Pest and Disease Control Strategies in Organic Fruit Production

K. Usha, Pankaj Kumar, and B. Singh

Pests and diseases cause huge economic losses to fruit growers by directly reducing 30–100% of fruit production. Additionally they deteriorate the physical appearance, market value and quality and nutritive value of fruits by sucking, chewing or boring into different reproductive parts causing spots, cracks and holes and rotting of fruits. Chemical pesticides have been in use for a long time to control insect pests and fungal diseases (Aktar et al. 2009). Pesticides used in fruit crops accumulate toxic residues in fruits used for human consumption causing health hazards to consumers. Their continuous use is adversely affecting environment by inducing development of resistance in many pests, resurgence and outbreak of new pests and health hazards to production workers and farm labourers due to incorrect or lack of knowledge of handling and use and pesticide poisoning (Groner 1990). Many synthetic pesticides like organochlorines, organophosphates, carbamates and organophthalides have been banned or restricted from use due to their harmful effect on the environment and their high toxicity in nature to the nontarget organisms like beneficial insects, amphibians, fishes and birds as well as to humans. However, attempts are now being made to replace the chemical pesticides with eco-friendly compounds which are safe to human and environment for the control of insect pests and diseases (Balandrin 1996; Adel et al. 2000; Beattie et al. 2002; Basta and Spooner-Hart 2003; Burgel et al. 2005; Cheok et al. 2014).

Organic fruit farming is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. It is an ecologically sustainable fruit production system which protects biodiversity, physico-chemical and biological health of our soils since it is based on minimal use of chemical inputs for sustaining crop health and protection against biotic threats. In

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India, organic fruit production was practised only by individual NGOs and entrepreneurs in isolated areas and is now slowly gaining popularity due to increased organic agribusiness trade, demand for safe food by the consumers, support from the government to organic fruit producers and income security to growers.

Among other production problems, the challenge in organic fruit production is timely control of several pests like hoppers, mealy bugs, stem bores and fruit flies and diseases like powdery mildew, anthracnose, sooty mould, mango malformation, etc. (Campbell 1992; Tiwari et al. 2006) that drastically reduce fruit yields and quality. For successful organic fruit production an integrated pest management (IPM) approach which involves underlying preventative approaches is recommended to minimize the occurrence and extent of problems. Those practising organic fruit cultivation in complementation with the adoption of IPM strategies observe greater yields and profits than organic farm cultivators without IPM. It may require some change in chemicals used for the control of specific pests and diseases. Efforts to secure the existing biodiversity of the organic farms, to attract and harbour beneficial predators, can better the efficiency of the employed IPM methods (Zehnder et al. 2007).

Success of organic farming, in general, encompasses use of crop varieties with high to moderate resistance to biotic challenges. However, use of varieties with partial resistance is preferred to high-level resistance, since the former shall support and maintain low-level pest densities that facilitate natural enemy populations. Growing resistant varieties are thus the best option available with the farm holders practising organic farming. However, any chosen variety cannot be resistant to all the pest problems; hence an alternate strategy to successfully control pests in organic fruit production is desirable. Some of these are discussed in the following sections.

Soil Management Practices to Reduce Pest Incidence

A critical review of the available literature indicates that pest and disease resistance in plants is related to realization of optimum physico-chemical and biological characteristics of cultivable soil. Researches reveal a lower resurgence of insect pests in the organic than the conventional practices of farm management. In the organically managed farms, a higher availability of organic matter and the associated biological activity ensures sufficient buffering capacity to facilitate optimal nutrient availability and nutrient balance in soil-plant continuum, which in turn determines the performance of phytophagous insects. Interventions like incorporation of organic mulches are useful organic farming practices to supplement not only the soil organic matter but also to reduce soil temperature and improve water holding capacity of the soil. A reduced aphid infestation and incidence of viral infection with the application of straw mulch have been reported across crops and may be attributed to a reduction in host finding ability and an increase in predation from the natural enemies. However, application of organic mulch does favour growth of some other pests such as the squash bug, *Anasa tristis*, and the American palm *cixiid*, *Myndus crudus*.

Another important recent farm intervention is conservation tillage, which along with cover cropping practice and mechanical cultivation helps to control weeds under organic cultivation. The above practice which helps in conservation of water and maintenance of soil health can significantly alter the population and diversity of arthropod pests and natural enemies. It also triggers development of rich soil biota which is important to improve soil-nutrient cycling and crop health. In addition to conservation tillage, other farm management practices like mechanical removal of weeds and grasses may further reduce the number of arthropod predators, particularly the spiders and the staphylinid beetles.

Field Management Practices to Reduce Pest Incidence

Pest and disease management in organic fruit production involves a wide range of long-term activities practised in complementation to support each other's cause of effective prevention against pests and disease attack by ensuring reduced pest population. On the other hand, an effective control strategy is a short-term activity and would involve killing of pests and pathogens. Management of pests and diseases rather than their control is preferred. The routine pest and disease control methods attempt to rout the cause of the problem rather than correcting the disease symptoms and that its management over the control becomes the priority.

A simple management strategy could involve selection of crop/production site where the persisting environment suits crop production and the development of natural enemy of the pest but not the development of the pest. This ensures that the area and the crop shall remain free of the crop pest and the related diseases for a long time and even if the pest starts to show up the presence of natural enemies of the pest will act to stall the development and resurgence of the pest population not allowing it to stabilize to a level that is detrimental to the economic production. The above characteristics can be exemplified by the fact that organic fruit farming in the USA is majorly executed in regions that are free and/or do not support the growth of insect pests such as the plum curculio, *Conotrachelus nenuphar*. Further control of pests can be achieved by isolating the susceptible crops from the target host crops which has been effective in preventing the spread of aphid-borne viral diseases.

To employ apt farm management practices, it is important to decode the extent, season and quantum of specific pest or disease problem at any given location as it can help manage production costs and ensure the production targets. Identified risks can be minimized by adopting robust organic management. For example, southern growing regions need to consider orchard varieties, farm plan, density, canopy structure and extent of pruning to avoid fungal attack. In organic fruit productions in overly wet condition during fruiting, neglected orchards are constant source for new outbreaks of pest or disease (or weeds) and reduce yields drastically. Intermittent placement of organic and conventional farms may alter the pest and disease dynamics; thus cooperation with conventional growers is desired. Constant monitoring of farm pest and diseases can help reduce costs of unnecessary sprays besides improving resistance. However, resistant planting materials should always be used wherever possible. Use of local varieties that exhibit tolerance to local environmental variation and pest and diseases will ensure healthy growth. Since, a healthy tree requires soil to be healthy; improving the biological activity of soils by supplying them with adequate organic matter and providing conditions that enhance nutrient cycling to facilitate balanced physico-chemical and biological activities of the soil must be achieved. Pruning of tree canopy to enable opening of the structure that allows efficiency aeration in the canopy and adequate internal lighting can minimize disease risk and help in development of quality fruits of desired coloration. Practices like removal of infected wood, dead branches and fruits, leaves and other plant tissue can help reduce the infestation and resurgence of pests and diseases. Besides these, a regular monitoring and timely intervention are important for effective pest and disease management. Maintaining soil nutritional health also enables in reducing disease incidence. Diseases like mildew, anthracnose and leaf spot diseases can be regulated with sulphur or copper preparations, which are permitted and must be adhered to in organic cultivation.

Physical Methods to Control Flying Pests

Strategies like light traps, fruit bagging, pheromone traps and sticky traps are effective physical methods available to control insect populations. Use of fruit bags prevents fruit flies from laying insects on fruits and helps in controlling pest damage to the fruits and effectively checks latex burns and fungal spots, thereby improving their marketability. Bagging also helps minimize physical injuries like scratching and scaring and improves quality and productivity of fruits from an organic farm. Insect traps, which use attractants (colours, lights, etc.) and traps (chemical scents) for achieving mass trapping, using glue to immobilize insects, and mating disruption are equally important for monitoring insect populations to decide on the control measure. Water traps are also useful for trapping thrips, leaf miners and aphids. These insect traps help in monitoring insect population besides helping in delaying the build-up of pests and in reducing existing insect populations. However, once water or sticky pad is covered with insects, it should be changed to continue harness benefits of the technology. Colour traps like yellow traps, however, also attract many beneficial insects. These traps should be checked regularly to monitor the population of insect pests. Use of light traps to attract and trap insects is another important pest management strategy. Light traps effectively and efficiently trap different moth species such as armyworms, cutworms, stem borers and other night flying insects particularly when these are planted not later than the emergence of the adult moth but before the egg laying stage. Use of solar energy to kindle light traps in the orchards can reduce cost and enable the grower to use in orchards where electricity is not available. Embedded sensors automatically protect from rain, control light, relative humidity and can automatically switch on the lights in the evening and turn off in the morning.

Sex pheromones are of great help in controlling the population of insect pests in the orchards and the vineyards as they effectively disrupt the mating behaviour of various lepidopteran pests (Vail et al. 1993). Majority of research on effectiveness of sex pheromones and other techniques of controlling lepidopteran pests focus on monitoring the population of damage-causing insect pests such as the pea moth, *Cydia nigricana*, the olive fruit fly *Bactrocera oleae* and the cutworm, *Agrotis* spp. Hanging pheromone traps containing methyl eugenol in fruit orchards help in catching fruit flies and other pests. A successful example has been reported from Australia which involved commercial rearing of the Australian endemic egg parasitoid *Trichogramma carverae* for their mass release in vineyards for regulating the population of the light brown apple moth, *Epiphyas postvittana*. Since the life of the parasitoids is short, it is important to ensure accurate monitoring so that the release of predator coincides with maximum host egg density in order to achieve unrestricted impact on the target. Further, the longevity and fecundity of this natural enemy can be bettered by making them feed on nectar-producing plants such as alyssum, *Lobularia maritima*, in organic vineyards. Wrapping a slippery plastic band around each fruit tree especially in mango trees in the lower trunk region will restrict the movement of the emerging mealy bugs from soil up the trunk to branches, floral parts and growing fruits. Migration of weevils to branches for egg laying can be reduced by tying sticky band.

Another effective insect repellant which has shown promise as a potential alternative to insecticide treatment in different crops is kaolin clay (Glenn et al. 1999; Puterka et al. 2000; Cottrell et al. 2002; Glenn et al. 2002; Pasqualini et al. 2002; Mazor and Erez 2004; Melgarejo et al. 2004; Burgel et al. 2005). Kaolin film makes a physical restriction and a hostile environment for insects to develop and to infest and also impedes their movement, feeding and egg laying capacity and thus ensures an effective control of aphids and other sucking pests and diseases of fruit crops.

Botanicals in Pest and Disease Control

Fruit crops have developed many ways to fight against pests and pathogens by using secondary metabolites or plant-derived compounds which are valuable biopesticides for sustainable and healthy fruit cultivation. Mineral oils extracted from several wild and medicinal plants can be used for pest and disease control. Plant-based insecticides such as pyrethrum, neem and plant oils are most common, while those from ryania, nicotine and sabadilla are used less frequently in organic farming (Taylor et al. 2004; Ntalli and Menkissoglu-Spiroudi 2011). In fruit orchards, mineral oils are commonly used in winters to eliminate the overwintering developmental stages of pests. Several of the plant oils and their constituents (neem oil and essential oils) exhibit remarkable toxicity (both as contact and fumigant) to a large number of economically important pathogenic fungi, insect pests and mites. Triterpenoid steroid saponins present in different parts like leaves, stems, roots, bark and flowers of many plants are non-volatile, surface-active compounds, well tested against several insect pests like aphids, beetles, weevils, leafhoppers, worms, moths and several pathogens for their antimicrobial, antioxidant, and insecticidal, nematicidal and molluscicidal activities (Vincken et al. 2007). Steroid saponins are present in eggplant, peppers, tomato, potato, oats, garlic, onion, leek, alfalfa, alliums, fenugreek, yam, yucca, ginseng, soybean, chickpea and asparagus (De Geyter et al. 2007; Da Silva et al. 2012; Faizal and Geelen 2013; Cheok et al. 2014). Triterpenoid saponins are common in legumes, chenopods, spinach, sugar beet, liquorice, sunflower, horse chestnut, soapbark tree, sarsaparilla, quinoa and tea. Saponins stored in the roots act as phytoprotectant against invading soilborne microbes that attack fruit trees. Use of these botanicals as soil applicant or foliar spray is environment-friendly and nontoxic to humans and animal health and constitutes an effective, economically viable and sustainable approach to control several pests and diseases in fruit crops (Moses et al. 2014).

Foliar spray with pyrethrum solution; plant extracts like neem, garlic, chilli and tephrosia; spraying with 1% soap solution in 1% alcohol; and application of paraffin oil (white oil) as a 3% water emulsion can reduce the pest incidence. Spraying of 0.2% nimbicidin or azadirachtin 3000 ppm@2 m/l at initial stage of hopper population can control hopper attack. In our study, strong antifungal activity and significant inhibition of floral malformation were observed when mango trees were sprayed with a concoction brewed from *Datura stramonium*, *Calotropis gigantea*, *Azadirachta indica* and cow manure at bud break stage and again at fruit set stage when compared with the control. All malformed panicles completely dried and dropped 2 days after foliar spray and did not require any manual deblossoming, a regular recommended practice which is not only tedious but is also labour intensive. Whereas in the control, the malformed panicles remained green and competed with the growing fruits for plant nutrients. All mealy buds either dropped from mango trees or died immediately after spraying with brewed tea. Soil application of neem cake or datura, calotropis and neem plant extracts helps in killing eggs and larval stages of soilborne pests, termites, nematodes and pathogens.

Microbial Bioagents in Pest Control

Biological control of plant diseases through the use of antagonistic microorganisms has been considered as a viable alternate method to chemical control. Several entomopathogens (viruses, bacteria, fungi and nematodes) are safe for the environment, beneficial insects, applicators and food supply, and they can be applied just prior to harvest (Shapiro-Ilan et al. 2002a, b). Various spore-forming and non-spore-forming bacteria are pathogens of insects. Bioinsecticides dominated by *Bacillus thuringiensis*-based products command little more than 1% of the global insecticide market (Silimela and Korsten 2006). It is now well known that a crystal protein toxins present in the parasporal inclusions that are produced during sporulation contributes towards insecticidal tendencies of *B. thuringiensis*. These toxic proteins are basically the stomach poisons that potentially kill the insect by disrupting the osmotic balance in the midgut epithelium. Biopesticides such as *Pseudomonas fluorescens*, *Verticillium lecanii* and *Beauveria bassiana* as foliar sprays help in controlling several fungal diseases. The granulovirus (CpGV) is safe to nontarget organisms, and its use is effective for control of codling moth and some closely related species and contributes to the conservation of other natural enemies in orchard agroecosystems (Tanada 1964; Falcon et al. 1968). Due to airborne nature of dissemination and infection of buds, foliar spray once before flowering and again at the time of flower bud initiation with *B. subtilis* reduced the extent of mango malformation. Protection of buds from infection when inoculums prevail is necessary to control the disease. Fungus *Verticillium lecanii* controls hopper population, while *fungi Aspergillus* sp. and *Beauveria bassiana* were found effective in mango weevil control. Biopesticides such as *Pseudomonas fluorescens*, *Verticillium lecanii* and *Beauveria bassiana* as foliar sprays on the infected parts will knock off many pests and diseases. Soil application of bioagents like *Trichoderma viride*, *Trichoderma harzianum* and *Bacillus subtilis* ensnares and consumes other fungi as well as nematodes that live in the soil. In other words the laboratory virulence may not necessarily and always translate into ability to achieve effective suppression in the field. For example, *S. feltiae* and *S. riobrave* showed equally high potency *of* virulence to *C. nenuphar* larvae under the *laboratory* conditions, but in the field only *S. riobrave* could successfully and effectively control the insect pests. Non-chemical means of pest control are successful in organic farming; however, regardless of their efficacy, cost competitiveness is a major hurdle in their popularization and limits their exploitation as the mainstream pest management extension recommendation. The use of nematodes for control of *D. abbreviatus* is a success story; however the relative high cost of nematodes has prevented their implementation in some cropping systems. On the other hand, the ease of handling and greater cost competitiveness in *B. thuringiensis* products has facilitated their success. Use of EPNs for *D. abbreviatus* is cost competitive because the applications are made only under the canopy, which harbours the insects, and not over the tree canopy and not between rows. Such targeted application of the pest control technology over much reduced orchard area enhances the economic feasibility of the pest management strategies in the organic fruit orchards. Soil application of bioagents like *B. subtilis*, *Trichoderma viride* and *Trichoderma harzianum* is an effective, economically viable approach to control several soilborne pests, diseases, nematodes, etc. A list of promising biocontrol agents for pest control in organic farming is presented as Table 1.

Fruit growers also use fermented teas using different ingredients for pest control. For example, cow urine, dung, milk and milk products, i.e. curd, and ghee are the chief ingredients of panchagavya; however, coconut water, bananas, toddy juice and sugarcane juice are added to improve its nutrient quality and efficacy and to reduce odour (Devi and Arumugam 2005). Panchagavya is a good source of macro- and micronutrients and beneficial fungi and bacteria, which induce growth and also repel risky pests. Similarly other organic formulations like dasagavya, Amrut Jal 10% solution can be applied to soil and foliar spray once in 15–30 days, which act

Table 1 Biocontrol agents used in fruit crops for pest control

Biocontrol agent	Against fruit crop pests	References
Bacillus thuringiensis	Lepidopteran pests Oriental fruit moths, chrysomelid pests, leafrollers, bud moths, fruitworms	Boscheri et al. (1992), Beegle and Yamamoto (1992), Pari et al. (1993), Crickmore et al. (1998), Lacey and Siegel (2000), Lacey et al. (2005), Garczynski and Siegel (2007), Delate et al. (2005), Blommers (1994), and De Reede et al. (1985)
Granulosis viruses	Codling moth, *Cydia pomonella* summer fruit tortrix	Falcon et al. (1968), Balazs et al. (1997) and Altieri (1992)
Baculoviruses	Species of Lepidoptera	Huber (1986), Groner (1990) and Miller (1997)
Entomopathogenic fungi (e.g. *Neozygites fresenii*, *Entomophaga maimaiga*) and *Hypocreales* (e.g. *Lecanicillium* spp., *Aschersonia* spp., *Hirsutella* spp.; *Beauveria bassiana*, *Metarhizium anisopliae*, *Paecilomyces fumosoroseus*)	Weevils, lepidopteran and dipteran pests, crickets, *C. caryae*	Tedders et al. (1973), Harrison and Gardner (1991), Lezama-Gutierrez et al. (2000) Zimmermann (2005), Shapiro-Ilan et al. (2003, 2004), Goettel et al. (2005), Wraight et al. (2007), Steinkraus (2007), Barnett et al. (1993), and Grewal et al. (2005)
Entomoparasitic nematodes, e.g. *Heterorhabditis bacteriophora*; *S. carpocapsae*	Weevils, lepidopteran and dipteran fruit flies, crickets; borers; navel orange worm	Cossentine et al. (1990), Yee and Lacey (2003), Kuske et al. (2005), Grewal et al. (2005), Agudelo-Silva et al. (1995), Lindegren et al. (1987)
Insect parasitoids, e.g. wasps	Aphids, leafhoppers, lepidopteran pests, whiteflies	Daane et al. (2005), Begum et al. (2004), and Wyss et al. (1999)
Insect predators, e.g. mites, coccinellid and lacewing	Aphids, psyllids, leafhoppers, spider mites	Peng and Christian (2005) and Kehrli and Wyss (2001)

as protective cover for beneficial insects and pathogens. Handi khata controls all pests and diseases when sprayed @20 ml/litre of water. Foliar spray with organic formulations like handi khata, panchagavya and dasagavya and bioagents like *Trichoderma harzianum*, *T. viride, Pseudomonas fluorescens*, *B. subtilis*, *Beauveria bassiana* and *Verticillium lecanii* is environment-friendly and nontoxic to humans and animal health and constitutes sustainable approach to control pests and diseases in organic orchards. Biofertilizers with special focus on vesicular arbuscular mycorrhiza and plant growth-promoting rhizobia when used in the nurseries and field help to control soilborne diseases.

Natural Enemies for Pest Management

Natural enemies such as lady beetle larva, wasps, spiders and parasitic fungi attack the maggots of fruit flies. Predators such as rove beetles, weaver ants, spiders, birds and bats are very efficient in protecting fruit trees from several pests, including fruit flies. Their presence and foraging activity hinder the fruit flies from laying eggs, resulting in reduced fruit fly damage. This technique demands utmost caution and thorough study, as it could go all wrong, if not managed properly.

A successful example has been reported from Australia which involved commercial rearing of the Australian endemic egg parasitoid *Trichogramma carverae* for their mass release in vineyards for regulating the population of the light brown apple moth, *Epiphyas postvittana*. Since the life of the parasitoids is short, it is important to ensure accurate monitoring so that the release of predator coincides with maximum host egg density in order to achieve unrestricted impact on the target pest. Further, the longevity and fecundity of this natural enemy can be bettered by making them feed on nectar-producing plants such as alyssum, *Lobularia maritima* in organic vineyards. The natural enemies, viz. a mite (*Rhizoglyphus* sp.), ants (*Camponotus* sp., *Monomorium* sp. and *Oecophylla smaragdina*), and fungus, *Aspergillus* sp. and *Beauveria bassiana*, were found effective in mango weevil control (De and Pande 1987). Female weevil lays eggs 55 days after flowering when fruits are about 29 g in weight. Bioagents must be released at this stage to control weevil population (Shapiro-Ilan 2003).

Sterile insect technique (SIT) is an important eco-friendly approach for the control of insect pests. This involves mass rearing of target insect and inducing sexual sterility with radiation in adults (especially males) without altering their mating vigour and competitiveness. Release of such sterile adults in overwhelming number in natural population would limit the reproductive ability of natural population and can bring down the insect population to a manageable level or even can eradicate completely. The first success story of SIT was eradication of screwworm fly (*Cochliomyia hominivorax*) from North America. The successful implementation of SIT against different fruit fly species has demonstrated the usefulness of radiation in the management of insect pests in fruit culture. At BARC, attempts have been initiated for the management of red palm weevil, a major insect pest in coconuts under a multilocation collaborative programme with Agricultural Universities in Maharashtra, Karnataka and Kerala.

Ecological Engineering Approaches

Scientists also advocate the strategy of conservation biological control which involves altering the environmental conditions and existing practices for better management of pest populations through enhanced efficacy and site-level abundance of the existing natural enemies at the community level. The conservation biological control approach is most suited for organic farming since it involves minimal application of broad-spectrum pesticides that are capable of disrupting the community structure and restrict the action of natural enemies. An increased activity of the natural processes also helps in limiting the necessity and use of synthetic inputs. It also enhances the ecosystem service potential of biological pest control provided by predators and parasitoids. Plant diversification is another strategy which can help realize the potential of resource-limited natural enemies by satisfying their requirements for food and shelter. Natural enemies get benefitted from the increased plant diversity in terms of achieving a favourable microclimate (shelter), the plants as food (nectar or pollen) and/or the source of alternative hosts or prey. One such recorded example involves raising of a semi-permanent strip of vegetation in the centre of the field (beetle bank) to harbour carabid and staphylinid beetles and spiders, as well as for birds and small mammals. These beetle banks in winter months can harbour more than 1000 predatory invertebrates per square metre and can help control orchard insect population as natural enemies. Another similar approach involves cultivation of flowering insectary strips to provide pollen and nectar, which can enhance natural enemy fitness to fight pests and diseases in organic fruit orchards. A fit natural enemy of predators and parasitoids possesses a better longevity and fecundity, which in the long run skews the sex ratio of the parasitoid offspring towards the females. Conservation biological control approach involving the use of flower strips can also alter the spatial distribution of natural enemies in and around crops, and strips that have grass and flower vegetation are most effective for increasing the rate of predation. Management of weed strips is thus an important concept for managing pest and diseases in organically grown fruit crops.

Biodiversity with Flowering Plants

It is important to engage in effective orchard management particularly that the floor management which should be done in a manner to better and/or maintain beneficial predators. Biodiversity should be enhanced by making windbreaks and shelterbelts as it helps in increasing parasitoids and predators' number due to availability of nectar, pollen and insects. One of the challenges that organic mango production faces is the need for space to increase fruit production and at the same time control pests and diseases organically. Cowpea, carrot, buckwheat, French bean, cluster bean, dandelion, maize, mustard, anise, tansy, caraway, dill, yarrow, zinnia, clover, alfalfa, parsley, cosmos, sunflower, chrysanthemum and marigold are flowering crops that attract the native wasp populations and provide good habitats for them. Growing these crops as border crops or trap crops can help in reducing the pest incidence on mango crop. One such recorded example involves raising of a semi-permanent strip of vegetation in the centre of the field (beetle bank) to harbour carabid and staphylinid beetles and spiders, as well as for birds and small mammals. These beetle banks in winter months can harbour more than 1000 predatory invertebrates per square metre and can help control farm insect population as natural enemies. Rows of flowering buckwheat planted as understories throughout the vineyard as a food reward for parasitoid wasps improves the control of *E. postvittana.* Raise flowering plants/compatible cash crops along the field border by arranging shorter plants towards main crop and taller plants towards the border to attract natural enemies as well as to avoid immigrating pest population. Grow selected flowering plants in fruit orchards as intercrops, on bunds, and wherever space is constraint, vertical gardens offer solutions. Growing different flowering, vegetables and herbs on vertical structures in organic orchards not only act attracting plants providing nectar and pollen for predators and parasitoids, but will also bring in additional income from sale of produce. Vertical gardening or farming deserves a place in twenty-first century inorganic farming techniques and practices. Clean cultivation by removing all weeds is often practised by growers in mango orchards. But do not uproot weed plants such as *Tridax procumbens*, *Ageratum* sp., *Alternanthera* sp., etc. growing naturally as they act as nectar source for natural enemies. The flowering plants attract natural enemies of the selected pests. Actual selection of flowering plants should be based on availability, agroclimatic conditions and soil types. An increase in population of predatory insects, particularly carabid beetles, but a decline in pest population was recorded under organic farm conditions. In a bid to achieve better control of *E. postvittana*, rows of flowering buckwheat were planted throughout the vineyard as a food reward for parasitoid wasps.

Intercrops to Check Pest Incidence

Intercropping of main crop with weeds or other subsidiary crop which interferes with the pest development is another practical approach for managing pests. The approved strategy operates on the well-known fact that availability of resources determines colonization of pest population and in crop-weed intercropping strategy, which is in line with the resource concentration hypothesis, that proposes that highly populated regions of host plants can easily be identified and colonized by herbivores. However, use of plants that are distinctly different from the favoured crop may interfere with the identification and colonization capacity of the specialized herbivores owing to visual and chemical level changes in the habitat. However, use of non-crop plants or weeds has no negative effect on the generalized herbivores as they can survive on either of the crop or non-crop plants. Establishing cover crops with Brassicaceae, which are known to possess large quantities of glucosinolates, a sulphur compound, is reported to help inhibit the development of soilborne pests and diseases through biofumigation.

Among the various diseases that attack fruit crop, gummosis is of great economic importance since the trees die within a very short time. Planting crops like turmeric, garlic and marigold as intercrops can help to reduce disease incidence. In our experiment conducted at village Murar in Bihar, using turmeric as intercrop showed promise in checking mango decline, soilborne diseases, nematodes, termites, etc. Fungal infection is also common in mango and is distributed throughout the tropics and subtropics, with affected trees showing symptoms of wilt and dieback (Korsten et al. 1992). More than 150 mango trees in village Murar in Bihar showed abundant gum secretion from branches and main trunk right from the tree base to tree top, wilting, dieback, vascular browning and death of several trees. The observed gummosis in mango trees was often accompanied by damage caused by a new species of trunk borer. The grubs caused severe damage by feeding on the bark inside the trunk, boring upward, making tunnels, thus hindering the transport of water and nutrients from the root to the shoot, resulting in wilting and drying of the shoot. Acting as a wounding agent and vector, the trunk borers probably assist in rapid spread of the disease in the orchard. Several chemicals tried to control mango decline showed little or no success. Turmeric plantation as intercrop in this severely declining mango orchard at village Murar in Bihar was helpful in suppressing the population of trunk borers, termites and gummosis causing pathogens in the soil and also provided additional income from the harvest of the rhizomes, 9 months after planting. Turmeric root exudates or curcumin in rhizomes present in soil probably assisted in disease suppression by reducing the activity and population of trunk borer larvae and soilborne fungus. The orchard also became free from termite attack after turmeric planting as intercrop in mango. This study indicates that turmeric plantation can be used as intercrop in organic farming systems to control various soilborne pests and diseases in several fruit orchards.

Trap Cropping

In general, conventionally the trap cropping is practised in complementation with use of pesticides. It, however, has tremendous scope and potential even in organic system of crop cultivation. However, for the success of the trap cropping strategy in pest management, it is important to ensure that the trap crop attracts the pest more than the main crop and pests prefer it as food or as the oviposition site. Thus, for successful adoption of the trap cropping strategy, both the relative attractiveness and size of the trap crop in a landscape are important and determine the relative pest control efficiency. Apart from the above-mentioned attributes, trap cropping also depends on various other factors such as plant type, justification for deployment and whether it is being used in isolation or in combination with other strategies of pest management. A successful example of controlling pest population in organic production system through the use of trap crop has surfaced from New Zealand. The density of the southern green stink bug was lowered, the timing of their colonization was delayed, and damage to crop was reduced when black mustard was grown around the perimeter of fields. Okra, marigold, sesamum, gingelly, sorghum, chrysanthemum, castor, sunflower and cucumber are commonly used as trap crops to attract pests like fruit borers and leaf minor. Marigold is used against nematodes. Crops like maize, sorghum or millet reduce white fly and aphid population in papaya crop.

Physical Methods to Control Postharvest Pests and Diseases

Merely enhancing fruit production is not enough. We must ensure its safety, reduce postharvest losses and facilitate fair distribution. The postharvest losses due to microbial spoilage, insect infestation, etc. add up to 30–50% depending on the commodity. Although India is a very large producer of fruits, the per capita production is only about 100 gm per person per day. Because of these losses, the per capita availability of fruits is only of the order of 75 gm per person per day, which is just half of the requirements of a balanced diet. A significant portion of this requirement can be met by cutting down the postharvest losses. A large number of physical methods such as gamma irradiation of insect pests, hot water treatment and vapour heat treatment are known; of these gamma irradiation can be practised under the organic farming condition as well as on postharvest produce, while other protocols are effective for postharvest control of insect pests and disease infestation alone. HACCP (Hazard Analysis Critical Control Points)-based quality assurance systems are suitable for establishing protocols and monitoring systems that meet organic requirements. Operations with existing HACCP-based quality assurance systems observe that only minor changes are required to be made in the existing system of organic cultivation to comply with the organic standards. Both pre- and postharvest disease controls are important under organic farming (Jones and Prusky 2001). It can be said that for better postharvest disease management while it is important to store the produce at optimum temperature and RH, it is also important to ensure a disease-free preharvest crop growth and orchard hygiene in the organic field. Use of proper equipment for cleaning of fruits and separating the rejected fruits from the better ones can reduce the transfer of fungal spores onto the new fruits. It is also important to differentiate and understand the need for pest control strategy depending on the markets and duration of storage required. For example, fruits to be sold in the domestic market are normally stored for short durations and hence may not require any pest control management, while fruits destined for export are stored for longer duration till they reach the ultimate consumer and thus require postharvest treatments for fungal control to restrict the incidence of fruit breakdown from the anthracnose and stem-end rot diseases.

For over 30 years, scientists at BARC have carried out studies on radiation processing of various fruits and fruit products. It involves controlled application of the energy of radiation such as gamma rays, X-rays and accelerated electrons. This ensures killing of pathogens and storage pests. Radiation at medium-dose levels can effectively destroy fruit-borne parasites and microorganisms responsible for human illness and thereby hygiene fruits. It can also reduce microbial load and extend shelf life of perishable fruits at their recommended temperature of storage (Kaya and Lacey 2007). The process is also referred to as cold pasteurization. Radiation processing is also effective in delaying ripening of fruits. Non-destructive X-ray imaging system is now available which can detect the seed weevils in mango varieties like alphonso, neelam and totapuri and spongy tissue in alphonso mangoes. The X-ray scanned mangoes are safe for consumption and there is no health hazard.

With the establishment of WTO, the globalization of trade in fruit and fruit commodities has been on the rise. Ensuring quarantine or bio-security in international trade would become mandatory for the exporting countries.

Hot water treatment, vapour heat treatment (VHT) and irradiation are physical methods of quarantine for export. After harvest, anthracnose and fruit fly damage can be controlled if the mango fruits are dipped in hot water at 55 °C for 3–5 min. In VHT, fruits are heated in a chamber with vapour saturated air until pulp reaches a temperature of 46 °C. This temperature is maintained for 10 min after which, the chamber is ventilated. This method is used to disinfest fruits from fruit flies. As per norms, it is mandatory to irradiate the king of fruits before being shipped to the USA. Around seven metric tonnes of mangoes are irradiated in 8-h shifts daily at the Lasalgaon facility.

Plant Products to Control Postharvest Pests and Diseases in Fruits

Fruits, due to their low pH, higher moisture content and nutrient composition are very susceptible to attack by more than 100 species of pathogenic fungi. Considerable postharvest damages caused by fungal plant pathogens include rots, decay and production of mycotoxins which make fruits unfit for consumption. Natural compounds like essential oils, acetaldehyde, benzaldehyde, hexanal, jasmonates, acetic acid, glucosinolates, propolis, fusapyrone and deoxyfusapyrone, chitosan, etc. can be used to prevent fruit decay caused by fungi (Knight et al. 2000; Murray 2000; Kharkwal et al. 2012; Moghimipour and Handali 2015). Thymol and other essential oils from leaves of *Melaleuca leucadendron*, *Ocimum canum* and *Citrus medica*, *Mentha arvensis*, *O. canum* and *Zingiber officinale* are effective in controlling grey mould, blue mould and brown rots on oranges, sweet cherries, apricots and plums and greatly reduced postharvest decay without causing any phytotoxicity. Many flavour compounds and volatiles express their effects at very low concentration as potential fungicides and their natural occurrence as part of the human diet; their ephemeral nature and their biodegradability suggest low toxic residue problems. Acetaldehyde, benzaldehyde, cinnamaldehyde, ethanol, benzyl alcohol, nerolidol and 2-nonanone produced by ripening fruits have antifungal activity against microorganisms such as *Erwinia carotovora*, *Pseudomonas fluorescens*, *Monilinia fructicola*, *Penicillium* spp. and yeast commonly found on fruits. (*E*)-2-Hexenal, an efficient fumigant, is strongly antifungal in nature to control moulds and other fruit diseases. Aldehydes are compounds released after tissue damage and have a use as antifungal agents in fruits such as pears, strawberries, bananas, pineapples and melons against growth of *Alternaria alternata* and *B. cinerea*. Use of these aldehydes in packaging of highly processed products of these commodities is a possible future option. Effective fumigation or surface sterilization by acetic acid that occurs naturally in many fruits can sterilize the fruit surface, killing surface-borne spores.

Fumigation with low concentrations of acetic acid protected grapes from spoilage for up to 2 months in modified atmosphere packaging at 0 °C and extended shelf life of wide range of fruits like apricots, plums, grapes and sweet cherries and for control of *B. cinerea* conidia on apple fruits without phytotoxic effect. Acetic acid vapour is inexpensive and can be used in relatively low concentrations to control decay in stored table grapes and to treat produce in airtight storage rooms or containers. The use of vinegar is even safer and still effective. A naturally occurring compound 7-geranoxy coumarin isolated from the flavedo tissue of 'Star Ruby' grapefruit (*Citrus paradisi*) or aqueous extract of *Acacia nilotica* exhibited showed pronounced antifungal activity against *P. italicum* and enhanced the shelf life of oranges for 6 days (Kerns and Wright 2001).

Postharvest application of jasmonates suppressed grey mould rot caused by *B. cinerea* in strawberry and *P. digitatum* of 'Marsh Seedless' grapefruit and reduced decay in several fruits. Methyl jasmonate has a pleasant aroma and is suitable for storage rooms or fumigation chambers, while jasmonic acid, which is more soluble in water, is suitable for use in solution as a drench or dip. The antifungal activity of glucosinolates, produced by the Cruciferae, has been tested against *Monilinia laxa* and several other postharvest pathogens. Exposure of pear fruit to an allyl isothiocyanate (AITC) a naturally occurring flavour compound in mustard and horseradish has a well-documented antimicrobial activity. AITC-enriched atmosphere resulted in good control of blue mould and can successfully be employed in modified atmosphere packaging or as a gaseous treatment before storage of pears with moderately low impact on the environment. Propolis, a natural resinous substance obtained from leaf and bark of poplar and conifer trees, and fusapyrone, an antifungal metabolite, chitosan and its derivatives have antifungal properties and can be used in solution, powder form, or as wettable coatings of fruits against blue mould especially in grapes and 'Red Delicious' apple fruits. Microbial antagonists have also been reported to protect a variety of harvested perishable commodities against a number of postharvest pathogens.

Conclusion

The challenge in organic fruit production is timely control of several pests like hoppers, mealy bugs, stem bores, fruit flies, bugs, caterpillars, mites and moth and diseases like powdery mildew, anthracnose, sooty mould, stem rot, gummosis, panama, moko disease, mango malformation, etc. that drastically reduce fruit yields and quality. Knowledge of what method to use, when to use and how much to use to reduce pest and disease incidence without compromising the fruit yield and quality are most essential. Successful organic production requires an integrated approach to managing pests and diseases. A range of preventative measures is important to minimize susceptibility to pest and disease pressures. Weekly orchard monitoring or a visual inspection of mango trees is important to notice the presence of pests and beneficial insects in order to consider when to make pest management decisions.

A large number of parasites, predator and pathogens are very active against pests of fruits crop in the fields. Their presence and foraging activity hinder the fruit flies from laying eggs, resulting in reduced pest damage. These natural enemies should be conserved in the field. Strategies like crop diversification and ecological engineering by selecting flowering plants that are available and suitable to the agroclimate region, along with management practices adopting physical and biological control methods, can reduce pests and disease incidence without need to use any chemicals. There is an urgent need to increase search for new technologies and create awareness among fruit growers on the available technologies to adopt organic fruit production in India on large scale.

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