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The shot hole borer (Ambrosia beetle): Deciphering component in wilt complex as an emerging issue in pomegranate-A review

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ABSTRACT

Ambrosia *i.e.* shot hole borer beetles are beetles of the weevil subfamilies Scolytinae and Platypodinae (Coleoptera, Curculionidae), which live in nutritional symbiosis with ambrosia fungi. The beetles excavate tunnels in preferably wilted dead, stressed plants and little bits in healthy trees in which they cultivate fungal gardensas their sole source of nutrition. The shot hole borer, *Xyleborus fornicatus* severely affected pomegranate as this pest occurs sporadically in Ahmednagar. Life cycle from egg emergence to adult life of this pest was completed in 34 days with 13:1 female to male ratio. The symbiotic fungus *Fusarium euwallaceae* is associated with *Euwallaceae fornicatus* causing branch dieback once introduced. Beetle play key role in the mechanical transmission of wilt pathogens. Because of haplodiploidy nature there is no need to find mates, brother-sister mating increases the chances of colonization and therefore, one or a few individuals are sufficient to establish a new population. As deciphering component, the wilt incidence reported from 0 to 46.3 per cent of survey report in Bagalkote followed by Belgavi in Karnataka and stated that the infestation of shot hole borer alone was not noticed. Furthermore, association of shot hole borer and nematode results in higher per cent disease incidence. Maintaining healthy trees by reducing physiological stress is the first recommendation for long term control. If growers maintain optimal condition the ubiquitous amborsia beetle will be in consequential. Pasting of geru with and drenching of emamectin benzoate at 2 g + propiconazole 1 ml per litre water in infested plant will be effective remedy for the management of pest with symbiotic fungal inoculum.

Introduction

Shot Hole Borer, *Euwallacea fornicatus* has a complex taxonomic history. *E. fornicatus* was originally described as *Xyleborus fornicatus* by Eichhoff in 1868 from an unknown host plant and locality (Danthanarayana, 1968). Outside Ceylon this species is known to occur only in Java, Malaya; Formosa and India. (Austin, 1956). It was referred to as *E. fornicatus* species complex. Without making any attempt to

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resolve the taxonomy, they were referred to as vernacular names, the polyphagous shot hole borer (PSHB), kuroshio shot hole borer (KSHB) and tea shot hole borer (TSHB). *Euwallacea* is a genus of over 40 species within the largest tribe of scolytine beetles the Xyleborini, which contains nearly 1200 described species (Hulcr*et al.,* 2015).

Ambrosia beetles are beetles of the weevil subfamilies Scolytinae and Platypodinae (Coleoptera, Curculionidae), which live in nutritional symbiosis with ambrosia fungi. The beetles excavate tunnels in wilted, dead, stressed and healthy trees in which they cultivate fungal gardens, their sole source of nutrition. In tunnel releases spores of its fungal symbiont. The fungus penetrates the plant's xylem tissue and extracts nutrients (Kasson *et al.,* 2016). Recent reports, in California have shown that invading beetle species might act as pests as they can carry plant pathogens within their symbionts (Hulcr and Dunn, 2011). This is in the case of beetles in the *Euwallacea fornicatus* (Eichhoff) species complex, which are native to Southeast Asia (Gomez *et al*., 2018). Ecological and biological features, such as fungus-farming, haplodiploidy reproduction and a wide host range, make the Xyleborini one of the most successful colonizers (Kirkendall *et al*., 2015). Most of the ambrosia beetle evolved from bark beetles bores into wood tissue and feed on it. However, ambrosia beetle not consume any wood tissue (Johnson *et al*., 2018). Despite, the common narrative in the scientific literature, most ambrosia fungi are poor wood degraders (Licht and Huang *et al*., 2019). About 5,812 species under two subfamilies 25 tribes and 225 genera are known from the world (Wood and Bright, 1992). Out of these, about 270 species, 65 genera, 18 tribes and two subfamilies are so far recorded from India. The fungus commonly associated with the ambrosia beetle *Xyleborus fornicatus* Eich., is described as new and named as *Monacrosporium ambrosium* (Gadd and loos, 1947) in Srilanka while in California and Israel it is *Fusarium euwallacea* (Freeman *et al*., 2013)

Economic importance of shot hole borer (Ambrosia beetle)

In Southern India and Sri Lanka, *E. fornicatus* is an important pest of tea crop (CABI, 2015; Walgama, 2012), but the information about quantified loss cause by this pest is little precise. In Sri Lanka, this pest covers more than 75% of the total tea growing extent (Walgama, 2014), characteristics such as concealed habit, wide distribution and wide host preference make pest control difficult (Walgama, 2014).This pest has recently become a serious pest of pomegranate in Southern India. In California, the Shot hole borer also threatens avocado tree. The losses could be high, as California is the main producer of avocado in the USA, and it is estimated at $350 million per year (Ploetz *et al.,* 2013).Currently, this pest having largest economic impact on avocado in Israel cover approximately 7,000 ha.

Life history: The life history was recorded from the commencement of boring a gallery to egg-laying (8 days); egg period (7 days); larval stage (15 days); pupal stage (7 days). Therefore, the life cycle from egg to egg was found to about 40 days. The total life cycle including longevity was about 42 days. Distinct sexual dimorphism was observed among adult beetles, and usually females were more in number than males with a sex ratio of 13 female: 1 male per tube (Jayanthi Kamala *et al.,* 2020).

Pomegranate shot hole borer: The spread of *E. fornicatus* to various regions around the world and the damage that has followed appear to suggest that this species is much more invasive and damaging than the remaining ones (Smith *et al*., 2019). While, some of the greatest damage in natural systems appear to be associated with tree stress including flooding and pollution (Boland and Woodward, 2019).

Host: The shot hole *borer, X. fornicates* infestation on pomegranate in Maharashtra was first r eported b y Mote f rom Ahmednagar district in the year 1991 and recorded new host for this pest from this area (Mote,1991). Further, *X. perforan* was observed as new record on pomegranate in Karnata-ka (Jagginavar and Naik, 2001) has been recorded as a new host of shot hole borer, *Xyleborus perforans* (Wollastan) in Karnataka (Naik and Nandihalli, 1996). Kumar *et al.* (2011) recorded new host plant for shot hole borer on *Persea bom-bycina* Kost (Lauraceae) from Jorhat of Assam in India and causes appreciable damage during year 2010. *E. fornicatus* is reported as a pest of tea in several places in south east Asia (CABI, 1973 and James, 2007).

Host selection: Even though ambrosia beetle often said to colonize stressed, dead or living trees. Only very few am-brosia beetle species and their fungal associates such as the black twig borer, *Xylosandrus compactus* are able to colonize healthy living trees, attack only the twigs of healthy trees causing the end of the twig to die. However, a few species including *E. fornicatus*, *E. kuroshio*, and *E. perbrevis*, colonize healthy trees and cause damage through mass accumulation (Hulcr and Stelinski, 2017). Owens *et al.* (2018) reported that the adult females usually disperse during the day, attacking hosts in a range of tens of meters (hundreds of feet). The SHB activities were observed in the wilt-infected pomegranate plants with symptoms of branch drying and leaf shedding ranging from 15.0 % to 100.0% (Jayanthi Kamala *et al*., 2020).

Factors influencing the shot hole borer attack: In nutrient enrichment increases their susceptibility to shot hole borer attack. After attacked by the KSHB, the trunks and branches of these nutrient enriched trees provide an environment con-ductive to the fast growth of the symbiotic fungi upon which

KSHB feeds (Boland and Woodward 2019). Nutrient enrichment influence wood characteristics, and heavy fertilization and irrigation leads to fast growth, low density wood and high moisture content in several species of trees (Hacke *et al.*, 2010 and West, 2014). The standard medium for growing ambrosia beetles and their symbiotic fungi in the laboratory is water based and rich in nutrients. The growth rates of the fungi and larvae of ambrosia beetles are positively correlated with the moisture content of host plant. (Jayanthi Kamala *et al.*, 2020).

Plant part affected and their symptoms: The severity of this pest was observed on main trunks and branches of pomegranate in Maharashtra (Mote and Tambe, 1991). Generally, shot hole borer occurs in maximum numbers at the base of the trunk in 0 to 30 cm, trunk height with more incidence on older plants than younger plants (Tambe and Mote, 1997). The correlation between age of the plant and total number of shot holes indicated a significantly positive relationship (Jagginavar and Naik, 2004). Jagginavar and Naik, 2001 observed the more activity at ground level (0 to 30 cm) than on the higher trunk level (31 to 90 cm).

Spread: From an infested tree adults migrate, within a month, to the nearest healthy trees and further infestation starts. The rate of spread of infestation at this time will be rapid and a whole orchard can show symptoms within 3 to 6 months. From one orchard, the infestation can spread to neighbouring orchards easily (Verghese and Jayanthi, 2001).

Potential impacts and challenges for its management

Ambrosia beetle exposure to surface-applied insecticides is minimal after internal trunk galleries are formed, so effective management requires insecticide treatments to be applied near the time of infestation or to have residual activity on the bark (Matthew *et al.,* 2020). With regard to the fungus, according to Batra 1985, since mutualistic insect pests in general will not survive or reproduce in nature without their mycosymbionts, it is evident that controlling the fungus may also control the insect. Several fungicides such as carbenzamin, prochloraz and tebuconazole, have been evaluated on avocado crop. In laboratory experiments, all of them seemed to inhibit fungus growth, however fungicides were not effective in field trials (Freeman *et al.,* 2012 and Mendel *et al.,* 2012).

Wilt disease component

Studies revealed that wilt disease shows symptoms caused by many contributing biotic and abiotic factors. Several biotic factors like fungal pathogens (viz. *Ceratocystis fimbriata*, *Fusarium spp*., *Macrophomina phaseolina*, *Phytophthora spp*., *Rhizoctonia bataticola*, *Rosellenia necatrix*, *Verticillium dahliae*), insects (scolytid beetle, *Xyleborus perforans* (Wollaston)) and nematodes (root-knot nematode, *Meloidogyne incognita*) were found to play a crucial role in disease progression (Darekar *et al.*, 1990). Similar observations were also recorded by (Shreeshail *et al.*, 2016) that *Ceratocystis fimbriata*, *Meloidogyne incognita* and shot hole borer are responsible for causing wilt complex with a high frequency of earlier two pathogens from soil and root sample.

The role of Island pinhole borer, *Xyleborus perforans* (Wollaston) popularly known as pomegranate shot hole borer (SHB), in causing pomegranate wilt is well established (Sharma *et al.*, 2010; Somasekhara and Wali, 2000). In Japan, the known causal agent of wilt disease on fig trees (*Ficus carica* L.) is *Ceratocystis ficicola* (Kajitani and Masuya., 2011). Fig wilt disease (FWD) has been found to be caused by the infestation of ambrosia beetle, *Euwallacea interjectus* (Blandford) (Kajii*et al.*, 2013).

Preventative and curative management

Beetles are not the cause of the tree stress but a sign of other stressors. Focusing management on the beetle is likely going to be less effective than ameliorating the underlying causes. If growers maintain healthy trees and optimal growing conditions, the ubiquitous ambrosia beetles will be mostly inconsequential (Hulcr and Skelton, 2023). The association of beetles with symbiotic and auxiliary fungi presents another challenge because the symbionts of beetles are known to be pathogenic on their hosts (Lynch *et al.,* 2016; Mendel *et al.*, 2012 and Na *et al.*, 2018). Mayorquin *et al.* (2018) highlighted the possibility for two levels of management: one to directly manage vector populations and a second level which aims to manage the fungal populations established by shot hole borer once a host has been invaded. One of the major challenges appears to be the effective introduction of the chemicals into the vascular system, particularly in infested trees where the distribution of the chemical may be disrupted by tunnelling and fungal colonization (Mayorquin *et al.*, 2018). Maintaining plant health by reducing physiological stress is the first recommendation for long-term control (Gugliuzzo *et al.*, 2021).

Control has been a difficult task as a result of concealed habit virtually protected from parasites and predators. Biological control using entomopathogenic fungus, *Beauvaria bassiana*is being viewed as an environmentally friendly alternative to chemical control in the light of growing concern on the usage of pesticides. Laboratory studies have shown that strains of this fungus are highly pathogenic to shot hole borer imparting more than 90 % mortality (Walgama *et al.,* 2006). Anonymous (1993) recommended preventing for control shot hole borer (*Xyleborus* spp.) which is associated with wilt disease, 10 litres preparation (paste) containing red soil (4 kg) + chlorpyriphos 20 EC (20 ml) + copper oxychloride 50 WP (25 g) needs to be applied on stem surface from plant base up to 2 ft. from second year onwards. Pasting should be done twice a year; once soon after the harvest and once at defoliation, before crop regulation. Mayorquin *et al.* (2018) in California conducted study on sycamore (*Platanus racemosa*) for chemical management of invasive shot hole borer and Fusarium dieback which revealed that, the fungicides revealed that pyraclostrobin, trifloxystrobin and azoxystrobin generally have lower effective concentration that reduces 50 % of mycelial growth (EC_{50}) values across all fungal symbionts of PSHB and KSHB. A one year field study showed that two insecticides, emamectin benzoate alone and in combination with propiconazole, and bifenthrin, could significantly reduce SHB attacks. Two injected fungicides (tebuconazole and a combination of carbendazim and debacarb) and one spray fungicide (metconazole) could also significantly reduce SHB attacks. In California Grosman *et al.* (2019) recorded that, the preventive treatments with Emamectin benzoate + propiconazole was the most effective treatment for reducing polyphagous shot hole borer attack levels, sap flow/bleeding from attack holes, proportion of beetle emergence and tree mortality. Emamectin Benzoate alone appears to be more durable lasting for one year when beetle pressure is high or as many as more than two years when pressure is relatively light. Emamectin benzoate + propiconazole had the greatest durability; being able to suppress beetle attacks for two years under high beetle pressure.

Jones and Paine (2018) noted that bifenthrin was the most effective insecticide for reducing beetle attacks and gallery formation in castor bean branches in laboratory with cut branches. Byrne *et al.,* (2020) conducted several field trials of trunk injection of systemic insecticide emamectin benzoate in avocado trees. Emamectin benzoate established quickly within trees at the threshold concentration in the areas most vulnerable to attack and colonization by KSHB. Injection of the insecticide in a more dilute form promoted both faster uptake and more rapid establishment of effective concentrations than the undiluted form.Rudinsky (1966) reported that a shortage of suitable breeding material is a decisive factor in limiting *Xyloborum fornicatus* numbers. Speyer (1917b) suggested that removing castor oil plants, which are an alternative host plant for *Xyleborus fornicatus*. The first attempt at biological control was made in 1909 (Austin 1956) with a predacious beetle, *Clerus fornicarious* Fischer, from Scotland, but the beetle larvae were too large to live in *Xyloborum fornicatus* galleries. The chalcid *Perniphora robusta*, a principal parasite of bark beetles in Europe was imported in 1970, whereas another chalcid, *Tricholasxylpcleptis* and a braconid, *Heterospilusater* were imported and released in the tea plantations in mid country but with no success as the parasites failed to establish (Danthanarayana, 1970; Sivapalan, 1974 and Thirugnanasundaran, 1989). Danthanarayana (1966) tested a strain of *B. bassiana* fungus showed promise in laboratory experiments, but attempts at control under field conditions proved futile.

Conclusion

Shot hole borer beetles belong to the weevil subfamily Scolytinae (Coleoptera, Curculionidae) and engage in a nutritional symbiosis with ambrosia fungi. These beetles create tunnels in wilted, dead, or stressed plants, cultivating fungal gardens that serve as their primary source of nutrition. To achieve long-term control in pomegranate cultivation, the first recommendation is to maintain plant health by minimizing physiological stress. Preventive measures for managing the shot hole borer (*Xyleborus spp.*), which is associated with wilt disease, include applying a trunk paste made from 10 litre preparation containing 4 kg of red soil, 20 ml of chlorpyrifos 20 EC, and 25 g of copper oxychloride 50 WP. This mixture should be applied to the stem surface from the base of the plant up to 2 feet, starting from the second year before crop regulation. Alternatively, drenching infested plants with a solution of 2 g of emamectin benzoate and 1 ml of propiconazole per litre of water can be an effective remedy for managing this pest along with its symbiotic fungal inoculum.

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References

Anonymous. 1993. Recommendation on Studies on management of shot hole borer, *X. fornicates* infesting pomegranate by Mahatma Phule Krishi Vidyapeeth, Rahuri presented in Research Review Meeting /joint agresco.1993. Pp. 32-35.

Austin, G. D. 1956. Historical review of shot-hole borer investigations. *Tea Quarterly*, 27: 97-102.

Batra, L. R. 1985. Ambrosia beetles and their associated fungi: Research trends and techniques. Proceedings of the Indian Academy of Science (Plant Sciences), 94:137-148.

Boland, J. M and Woodward, D. L. 2019. Impacts of the invasive shot hole borer (*Euwallacea kuroshio*) are linked to sewage pollution in southern California: The Enriched Tree Hypothesis. *Peer J7*: e6812.

Byrne, J. Frank. Almanzor, Janine, Tellez Ivan, Eskalen Akif, Grosman M Donald and Morse G. Joseph. 2020. Evaluation of trunk-injected emamectin benzoate as a potential management strategy for kurushio shot hole borer in avocado trees. *Crop Protection,* 132: 105-136.

CABI, 1973. Distribution Maps of Plant Pests, *Xyleborus fornicatus*.

Map 319. *CAB International*, Nosworthy Way, Wallingford, Oxfordshire, Oxio 8de, UK.

CABI, 2015. *Euwallacea fornicatus*. In: Crop Protection Compendium. Wallingford, UK: CAB *CAB International*. www.cabi.org/cpc.

Danthanarayana, W. 1968. The distribution and host-range of the shot-hole borer (*xyleborus fornicatus Eichh*). *Tea Quarterly,* 39(3): 61-69.

Danthanarayana, W. 1966. Shot-hole borer control. *Tea Quarterly,* 37: 100-105.

Danthanarayana, W. 1970. The control of shot-hole borer (*Xyleborus fornicatus* Eichh). of tea. First Annual Report of Research Conducted Under Grant Authorized by U.S. Public Law 480. Tea Research Institute of Ceylon, Talawakelle, Sri Lanka.

Darekar, K. S., Shelke, S. S. and Mhase, N. L. 1990. *Int. Nematol. Netw. Newsl.*, 7, 11-12.

De, Fine Licht, H. H. and Biedermann, P. H. W. 2012. *Front. Zool.*, 9-13.

Freeman, S., Sharon, M., Maymon, M., Mendel, Z., Protasov, A., Aoki, T. and O'Donnell, K. 2013. *Fusarium euwallaceae* sp. nov. - a symbiotic fungus of Euwallacea sp., an invasive ambrosia beetle in Israel and California. *Mycologia*, 105(6), 1595-1606.

Freeman, S., Sharon, M., Okon-Levy, N., Protasov, A., Eliyahu, M., Noi, M., O Donnell, K. and Mendel, Z. 2012. Fungicide screening for inhibition of the fungal symbiont Fusarium sp. In: Israel Invasive Ambrosia Beetle Conference. The Situation in California. Riverside, California (USA).

Gadd, C. H. and Loos, C. A. 1947. The ambrosia fungus of *Xyleborus fornicates* Eichh. *Trans. Br. Mycol. Soc.,* 31: 13-18.

Gomez, D.F., Skelton, J., Steininger, M.S., Stouthamer, R., Rugman-Jones, P., Sittichaya, W., Rabaglia, R.J. and Hulcr, J. 2018. Species delineation within the *Euwallacea fornicatus* (Coleoptera: Curculionidae) complex revealed by morphometric and phylogenetic analyses. *Insect Syst. Divers*, 2(2): 1–11.

Grosman, D. M., Eskalen, A. and Brownie, C., 2019. Evaluation of emamectin benzoate and propiconazole for management of a new invasive shot hole borer (*Euwallacea* nr. *fornicatus*, Coleoptera: Curculionidae) and symbiotic fungi in California sycamores. *Journal of Economic Entomology*, 112(3):1267-1273.

Gugliuzzo, A., Biedermann, P. H., Carrillo, D., Castrillo, L. A., Egonyu, J. P., Gallego, D. and Biondi, A. 2021. Recent advances toward the sustainable management of invasive Xylosandrus ambrosia beetles. *Journal of Pest Science*, 94: 615-637.

Hacke, U G., Plavcova, L., Almeida-Rodriguez, A., King-Jones, S, Zhou, W. and Cooke, J.E.K. 2010. Influence of nitrogen fertilization on xylem traits and aquaporin expression in stems of hybrid poplar. *Tree Physiology,* 30(8): 1016-1056.

Huang, Y-T., Skelton, J. and Hulcr, J. 2019. Multiple evolutionary origins lead to diversity in the metabolic profiles of ambrosia fungi. *Fungal Ecol.,* 38: 80–88.

Hulcr, J., Atkinson, T. H., Cognato, A. I., Jordal, B. H. and McKenna, D. D. 2015. Morphology, taxonomy andphylogenetics of Bark Beetles. In: Vega FE, Hofstetter RW (eds) Bark Beetles. *Elsevier*, 41–84.

Hulcr, J. and Stelinski, L.L. 2017. The ambrosia symbiosis: from evolutionary ecology to practical management. *Annual Review of Entomology*, 62: 285-303.

Hulcr, J. and Dunn, R.R. 2011. The sudden emergence of pathogenicity in insect-fungus symbioses threatens naive forest ecosystems. *Proc. R. Soc. Biol. Sci*., 278: 2866–2873.

Hulcr, J. and Skelton, J. 2023. Ambrosia Beetles. In: D. Allison, J., Paine, T.D., Slippers, B., Wingfield, M.J. (eds) *Forest Entomology and Pathology*, Springer, Cham.

Jagginavar, S. B. and Krishna Naik, L. 2001. A new species of shot hole borer attacking pomegranate. *Insect Environ*., 6(4):167-168.

Jagginavar, S. B. and Krishna Naik, L. 2004. Distribution of pomegranate shot hole borer, *Xyleborus perforans* (Wollastan) (Coleoptera: Scolytidae) in northern Karnataka. *Indian J. Agric. Res*., 38(1):8-14.

James, P. Egonyu, John Baguma, Isaac Ogari, Gladys Ahumuza, Samuel Kyamanywa, Patrick Kucel, Godfrey H. Kagezi, Mark Erbaugh, Noah Phiri, Barbara J. Ritchie and William W. Wagoire. 2015. The formicid ant, *Plagiolepis sp*., as a predator of the coffee twig borer, *Xylosandrus compactus*. *Biological Control,* 91 42–46.

James, S.P. 2007. Studies on certain plant volatiles attracting the shot hole borer, *Euwallaceafornicatus* (Eichhoff) (Scolytidae: Coleoptera) infesting tea. Bharathiar University. Pp. 126.

Jayanthi Kamala, P. D., Raghava, T., Nagaraja, T. and Sreedevi, K. 2020. In vitro rearing and gallery tunnelling pattern of Island pinhole borer, *Xyleborus perforans* (Wollaston), a scolytid associated with pomegranate wilt complex. *Current Science,* 118(2):195-198.

Johnson, A. J., McKenna, D. D., Jordal, B. H., Cognato, A. I., Smith, S. M., Lemmon, A. R., Lemmon, ELM. and Hulcr, J. 2018. Phylogenomics clarifies repeated evolutionary origins of inbreeding and fungus farming in bark beetles (Curculionidae, Scolytinae). *Mol. Phylogenetics Evol.,* 127:229–238.

Jones,Michele Eatough and Paine, Timothy D. 2017. Potential pesticides for control of a recently introduced ambrosia beetle (*Euwallacea sp*.) in southern California. *Journal of Pest Science*, 91(1): 237-246.

Kajii, C., Morita, T., Jikumaru, S., Kajimura, H., Yamaoka, Y. and Kuroda, K. 2013. Xylem dysfunction in *Ficus carica* infected with wilt fungus *Ceratocystis ficicola* and the role of the vector beetle *Euwallacea interjectus*. IAWA. 34, 301–312.

Kajitani, Y. and Masuya, H. 2011. *Ceratocystis ficicola* sp. nov., a causal fungus of fig canker in Japan. *Mycoscience*, 52: 349–353.

Kasson, M.T., Wickert, K.L., Stauder, C.M., Macias, A.M., Berger, M.C., Simmons, D.R., Short, D.P., DeVallance, D.B. and

Hulcr, J., 2016. Mutualism with aggressive wood-degrading *Flavodonambrosius* (Polyporales) facilitates niche expansion and communal social structure in Ambrosiophilus ambrosia beetles. *Fungal Ecology*, 23: 86-96.

Kirkendall, L.R., Biedermann, P.H.W. and Jordal, B.H. Evolution and diversity of bark and ambrosia beetles. In Biology and Ecology of Native and Invasive Species; Vega, F.E., Hofstetter, R.W., Eds.; Academic Press: London, UK, 2015. pp. 85–156.

Kumar, R., Rajkhowa, G., Sankar, M. and Raja, R.K. 2011. A new host plant for the shoot-hole borer, *Euwallaceafornicatus* (Eichhoff) (Coleoptera: Scolytidae) from India. *Acta Entomologica Sinica*, 54(6): 734-738.

Lantschner, M. V., J. C. Corley, and A. M. Liebhold. 2020. Drivers of global Scolytinae invasion patterns. *Ecol. Appl.,* 30: e02103.

Lynch, S. C., Twizeyimana, M., Mayorquin, J. S., Wang, D. H., Na, F., Kayim, M., Kasson, M. T., Thu, P. Q., Bateman, C., Rugman-Jones, P. and Hulcr, J. 2016. Identification, pathogenicity and abundance of *Paracremoniumpembeum* sp. nov. and *Graphium euwallaceae* sp. nov. two newly discovered mycangial associates of the polyphagous shot hole borer (*Euwallacea sp.*) in California. *Mycologia*, 108: 313-329.

Matthew S. Brown, Karla M. Addesso, Fulya Baysal-Gurel, Nadeer N. Youssef, and Jason B. Oliver 2020. Permethrin residual activity against Ambrosia Beetle (Coleoptera: Curculionidae: Scolytinae) attacks following field aging and simulated rainfall weathering. *Journal of Economic Entomology*, 113: 5.

Mayorquin, Joey S., Carrilo, Joseph D., Twizeyimanamathias, Peacock Beth B., Sugino Y Kameron, Na Francis and Wang H Danny. 2018. Chemical management of invasive shot hole borer and fusarium dieback in California sycamore (*Platanus racemosa*) in southern California. *Plant Disease,* 102: 1307-1315.

Mendel, Z., A. Protasov, M. Sharon, A. Zveibil, S. Ben Yehuda, K. O'Donnell, R. Rabaglia, M. Wysoki, and S. Freeman. 2012. An Asian ambrosia beetle *Euwallacea fornicatus* and its novel symbiotic fungus Fusarium sp. pose a serious threat to the Israeli avocado industry. *Phytoparasitica,* 40: 235–238.

Mendel, Z., Protasov, A., Sharon, M., Okon-Levy, N., Eliahu, M., Maoz, Y., Golan, O., Noy, M. and Freeman, S. 2012. Lessons and insights from the chemical control trials of *E. fornicates* and its fungal symbiont in avocado plantations in Israel. Invasive Ambrosia Beetle Conference. The Situation in California. Riverside, California.

Mote, U. N. and Tambe, A. B. 1991. Observations on extent of damage caused by shothole borer on pomegranate and castor. *J. Maharashtra Agric. Univ*., 16: 439-440.

Mote, U.N 1991. New pest in India. *Tropical Pest Management*, 37(1):100.

Na, F., Carrillo, J. D., Mayorquin, J. S., Ndinga-Muniania, C., Stajich, J. E., Stouthamer, R., Huang, Y. T., Lin, Y. T., Chen, C. Y. and Eskalen, A. 2018. Two novel fungal symbionts *Fusarium kuroshium* sp. nov. and *Graphiumku roshium* sp. nov. of Kuroshio shot hole borer (*Euwallacea nr. fornicatus)* cause Fusarium dieback on woody host species in California. *Plant Disease*, 102: 1154-1164.

Naik Krishna, L. and Nandihalli, B.S. 1996. Observation on peculiar attack of shot hole borer on pomegranate in Karnataka. *Pestology,* 20(10):31-33.

Owens, D., L. F. Cruz, W. S. Montgomery, T. I. Narvaez, E. Q. Schnell, Tabanca, N., R. E. Duncan, D. Carillo and P. E. Kendra. 2018. Host range expansion and increasing damage potential of *Euwallacea fornicatus* (Coleoptera: Curculionidae) in Florida. *Florida Entomologist,* 101 (2): 229–236.

Ploetz, R.C., Hulcr, J., Wingfield, M.J. and Willhelm de Beer, Z. 2013. Destructive tree diseases associated with Ambrosia and bark beetles: Black Swan events in tree pathology. *Plant Disease*, 95(7): 856-872.

Rudinsky, A. 1966. Ecology of Scolytidae. *Annual Review of Entomology*, 7: 327–348.

Saranya, R. Yashoda, R. Hegde and Lingaraju, S.2023. Deciphering Components of Wilt Complex inPomegranate: A Case Study Based on Survey in Northern Karnataka. *Annals of Arid Zone*, 62(4): 281-289.

Sharma, K. K., Sharma, J. and Jadhav, V. T. 2010. Etiology of pomegranate wilt and its management. In: Fruit, Vegetable and Cereal Science and Biotechnology. Global Science Books. Pp. 96-101.

Shreeshail, Sonyal, Nargund, V.B., Puneeth, M.E., Benagi, V.I., Palanna, K.B., Madhu, Giri, S., Shivalingappa, H., Mahesha, H. S., Devanshu Dev, Anil Pappachan and YallappaJagarkall. 2016. Survey for pomegranate wilt complex caused by *Ceratocystisfimbriata* and Meloidogyne incognita in northern Karnataka. *Journal of Pure and Applied Microbiology*, 10(1).

Sivapalan, P. 1974. The control of shot-hole borer (*Xyleborus fornicatus*) of tea. Second Annual Report of Research Conducted Under Grant Authorized by U.S. Public Law 480. Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka.

Smith, Sarah, M., Gomez Demian, F., Beaver Roger, A., Hulcr Jiri and Cognato Anthony, I. 2019. Reassessment of the Species in the *Euwallacea Fornicatus* (Coleoptera: Curculionidae: Scolytinae) Complex after the Rediscovery of the "Lost" Type Specimen. *Insects*, 10, 261.

Somasekhara, Y. M. and Wali, S. Y. 2000. *Orissa J. Hortic*., 28, 84-89.

Speyer, E. R. 1917b. Shot-hole borer of tea. *Tropical Agriculturist,* 49: 17–21.

Storer, C., A. Payton, S. McDaniel, B. Jordal, and J. Hulcr. 2017. Cryptic genetic variation in an inbreeding and cosmopolitan pest, *Xylosandrus crassiusculus*, revealed using dd RAD seq. *Ecology and Evolution,* 7(24): 10974–10986.

Tambe, A. B. and Mote, U. N. 1997. Studies of shot-hole borer activity during different periods on pomegranate plants. *Pestology*, 21(6):55-59.

Thirugnanasundaran, K. 1989. A review on control methods of shot-hole borer in tea in Sri Lanka. Sri Lanka Journal of Tea Science, pp. 113–122. Conference Issue. Proceedings of the Regional Tea (Scientific) Conference, 19 –21 January 1988, Colombo, Sri Lanka.

UPASI Tea Research Foundation, 2003. *Annual Report UPASI Tea Research Foundation*, 76 India: *UPASI Tea Research Foundation*, 48-49.

Verghese, A. and Jayanthi, P. D. K. 2001. Integrated pest management (IPM) in major fruit crops. p.12-15. In: P. Parvatha Reddy, A. Verghese and N.K. Krishna Kumar (eds.), Integrated Pest Management in Horticultural Ecosystems, Capital Publishing Company, New Delhi.

Walgama, R. S. 2012. Ecology and Integrated Pest Management of *Xyleborus fornicatus* (Coleoptera: Scolytidae) in Sri Lanka. *Journal of Integrated Pest Management*, 3(4): A1-A8 (8).

Walgama, R. S., Senanayake, P. and De Seram, C. 2006. Exploring natural resources for sustainable management of ecosystems future challenges for control and management of *Xyleborusfornicatus*eichh. (Coleoptera Scolytidae), the shot-hole borer of tea in Sri Lanka. In: *Proceedings of International Forestry and Environment Symposium*.

Walgama, R.S. 2014. Symbiotic relationship in the tea ecosystem: Tea Shot-hole borer of Sri Lanka. Academic and Technical Workshop on *Xyleborusglabratus* and *Euwallacea sp*. Simposio Internacional sobremanejo y Control de PlagasCuarentenariasenelAguacatero.

West, P W. 2014. Growing Plantation Forests. London: Springer.

Wood, S.L. and Bright, D.E. 1992. A catalog of Scolytidae and Platypodidae (Coleoptera), Part 2: Taxonomic index. *Great Basin Nat. Mem*., 13, 1–1533.