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Integrated Pest Management of *Zeuzera coffeae* Nietner: An Efficient Approach to Reduce the Infestation of Walnut Trees

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ABSTRACT

Walnut (*Juglans regia*) is a valuable tree for its fruit, furniture wood and ecological purposes. It is widely grown on farmlands in Northern Areas of Pakistan, where it is a cash crop ranked third in value of exports after onion and tomato. It is attacked by a number of insect pests including walnut borer (*Zeuzera coffeae* Nietner) that adversely affects the yield and quality of the fruit and wood. This study describes the life cycle of the pest, the nature and extent of damage done to walnut, and the preventive measures applied under integrated pest management program (IPM) and includes the cautious use of chemical insecticides, mechanical means, cultural and biological control methods for the substantial control of walnut borer. The present study offers valuable information through IPM, which appears to be a promising approach for the control of walnut borer. Collectively this strategy has resulted in significant reduction of the pest population in the target area of district Dir, Pakistan.

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Key words
***Juglans regia*, Walnut borer, Integrated Pest control, Lepidoptera caterpillar.**

INTRODUCTION

Dir is a mountainous district of Pakistan that covers 5,280 sq. kms and has a population of 1.5 million. It is located ~ 120 kms north of Peshawar. It borders Afghanistan in the West, Chitral and Swat districts in the North East and Bajaur and Malakand agencies in the South. The district is traversed throughout its length by the Panjkora River, which rises at latitude 35-45 N to nearly 3,500 meters altitude near its northern most point and flows into the Swat River at its extreme south western point at latitude 34-40° N. In district Dir highest rainfall of < 200 mm is received in the month of March while lowest in the months of July, October, and November. The mean minimum winter temperature is ~ -2 ^{0}C and the summer mean maximum of ~ 38 ^{0}C (Khan *et al*., 2010; Ahmed *et al*., 2009; Siddiqui *et al*., 2009; Wahab *et al*., 2008; Ali *et al*., 2007; Anonymous, 1998; Champion and Seth, 1965).

Walnut (*Juglans regia*) belongs to Juglandaceae family and is indigenous to temperate regions of the world (Ozcan, 2009). It is cultivated in the northern areas of Pakistan. The walnut trees needs more water than pine species, which is the natural forest of district Dir. Walnut trees are cultivated close to watercourses and gullies. It is planted due to its quality timber and nuts. Walnut has played a significant role in the food industry (Martinez *et al*., 2008). Its nuts are known for organoleptic characteristics (Lopez *et al*., 1995), hypocholesterolemic effects (Sabate and Fraser, 1994; Abbey *et al*., 1994; Savage, 2005; Dogan and Akgulb, 2005; Pereira *et al*., 2008) and antihypertensive effects (Mexis *et al*., 2008; Arranz *et al*., 2008) and the bark of walnut is used for teeth cleaning (Ibrar *et al*., 2007). Walnut is a favorite dry fruit and the wood is used for manufacturing quality furniture. Because of the value of the wood to the farmer, it has been widely planted in recent years along with other fruit trees and fast growing fuelwood species. Walnut species are also cultivated in the temperate regions of the world for its nuts and timber (Zhang *et al*., 2009; Li *et al*., 2007; Khan and Khatoon, 2007).

The walnut trees are attacked by different insect pests causing damage to leaves, shoots and fruits. Recently, a serious attack of Walnut borer broke out in district Dir that affected the trees of all ages. The problem was tackled by conducting research and developing safer, practical and economic control measures. There is a great concern and awareness for environmental pollution.

In the current study, identification, life history and phenology of the insect was carried out and its natural predators were investigated and identified. As, the larvae resides inside the terminal tender shots of walnut trees therefore the pesticides use is not an effective way to control the pest. In current study, *Z. coffeae* infestation is efficiently minimized by applying IPM approach in the infested area. Different control methods (mechanical, cultural, chemical and biological) were used that minimized the infestation rate of walnut borer in the target area of district Dir.

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MATERIALS AND METHODS

Study areas

The current study was conducted in Sultan Khel (Upper and Lower), Usherai, Tormang, Laram and Karo Valleys of district Dir to find out the extent of damage caused by walnut borers and to record the extent of infestation of walnut trees.

Sampling scheme

The walnut trees from 1-50 years old on the farmlands were selected to observe the *Z. coffeae* infestation. The dry infested branches were collected to record the intensity of damage. In each locality 10 infested trees were observed and the sampling sites were plotted on the geographical map of district Dir.

Integrated pest management (IPM) program

Integrated pest management (IPM) which is an environmental friendly program was applied in the studied area to minimize the *Z. coffeae* infestation in walnut trees. In IPM program different control methods i.e. mechanical, cultural, chemical and biological were applied in order to minimize the infestation rate of walnut borer in the target area of district Dir.

Statistical analysis

Data were expressed as Mean±SEM. The infested trees and branches per tree before and after treatment in different localities were compared separately using ANOVA followed by Tukey's Test for multiple comparisons. Regression analysis was used to determine the relationship between gallery length and body length of pest. All statistical analyses were performed using Minitab version 17.1.0 (Minitab Inc. State College, PA 16801 USA).

RESULTS

Nature of pest damage

The sampling sites were plotted on the geographical map of district Dir (Fig. 1). The insect was found in the larval stage in 1-2 feet long tunnel excavated from the top of the tender shoot down to the main branches. The caterpillars are present at an elevation of 900-1550 meter in trees of all ages. The farmers of district Dir did not observed the pest before 2010 on walnut trees. It seems that the pest arrived by some means and has established its population within the last 4-5 years. It has been noted that the severity of infestation increases with time. There is a possibility that the population of walnut trees will perish if pest is not controlled.

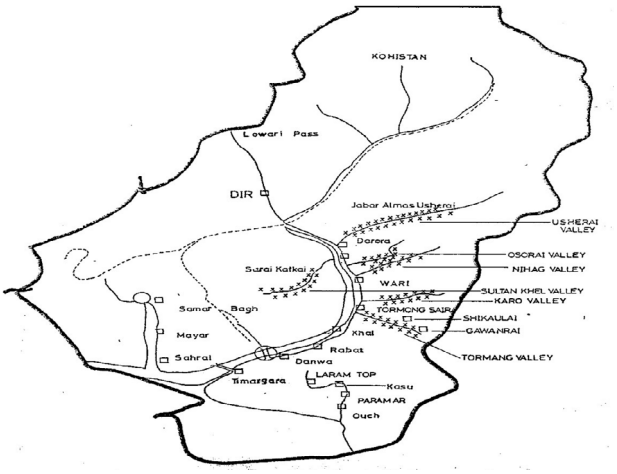

Fig. 1. Geographical map of district Dir where symbol x shows the walnut borer infestation.

Mechanical control of Z. coffeae

Z. coffeae was found in the larval stage, which feeds on the tender branches of infested walnut trees. The larvae were inside the branches so it was difficult to control it by spraying pesticide. Infested dry twigs were pruned from walnut trees to study the life cycle of the pest as well as to record its natural predators.

Chemical control of Z. coffeae

The larvae of *Z. Coffeae* feed inside the terminal shoots as a concealed feeder. However, the trunk borer can be controlled by placement of Odonil inside the tunnels and closing the holes with mud (Odonil-plugging) (Gupta and Tara, 2014). The treatment showed 55% decrease in pest population within 15 days of its application, while the Naphthalene-plugging resulted in 50% control (Gaffar and Bhat, 1991). The placement of Detia Tab, with mud also controlled the borer albeit less effectively.

Biological control of Z. coffeae

During the biological assessment of pest damage, Sphecid wasps were collected from the galleries of the borers. The wasps were winged and its body length ranged from 18-25 mm. The female wasp paralyze the caterpillar by stinging and deposit eggs inside its body followed by storing of infected larvae in a nest dug in the ground or in the hollowed stem of a plant. In the closed nest, wasp eggs hatch and the larvae feed to full size on the flesh of the caterpillar. The caterpillar is kept in fresh state probably due to antiseptic properties of the wasp venom. In addition to Sphecid wasp a fly of genus Anthrox, specie of the family Bombyliidae was also recorded as pupal parasites of the *Z. Coffeae*.

Table I.- Pre and post-treatment means of infested trees and infested branches per tree in different Valleys of district Dir.

Locality	Pre-treatment		Post-treatment	
	Infested trees	Infested branches / tree	Infested trees	Infested branches / tree
Sultan Khel Valley				
Baboo Kalley	51.2 ± 2.59C	13.2 ± 1.53GH	40.6 ± 1.96DE	4.80 ± 0.20I
Charkum	47.6 ± 1.03CD	13.2 ± 1.28GH	38.4 ± 2.37EF	5.80 ± 1.06GHI
Kotkay	86.2 ± 1.15B	13.4 ± 0.50G	52.0 ± 3.50C	5.60 ± 0.40GHI
Serai	97.6 ± 1.43A	12.0 ± 0.70GHI	81.0 ± 2.53B	5.40 ± 0.74HI
Umaralai	49.8 ± 1.71C	12.0 ± 0.94GHI	32.2 ± 1.88F	4.20 ± 0.20I
Usherai Valley				
Almas	13.8 ± 1.20BCD	6.60 ± 0.81EF	6.00 ± 0.701EF	2.60 ± 0.24F
Jabar	31.0 ± 2.19A	10.8 ± 0.58DE	18.8 ± 2.81B	2.40 ± 0.40F
Usheral	16.4 ± 1.20BC	6.40 ± 0.50EF	11.4 ± 0.67CDE	1.80 ± 0.37F
Kadi Khel Valley				
Jogha Jal	12.0 ± 1.04BC	6.20 ± 0.66DE	8.60 ± 0.67CD	2.80 ± 0.37E
Malanga	22.0 ± 2.40A	8.20 ± 0.66CD	14.0 ± 1.14B	2.60 ± 0.24E
Karo Valley				
Awarai	5.60 ± 0.40EFG	6.80 ± 0.86DEF	2.60 ± 0.87FG	1.40 ± 0.24G
Batan	11.0 ± 1.58BCD	9.00 ± 0.70CDE	5.80 ± 0.37EFG	3.00 ± 0.89FG
Darokal	23.4 ± 2.56A	6.80 ± 0.73DEF	13.0 ± 1.78BC	6.20 ± 0.58DEFG
Karkabunj	15.8 ± 0.96B	14.2 ± 1.35B	7.00 ± 1.14DEF	7.00 ± 0.54DEF
Kumera	6.00 ± 0.44EFG	4.80 ± 0.66EFG	2.80 ± 0.66FG	1.60 ± 0.24G
Pashta	6.20 ± 0.37DEFG	5.80 ± 0.66EFG	2.60 ± 0.74FG	1.40 ± 0.24G
Kare Valley				
Amluknar	13.0 ± 1.04B	6.80 ± 0.58CD	6.00 ± 0.31CD	4.00 ± 0.31DE
Bibyor	18.2 ± 2.03A	7.60 ± 0.92CD	10.0 ± 1.04BC	1.40 ± 0.24E
Tormong Valley				
Gawanai	7.60 ± 0.74C	5.40 ± 0.92CDE	3.20 ± 1.24DEF	1.40 ± 0.24F
Sair	18.6 ± 0.50A	8.20 ± 1.02BC	11.8 ± 1.28B	2.60 ± 0.24EF
Shikawlai	11.40 ± 0.8124B	6.600 ± 0.6782CD	3.20 ± 0.96DEF	2.00 ± 0.31EF
Nihag Valley				
Kasuna	8.00 ± 0.31B	4.40 ± 0.92C	5.20 ± 0.58C	1.80 ± 0.20D
Mashmano banda	13.2 ± 0.73A	6.00 ± 0.70BC	6.80 ± 0.66BC	1.60 ± 0.24D
Valleys in Sultan Khel Payan				
Adohkay	59.8 ± 2.03A	12.4 ± 0.50HI	34.8 ± 1.59DE	6.60 ± 0.40JK
Galkore	50.4 ± 1.83B	8.80 ± 0.86IJ	28.0 ± 1.48FG	3.60 ± 0.50JK
Jaderai	49.8 ± 1.11B	8.20 ± 0.73IJ	27.0 ± 0.70FG	4.40 ± 0.24JK
Kohay	39.6 ± 1.43CD	8.60 ± 0.50IJ	23.6 ± 1.36G	3.60 ± 0.40JK
Laloo	43.0 ± 1.26C	6.60 ± 0.40JK	24.2 ± 1.65G	2.00 ± 0.44K
Luqman Banda	32.4 ± 1.20EF	7.00 ± 0.89IJK	17.6 ± 1.88H	1.60 ± 0.24K
Valleys in Dir and Barawal				
Barawal Bandai	7.60 ± 0.92DEF	4.80 ± 0.37EFG	3.20 ± 0.58FG	1.40 ± 0.24G
Narva	44.4 ± 1.72B	8.60 ± 0.87DE	26.6 ± 1.56C	3.40 ± 0.40FG
Sromanzo	65.0 ± 1.94A	10.6 ± 0.40D	46.0 ± 1.14B	3.60 ± 0.50FG

Standard Error of Mean ± SEM followed by the same letter among villages of each locality are not significantly different (Tukey's Test, $p > 0.05$).

Infestation and the life cycle of Z. coffeae

During the last week of May, larvae were collected for rearing. The pupal period lasted for 17-21 days. After completion of pupal period, the moths emerged. Feeding of the larvae lasted for 150 days. When the larvae were ready to pupate, they were found to cut circular opening in the outer wall of the tunnel. The pupa is about 25mm long with brown chest and a short blunt process above the eye with transverse rows of backwardly projecting asperities on the dorsal surface of the abdominal segments.

The moth emerges by leaving the empty pupal skin protruding from the hole in the bark. It takes about 20 minutes for the wings to expand and dry. The moth is white with a pair of small black spots and streaks on the forewing and a few black spots on the hind edge of the hindwing, expanded 35 to 45mm and lives for 2 to 6 days.

Eighty-one larvae of *Z. coffeae* were recovered from the infested walnut branches that were released in the fresh billets of walnuts in artificial galleries. The billets were caged for emergence of the pest as well as its natural predators. The pest was hibernated in its larval stage from November to January. In February, it starts feeding both under the field and laboratory conditions. Regression analysis indicated that the gallery length was significantly correlated with body length of the pest ($R^2 = 0.1806$; $F = 12.78$; df = 1, 58; $p < 0.001$). Relationship between gallery length and body length is expressed as: body length = 2.949 + 0.2052 gallery length (Fig. 2).

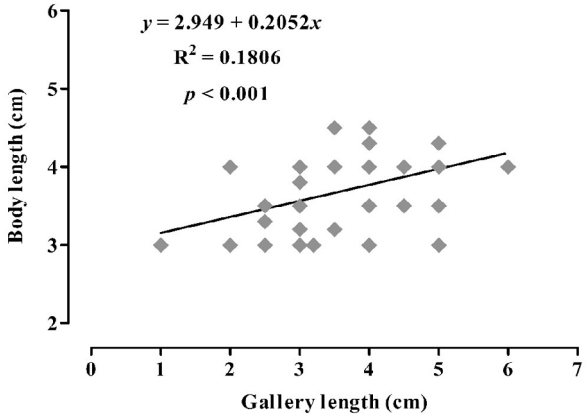

Fig. 2. Relationship between gallery length and body length. The mean gallery length was positively correlated with increased body length of pest.

Pre and post-treatment of walnut trees in different villages of district Dir

The nature and extent of damage on the number of trees and branches per walnut tree in different areas of district Dir, is shown in Table I. As compared to untreated trees and branches, treatment with IPM practices has caused significant reduction in infested trees and branches in Sultan Khel Valley ($F = 324.9$; df = 19, 80; $p < 0.0001$), Usherai Valley ($F = 47.38$; df = 11, 48; $p < 0.0001$), Kadi Khel Valley ($F = 33.87$; df = 7, 32; $p < 0.0001$), Karo Valley ($F = 28.57$; df = 23, 96; $p < 0.0001$), Kare Valley ($F = 28.88$; df = 7, 32; $p < 0.0001$), Tormong Valley ($F = 38.11$; df = 11, 48; $p < 0.0001$), Nihag Valley ($F = 38.32$; df = 7, 32; $p < 0.0001$), Sultan Khel Payan ($F = 244.1$; df = 23, 96; $p < 0.0001$) and Dir and Barawal ($F = 419.4$; df = 11, 48; $p < 0.0001$).

DISCUSSION

Walnut trees are grown in gullies along the natural streams and on lower lands in district Dir. Walnut borer (*Zeuzera coffeae*) attacks walnut trees. Recently the infestation has increased significantly that has raised an alarming threat for the economy of district Dir. Pesticides are used for pest control, which not only pollutes the environment but also hazardous for human beings and other life. To overcome this problem, IPM was adopted which is an environmental friendly approach. In IPM, the pest is controlled effectively by a combination of methods such as cultural, mechanical, chemical and biological including the development of resistant plant varieties (Abro *et al*., 2003).

The newly hatched larva of *Z. coffeae* first penetrates into a young twig and moves to tree trunk for its larval development. The excreta of larvae from a penetrated hole characterize the infested twig. A damaged twig becomes fragile and easily broken off, from just beneath the hole followed by sudden leaf twig withering. In the case of seriously damaged plants, the entire tree is destroyed. The mature larva of *Z. coffeae* pupates in the larval burrow, which before emerging as an adult, escapes outside the burrow during the period of July-August. Longevity of adults is estimated around 2-6 days, which deposit ~ 100-400 eggs. Eggs, Larval, Pupal stages last 9-30, 73-205 and 19-36 days respectively (Chang, 1984).

Our current research on walnut borer is supported by the previous reports on Quetta borer (*Aeolesthes sarta*) which is widely distributed in the mountainous region of Afghanistan, Turkistan and Western Tibet where it is a pest of forest and fruit trees (Janjua and Chaudhry, 1964). In Pakistan, it has been recorded from Khyber Pakhtunkhwa, Quetta and Kashmir as a serious pest of walnut, apple, quince, apricot and peaches. Malakand Fruit and Vegetable Development Project has reported the pest from poplar, chinar, elm and willow trees (Mohyuddin, 1989).

In Pakistan, *A. sarta* severely attack apple and poplar trees. Its biology on walnut is thought to be similar to that

of apple tree. It was found that at high altitudes, *A. sarta* adults starts emerging during May-August whereas at lower altitudes (Peshawar) it emerges in April-May. It completes its life cycle in two years. The trees attacked by *A. sarta* can be recognized by the presence of small holes and rotting area on the bark of the main stems and branches. Bark at the attacked sites expose the tender wood beneath, which is riddled with the galleries formed by the larvae. An infested tree may die in 3-4 years (Janjua and Chaudhry, 1964).

There are some insects that belong to the family of Cosssidae, also known as goat moths or carpenter moths (Lepidoptera) that are of considerable economic importance in agriculture and forestry as a pest of a variety of plantation crops. Their caterpillars are wood boring in habit and live inside the stem or branches of trees or saplings. They are nocturnal in habit and lay the eggs on the bark of trees or in the tunnel from which they emerge. Literature record of the Cossidie pests of the world indicates that only a few species have been reported that cause economic damage. This includes the European goat moth (Ligniperda), the hardwood borer (*Prionoxyotus robiniae*) and the leopard moth (*Z. pyrine*) that attacks a variety of trees like walnut, alder, ash, beech, birch, elm, maple, oak, apple etc. in the European and American countries. The bee hole borer (*Xyleutes ceramica*) of teak in Burma, teak borer (*Cossus cadambae*) in southern India, pest of tea (*Z. coffeae*) in the India sub-region and pest of cherry (*Z. multistirigata*) in northern India has been reported (Mathew, 1987). The shoot borers (*Z. coffeae*) that attacks walnut has been recorded from India, Bangladesh, Burma, Indonesia, Malaysia, Thailand, Australia and Pacific islands (Anonymous, 1992). In Pakistan, PARC-IIBC station (International Institute of Biological Control) at Rawalpindi recorded this pest in district Dir, Peshawar, Murree and Kashmir (Anonymous, 1969).

CONCLUSION

The current work provides useful information for the control of walnut borer (*Zeuzera coffeae* Nietner) through integrated pest management, which appears to be a promising strategy for the control of walnut borer. The integrated pest management (IPM) program has resulted in significant reduction of the pest population in the target area of district Dir, Pakistan. The strategy reported here will be valuable in alleviating the infestation of walnut trees with concomitant economic benefits for the farmer community.

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Conflict of interest statement

The author declare that there is no conflict of interest regarding the publication of this article.

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