



New insights of processionary moth, *Thaumetopoea cheela* on pistachio nut (*Pistacia vera*): Interaction effect on flowering and nut yield

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ABSTRACT

The processionary moth, *Thaumetopoea cheela* (Moore) was found as a serious defoliator of Pistachio nut (*Pistacia vera* L.), which is a new record. The development of egg, larva and pupa was completed in 196.5 ± 0.40 , 68.1 ± 1.97 and 86.9 ± 0.62 days, respectively. The adult longevity was 2–3 days and each female laid an average of 179 eggs in a cluster. The insect overwintered in egg stage. The moth followed Dyar's law and the Dyar's ratio varied from 1.67–1.73. The occurrence and severity of this pest on the sparse host plantation warrants its regular monitoring on other possible alternate hosts and development of IPM strategy. The magnitude of the damage depends on the extent of defoliation, time of incidence and the vigour of the affected tree. Leaf defoliation prior to development of flower buds reduced the number of reproductive stalks, flower buds, flowers and the nut yield of pistachio plantation.

Key words: Dry temperate, Incidence, Lepidoptera, Nut fruit pest

Pistachio nut (*Pistacia vera* L.) is a native to western Asia and Asia Minor from Syria to Caucasus and Afghanistan. It is one of the most important and highly remunerative nut crops, cultivated in dry and hot areas under saline conditions (Metheney *et al.* 1998). Pistachio kernel contains 80.2–93.8% split nuts which are rich source of fats (49.79–57.62%) and proteins (18.99–21.87%) (Tsantili *et al.* 2010). In India, the cultivation of pistachio is at infancy and the only plantation exists at Sharbo and Bogtu locations around Reckong Peo in Kinnaur, Himachal Pradesh, India (Thakur and Mehta 2010). Kinnaur, vested with dry-temperate climate (hot summer, extremely cool winter and negligible rainfall) is highly suitable for the cultivation of pistachio. After the initial success, an orchard of two commercial cultivars, viz. Kerman (main variety) and Peter (pollinizer), imported from Tucson, USA, was established at Sharbo during 2001. Various issues like irrigation facilities, pollination, tree nutrition, training-pruning, alternate bearing, marketing, insect pests and diseases are crucial for successful cultivation of pistachio (Sedaghat 2011). Among insect-pests, psyllids, bugs, scales, leafhoppers, borers, seed wasps, mites and beetles are the major pests reported worldwide (Mehrnejad 2001, 2014).

Interestingly, the major pests reported from other parts of the world have not been recorded on pistachio in India. Recently, a processionary moth, identified as *Thaumetopoea cheela* (Moore) (Lepidoptera: Notodontidae) has been recorded defoliating seriously pistachio plants. The genus *Thaumetopoea* includes about a dozen of species which are serious defoliators of many economically important plants and allergic to human beings and domestic animals (Battisti *et al.* 2011, Basso *et al.* 2016). Serious threat of this defoliator to pistachio cultivation at its infancy in India would become a major limiting factor in its adoption and further expansion. The invasion of the pest into the region, therefore, calls for immediate need to study its bio-ecology to develop future management strategies for the pest. Keeping in view the economic importance of the crop and the pest, the present study on the occurrence and developmental biology *Thaumetopoea cheela* on Pistachio nut has been carried out.

MATERIALS AND METHODS

The experiment was conducted at RHRTS and Farm Science Centre (KVK) of YSP University of Horticulture and Forestry at Sharbo (Reckong Peo), Himachal Pradesh, India ($31^{\circ}32'20''$ N and $78^{\circ}16'03''$ E). The experimental area was typically a dry temperate region, having annual rainfall between 350–400 mm and the average temperature remains as low as -4°C in January and February. During 2014, the caterpillars of the insect were seen feeding on the foliage of the pistachio nut. These larvae were collected and kept in the insect rearing cages on the leaves of pistachio nut in the research laboratory. The larvae did not feed inside the cages

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and after 1–2 days the larval groups showed a tendency to move down from the host leaves and settle or congregate on one side of the cage and died after 5–6 days due to starvation. Thereafter, rearing was done under natural outdoor conditions by enclosing the whole plant/seedling with net. The larval groups were observed daily (three h period) in the morning throughout their developmental period, viz. till emergence of moths. Moths, thus obtained were sent to Dr. Peter Smetacek (an authority on Indian butterflies and moths), Butterfly Research Centre, Uttarakhand for identification. Dr. Smetacek identified the moth as *Thaumetopoea cheela* (Moore) (Lepidoptera: Notodontidae). During 2015, developmental biology and morphometrics of the pest was studied. For this purpose the seedlings having egg clusters (deposited during October 2014) were enclosed under the net cages. Larvae developed from these eggs were allowed to feed on the foliage and observed daily to record the observations on the developmental period of different stages, fecundity, longevity, etc. Morphometrics of different life stages of the insect were also measured. The size of different stages of the insect was measured with the help of a digital vernier calliper, whereas, the width of the head capsules was measured under a stereo zoom binocular microscope (Olympus SZ 61) with the help of an ocular scale calibrated with stage micrometer. The width of the head capsule of different larval instars was used to calculate the Dyar's ratio to verify the Dyar's law.

RESULTS AND DISCUSSION

Developmental biology and morphometric traits: Several climatic parameters were expected to affect moth population dynamics. Winter temperatures were found to be the main limiting factor for the moth development and range expansion mainly in the dry temperate part of the pest geographical distribution. Warmer temperature contributed to an improvement of larval performance, and therefore winter survival, in concert with to a decreased probability of occurrence of lethal temperatures. The high day temperature is obtained through exposure of the larval tents to solar radiation, even the air temperature. In addition, the translocation of the moth as pupae in the soil has overcome the natural dispersal limitation and resulted in the establishment of populations outside of the range, due to improved thermal conditions. The results of the present study reveal that the moths of *T. cheela* (Fig 1d) started emerging from the pupae during late September and continued to emerge for about 15 days i.e. up to early October with peak during the first week of October. Moths lived for 2–3 days and each female laid 66–249 eggs with an average of 179 eggs during its life. The eggs were deposited on the branches, arranged in several rows, oriented in one direction only and covered with protective layer of scales deposited on the eggs from the apex of the female's abdomen (Fig 1a). Each female laid only one cluster of eggs and the peak oviposition coincided with the peak of moth emergence which occurred during the first week of October. The colour of the eggs camouflage

with the colour of the branch on which they are laid thus, making them difficult to detect by the enemies. The insect passed the winter (October–April) in egg stage and the eggs hatched in next April. In the present study the first batch of eggs (laid in first week of October, 2014) hatched between 20th and 23rd of April, 2015. After egg hatched, the egg shell remained glued (Fig. 1b) to the branches for the next year, though, the colour of the scales on the egg shell faded with time from deep brown in the beginning to light brown afterwards. The emergence of larvae (Fig 1c) coincided with the bud break or first leaf emergence in the host plant. Larvae proceeded to feed together in a processionary manner on the leaves of the pistachio nut plants throughout their life. The larvae, thus, first impair pistachio buds in early season (Fig. 1b), reducing the number of shoots emerging, and then voraciously consume the leaves until pupation. A high insect population, especially on young trees, completely defoliate the plant and hamper the development of the plant.

The insect took 60–77 days to complete the larval development under natural conditions from 20th April–3rd July before pupation. *T. cheela* passed through 5 larval stages and the first, second, third, fourth and fifth instar was completed in 6–9, 11–13, 12–16, 11–13 and 20–26 days, respectively (Table 1). The mean duration of the respective instars was 7.2 ± 0.36 , 12 ± 0.3 , 14.5 ± 0.52 , 12.5 ± 0.22 and 23.7 ± 0.8 days. On the trees, the larvae feed together in groups, move in a line but did not form a tent. In the final instar these larval groups are quite evident from a distance as flags on the branches. The larval body is covered with dense white hairs. The moulting occurred in mass on the branches in the first two instars and later in the soil under the tree basin. Before pupation, there was a period of wandering and pre-pupation which lasted for about one week. Pupation took place below the surface of soil, in the debris, under the stones or in the bunds in a woven silk cocoon. The pupal period lasted for 85–90 days (mean: 86.9 ± 0.62) extending from July–late September or early October. Only one generation was completed in a year.

The eggs of the moth were oval in shape measuring 1.03–1.1 mm (mean: 1.07 ± 0.03 mm) in length and 0.95–1.01 mm (mean: 0.98 ± 0.02 mm) in breadth (Table 1). The first, second, third, fourth and fifth instar larvae varied in length from 1–3 mm (mean: 2.0 ± 0.2 mm), 3–6 mm (mean: 4.4 ± 0.27 mm), 7–10 mm (mean: 8.5 ± 0.27 mm), 12–17 mm (mean: 15.1 ± 0.43) and 27–33 mm (mean: 28.8 ± 0.55 mm), respectively. Pupa was 19–22 mm (mean: 20.3 ± 0.91 mm) long and 6–7 mm (mean: 6.82 ± 0.46 mm) wide. Female moth was slightly bigger in size than the male. The female was 11–14 mm (mean: 12.6 ± 0.53 mm) long with wing expanse of 34–38 mm (mean: 35.8 ± 1.32 mm), while, the male was 10–13 mm (mean: 11.1 ± 0.22 mm) in length with a wing expanse of 31–34 mm (mean: 32.3 ± 0.78 mm). The width of the head capsule of the first, second, third, fourth and fifth instar larvae was 0.26 ± 0.01 , 0.45 ± 0.004 , 0.78 ± 0.01 , 1.3 ± 0.02 and 2.19 ± 0.02 mm (Table 2). The species followed Dyar's law and the ratio of the width of head capsule of



Fig 1 Developmental stages of *T. cheela*; a) egg cluster, b) young larvae, c) pupa and d) adult

second to first, third to second, fourth to third and fifth to fourth was 1.73, 1.73, 1.67 and 1.68, respectively.

The zoogeographic distribution of most species in the genus *Thaumetopoea* (10 species) is Mediterranean with one Euro-Siberian species, one Saharo-Arabian species and one Irano-Turanian species. Among different species of *Thaumetopoea*, *T. cheela* has not been recorded on pistachio nut so far. The only information on the species available indicates its distribution from Afghanistan to north-west India feeding on *Rhus cotinus* L. (Furth and Halperin 1979, Basso *et al.* 2016). The present study reports the occurrence of *T. cheela* on *P. vera* and its distribution for the first time in north western Himalayan dry temperate region of India.

There are about a dozen of species of processionary moths under the genus *Thaumetopoea* and most of them occur in Western Palaearctic region (Agenjo *et al.* 1970, Kiriakoff 1941). These moths are also reported to quickly expand their distribution range in response to climate change (Battisti *et al.* 2005) and are serious pests of forest trees (Furth and Halperin 1979, Halperin 1990) and most of them feed either on *Pinus* spp., *Cedrus* spp. or *Quercus* spp. In the present study, *T. cheela* has been reported only from *Pistacia vera*, though, thick forests of *Cedrus deodara*,

Pinus zerardiana and *Quercus semilcarpifolia* were also present nearby, indicating the specificity of the pest towards the species. Earlier, *T. solitaria* and *T. jordana* have been reported to feed on *Pistacia* spp. and *Rhus tripartita*, respectively (Halperin 1983, Basso *et al.* 2016). *T. cheela* feed voraciously on *P. vera* from April–July in dry temperate region of Himachal Pradesh, India. Halperin (1983) described *T. solitaria* Freyer as the main pest of *Pistacia* spp. in Israel, occurring throughout *Pistacia* growing areas. The larvae feed mainly on indigenous *Pistacia* spp., viz. *P. palaestina* (Boiss) and *P. atlantica*, to a lesser degree on *P. vera* and rarely on *P. lentiscus*. He further reported that the main flight period was in the first 3 weeks of October, the average duration of the incubation, larval development and hypogaeous stages was 143, 52 and 170 days, respectively.

Flowering and nut yield: The magnitude of the damage depends on the extent of defoliation, time of incidence, tree species and the general vigour of the affected tree. Defoliation is also an essential operation for inducing off-season flowering and fruiting to yield better quality and quantity in different fruit crops. Although, a light defoliation did not cause serious damage but moderate to heavy insect populations caused serious defoliation which significantly

Table 1 Developmental biology and morphometrics of *T. cheela* reared on *Pistacia vera*.

Developmental stage	Duration (Days)		Size (mm)	
	Range	Mean $\pm$ SE	Range	Mean $\pm$ SE
Egg	195-198	196.5 $\pm$ 0.40	1.03-1.10 (L) 0.95-1.01(W)	1.07 $\pm$ 0.03 0.98 $\pm$ 0.02
Larva				
1st instar	6-9	7.2 $\pm$ 0.36	1-3	2.0 $\pm$ 0.2
2nd instar	11-13	12.0 $\pm$ 0.30	3-6	4.4 $\pm$ 0.27
3rd instar	12-16	14.5 $\pm$ 0.52	7-10	8.5 $\pm$ 0.27
4th instar	11-13	12.5 $\pm$ 0.22	12-17	15.1 $\pm$ 0.43
5th instar	20-26	23.7 $\pm$ 0.80	27-33	28.8 $\pm$ 0.55
Total larval period	60-77	68.1 $\pm$ 1.97		
Pupa	85-90	86.9 $\pm$ 0.62	19-22 (L) 6-7 (W)	20.3 $\pm$ 0.91 6.82 $\pm$ 0.46
Adult				
Female	2-3	2.6 $\pm$ 0.16	11-14 (L) 34-38 (WE)	12.6 $\pm$ 0.53 35.8 $\pm$ 1.32
Male	2-3	2.4 $\pm$ 0.16	10-13 (L) 31-34 (WE)	11.1 $\pm$ 0.22 32.3 $\pm$ 0.78

L, length; W, width; WE, wing expanse.

impacted the tree health. Successive defoliation over 2–3 years led to twig dieback besides reducing the average size of individual nuts and caused a general decline in nut production. The emergence of insect pest coincided with the emergence of leaves and floral panicles in late April. Thus, defoliation prior to development of flower buds reduced the number of reproductive stalks, flower buds and flowers, and consequently affected the nut yield of the tree. Severe herbivory, after flower buds appeared, decreased the quality and final number of nuts. Also, 100% defoliation by the insects induced off-season flowering in the trees towards late summer but these flower panicles yielded no nuts as they remained rudimentary and shed in the due course of time. In Sumatra and Honduras, reduction of 10–25 and 22–36% respectively, in yield of oil palm was recorded due to defoliators (Sipayaung *et al.* 1989). Whereas in Colombia, populations of 4000–5000 larvae of defoliators per leaf, caused losses of foliage of as much as 95%. Loss of 60–66% of the foliage has caused accumulated reductions in the yield of 36–40% in three years. Defoliation of less than 29–38% has caused losses in yield of 9%. In Sabah, Malaysia reduction of 27 times of FFB occurred during

Table 2 Head capsule width and Dyar's ratio of larval instars of *T. cheela* reared on pistachio nut.

Instar	Head capsule width (mm $\pm$ SE)	Dyar's ratio
I	0.26 $\pm$ 0.01	-
II	0.45 $\pm$ 0.004	1.73
III	0.78 $\pm$ 0.01	1.73
IV	1.30 $\pm$ 0.02	1.67
V	2.19 $\pm$ 0.02	1.68

the 30 months following the defoliation of 60% by *Setora nitens* (Syed and Saleh 1998). In coastal parts of Andhra Pradesh, the defoliation caused by *Acria* species resulted to yield losses of 29% in first year, 31% in the second year and 21% in consequent years. In areas of severe damage by *Rhinoceros* beetle, *Oryctes rhinoceros*, as much as 15% of the leaf area can be lost (Samsudin *et al.* 1993), resulting in a yield decline of up to 25% (Liau and Ahmad 1991).

The outcome of the study revealed an interesting and economically important new host plant- pest interaction. The insect-pest *T. cheela* was recorded infesting *Pistacia vera*, planted at two locations in the dry temperate region of Himachal Pradesh, India. The occurrence and severity of this pest on the sparse host plantation also warrants its regular monitoring on other possible alternate hosts like *C. deodara*, *P. gerardiana* and *Q. semecarpifolia* present in the surroundings as dense forests. An effective IPM strategy needs to be developed before any attempt to expand the plantations of *P. vera*.

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