81 followed by Punjab padding, VRO 3, Bhendi Vaphy, IIVR 11, IIVR 10, Kashi pragti, EC 35638, IC 282273 and IC 282272. The per cent shoot infest station by *E. vittella* was minimum in okra variety Bhendi vaphy (10.00) and was found to be resistant. Okra varieties, namely VRO-3, EMS-8-1 and IIVR-11 (8–10%) had shown significantly lower infestation. These were graded as moderately resistant varieties (Wargantiwar et al., 2013). Some of the genotypes of okra namely Bhendi Red-1, Bhendi Red-11 and Red Wonder were reported relatively tolerant to shoot and fruit borer. Late flowering varieties of okra irrespective of hairiness were reported susceptible to fruit borer. At Rahuri (Maharashtra), minimum infestation of fruits was observed in cultivar Wonderful Pink (11.68%) while the variety Pusa Sawani was highly susceptible (42.39% infested fruits). Wild species, *A. mannihot* and *H. tetraphyllus*, were respectively immune and highly resistant to the attack of pest (Raut & Sonone, 1979). Among 72 genotypes of okra screened against *Earias* spp. under field conditions at Hisar (Haryana), Narnaul Special, 6(2), Harbhajan, Clemson Spineless, White Snow and Sel Round revealed less than 10% infestation while the remaining genotypes exhibited 10–50% infestation (Kashyap & Verma, 1983). At Dapoli (Maharashtra), cultivars, namely A.E.-75 was tolerant. Resistance to fruit infestation was correlated with increased fruit hair density (Madav & Dumbre, 1985). Singh et al. (1986) found P-8 and Ludhiana Selection-2 genotypes as resistant to okra shoot and fruit borer. At Hisar (Haryana), number of infested fruits per plant was lowest in Long Green Smooth (14.4%). At Jachh (Himachal Pradesh), maximum incidence was observed on P-8 followed by Harbhajan, Parbhani Kranti, Punjab 7 and Pusa Sawani (Raj et al., 1993). At Jabalpur (Madhya Pradesh), varieties AROH 2 and Komal hybrid F1 showed 21 lowest shoot damage (4 and 5%, respectively) but were poor yielders (27.80 and 19.70 qha^{-1}, respectively). Variety Ankur 35 and Parbhani Kranti, however, registered significantly higher shoot damage (7.5 and 8.0%) but produced higher healthy fruit yields of 72.81 and 62.06 qha^{-1}, respectively (Shukla et al., 1998). At Bangalore (Karnataka), none of the cultivars was completely free from infestation, the most susceptible variety being GOH-1 (Srinivasa & Sugeetha, 2001). At Mohanpur (West Bengal), fruit damage was lowest in Hybrid No. 8 followed by Jaya, OH-1, Arka Abhoy, Harsha, Vijaya, Arka Anamika and Soumya (Naresh et al., 2003). At Faizabad (Uttar Pradesh), KS-410, A-4 and NDO-10 showed lower damage on shoots as well as fruits. At Central Research farm, Gayeshpur (West Bengal), only one variety showed tolerant, ten moderately resistance and four highly resistance (Konsam et al. (2015). Minimum shoot infestation (1.41%) was recorded in Jaya which was at par with Shreya (Dawar, 2017).

Earias vitella and *E. insulana* are the two borer species affecting okra. The ovipositional preference was found to be influenced by the density of hair on the fruits (Teli & Dalaya, 1981). AE-22, AE-52, AE-79, AE-47, Wonderful Pink, AE-22, AE-57, AE-52, AE-79, AE-3, AE-79, AE-72, AE-57, AE-3 Wonderful pink, Pusa Sawani, Long Green, Indo American Hybrid, Velvet, BC2F5 advanced generation of Pusa, Reshmi X Ghana, Ludhiana, Sel-2, EMS-8-1, EMS-8, IIHR 4, EMS-8 and Ludhiana Selection-2, MR 9-2,MR 9, MR 9-1, PB 57, Siswal-1, Siswal-2, PMS 8, Parkins long green, PKX 9275 and Karnual special are less susceptible to the fruit borers. Okra variety N-6, Arka Anamika and Selection-2 are less susceptible to the shoot and fruit borer *Earias* spp recording below 5% damage as compared to the susceptible check variety Champion (15.10%) (Sharma et al., 2007).

At Bangalore *E. vitella, E. insulana* and *H. armigera* constituted the borer complex on okra. Five as moderately resistant NOH-303, SOH-1016, OH-3, OH-5, Evergreen (P-43) and one hybrid Saloni (4.39% fruit infestation) reacted as resistant with higher standard heterosis for fruit yield over commercial check. The hybrid Saloni (216.74 g/plant) which registered better yield with resistance to fruit borer can be recommended for cultivation. Pusa Sawani also showed considerable degree of resistance with non-preference to oviposition and larval feeding Koujalagi et al. (2009). Okra cultivar Arka Abhay, Arka Anamika, HRB-9-2, GOH-I, GO-2 and P-7 were found less susceptible to *Helicoverpa armigera* and showed good yield potential (Parmar et al., 2007).

Okra variety Subpar is known to harbour the minimum of 3.17 whiteflies/leaf (*Bemesiatabaci)*, while Noori-786 has harboured the maximum of 4.46 white flies (Mastoi et al., 2013). In respect of whitefly infestation the lowest infestation were found in varieties VRO 3 and VRO 4, Bhendi vaphy, llVR 11, VRO 3 and EMSB 1 (Raut et al., 2013). The minimum number of white flies was recorded with variety V3 (Gujarat Okra-2) (Pawar & Varma, 2014). Both Arka Anamika and Parbhani Kranti have shown moderate resistance to the whiteflies (Ghosh et al., 1999). Minimum number of whiteflies (2.34%) was recorded in Swati (Dawar, 2017). Variety Shreya found less susceptible to the whitefly and shoot and fruit borer (Dawar, 2017).

The variety Pusa Sawani showed moderate resistance to *Aphis gossypii*. In Orissa, Okra Selection 2-2 was the least susceptible to *Aphis gossypii* (because of its thick leaves) and Selection-1 was the most susceptible (Roy, 1990). It was found that both Arka Anamika and Parbhani Kranti showed moderate resistance against aphids (Ghosh et al., 1999). Okra cultivars Arka Abhay and GOH- 1 recorded low number of red cotton bugs (*Dysdercuscingulatus)* while Parbhani Kranti and KS 410 recorded high bug population (Srinivasa & Sugeetha, 2001).

7.19 Onion

Many sweet Spanish onion varieties are found resistant to *Thrips tabaci*. Resistant genotypes were also reported from Brazil, Iran and Pakistan. In India, commercial varieties N-2-4-1 and Pusa Ratnar are found resistant to *T. tabaci* in Punjab (Brar et al., 1993). The variety B-780 is moderately resistant to thrips. In Bihar, Pusa Red and N-53 are found less susceptible to thrips while Patna Red and Arka Niketan are highly susceptible (Sinha et al., 1993). Onion cultivars PBR-2, PBR-6, Arka Niketan, Pusa Ratnar, PBR-4, PBR-5 and PBR-6 are tolerant to *Thrips tabaci.* TNAU hybrids CO2, CO3 and CO4 are found less susceptible to onion thrips. Some of the wild species like *Allium gallanthum* and *A. ampeloprasam* and some genotypes of *A. fistulosum* are found highly resistant to thrips. However, incompatibility in breeding these species with cultivated ones needs to be worked out for a resistance breeding programme.

7.20 Snake Gourd

Early maturing varieties are less affected by fruit flies than later ones. Less damage by semilooper *Anadevidia peponis* is observed in cultivars Kulithalai Local Short, Kumbakonam local short, Kumbakonam local long, Madurai local long and PKM-1 types (43–49.70 larvae per vine). While the genotypes, *namely* IC418478, IC411877, IC411878 and IC410160 recorded a higher semilooper infestation (91.0, 84.7, 77.0 and 72.0 larvae per vine respectively) and the yields recorded from these genotypes were significantly lower than the local types (Devi & Jayaraj, 2017).

7.21 Cucumber

The genotypes IC-350933and IC-373479 were found to be highly resistant; IC-351005, IC-351088, IC-258131 and DKS 2011/01 were found to be resistant to fruit fly. The phenols ($r = -0.90$), tannin ($r = -0.89$), total alkaloids ($r = -0.80$) and flavonoid ($r = -0.96$) contents had significant negative correlations with per cent fruit fly infestation. Flavinoid and tannin contents explained (91.2 and 92.1%, respectively) of the total variation in fruit fly infestation and in larval density per fruit. Based on the Kaiser Normalization method, two principal components (PCs) were extracted explaining the cumulative variation of 88.2% in melon fruit fly infestation. PC1 explained 71.6% of the variation while PC2 explained 16.6% of the variation.

7.22 Pumpkin

Pumpkin cultivar Arka Suryamukhi is found tolerant to the fruit fly *Bactocera cucurbitae.* Pumpkin germplasm lines 596-2 and 613 have shown resistance to red pumpkin beetle *Aulocophora foveicollis* on the basis of having low cucurbitacin content (Pal et al., 1978). The Pumpkin LC 28 is found highly resistant to the pumpkin beetle.

7.23 Bitter Gourd

Bitter gourd cultivar Hissar-II is found tolerant to the fruit fly B. *cucurbitae.* Hissar-II is tolerant to *B. Cucurbitae.*

7.24 Bottle Gourd

Bottle gourd cultivar NB 28 was found highly resistant to *Raphidopalpa foveicollis* (Nath & Thakur, 1965). The bottle gourd germplasm VRBG-91 is reported as resistant to *R. foveicollis* in Uttar Pradesh (Satpathy et al., 2002). Bottle gourd cultivars Arka Bahar, Dharwad, Narendra Rashmi, Wardan, NDBGH-4 and Narendra Madhuri (1.20–1.62 beetles/plant) are found less susceptible to the beetle pest. These varieties also registered high potential in producing the fruit yield and less avoidable loss due to red pumpkin beetle (Shrikrushna, 2012). *Lagenaria vulgaris* cultivar S 28 is highly tolerant to *R. foveicollis* (Vashistha & Choudhury, 1974). Bottle gourd cultivars, DIK round green, SW sweet yellow are tolerant to *A. foveicollis* (Saljoqi & Khan, 2007).

7.25 7.25 Sponge Gourd

The sponge gourd lines NS 9, NS 10, NS 11, NS 12, NS 14, NS 16 and NS 17 are highly resistant to the pumpkin beetle (Nath & Thakur, 1965). At Peshawar valley, two sponge gourd (*Luffa scutannils*) cultivars, RKS-6, RKS-7 are found resistant to *R. foveicollis* (Saljoqi & Khan, 2007). Sponge gourd cultivar Swarna Prabha is tolerant to the leaf miner.

7.26 Ridge Gourd

Ridge gourd cultivars including the Pusa Chikni and Pusa Nasdar and the ridge gourd lines NR 1, NR 2, NR 4, NR 5 and NR 7 were highly resistant to the pumpkin beetle *R. foveicollis* (Nath & Thakur, 1965).

7.27 Musk Melon

Musk melon cultivars MM 102-1, IHR-19, 22, 32, 40 and Karda are tolerant to the fruit fly. Casaba and PI 70683 were highly tolerant to *R. foveicollis* (Vashistha & Choudhury, 1974). Punjab Hybrid-1 is highly tolerant to *R. foveicollis*. Muskmelon cultivars, namely AHMM/BR-1, RM-50 and AHMM/BR-8 were the most resistant; MHY-5, Durgapura Madhu and Pusa Sarabati were moderately resistant genotypes to fruit fly in arid region. Total sugar, reducing sugar, non-reducing sugar and pH were lowest in resistant and highest in susceptible genotypes whereas tannins, phenols, alkaloids and flavinoid contents were highest in resistant and lowest in susceptible genotypes. Total alkaloid and pH contents explained 97.96% of the total variation in fruit fly infestation and 92.83% of the total variation in larval density per fruit due to alkaloids and total sugar contents.

7.28 Water Melon

Cultivars S 72, S 98 and Afghan were highly resistant to *A. foveicollis* (Vashistha & Choudhury, 1974). The genotypes Asahi Yamato, AHW/BR-16 and Thar Manak were found to be resistant to fruit fly infestation. Free amino acid content was lowest in the resistant 'Asahi Yamato' and highest in the susceptible 'BSM-1', whereas the contents of phenols, tannins, total alkaloids and flavonoids were highest in resistant and lowest in susceptible genotypes. Flavonoid and total alkaloid contents explained 88.4 and 92.0%, respectively, of the total variation in fruit fly infestation and in larval density per fruit.

7.29 Spine Gourd (Momordica diotica)

At Ambikapur (MP), the genotype RMF-17 recorded least damage (4.84%) by Margaronia while other genotypes RMF-1, RMF-27, RMF-37, RMF-5-P-4, and RMF-7-P-1 recorded 10–19% damage by *Margaronia indica.* RMF-17 also recorded the least fruit damage of 1.06% by *H. armigera* (Shaw et al., 1998)

7.30 Other Cucucrbits

Squash cultivar Punjab Chappan Kaddu- 1 is tolerant to the pumpkin beetle *A. foveicollis.* Round gourd variety Arka Tinda is tolerant to *B. cucurbitae.* French bean varieties Swarna Priya and Swarna Lata are tolerant to the leaf miner.

7.31 Chillies

Based on the observation on per cent leaf curl index, four genotypes were categorized as moderately resistant (BK-16, BK-26, BK-31, BK-47, BK-48) to chilli thrips *Scirtothrips dorsalis* Hood (Jayasree et al., 2018). The cuticle which was hard in nature was quite resistant to sucking pests. The plant height has positive association with thrips damage, the increase in plant height results in more young flesh which attracts the thrips population. Further, hybrid Tejaswini performed better with respect to yield and showed resistance to murda complex due to its rough leaf and higher phenol with moderate potassium content might have repelled the thrips population and resulted less thrips infestation. Similarly, Guntur-4, Pusa Jwala and hybrid Tejaswini recorded less population of mites, thrips and the lowest leaf curl index, and proved tolerant to pest damage which has thick leaf, low sugar content, high chlorophyll and phenol content might have favoured the tolerance. Any leaf character that interferes with the thrips life-cycle is a potential resistance factor which may contribute to the mechanism of defence against thrips. Chillie cultivars Pusa Jwala and Phule Jyoti are found to be tolerant to chilli thrips. NT46A (T), Punjab Lal, Pusa Jwala, Phule Jyoti, Arka Meghana and Pant C 1 are found less susceptible to chilli thrips. The genotype GCh 3 was found resistant against thrips, while eleven other genotypes were grouped under susceptible category (Rajput et al., 2017).

Capsicum Accessions CA9, CA28, CA29, ACC 05, ACC 16, ACC18 and ACC 29 were found to be less preferred by the whitefly- *Bemisia tabaci* whereas accessions CA17, CA30, CA187, CA189, CA247 and ACC08 were the most preferred one. The number of eggs laid and the percentage of nymphal and adult emergence were low on resistant accessions, namely CA9, CA28, CA29, ACC 05, ACC 16, ACC18 and ACC 29. In population build-up study, significantly lower numbers of progeny were observed on accessions CA9, CA28 and ACC05. Conversely, the number of progeny produced by F2 was significantly greater on ACC 08. Additional experiment indicated that tolerance category of resistance was present in the accessions, namely K2, CA 247, CA 189 and CA 187 for *B. tabaci* feeding. The accessions CA 9, CA28 and ACC 05 have displayed strong antixenotic and antibiotic effect against whitefly*, Bemisia tabaci* (Niranjanadevi et al., 2018). Capsicum cultivars, namely California Wonder, Yolo Wonder and Koral are found less susceptible to the whiteflies. Pusa Jwala and Phule Jyoti are less susceptible to thrips on capsicum.

In Gujarat, genotypes of chilli, GCh 3 and GCh 2 were resistant to *Aphis gossypii* Glover, yellow mite *(Polyphagotarsonemus latus* Banks, whitefly *Bemisia tabcai* Genn. and leafhopper *Amrasca biguttula biguttula* Ishida. The genotype GCh 3 was found resistant against thrips while the genotype GCh 3 and GCh 1 showed resistance against the fruit borer *H.* Hubner (Rajput et al., 2017).

7.32 Cowpea

Varieties namely TVu 123 and Vita 3 are less susceptible to the leaf hopper *Empoasca kerri* Pruthi. Cowpea cultivars TVu 310, TVu 801, TVu 408 and 3000 are less susceptible to *Aphis craccivora* Koch, while TVu 946,TVu 1896,AG,H51-1 and 2AK less susceptible to the pod borers *Etiella zinckenella, Maruca vitrata* and *Lampides boeticus.* Pigeon pea ICPL 88034 and MPG 679 show low Maruca damage (10–25%). Sugars, phenols and proteins were associated with resistant in pigeon pea. High sugar content in flower (22%) and pods (10.6%) was responsible for the susceptibility of ICPL 88034, while high phenol concentration in flowers (6.5%) and pods (9.3%) in ICPL 98003 was responsible for resistance. Protein content in pods was significantly higher (25.5%) in susceptible ICPL 88034 when compared with resistant ICPL 98003 (16.5%). Determinate lines with clustered inflorescence of pigeon pea cultivars were more susceptible than the indeterminate types. Fifty-six per cent of indeterminate lines had $<$50% damage in contrast to 15% of the determinate lines. Erect and profuse flowering contributed to the resistance of TVu 946 to *Maruca vitrata*. Open canopy, long peduncles, erect pods with wide angle, profuse flowering, pod size and rate of pod growth can be used to select for resistance to *M. vitrata*. Pubescence in wild and cultivated cowpea *Vigna vexillata* and *V. unguiculata* adversely affected oviposition, mobility, food consumption and utilization by the legume pod borer in tests conducted with TVNu 729 wild, highly resistant and highly pubescent, TVNu 946 (semi wild, moderately resistant and pubescent) and IT 82D-716 (cultivated, highly susceptible and pubescent). The components, namely high crude fibre and non-reducing sugars with low percentage of starch have also been found to be associated with resistance to *H. armigera* in GL 645 of cowpea. High percentage of cellulose, hemi celluloses and lignin in the pod wall inhibits pod damage by *H. armigera*. Low acidity in the leaf extracts is associated with susceptibility to *H. armigera*. At Durgapura cowpea cultivars Banswara, G 20, C 55, CR 2-55, P 1461 are less susceptible to pod borers, JG 10-72, NS 19-4-1, C 152, 3-779 to the leafhoppers, P 1473, P 1476 to the aphid and at Coimbatore MS 9369 is less susceptible to the aphid (Soundararajan et al., 2013).

7.33 Crucifers

Efforts are being made to alter waxyness and glossiness characteristics to make the plants resistant to insect attack. Two types of resistance have been developed in Dickson's programme. Descendants of PI 234599 having shiny (glossy) leaves (as compared with the whitish appearance of standard cultivated crucifers [normal bloom]) are highly resistant to DBM and other Lepidoptera. Resistance in PI 234599 was a result of reduced DBM survival. The glossy trait from PI 234599 is inherited as a simple recessive Mendelian gene (Dickson & Eckenrode, 1980). Larval survival on glossy wax genotypes (lacking the normal bloom) is reduced to as low as 1%, compared with standard cultivars. Glossy resistance is associated with reduced wax and reduced density of wax crystalline structures (crystallites) on leaf surfaces. Glossy leaf waxes apparently elicit non-acceptance behaviours in neonate larvae which result in their failure to successfully establish on these plants. In Kulu valley (Himachal Pradesh), Cabbage cultivars All season, Red Drum Head, Sure Head and Express Mail are found to be tolerant to the aphid *Brevicoryne brassicae.* Cauliflower cultivars Early Patna, EMS-3, KW-5, KW-8, and Kathmandu Local are found to be tolerant to the stem borer *Hellula undalis*. Larval survival on glossy wax genotypes (lacking the normal bloom) is reduced to as low as 1%, compared with standard cultivars. Glossy resistance is associated with reduced wax and reduced density of wax crystalline structures (crystallites) on leaf surfaces.

7.34 Potato

Host plant resistance to potato leafhoppers and the Colorado potato beetle has been demonstrated in the wild Bolivian potato species, *Solanum berthaultii*. This resistance is due to glandular trichomes that exude a viscous fluid, entrapping small arthropods and covering the appendages of larger ones. The potato cultivar 'Prince Hairy' (breeding line NYL235-4) was developed at Cornell University through conventional cross-breeding techniques using *S. berthaultii* and in field trials was shown to reduce the number of sprays needed for control of Colorado potato beetle, the glandular trichome varieties had a significant impact in control of leaf hopper damage (Ghidiu et al., 2011).

7.35 Drumstick

Accessions MT_{18}, MT_6, MT_{28} are classified as resistant, H_7, H_{11}, H_{24} are moderately resistant and the accessions MT_5, M_{17}, M_{21} as highly susceptible to the pod fly *Gitona distigma* (Meigen) (Ragumoorthi, 1996). Among various germplasms of moringa screened, Moolanur Short has been reported to harbour lower fauna of pests, and higher number of natural enemies followed by Moolanur Long, Epodhum Vendran, H-7, H-5, C-12, PKM 1 and PKM 2, registering more number of pests and less number of natural enemies (Selvi, 2007).

7.36 Sweet Potato

The sweet potato weevil *Cylas formicarius* F. is a major pest causing direct damage and yield loss. Low yielding entries with small roots are less infested than higher yielding entries. Beta-carotene-rich accessions were found to be susceptible to the weevil. Isolation of clones that are resistant or less susceptible to weevil has been one of the important lines of work. Clones with long neck and deep rooting nature escape severe damage. Some of the clones with moderately long stalk and deep rooting nature, namely S 3, S 13, S 234, S 238 and S 248 showed lower susceptibility to weevil. The resistance can be considered only in relative terms in sweet potato, as purely resistant genotypes are not available in India or elsewhere. The cultivation of less susceptible or relatively resistant clones under good agronomic practices will help to reduce weevil damage leading to increased production (Palaniswami & Mohandas, 1992). The physical attributes of the tuber, namely the shape, length, neck length and thickness plays in important role in preference by *C. formicarius* apart from the inherent nutritional quality of the sweet potato plant and tuber. Round tubers are preferred more than elongate and spindle-shaped ones. While screening the varieties for weevil resistance, it was found that tuber damage was less in deep rooting varieties having the neck length of more than 10 cm. The varieties having short neck of less than 2.5 cm were found as highly susceptible as the weevil could easily enter into the tuber from the plant base. In short necked varieties the shape of tuber is more likely to be globular and as such more surface area is superficially exposed for the weevil to feed and breed. In deep rooting and long necked varieties, the tubers are mostly elongate or spindle-shaped, and the weevil cannot that easily enter into the tuber from the plant base as long necked and deep rooting nature afford physical barrier. However, when there is great residual population of the pest in the soil (in plant debris) due to repeated monoculture, the long necked nature may not help much, as the weevil can directly reach the tubers from soil. Teli and Salunkhe (1996) reported that round and oval tubers of sweet potato were more infested in the field by *C. formicarius* than long stalked, spindle and elongate ones. Pink and red coloured cultivars are considered less susceptible than white and brown coloured ones. Cultivars with thin foliage and lobed leaves with purple coloration at emergence were found less susceptible. Drought stress may increase the activity of oviposition stimulant present in the genotypes because weevils deposited more eggs on drought-stressed plants (Mao et al., 2004). Some of the plant metabolites are produced and influenced by environment, which would have a bearing on resistance or tolerance. Recent analyses showed that the levels of resin glycosides and caffeic acid vary between sweet potato genotypes and within genotypes among years or areas of production, indicating a relationship between the quantity of these compounds and the antibiosis of sweet potato. Sweet potato varieties H 85-168 had the least weevil damage in Orissa (Bhat & Naskar, 1994). Variation in preference of weevil to genotypes is attributed to differential emission of volatiles from aerial parts and roots. Korada (2010) has identified sweet potato genotypes S-643, Howrah, 90/235, SB72/7 BP-2, BX102, 90/693 and 1197 with high degree of weevil resistance.

7.37 Cassava

Cassava accessions at CTCRI, namely CE-4, CE-14, CE-38 and CE-139 are found highly resistant to spider mites *Tetranychus cinnabarinus* (Boisd.) and *T. neocaledonicus* (Andre) *Eutetranychus orientalis* (Klien) and *Oligonychus biharensis* (Hirst). The host plant resistance is the most satisfactory and long range solution to control mites on cassava.

7.38 Dioscorea

The white scale insect *(Aspidiella hartii* Ckll.*)* is an important pest of yams in India. Among the different species of *Dioscorea, D. alata, D. esculenta* and *D. rotundata* were found attacked more by the white scale insect *Aspidiella hartii* Ckll, while *D. hispida* and *D. bulbifera* were relatively free from scale insect attack. About 190 accessions of *D. alata,* 97 accessions were found infested with scale insect, 38 accessions had recurring infestation for more than three seasons, and the remaining 93 accessions were identified as resistant to tolerant to scale insect. Depending upon the grade of scale infestation on tubers, the infested 97 accessions were grouped into mild (70), moderate (9), severe (9) and very severe (9) insusceptibility to the scale insect. The white grub *Leucopholis coneophora* Burm damage was free in as many as 174 accessions of *D. alata,* while 16 accessions were identified as susceptible with maximum damage (46%) in Da 172. About 156 accessions did not show any termite attack, 34 accessions showed termite attack with cent per cent infestation on DA 15, Da 35, Da 58, Da 102, Da 135, Da 176, Da 177 and Da 187 (Palaniswami, 1999).

7.39 Taro

Among the accessions/varieties of taro, Thamarakkannan (C9), Kovvur, Panchamuki were observed to be susceptible to major pests (leaf eating caterpillars, aphids, mites and thrips), while the accessions C82, C135 and C266 were fairly resistant to these pests. Among the 25 taro varieties screened for cormborer

Aplosonyx chalybaeus resistance, var. Surya Mukhi and var. Bk-Col-1 were found promising with less than 20% infestation (Korada, 2012).

7.40 Elephant Foot Yam

Among the germplasm collections of elephant foot yam in Thiruvanathapuram, 14 were grouped as susceptible to mealybugs with 12–45% field infestation and about 17 accessions were found to be field resistant.

7.41 Rose

Under polyhouse conditions rose cultivar Versilia is found relatively resistant while 'First Red' and 'Grand Gala' are more susceptible to *Scirtothrips dorsalis* (Jhansi Rani & Sridhar, 2003). At, Chatha (Jammu), rose genotype Superstar was found to be highly resistant against aphid *Macrosiphum rosae*. Two varieties, namely Rose Local and Arjun, were found low resistant to aphids and thrips. Pusa Mohit, First Red, Sonika and Sughandha were the varieties which were found low susceptible to the aphids and thrips. While as Jaya and Angelica were found moderately susceptible against aphids and thrips *Scirtothrips dorsalis* (Norboo et al., 2017). At Chatha (Jammu), three cultivars, namely Arjun, Shanti and Taj Mahal showed moderate resistance to *Macrosiphum rosae* and the cultivars with low resistance were Australian Gold, Raktima and Glory. The cultivars with moderate susceptibility were Dr. B. P. Pal, Naveen, Black beauty and Jaya while lowly susceptible cultivars were Rose Local, Sonika, First Red, Pusa Mohit, Angelica, Girija, Sugandha, Pusa Muskan, Super Star and Golden showers. The moderately and low resistant cultivars possessed dark green and green colour besides having pubescence, and light green coloured leaves (Sharma et al., 2014).

7.42 Carnation

Cultivar Randez Vous, Liberty and Lisa are identified as less susceptible to thrips with lowest thrips population and higher number of healthy flowers (Manju, 2013).

7.43 Chrysanthemum

Cultivars Chandrika, Bangalore Local Yellow Double, M-7, Pankaj and Yellow Star are found resistant to *Microcephalothrips abdominalis in chrysanthemum.* At

Bangalore, seven Chrysanthemum genotypes, namely 'Aparajitha', 'Asha', 'F-52', 'Heritage', 'PC-31', 'Punjab Anuradha' and 'Rangoli' were less susceptible to the aphid *Macrosiphoniella sanbornii* (Gillette) (Janakiram et al., 2006). Three species of thrips were observed on chrysanthemum germplasm collections of which *Frankliniella occidentalis* (Pergande) was the predominant species followed by *Frankliniella schultzei* (Trybom) and *Thrips palmi* Karny in the ratio of 63:28:9. The incidence of thrips was at peak during flowering period. Maximum thrips population was recorded on Raichur (yellow flowered) and lowest on Redstone (Red flowered). It was also observed that maximum thrips population was recorded on five yellow varieties and least in red varieties and one white variety showing a distinct colour preference by thrips. Yellow flowered cultivars were most susceptible followed by white flowered cultivars for thrips incidence (Saicharan et al., 2017). The incidence of thrips would be maximum on yellow flowered followed by white flowered cultivars and least on red flowered cultivars (Reddy & Janakiram, 2010).

7.44 Gerbera

Under polyhouse conditions at Bangalore, Cultivars Eva and Carocci have shown combined resistance to both whitefly *Bemisia tabaci* (Genn.) and thrips *Thrips palmi* (Karney). Gerbera varieties Alberino' 'Dil and 'Cassiona' are found highly susceptible to both the pests (Reddy & Aswath, 2008). Gerbera varieties Jaguar Pink, Jaguar Rose Deep, Jaguar Salmon Pastel and Revolution Spring Paste' are found the least damaged by the leaf miner *Liriomyza trifolii* (Burgess) (Abraham et al., 2013).

7.45 Black Pepper

Black pepper cultivars Kalluvally Type II was less susceptible to pollu beetle *Longitarsus nigripennis* Mots. Six wild species of *Piper* namely, *P. colubrinum*, *P. chaba*, *P. longum*, *P. attenuatum*, *P. barberi* and *P. hymenophyllum* are found to be resistant to *L. nigripennis*. These resistant lines are being utilized in breeding programmes for developing pest-resistant varieties to various insect pests of black pepper (Devasahayam, 2000).

7.46 Turmeric and Ginger

Turmeric cultivar Dindigam Ca-69 (Sheila et al., 1980) is relatively less susceptible to the shoot borer *Dichocrocis* (=*Conogethes) punctiferalis* (Guenée) at Vellanikara (Kerala). Velayudhan and Liji (2003) recorded the lowest incidence of the shoot borer in Morphotype 2. At Peruvannamuzhi, 34 accessions were moderately resistant to the pest (Devasahayam et al., 2011). Krishna, a clonal selection from Tekurpet (Andhra Pradesh), is moderately resistant to rhizome fly *rhizome fly Mimegralla coeruleifrons* Macquart in turmeric. Ginger cultivar Mannuthy Local is relatively less susceptible to *D. punctiferalis* (Philip & Nair, 1981).

7.47 Cardamom

At Mudigere (Karnataka), three elite clones, namely D-514, D-769 and CI-754 are found to relatively tolerant to *Sciothrips cardamomi* (Ramk.) in the field with less than 10% infestation on the capsules. At Saklesphur, two accessions, namely Malabar Local (28.7% infestation) and SKP-97 (31.4% infestation) are found moderately tolerant to cardamom thrips (Singh et al., 1996). The cultivar Malabar is more tolerant to the shoot and capsule borer *C. punctiferalis.* Tolerance of the Malabar type PV-1 to the shoot borer was probably due to the smaller girth of pseudostem (Rajkumar et al., 2002).

7.48 Coriander

Coriander cultivar ND COR—35 is moderately resistant to the aphid *Hyadaphis coriandri* in U.P. (Nath et al., 2004); PKD—5, PKD—7, SKT—3, CS—7, PMIN—5, MCS—1, MCS—5, UD—20 are least susceptible to *H. coriandri* in M.P. (Verma & Jaiswal, 2004); Less susceptible varieties to *H. coriandri* include RD—44, DH—205 in W. Bengal (Pal & Chaudhari, 2003); Moderately susceptible varieties include UD—686, RCr—446, RCr—436 in Rajasthan (Meena et al., 2002) and JCO—115, UD—686, JCO—18, JCO—130, GC—43, RD—23, UD—255 in Bihar.

7.49 Cumin

Cumin cultivars UC—187, UC—154, UC—150, UC—88 and UC—33 are less susceptible to *H. coriandri* in Rajasthan (Gupta & Yadav, 1986).

7.50 Fennel

RC-7b, RC-9 and RC-31b are to be tolerant to *H. coriandri* in Rajasthan (Bharagava et al., 1971).

7.51 Fenugreek

Cultivars namely RMT—1, UM—129 and PRT—4 are least susceptible to the aphid *Acyrthosiphon pisum* in Rajasthan while JF—10, Um—127, JF—8, HM—57, TG—268, JG—53 are susceptible (Baloda et al., 2004). Sel 95—13 is resistant to *Aphis craccivora* and Sel—38 and Sel 95—11 are moderately resistant to *A. craccivora* in Maharashtra (Pawar et al., 2001). Fenugreek varieties BDJ—11, BDJ—86, BDJ—59, BDJ—193, BDJ—319, BDJ—336, PLM—78, PLM—80 are moderately susceptible to *A. raccivora* in Punjab.

7.52 Tea

UPASI-17 is highly susceptible to the attack by the lepidopterous caterpillars such as tea leaf roller *Caloptilia theivora* (Walsingham), tea tortrix *Homona cofferia* Nietner, Cutworm *Spodptera litura* (Fab) and the tea flush worm *Cydia leuocostoma* (Meyrick). Tea cultivars UPASI-1 was found less damaged by the above caterpillars. Sri Lankan tea selections such as TRI-2024 and TRI-2025 are highly susceptible to the attack of tea shot hole borer *Euwallacea fornicatus* (Eichhoff) in South India. Clones with a high content of spinasterol are more susceptible to the attack of shot hole borer. The levels of this sterol is determined by the presence of several others like calcium, saponins, theanine, arginine and chebulagic acid. Saponins could bind sterols and become a determinant of host resistance to shot-hole borer (Wickramasinghe, 1978). Murthy and Rao (1979) considered UPASI-10, UPASI-12 and UPASI-20 as tolerant to the attack of these beetles.

7.53 Coffee

In some Indian coffee selections, the damage by the white stem borer *Xylotrechus quadripes* is considerably less. Histo-anatomical studies on the stems and enzyme assays on the bark tissues revealed the presence of three main components of resistance in these selections. These are: presence of more layers of lignified sclerotic parenchyma cells in the bark, the presence of abundant tannins in the sclerotic parenchyma cells and the higher levels of endogenous chitinase activity in the green (phloem and cambium) tissues of the bark. Some genes conditioning resistance to white stem borer from *Coffea liberica* are present in S.333 (Doobla hybrid 2) that is involved in the derivation of Sln.5B that manifests relatively lower damage by the white stem borer. In the lineage of Sln.6 (Robarbica hybrids), Robusta (S.274) was involved as the ♀ parent and thus possibly contributed the cytoplasmic-genetic endowments. Borer damage on this selection is also relatively much less than that on pure Arabica strains. Pedigree lines from this hybrid Sln.8 (Hibrido de Timor) (a spontaneous hybrid of putative Arabica-Robusta parentage) are exploited as Sln.8 in India and are observed to be much less damaged by the white stem borer. Thus, full retention of leaves by all the plants of above-mentioned selections is possibly contributing significantly to their protection against the white stem borer. An important aspect of all these selections is that all of them carry genes introgressed from the diploid species *C. canephora* and/or *C. liberica*. The direction of selection and evolution is towards the type of C. *arabica* and all the selections manifest Arabica features. A composite of these selections is expected to resist the insect very strongly without compromising the characters under selection (such as quality and yield) due to the gene pyramiding effect in this multi-line (Ram et al., 2008).

At Thandigudi, Tamil Nadu, India, two genotypes, namely *Coffea abeokulae* (0.35%) and *Coffea exelsa* (0.72%), recorded a damage scale of I (>0–1% infestation) and found consistently resistant to coffee berry borer as against the maximum of 12.13% recorded in C. *caneophora* which had a high susceptible rating of 9 (>10% infestation). *Coffea abeokulae* and *Coffea exelsa* were found free from coffee berry borer eggs, larvae, pupae and adults, and this may be due to the antibiosis mechanism. (Irulandi et al., 2007)

7.54 Cashew

Tender cashew shoots have an innate active phenol-phenolase system. Hence, any feeding injury leads to rapid hypersensitive reactions resulting in necrosis on tender shoots, inflorescences and developing fruits by the tea mosquito bugs (*Helopeltis antonii*, *H. bradyi*, *H. Theivora* & *Pachypeltis maesarum).* Well-matured shoots of cashew exhibited highest feeding deterrence to the pest, irrespective of varieties. Consequently, this phenological stage checks any further build-up of pest population during non-flushing period (June-September). Mid season or late season flowering varieties could escape from the severity of the pest infestation. A cashew accession, Goa 11/6, exhibited consistently moderate level of pest incidence due to mid–late season flowering and also had a satisfactory nut yield of 2.0 t/ha. Hence, this accession has been later released as ‘Bhaskara’ from the ICAR-Directorate of Cashew Research, Puttur (Sundararaju et al., 2006). There was least larval density of the leaf miner—*Acrocercops syngramma* Meyrick on NRCC Sel.-2 followed by Vengurla-4. Highest larval density was recorded on Ullal-4, V-7, VRI-3 and MDK-2. There was no significant relationship between the leaf area and the number of leaf miner larvae. Bhaskara was identified as susceptible (17.4 larvae/leaf) while V-1 was found tolerant with 29.1 larvae/leaf (Vanitha et al., 2015).

7.55 Betelvine

Betelvine cultivars Simurali Sanchi and Kalipatti (both are of Sanchi type) were found to be moderately resistant betelvine whitefly *Singhiella pallida* (Singh). The levels of population of adult whitefly and percentages of adult emergence in Simurali Sanchi and Kalipatti were very low. Cultivars belonging to Sanchi type harboured comparatively low population of whitefly. It might be due to low preference for food and oviposition. Stear-aldehyde compound present in Sanchi type might have exerted antibiosis effect on betelvine whitefly. A reduction in adult emergence could either be due to reduction in egg hatching or high nymphal mortality or both. The low level of adult emergence indicated the presence of higher level of antibiosis effect against betelvine whitefly (Das & Mallick, 2010).

8 Limitations of HPR

Plant resistance is not a panacea for solving all the pest problems. Certain limitation and problems will always be set any insect control programme, and HPR is no exception.

1. It takes long time to identify and develop insect resistant cultivars. Sometimes, it takes 5–15 years to identify the sources of resistance and transfer the resistance traits into cultivars with high yielding potential and desirable quality traits.
2. Development of insect resistant crop varieties requires a great deal of expertise and resources. It requires a multidisciplinary team of plant breeders and entomologists. Plant breeders usually give importance to develop yielding varieties. One might expect a negative correlation between the potential yield and its level of resistance to the target pest.
3. Commitment of relatively long-term funding is a critical factor in the ultimate success of plant resistance programme.
4. Absence of adequate levels of resistance in the available *germplasm* may deter the use of plant resistance for managing certain pests. Such limitations can now be overcome through the use of interspecific hybridization, mutations and genetic transformations.
5. Insects can evolve into new biotypes to overcome antibiosis mechanism. Occurrence of new biotypes of the target pests may limit the use of certain insect-resistant varieties in time and space. Under such situation one has to go for polygenic resistance or continuously search for new genes, and transfer them into high yielding varieties.
6. Certain plant characters may confer resistance to one pest but render such plants more susceptible to other pests.
7. Usually plant characters may confer resistance to one pest in the crop which is attacked by many pests requiring other methods of control including the use of broad spectrum insecticides.

8. Plant resistance at times may be associated with low yield or factors resulting in poor of unacceptable produce.

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