Bitki Koruma Bülteni / Plant Protection Bulletin

http://dergipark.gov.tr/bitkorb

Original article

An updated data on bionomics of walnut weevil, *Alcidodes porrectirostris* Marshal (Coleoptera: Curculionidae) under laboratory conditions and its extent of damage in *Juglans regia* (L.) of the Kashmir valley, India

Ceviz kurdu, *Alcidodes porrectirostris* Marshal (Coleoptera: Curculionidae)'nin laboratuvar koşulları altında biyonomisi ve Hindistan'ın Keşmir vadisinde *Juglans regia*'daki (L.) zarar derecesi hakkında güncellenmiş veri

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ARTICLE INFO

Article history:
DOI: 10.16955/bitkorb.1294453
Received : 09-05-2023
Accepted : 21-08-2023

Keywords:
nut, walnut weevil, life cycle, rearing, extent of damage

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ABSTRACT

Walnut is one of the most important fruits, which has been defined as a "Superfood" in recent years. It is infected by a wide array of insect pests. Among these pests, the walnut weevil is a destructive one. Its adults feed on flowers and buds while its larvae feed inside the fruits and are extremely destructive in causing premature dropping. We report two generations of walnut weevil in a year and only a single larva per fruit. Adults emerge from the soil in April and feed on walnut leaf buds, petioles of leaves, and floral buds. Adult females lay 1-2 eggs on fruits, mainly in May and early June, hatch in 4.9±0.74 (SD) days and 4.5±0.97 days in the first and second generations. They develop through three instars and the total developmental time lies in the range of 46-55 days (49.1±2.51). The adults of the second generation undergo overwintering to avoid harsh environmental conditions. Comprehension of biology, life cycles, and the nature of damage aids in keeping track of specific insect pests at the proper time.

INTRODUCTION

English walnut, *Juglans regia* L. (Juglandaceae: Fagales) is an important and widely distributed cultivated nut species acclaimed for its nutritious kernels and timber (Bayazit et al. 2007). It has evolved in ancient Persia (Mahmoodi et al. 2019). It is one of the important hard-shelled fruit species with a widespread area in the world and is the most significant species traded among many species due to its excellent fruit characteristics (Guney et al. 2021, Kafkas et al. 2020). On a global scale, walnut ranks first in nut production after cashews and almonds (Anonymous 2019a) with India holding the

seventh rank in its production globally. It is assessed least concerned species according to the International Union for Conservation of Nature (IUCN) Red List of threatened species (Rivers and Allen 2017) and is included in the group of priority plants by FAO (Raja et al. 2017) and is a lucrative crop that is in high demand globally (Hassankhah et al. 2017). It possesses a wide range of medicinal properties in almost every part like bark, kernel, fruit, leaves, green husk, and flower, and contains phenolic compounds with high antioxidant activity (Jahanban-Esfahlan et al. 2019). It is found between altitudes of 1200 to 2100 meters from Kashmir to Bhutan, Khasia, S. Tibet, and Nepal (Anonymous 2019b). However, several insect pests infest walnut orchards as well as nurseries globally. They are attacked by leaf defoliators that harm leaves, twigs, and branches leading to nut drops (Abbas et al. 2015). Beetles can be considered pests and a few of them cause considerable direct and indirect loss damage (Kailash et al. 2015, Paunikar 2015). Certain grubs of insect pests dig extensive tunnels into the roots and stems feeding in the interior tissue as they progress upwards (Khan et al. 2013). Some of the most serious pests that damage walnuts around the world are the European red mite (*Panonychus ulmi* Koch), Codling moth (*Cydia pomonella* L.), Walnut aphid (*Chromaphis juglandicola* Kalt.) Walnut scale (*Quadraspidiotus juglansregiae* Comstock) and San Jose scale (*Quadraspidiotus perniciosus* Comstock) (Ohlendorf and O'Neill 2009). Asian walnut moth, *Garella musculana* Erschoff is also a serious pest of *J. regia* (Bostanci et al. 2021, EPPO 2019, Khan et al. 2023) and *J. nigra* (Bostanci et al. 2019). In the plethora of insect pests affecting the walnut trees in Jammu and Kashmir (J&K), Walnut weevil, *Alcidiodes porrectirostris* Marshal (Coleoptera: Curculionidae) is one of the most destructive pests causing about 36.7% fruit damage (Mir and Wani 2005) and in some situations up to 90% output loss (Caliskan et al. 2020). The walnut weevil is a medium-sized pest with characteristics of the Mecysolobini tribe of the weevil family Curculionidae (Bhagat 2017). It was reported as a new insect pest on walnuts in the Kashmir division of J&K in 1990 (Gaffar and Bhat 1990). Coleoptera insects have a large array of adaptability to environmental conditions and have a cosmopolitan distribution (Kritika and Jaimala 2017). They are holometabolous with separate phases of development: egg, 1 to n instar larvae, pupa, and adult (Zhang and Zhang 2008). The majority of super family curculionids of order Coleoptera attack fruits, seeds, and leaves of cereals and grains (Bhatti et al. 2018). The adults and grubs of *A. porrectirostris* are damaging in nature with the former feeding on exposed aerial parts of the tree (petioles, leaves, and branches) and the latter feeding inside the fruit and destroying the kernels.

Walnuts are one of the major cash crops and a significant component of Kashmir's economy. *A. porrectirostris* infestation can lead to severe yield and quality loss to walnuts. In addition, the pest is monophagous and attacks *J. regia,* which can be a challenge to manage and control in outbreak years. It can cause heavy economic losses in years with higher infestation levels and has developed resistance to a variety of insecticides. Understanding the life cycle of insects and the type of crop affected can go a long way in helping with the production of agriculture to translate conclusively the stage that causes the kernel damage and devise future management plans for this destructive insect pest. Keeping in view the economic importance of walnut in Jammu and Kashmir the present work was therefore, undertaken to elucidate the complete biological aspect of *A. porrectirostris* and the nature and mode of extent of damage it causes to walnut trees.

MATERIALS AND METHODS

Study area

The field surveys were conducted across the Kashmir Valley, a part of the North western Himalayas. The Kashmir valley lies between the Great Himalaya and Pir Panjal region that includes all ten districts of Union Territory (UT), J&K to record infestation to common walnut trees by the coleopteran insect pest *A. porrectirostris*. The Kashmir Valley lies between latitude 33° and 35°N, and longitude 73° and 76°E. At all places, walnut trees suffering from pest attacks were selected randomly and shoots/fruits/branches were examined for infestation. The study was conducted from 2017-2019 and the location maps of the sampling sites are represented in Figure 1.

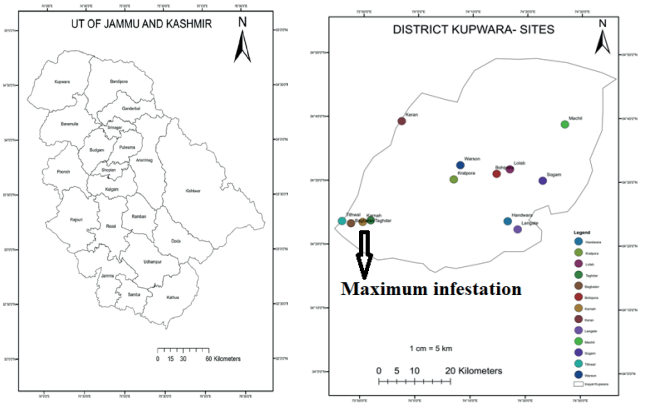

Figure 1. Map of UT of J&K and Sampling sites in district Kupwara

Laboratory rearing (stock culture)

A new progeny was obtained from male and female adults of *A. porrectirostris* collected from the walnut fields by hand picking and placed in (12×12×12) cm glass containers, with whole, unshelled, unprocessed walnuts, and leaves as food and substrate. About sixty adult specimens were collected and observed daily for pre-mating, mating, pre-oviposition,

and oviposition behaviour and duration until new breeding was obtained. The eggs laid were transferred cautiously and larvae were removed carefully with a fine hairbrush and placed in another glass container of the same dimensions along with the same food for their development. Pupae were separated and put into different containers until they reached the adult stage. Each glass container was covered with meshed cages (Olivero-Verbel et al. 2013).

Life cycle estimation of Alcidiodes porrectirostris in the laboratory

Twenty pairs of recently emerged adults were randomly selected to characterize their life cycles. These specimens were placed in glass jar containers covered with a plastic mesh, allowing them to copulate. Ten eggs were collected and individually placed in petri dishes of dimensions (10×1) cm and each one was designated as a replicate. Each egg was observed daily until its hatching to witness the hatching period. Emerge larvae were examined every day; recording growth and survival for each instar (Leon et al. 2005). The modification from one instar to the next was manifested by the existence of the exuvia. After attaining the pupal stage, every specimen was examined daily, and its development was recorded up to the emergence of the adult. The length of each instar and subsequent pupae were measured and the mean was calculated with standard error and standard deviation in MS Excel 2010. Identification of the specimens was done using the taxonomic literature of Kumar et al. (2020).

Statistical analysis

Biological parameters, such as duration, and size of each developmental stage were analyzed using descriptive statistics with the calculation of means and SD.

RESULTS

Holometaboly is the most prevalent life cycle type in beetles, in which individuals hatch from eggs as larvae, develop through several instars, pupate, and eventually emerge as adults (Bouchard et al. 2009). The life cycle of *A. porrectirostris* was characterized in this study, and each stage of development is described below.

Eggs

During the act of copulation, the male weevil initially taps the body of the female with its snout and after getting a green signal, it then mounts on the top of the body of the female weevil. The copulation lasts for more than one hour and takes place during the daytime before noon. The female lays its eggs on the developing fruits. Using its mandibles, it makes a pit on the rind of the fruit measuring about 1 to 2 mm in diameter. These were observed laying 1-2 (1.4±0.52) eggs singly in one pit usually on the opposite end of the fruit (stalk end of the fruit) and near the node of the walnut twig. The eggs are spindle-shaped and snowy white in colour. It measures 0.2-1.0 mm in length and 0.6 mm in breadth (Figure 2). The eggs hatch between 4-7 days (5.4±1.07) in the first generation whereas it ranges between 3-6 days (4.8±1.13) in the second generation.

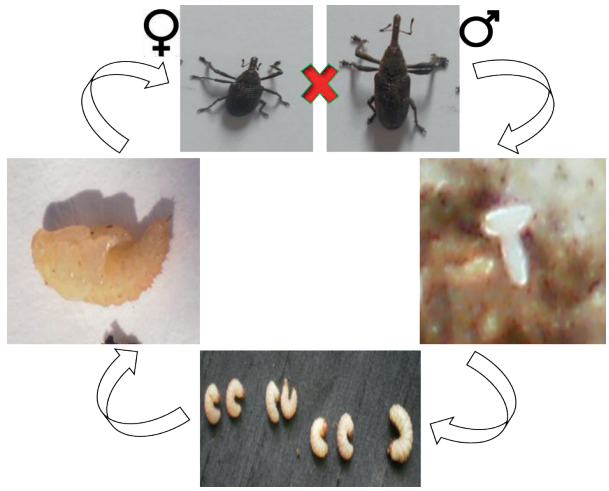

Figure 2. Life cycle of *Alcidiodes porrectirostris* Marshal (Coleoptera: Curculionidae) on common walnut (*Juglans regia*) in Kashmir Valley

Larval instars and duration

The three larval instars were reported in the pest development (Figure 3a-c). The complete larval development takes place inside the immature walnut fruit until its complete development to adulthood.

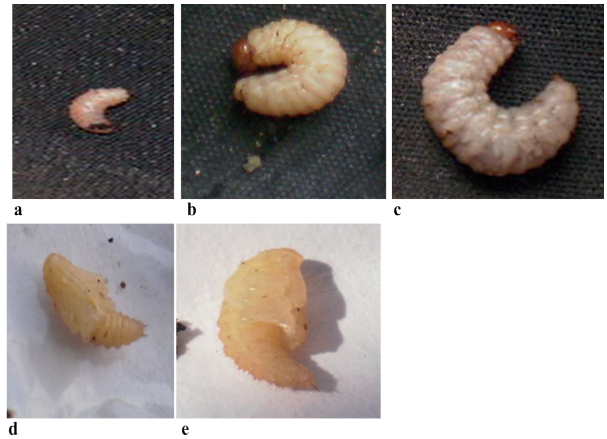

Figure 3. Larval instars of *Alcidiodes porrectirostris* Marshal (Coleoptera: Curculionidae) and pupa (a-c). First, second and third instar, (d-e). Pupa formation

First Instar-The colour of the first instar is creamy white. It measures 2-3 mm in length and 1-1.2 mm in breadth.

Second Instar- It intensifies in growth and measures 4-6 mm in length and 1.2-1.5 mm in breadth. It is bulky and dark creamy white in colour. The segmentation is visible.

Third Instar- It is a mature bulky, creamy white larva that intensifies in growth, and because of its large size, it occupies a major portion of immature walnut fruits. It measures 10-18 mm in length and 2.5-3 mm in breadth. It is the voracious feeder of immature walnut meat.

The total larval duration was observed between 32-44 (37.3±3.89) days in the study area. The first instar stage (1st generation) lasts between 10-14 days (11.9±1.29) in May and the 2nd generation lasts between 10-16 days (12.9±1.91) in August. The second instar stage (1st generation) lasts between 8-12 days (10.44±1.33) in May and (the 2nd generation) lasts between 10-16 days (12.6±1.84) in August. The third instar stage (1st generation) lasts between 12-20 days (14.6±2.71) in June and (the 2nd generation) lasts between 11-19 days (13.6±2.55) in September.

Pupa

The pupa is naked and develops inside the infested fruit in the midst of black decayed nutmeat in 1st generation whereas in 2nd generation it develops inside the rind of the walnut (Figure 3d-e). It ranges in size between 10-11 (10.5±0.53) mm in length and 5-6 (5.4±0.52) mm in breadth and is creamy white in colour. The curved rows of fine bristles are present on all the segments. There were also two spines at the extremity of the abdomen. A thick rostrum lies beneath the head and is directed backward. The antennae, whipcords, and legs are just below and along the sides of the snout. The pupal period of 1st generation ranges between 10-15 (11.8±1.93) days and the pupal period of 2nd generation ranges between 13-18 (14.6±1.51) days. During the pupal phase, the minimum and maximum temperature was recorded between 7.5 °C to 35 °C (21.25 °C), and the minimum and maximum humidity was recorded between 42-96% (69%). The pupation of 1st generation takes place inside the fruit whereas that of 2nd generation takes place inside the rind of the fruit as in case of 2nd generation the delicate first instar larva is not able to bore through the solid shell of the walnut fruit. To tide over the cold temperature of the study area, the second-generation adult hibernates inside the soil and becomes active in April (next) when favourable atmospheric condition sets in. The total life cycle duration of *A. porrectirostris* from egg laying to adult emergence lies in the range of 46-55 (49.1±2.51) and is presented in a tabular form (Table 1).

Adults

The adult weevil excavates a small oval shaped emergence hole with the help of its strong snout and makes its way out into surrounding from its pupal chamber (Figure 4). The adult weevils after emergence usually feed on normal walnut leaf buds, leaf petioles, floral buds, and fruits. The male ranges in size between 10-11 mm in length and 3-4 mm in breadth whereas the female ranges in size between 12-13 mm in length and 3.5-4 mm in breadth. The head and rostrum are smooth but the surface of thorax and elytra are granulated. Its apical end is wider than middle. Eyes are large, oval, and black in colour (Figure 5).

Figure 4. Intra fruit development of *Alcidiodes porrectirostris* Marshal (Coleoptera: Curculionidae) and its emergence through emergence hole of walnut fruit, (d). Leaf damage

Table 1. Time line of *Alcidodes porrectirostris* Marshal (Coleoptera: Curculionidae)

Stage	Timeline	Duration	Average	Temperature (°C)			Rel. Humidity (%)		Average (%)
				Min.	Max	Avg	Min	Max	
Incubation	April-May	04-07	5.5	3	29.5	16.5	30	96	63
1st instar	May	10-14	11.9±1.29	3	35	19	31	96	63.7
2nd instar	May	8-12	10.44 ±1.33						
3rd instar	June	12-20	14.6±2.71						
Total larval period	April-June	32-45	37.8±5.31						
Pupation	June -July	10-15	11.8±1.93	7.5	35	21.25	42	96	69
Total Duration	April-July	46–55	49.1±2.51						

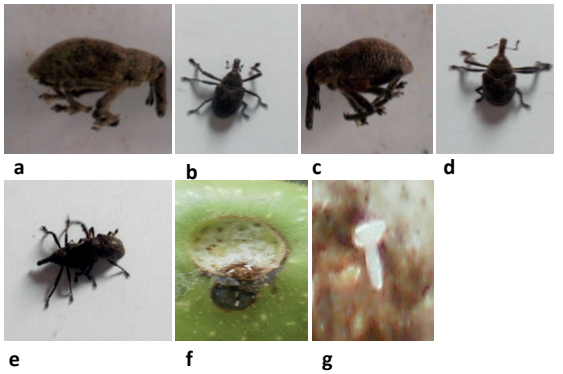

Figure 5. General habitus of *Alcidiodes porrectirostris* Marshal (Coleoptera: Curculionidae) and their eggs (a–b). Lateral and dorsal view of male adult, (c-d). Lateral and dorsal view of female adult, e. Mating, f-g. Site of oviposition with eggs

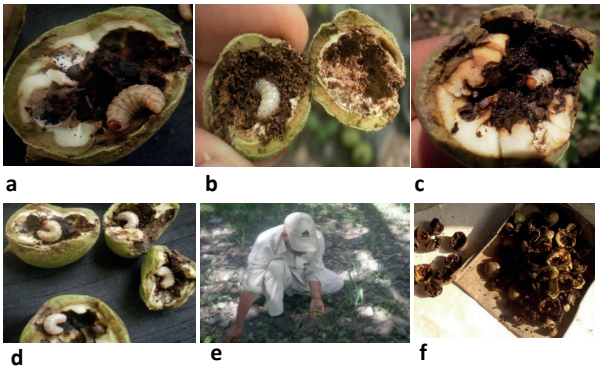

Figure 6. Walnut damage by the larvae of *Alcidiodes porrectirostris* Marshal (Coleoptera: *Curculonidae*) (a-c). Black rotten mass by the action of larva inside the fruit, (d) Presence of a single larva in each nut, (e-f). Collection of walnuts for yield estimation

Life cycle of Alcidiodes porrectirostris

Egg laying, larval development (3 instars), pupation and emergence of the adult in 1st generation take place from April up to July whereas in 2nd generation the egg laying, larval development (3 instars), pupation, and emergence of the adults take place July up to September. To tide over the harsh conditions of the study area the adults of 2nd generation undergo overwintering from October up to April (next) till the suitable climatic factors set in. The 2nd generation of the same pest ranges between 226-265 days (245.5 days) from July up to April (next) including the overwintering period of 180-190 days (90 days) of the adult from October up to April (next).

Mode and extent of damage

A. porrectirostris has been recorded in all the walnut growing regions throughout the world including in J&K. In the Kashmir division, the pest has been found to attack the walnut fruits in the Karnah region of Kupwara district where its percentage of damage lies above 35%. The pest prefers the superior thin shelled to less valuable thick-shelled types of walnut fruit. It is found at a height of 6000-7000 above mean sea levels, causing serious damage to walnut fruit. The attack is more often so serious that no tree produces any normal fruit. The adult weevils were found to feed on leaf buds, petioles of leaves, female floral buds, and male fruit. The larva bores inside walnut fruits, converts the kernels into rotten black powder (Figure 6a-c), and causes the fruits to drop before their maturity. The larva damages the inner side of walnut till its shell hardens. The adults of 2nd generation after their emergence from infested walnuts were observed to cause notch type damage in the rind of the normal fruit.

DISCUSSION

Walnut weevil, *A. porrectirostris* has brought considerable damage to *Juglans regia* across Jammu and Kashmir thereby causing economic loss to the farmers. Hence, it was imperative to study the life cycle of this weevil in walnut growing areas of the Kashmir region to translate conclusively the stage that causes the kernel damage. During the investigations, it became apparent that *A. porrectirostris* has two generations per year (bivoltine), starting from the last week of April or the first week of May when egg production begins. These findings conform with the results of Hussain and Khan (1949) who also reported two generations of the pest in the Northern Himalayas but against the study conducted by Guroo et al. (2021) and Shah et al. (2012) who reported only one generation in Jammu region of J&K and Manoor valley (Kaghan) of Pakistan respectively. The differences in life cycle duration can be due to altitude and temperature variations (Inward et al. 2012). Besides, in our study, the number of larvae found in the infected fruit was against the studies of Mir and Wani (2007) who reported 3-4 larvae in a single fruit while Guroo et al. (2021) reported two larvae in a single fruit and Hussain and Khan (1949) reported eleven larvae in a single infected nut. The total number of larvae reported per nut was found to be independent of nut size and number of punctures, as previously documented in pecan weevil infestations (Harris 1976). The pupation in *A. porrectirostris* takes place within the seed and second generation adult emerges through the emergence hole of the dry nut and hibernates within the soil. The harsh and below freezing temperature may be the reason for second generation adults to hibernate inside the soil. Besides the adult diapauses in coleopteran, occur in 90% of beetle species (Danks 1987) that belong to

families Coccinellidae and Curculionidae. Pupation inside the soil has been reported in the larvae of other weevils such as *Curculio caryae* (Boethel and Eikenbary 1979) and *Conotrachelus juglandis* (Corneil and Wilson 1979). After overwintering the adult weevils lay white creamy eggs and hatch directly into the nuts and feed on liquid endosperm which results in early fruit dropping from the second week of May with larva found pupating either in fallen fruit or inside the soil. Usually, the larvae after emerging from the dropped nuts enter into the ground and pupate there (Stebbing 1902) and in those situations where two generations per year are found, the larvae of 1st generation pupate inside the fruit whereas, that of 2nd generation inside the rind of the fruit (Hussain and Khan 1949). Overall, these findings suggest that either pupa formation can occur in a variety of places, due to the hardness of the soil forming a physical barrier that prevents the larvae from entering it (Schraer et al. 1998) or mature larvae may not be able to leave their shells, forcing them to pupate inside the fallen fruit.

Pupation inside the soil has been reported in the larvae of other weevils such as pecan weevil (Boethel and Eikenbary 1979, Harp and Van Cleave 1976) and Butternut curculio (Corneil and Wilson 1979), etc. The emergence of adults from pupae started in the last week of June. These adults continued feeding on walnut leaves till the end of September before overwintering from early October to the third week of April next year. However, it must be noted that the time of adult emergence from the soil cannot be precisely so as reported above, this is because the weevil emergence from the soil depends upon various factors which can pre or postpone the emergence of the walnut weevils. For example, an increase in soil moisture due to rainfall can lead to the early emergence of weevils (Hinrichs and Thompson 1955, Tedders 1974) while as prevalence of drought conditions and hardness can delay the emergence of weevils from soil (Alverson et al. 1984, Harris and Ring 1980). Hence, it can be abstracted that the weevil emergence from soil can vary depending upon the prevailing weather conditions at that time. Furthermore, it can be established that the proper management of adults through the application of insecticides, when necessary, depends greatly on the regular monitoring of weevil emergence from the soil (Harris 1983). Otherwise, applied chemicals will result in waste.

The walnut weevil is a very serious insect pest of Persian walnut. These damaging insect pests begin attacking the kernels in the developing nuts while the nuts are still on the canopy, decreasing the yield until not harvested. The affected fruits also show dark brown spots, which are dried resinous excretions that render a large portion of the crop unmarketable. The feeding of weevil during the watery stage typically causes the fruit to abort and fall to the ground (Boethel and Eikenbary 1979, Calcote 1975). Females make shallow punctures with their beaks in the shucks of immature nuts and deposit 1-2 eggs in each nut. Similarly, females of *Curculio dieckmanni* (Coleoptera: Curculionidae) lays eggs on developing hazelnuts and the larva feeds on the kernels upon hatching (Zhang et al. 2021). Both phases (adult and larval form) are destructive in nature. Mid-season adult feeding on nut-lets causes premature nut drop and grub damage to kernel occurs after shell hardening. It overwinters as adults in the soil and emerges in spring when the environmental conditions become feasible. The complicated nature of the life cycle, behaviours, and habitat of weevils make some insecticides difficult to spray as the larva and pupa occur inside nuts and soil (Ree et al. 2011) thereby leaving the opportunities to control the weevil limited to adults only.

CONCLUSIONS

Juglans regia is a significant nut fruit crop with more than 90% production in the UT of J&K. It is a precious crop in terms of its nutritional value, wood products, and rural development. However, several insect pests have been attacking this crop. Our visual observations demonstrate that *Alcidodes porrectirostris* has caused more harm in the Kupwara district than rest of the studied locations. Hence, the required management techniques must be employed at proper moment to halt further damage to other walnut growing areas of the Kashmir Valley. The crucial components in effectively managing walnut weevils involve monitoring walnut phenology, initial walnut weevil emergence from the soil, and activity of adults in the canopy. Monitoring data should be integrated with details on walnut cultivars, price estimates, and treatment costs to aid in making management decisions. Nuts become vulnerable to oviposition with the onset of spring and various traps can detect the emergence of walnut weevil and thereby prevent economic loss. To reduce losses, an integrated pest management (IPM) strategy uses resistant varieties, scouting and economic thresholds, pheromone traps and biological insecticides, and synthetic pesticides to minimize losses. The reliance on chemicals for insect pest management, combined with their careless and imprudent application, has had several negative repercussions on these crops, including environmental contamination, ecological imbalance, pesticide resistance, pest revival, secondary pest outbreaks, etc. The several biological control agents that could be used as a crucial tool in IPM include predators, parasites, pathogenic microorganisms, and competitors (Khan et al. 2009). Future research is indispensable on the biology, ecology, and management of the weevils, especially

A. porrectirostris which is expected to pose economic concerns to J&K, India, and other nations.

ACKNOWLEDGEMENTS

We greatly acknowledge the anonymous reviewers for their suggestions for improving the manuscript.

Author's Contributions

Maximum contribution by Sajad Ahmad by 65% and 35% equally by Inayat Ullah Lone, Deen Mohd Bhat, and Mohd Feroz.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

ÖZET

Ceviz, son yıllarda "Süper gıda" olarak tanımlanan en önemli meyvelerden biridir. Çok çeşitli böcek zararlıları tarafından enfekte edilir. Bu zararlılardan birisi de ceviz kurdudur. Erginleri çiçeklerle ve tomurcuklarla beslenirken, larvaları meyvelerin içinden beslenir ve erken döküme neden olarak son derece zarar verir. Ceviz kurdunun yılda iki döl verdiği ve meyve başına sadece tek bir larva bulunduğu belirlenmiştir. Erginler, nisan ayında topraktan çıkar ve ceviz yaprağının tomurcukları, yaprak sapları ve çiçek tomurcukları ile beslenir. Ergin dişiler özellikle mayıs ve haziran ayı başında meyvelere 1-2 yumurta bırakır, birinci dölde 4.9±0.74 (SD) günde, ikinci dölde ise 4.5±0.97 günde yumurtadan çıkarlar. Üç dönem boyunca gelişirler ve toplam gelişim süresi 46-55 gün (49.1±2.51) aralığındadır. İkinci dölün erginleri, sert çevre koşullarından kaçınmak için kışlamaya girerek kışı geçirirler. Biyolojisinin, hayat çemberi ve hasar durumunun anlaşılması, belirli böcek zararlılarının uygun zamanda takip edilmesine yardımcı olacaktır.

Anahtar kelimeler: fındık, ceviz kurdu, yaşam döngüsü, yetiştirme, zararın boyutu

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Cite this article: Khan, S., Lone, I., Bhat, D., Feroz, M. (2023). An updated data on bionomics of walnut weevil, *Alcidodes porrectirostris* Marshal (Coleoptera: Curculionidae) under laboratory conditions and its extent of damage in *Juglans regia* (L.) of the Kashmir valley, India. Plant Protection Bulletin, 63-4. DOI: 10.16955/bitkorb.1294453

Atıf için: Khan, S., Lone, I., Bhat, D., Feroz, M. (2023). Ceviz kurdu, *Alcidodes porrectirostris* Marshal (Coleoptera: Curculionidae)'nin laboratuvar koşulları altında biyonomisi ve Hindistan'ın Keşmir vadisinde *Juglans regia*'daki (L.) zarar derecesi hakkında güncellenmiş veri. Bitki Koruma Bülteni, 63-4. DOI: 10.16955/bitkorb.1294453