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The current situation of 'ambrosia wilt' in avocado plantations in Israel caused by the shot hole borer and its fungal symbiont *Fusarium*

Avocado in Israel is a growing industry. The plantations cover an area of approximately 7,000 ha with 'Hass', 'Ettinger' and 'Pinkerton' comprising the main varieties. During the 2010/11 season about 85,000 tons were produced (from a bearing area of 5,500 ha), with approximately 65% of the crop exported. For decades the use of frequent, prophylactic or responsive sprays has been avoided in avocado cultivation in Israel. However, the situation is now requiring the growers to consider the use of integrated pest management (IPM) schemes due to the establishment of the shot hole borer.

Host plant and symptom of injury of the shot hole borer

The shot hole borer, an ambrosia beetle, *Euwallacea* sp. near *fornicatus*, (Scolytinae) was first recorded in Israel in 2009 in an avocado plantation in Glil Yam (central coastal area). Soon after the beetle and its fungal symbiont *Fusarium* sp. nov. were found in other avocado plantations in that area and also in three other plant hosts, castor bean (*Ricinus communis*, a weed), box elder (*Acer negundo*) and *Quercus pedunculifolia* (Mendel et al. 2012). The latter 2 tree species are exotic ornamental trees. None of these four tree species are among the original hosts of the two ambrosia-associated beetle fungus organisms in their native habitat. The phenomena of ambrosia beetles attacking new tree species occurs following invasion into new areas with susceptible trees selected by the beetle, and when the fungus is able to overcome the tree resistance and colonize the botanical host (Hulcr and Dunn 2011). *Euwallacea* sp. near *fornicatus* tends to "test" different hosts in order to establish its fungal garden. So far only the four above mentioned tree species have been found to be suitable for the beetle reproduction in Israel. Successful colonization of the tree results in deterioration of the tree vitality followed by typical wilt, which may culminate, in the death of the infested branch and ultimately the entire tree. Mass attack of the beetle on tree species unsuitable for reproduction may also lead to severe injury. This scenario is often observed in Israel at the edges of persimmon plantations, and in case of several ornamental tree species, growing adjacent to suitable, infested host trees such as avocado (Fig. 1).

Figure 1: Shot hole borer attack on persimmon branches with the typical black gum pitchout.

The most typical symptom of infestation of avocado trees is the exudation of a white powdery sugar substance, perseitol, which pinpoints new penetration spots. Stems and branches of various diameters (2 - >30cm, corresponding more or less to 1 to 30 yr-old growth) may become infested by the beetle and display this symptom. These sugar pitchouts develop within a few days after infection turning into typical cankers that become larger with the beetle and fungus development in the xylem (Figs. 2,3,4). Trees further weakened by the beetle-fungus as-

Figure 2: Heavily infested stem (left) and the inside with xylem almost completely infested by *Fusarium* sp. nov.

Figure 3: Fresh (right) and less fresh (left) perseitol sugar exudate which pinpoints a new penetration spots by the shot hole borer..

Figure 4: Typical developed canker surrounding the initial penetration spot on an avocado tree indicating successful infestation of the wood with beetle galleries and the symbiotic fungus.

sault become more susceptible. At this stage, new beetle penetrations are not associated with massive sugar exudation. Exposure of the galleries within infested trees will reveal the various life stages of the beetle; eggs and larvae (Fig. 5,6) and adult male and female beetles (Fig. 7).

It is suggested that the problem had not been originally identified as a situation that required full attention. Avocado growers tended

Figure 5: The shot hole borer gallery in castor bean with eggs and young larvae.

Figure 6:Larvae of the shot hole borer in avocado xylem.

Figure 7: The female shot hole borer (left) next to young male taken out of the gallery in avocado xylem. Note the red discoloration of the wood tissue due to the symbiotic fungal infection of *Fusarium* sp. nov.

to relate the perseitol exudation to mechanical injury which exhibits similar symptoms. Furthermore, there is no visible injury to the cortex at this stage of beetle colonization, and only exposure of the wood under the infested spot reveals the conspicuous brownish-red color xylem strips stained by the fungus (Figs. 8,9). Further symptoms appear to develop after one or two growing seasons after initial tree colonization, which eventually becomes conspicuous with respect to beetle density and diameter of the affected branch. These symptoms include: (Figs. 10,11) (i) wilting of branches and discoloration of the leaves (); (ii) breakage of dying and live branches laden with heavy yield; branches broken at the section where the beetle galleries were established (Fig. 12); and (iii) eventual mortality of young and mature trees. In many cases infested avocado trees growing in back yards of private homes seem to survive

Figure 8: A typical colored discoloration of the wood as a result of a newly established gallery of the shot borer in an avocado branch indicating on the spread of the fungus.

Figure 9: The red brownish staining on the section surface implies that most of the xylem is already damaged by the fungus..

Figure 10: Small diameter branches, usually inside the tree crown are the first to display the typical wilt symptoms.

Figure 11: Wilting of large branches in heavily infested avocado orchard.

Figure 12: Branches with heavy yield are frequently broken at the point where the beetle galleries were established.

but display a steep reduction of fruit set and eventual yield. The symptoms of infestation in avocado differ from the typical signs of infestation on other suitable or non-suitable host tree species. However, the typical wilting of a colonized tree organ is rather similar among the various affected trees (Mendel et al. 2012).

All avocado varieties are susceptible to some degree, with 'Hass', 'Reed', 'Pinkerton' and 'Pino' being preferred by the beetle and resulting in the most damage. 'Ettinger' and 'Fuerte' appear to be least susceptible. The beetles may penetrate any branch of any width, however, predominant development was observed on >4 cm diameter branches.

Spread of the problem in Israel

In retrospect, circumstantial observations by the growers of the perseitol exudate phenomenon were reported and documented as early as 2007, suggesting that the beetle had been introduced to Israel around 2004. However, the growers did not relate the symptoms of infestation with any substantial damage. As yield is not affected during the early stages of beetle colonization, no action was taken to stop or to slow the spread of the pest. Furthermore, past outbreaks of local or introduced arthropod pests were relatively quickly overcome usually by local and in few cases by introduced natural enemies (Swirski et al. 1995). Upon discovery of the shot hole borer the growers' general attitude was to ignore the problem with the idea that it would decline by itself, similar to the problem of the persea mite, *Olygonychus* perseae, that had spread in local avocado plantations in the early 2000's and was effectively restrained by local Phytoseiid predators (Maoz et al. 2007). However, between 2009 and the autumn of 2012 the infected problematic area colonized by the ambrosia beetle grew from a few reported plantations in the vicinity of Tel Aviv to all the central and southern Coastal areas, with the number of infested plots and the severity of the damage increasing at an alarming rate. Lately (September 2012), a new infested avocado plantation was detected in the upper Galilee region. The role of other suitable host species acting as a springboard in the spread of the beetle and its symbiotic fungus has not been thoroughly studied. However, in several occasions we observed infested castor bean plants growing adjacent to avocado plantations not yet colonized by the beetle. In certain cases, the infestation has spread to these previously non-infested avocado orchards.

In the case of redbay laurel (Persea borbonia) trees in the southeastern region of the United States, few individuals of the ambrosia beetle, *Xyleborus glabratus*, are sufficient to infect a tree with the symbiotic fungus, *Raffaelea lauricola*, which rapidly spreads in the sapwood and the entire crown eventually wilts over a period that may take from a few weeks to 2-3 months (Jorge Peña, personal communication) Preliminary observations suggest that the *Fusarium* sp. nov introduced by *Euwallacea* sp. near *fornicatus* spreads much slower in avocado trees. It seems that repeated beetle attacks and the presence of the beetles are required for a more rapid spread of the fungus. The fungus may spread to a distance of at least 150 cm along the tracheids in the xylem tissue from the infestation point in the avocado tree. However, the exact rate of and factors related to spread of the fungus still need to be studied.

The management challenge of the shot hole borer and its symbiotic fungus

Management of insect pathogen vectors to prevent infection is difficult since only a small number of flying individuals are needed to cause rapid spread of the pathogen to new plant hosts. There is a general agreement that insect-vectored diseases may cause complex problems that are difficult to manage and need serious research attention. These problems are characterized by additional vectoring of systemic pathogens usually difficult to control (viruses) and/or to reach (fungi that develop in the tree xylem). The insect vectors also pose a management challenge whereas in many cases they are not good candidates for efficient biological control or management by application of semiochemicals (such as leaf and plant hoppers or Scolytinae ambrosia beetles). In the case of *Euwallacea* sp. near *fornicatus*, emphasis on the control and mainly on prevention of beetle infestation should be the preferred approach since few beetles will not be able to cause serious damage and spread of the fungus is relatively slow.

In the current absence of any good management recommendations of similar cases, contact insecticides are normally thought to be useful. However, the use of persistent insecticides, both cover and systemic compounds will need to be applied frequently. This will impose a dramatic negative change in the management of the local avocado plantations in Israel, where pest control procedures until late were much similar to that practiced in organic farms.

The potential use of several pesticides to cope with the problem was evaluated in both laboratory and field trials. In an effort to control the fungal pathogen, various fungicides and insecticides, mainly possessing systemic modes of action, were screened for inhibition of fungal growth in vitro in Petri dishes. Of the 27 fungicides tested, five (carbendazim, prochloraz, tebuconazole, metaconazole and bromuconazole) inhibited fungal growth between 90 to 100% *in vitro*. Of the 10 insecticides tested in the lab, four gave good results (Emamectin benzoate, Imidacloprid, Acetamiprid and Thiamethoxam). However, field trials, with these compounds, tested by different methods of application (injection, spray and/or drench) which seemed to be promising in the lab, did not display convincing results. All of which did not seem to reduce infestation or the fungal spread to acceptable levels. Systemic pesticides are considered less hazardous to the fragile biological balance in local avocado plantations. Imidacloprid for example has been successfully applied against different Hemiptera (sucking insects) vectors of various pathogens, but there is no evidence of its efficacy against wood dwelling beetles. Therefore, it appears that under the current epidemic in Israel a cover spray with more potent insecticides should be used to halt the buildup and the spread of the beetle population, especially to non-infested areas.

What went wrong?

The information about the occurrence of the ambrosia problem and risk posed by this threat was not disseminated widely enough to the growers' community. Although several meetings with growers from different avocado production areas were conducted and seminars focusing on the beetle and the fungus role in the syndrome were well described, not much has changed in light of the severity of the problem. The holistic approach to the problem has not been considered as well as the idea that, from the economical perspective, prevention may be the best solution and least expensive in the short term. The growers tended to postpone the treatment against the beetle in seriously infested plantations for different reasons, for example, by delaying the treatments after the fruit picking season in order to avoid insecticide residues in fruit. Others avoided insecticide application as long as honeybee activity was present. The results of the unwillingness to make an effort to control the beetle population in those particular plots are understandable from the grower's perspective given the lack of information at the time of the first infestations. In retrospect this was a strategic mistake since the beetle populations grew and spread exponentially from these "islands" of small infested plots to the larger avocado area, free of the pest. The idea that prevention can reduce the severity of the problem at the country level was put aside. During the past months a major effort was conducted by the growers to treat the heavily infested groves with a cocktail of two organophosphate insecticides, Methomyl and Chlorpyrifos-ethyl (two consecutive treatments within a two-week interval). These compounds were selected (although their efficacy is not sufficiently high) based on the idea that their residues will be as low as practically possible and within the "safe" limits. However, focusing on the heavily infested plot alone may not be enough to stop or even to reduce the spread of the beetle to neighboring plots and adjacent non-infested areas.

Suggestions for immediate action by the avocado growers in Israel

Although we lack essential knowledge how to cope with this serious situation of the risk posed by the beetle and its symbiotic fungus, there are several steps that should be implemented immediately to prevent the approaching disaster to the avocado industry. Based on the lack of effective suitable insecticides to cope with the problem an area-wide management should be considered as a major solution to the damage caused by the avocado shot hole borer. We propose a comprehensive and integrated approach to managing the population of the beetle in Israel.

The most immediate action aims at developing a comprehensive sampling network for infested trees mainly for the avocado plantations and pockets of the castor bean plants. This should include the categorizing of the avocado plantations according to the four following groups: (a) heavily infested plantations, (b) plots with first symptoms of infestation, (c) symptom-free plots adjacent (< 2km) to infested plots of other trees (for example pockets of castor bean bushes) and (d) symptom-free plantations within or out of range of the infested avocado areas. The other set-up actions should include effective spray management schemes. Four modes of action are suggested with respect to the target habitat: (1) cover spray applied on the stems and branches of the trees in heavily infested plots, (2) pinpoint application of insecticides on new penetration points in newly infested plots, (3) preventive treatments on the borderline between infested and non-infested plantations, (4) since eradication of the pockets of castor bean bushes is probably impractical, the idea to employ them as trap trees by treating them with insecticides, may be considered. In each of the four above categories of infestation, different compounds should be used.

Concluding remarks

The shot hole borers found in Israel and California are identical and carry the same fungal symbiont *Fusarium* sp. (nov.). Comparisons of the mtDNA and rRNA of the typical *Euwallacea fornicatus* tea shot hole borer native to Sri Lanka and that of the Israeli and California shot hole borer of avocado show that they are different but appear to be closely related species. So far there is no effective solution for management of the problem. The conspicuous penetration points make the monitoring and 'surgical' treatments of the initial beetle infestation feasible. For the moment, preventive management, including surveys, sanitation and intensive chemical treatments should be considered in order to stop or reduce the spread of the pest.

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