mone lures within a few days makes it impossible to use as a synthetic pheromone for pea moth monitoring in field traps. A less attractive pheromone mimic is used instead.

Isomerization of the main pheromone compound is, on the other hand, not an obstacle for pheromone-mediated mating disruption. A repellent blend of pheromone and antagonistic isomers has been shown to be effective for population control by disrupting mating in isolated pea fields. The main obstacles to a more widespread use of mating disruption in pea moth control are the availability of a suitable dispenser material and the cost of dispenser application in pea fields. In comparison, mating disruption has been successfully used against codling moth, a closely related species.

Integrated pest management. Early sowing, short-duration plant genotypes, and intercropping can be combined with insecticide treatments. Pheromone-baited monitoring traps are an inexpensive and efficient tool to direct timely application of insecticides. Further development of pheromone-mediated mating disruption, resistant cultivars, and identification of plant volatile cues that attract gravid females for oviposition would be a significant step toward sustainable and more efficient control of pea moth.

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(Prepared by G. Thöming, H. Saucke, and P. Witzgall)

Pod Borers

Of the nearly 60 insect species known to feed on chickpea, the pod borers *Helicoverpa armigera* and *H. punctigera* (Lepidoptera: Noctuidae) are the major pests. The former is a major pest of chickpea in Africa, Asia, and Australia, while the latter is confined to Australia. *Helicoverpa*-inflicted losses to chickpea crops in the semiarid tropics are estimated at over US$328 million annually. Pod borers rarely become a serious pest on lentil. Worldwide, losses caused by *Helicoverpa* (*Heliothis*) spp. in crops including cotton, legumes, vegetables, and cereals exceed $2 billion, and the cost of insecticides used to control these pests is over $1 billion annually. There are several common names for pod borers: African cotton bollworm, corn earworm, cotton bollworm, gram pod borer, legume pod borer, native budworm, old world bollworm, and tomato fruit worm.

Geographic Distribution

H. armigera is widely distributed in Africa, Asia, Australia, and Mediterranean Europe, while *H. punctigera* is restricted to southern regions of Australia. Additionally, there are reports of *H. armigera* outbreaks in Hungary, Italy, Romania, Slovakia, Spain, Sweden, Switzerland, and the United Kingdom.

Host Range

H. armigera and *H. punctigera* are major pests of chickpea, cotton, forest trees, fruits (e.g., *Prunus* and *Citrus* spp.), linseed, maize, okra, pearl millet, *Phaseolus* spp., pigeonpea, sorghum, sunflower, tobacco, tomato, and vegetables. In recent years, *H. armigera* damage has been reported in apple, carnation, finger millet, grapevine, and strawberry. *H. punctigera* is a major pest of chickpea and other grain legumes, corn, cotton, sorghum, and tomato.

Nature of Damage

The larvae initially feed on the young leaves in chickpea and a few other legumes, causing extensive damage (Fig. 229). Damage in cotton and pigeonpea is mostly to flowers and flower buds. Young chickpea seedlings may be destroyed completely, particularly under tropical conditions in southern India. Larger larvae bore into pods or bolls and consume the developing seeds inside (Fig. 230). In Australia, where the climate is cooler, pod borer populations increase in the spring, attacking chickpea in late spring before moving on to summer crops in subtropical regions.

Fig. 229. Damage caused by *Helicoverpa armigera* to chickpea leaves. (Courtesy ICRISAT)

Life Cycle

The oviposition period lasts 5–24 days, and a female may lay up to 3,000 eggs, mainly at night, on leaves, flowers, and pods (Fig. 231). The egg incubation period depends on temperature and varies from 2 and 5 days (usually 3 days). Duration of larval development depends not only on the temperature, but also on the nature and quality of the host plant and varies from 15.2 days on maize to 23.8 days on tomato (Fig. 232). The number of larval instars varies from five to seven, with six being most common. The larvae pupate in the soil (Fig. 233). The prepupal period lasts 1–4 days. The larvae spin a loose web of silk before pupation. In non-diapausing pupae, the pupal period ranges from about 6 days at 35°C to over 30 days at 15°C. The diapausing period for pupae may last several months. Pale adults are produced from pupae exposed to temperatures exceeding 30°C. In captivity, longevity varies from 1 to 23 days for males and 5 to 28 days for females (Fig. 234).

H. armigera exhibits a facultative diapause, which enables it to survive adverse weather conditions during both winter and summer. The winter diapause is induced by exposure of the larvae to short photoperiods and low temperatures. In China and India, *H. armigera* populations comprise tropical, subtropical, and temperate ecotypes. In subtropical Australia, *H. armigera* undergoes diapause during winters when the temperatures are low. High temperatures can also induce diapause. The insect enters a true summer diapause when the larvae are exposed to very high temperatures (43°C for 8 h daily), although the proportion of females entering diapause is only half that of males. At these temperatures, non-diapausing males are sterile. In Australia, *H. punctigera* has been observed to enter a diapause in spring when temperatures are quite high and plant hosts are scarce.

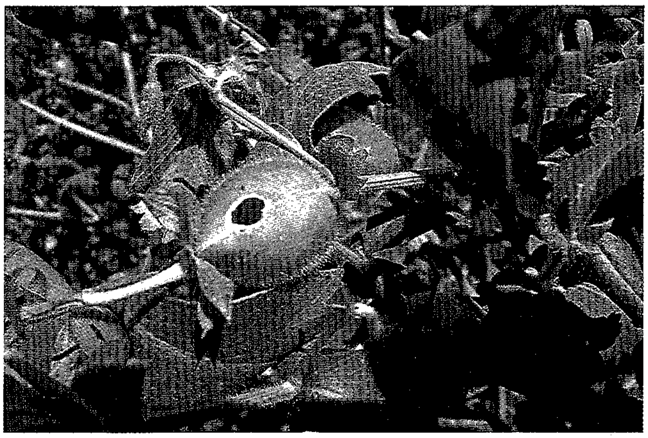

Fig. 230. Chickpea pod with an entry hole created by a pod borer larva. (Courtesy W. Chen)

Fig. 231. *Helicoverpa armigera* eggs on chickpea. (Courtesy ICRISAT)

Management

Economic thresholds. Monitoring of pod borer populations is necessary to determine whether the threshold has been exceeded and control measures are required. Action thresholds based on egg numbers have been used to make control decisions. One larva per meter row in chickpea causes economic loss. A simple rule of thumb based on monsoon rains and November rainfall has been developed to forecast *H. armigera* populations in India. Models for long-range forecasts of

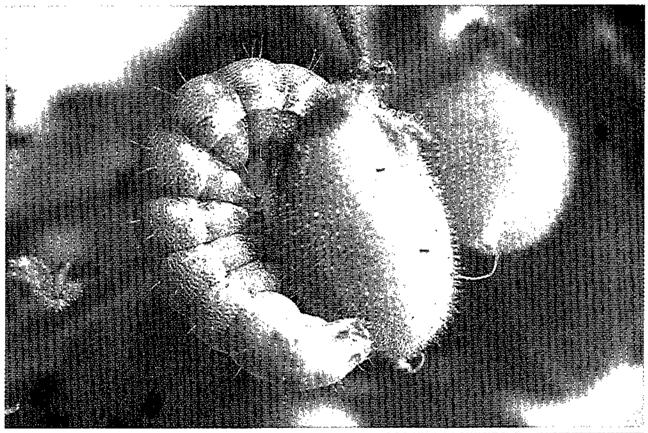

Fig. 232. Pod borer larvae on chickpea. Top, *Helicoverpa armigera;* bottom, *H. punctigera.* (Courtesy ICRISAT [top] and R. Lloyd [bottom])

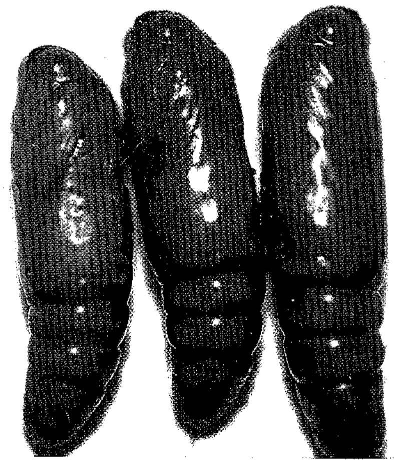

Fig. 233. Pupae of *Helicoverpa armigera.* (Courtesy ICRISAT)

H. armigera and *H. punctigera* populations in Australia have also been developed. These population-forecasting models may be incorporated into crop-production models for pest management. In Australia, three crops (cotton, tomato, and maize) have high levels of pod borer attack and require multiple sprays of pesticides. Of the legume crops, field pea and chickpea are spring-flowering crops grown in the southern regions of Australia and usually suffer sporadic damage from *H. punctigera*, requiring a single pesticide application only.

Host plant resistance. The development of cultivars resistant or tolerant to *H. armigera* and *H. punctigera* has considerable potential for use in integrated pest management, particularly under subsistence farming conditions in developing countries. Several chickpea germplasm accessions (ICC 506EB, ICC 10667, ICC 10619, ICC 4935, ICC 10243, ICCV 95992, and ICC 10817) with resistance to *H. armigera* have been identified, and lines such as ICCV 7, ICCV 10, and ICCL 86103 with moderate levels of resistance have been released for cultivation. However, most of these lines are highly susceptible to Fusarium wilt. Therefore, concerted efforts have been made to break the linkage by raising a large population of crosses between *H. armigera*-resistant and wilt-resistant parents. Several wild relatives of chickpea have shown high levels of resistance to *H. armigera*, and efforts are underway to transfer resistance into high-yielding cultivars of chickpea.

Genetically modified crops. In recent years, genetic engineering has enabled the introgression of genes from distantly related organisms (e.g., *Bacillus thuringiensis* [*Bt*]) into crops such as chickpea, corn, cotton, and pigeonpea. Chickpea cultivars ICCV 1 and ICCV 6 have been transformed with the *cry1Ac* gene. Insect-feeding assays indicate that the expression level of the *cry1Ac* gene is inhibitory to development and feeding by *H. armigera*. Efforts are underway at ICRISAT to develop transgenic chickpea resistant to pod borer. A resistance-management strategy has been developed for transgenic cotton growing in Australia to prevent undesirable side effects, including the development of resistance to *Bt*, which will also be applicable to chickpea in case transgenic chickpea is released for cultivation.

Cultural manipulation of the crop and its environment. A number of cultural practices such as time of sowing, spacing, fertilizer application, deep ploughing, interculture, and flooding have been reported to reduce survival of and damage by *Helicoverpa* species. Intercropping or strip cropping with coriander, linseed, marigold, mustard, or sunflower can minimize the extent of damage to the main crop. Strip cropping also increases the efficiency of chemical control. Hand-picking of large larvae can reduce pod borer damage. However, the adoption of cultural practices depends on the crop-husbandry practices in a particular agroecosystem. An area-wide management strategy has been implemented in regions of Queensland and New South Wales, Australia, to suppress local population densities of *H. armigera*, with chickpea trap crops playing an important role. The chickpea trap crop is planted after the commercial crops in order to attract *H. armigera* emerging from winter diapause. The trap crops are destroyed before larvae commence pupation. As a result, the overall *H. armigera* pressure on summer crops is reduced, resulting in greater opportunity for adoption of soft control options, reduced insecticide use, and greater abundance of natural enemies.

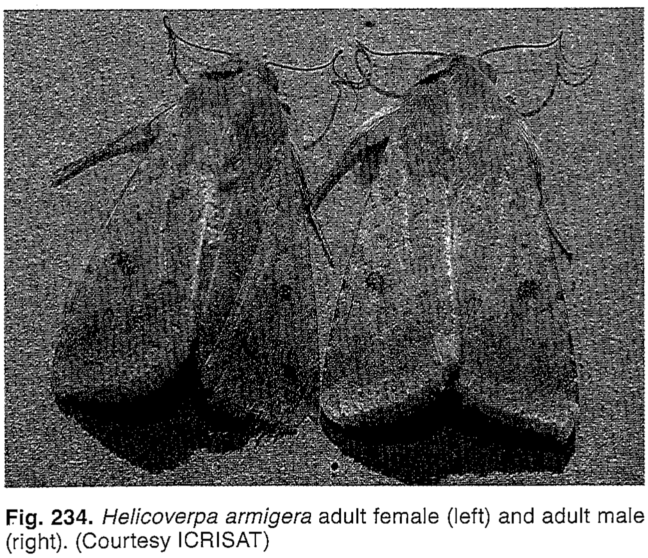

Fig. 234. *Helicoverpa armigera* adult female (left) and adult male (right). (Courtesy ICRISAT)

Natural enemies. The importance of biotic and abiotic factors on the seasonal abundance of *H. armigera* and *H. punctigera* is poorly understood. Some parasitic wasps avoid chickpea because of its dense layers of trichomes and their acidic exudates. Species of *Trichogramma* egg parasitoids are seldom present in high numbers in chickpea crops in India. The ichneumonid wasp, *Campoletis chlorideae*, is an important larval parasitoid of *H. armigera* on chickpea in India. The dipteran parasitoids *Carcelia illota*, *Goniophthalmus halli*, and *Palexorista laxa* have been reported to parasitize up to 54% of the larvae on chickpea. Predators such as *Chrysopa* spp., *Chrysoperla* spp., *Nabis* spp., *Geocoris* spp., *Orius* spp., and *Polistes* spp. are common in India. Providing bird perches or planting tall crops that serve as resting sites for insectivorous birds such as myna (*Acridotheres tritis*) and drongo (*Dicrurus macrocercus*) also helps to reduce the numbers of *H. armigera* larvae.

Biopesticides and natural plant products. The use of microbial pathogens such as *H. armigera* nuclear polyhedrosis virus (HaNPV), entomopathogenic fungi, *Bt*, nematodes, and natural plant products such as neem, custard apple, and karanj (*Pongamia pinnata*) kernel extracts have shown some potential to control *H. armigera*. HaNPV has been reported to be a viable option to control *H. armigera* in chickpea in India. Jaggery (locally made brown sugar from sugarcane juice) (0.5%), sucrose (0.5%), egg white (3%), and chickpea flour (1%) increase the activity of HaNPV. In Australia, the efficacy of HaNPV in chickpea has been increased by the addition of milk powder and more recently by the additive Aminofeed. The entomopathogenic fungus *Nomuraea rileyi* at 10^6 spores per milliliter resulted in 90–100% mortality of larvae. Another entomopathogenic fungus, *Beauveria bassiana*, at 2.68×10^7 spores per milliliter, resulted in a 10% reduction in damage by *H. armigera* compared with the control plants. *Bt* formulations are also used as sprays to control *Helicoverpa* spp. Spraying *Bt* formulations in the evening results in better control than spraying at other times of the day.

Chemical control. Management of *Helicoverpa* spp. in India and Australia in chickpea and other high-value crops relies heavily on insecticides. There is substantial literature on the comparative efficacy of different insecticides. Endosulfan, cypermethrin, fenvalerate, methomyl, thiodicarb, profenophos, spinosad, and indoxacarb have been found to be effective for controlling *H. armigera*. Spray initiation at 50% flowering has been found to be most effective. Development of resistance to insecticides is a major problem with *H. armigera*, but not with *H. punctigera* because of its high mobility. *H. armigera* populations in several regions have developed resistance to pyrethroids, carbamates, and organophosphates. Introduction of new compounds such as thiodicarb, indoxacarb, and spinosad has helped in overcoming development of resistance to conventional insecticides.

Integrated pest management. Several management tactics have been investigated to provide a framework for improved management of pod borers in chickpea and lentil cropping systems worldwide. For example, crop cultivars with resistance to *Helicoverpa* spp. (derived through conventional plant breeding or biotechnological approaches) can play an important role. Cultural practices such as deep plowing, interculture, flooding, and intercropping could potentially reduce the intensity of *Helicoverpa* spp. Although the role of natural enemies as biological control agents is unclear, their impact could be improved by reducing pesticide applications and adopting cropping practices that encourage their activity. Most studies have shown that insecticide applications are more effective than neem kernel extracts, *Bt*, HaNPV, or augmentative releases of natural enemies. However, biopesticides and synthetic insecticides, applied alone, together, or in rotation, are effective for control of *Helicoverpa* spp. in chickpea. Moreover, scouting for eggs and young larvae is critical for initiating timely control measures. Insecticides with ovicidal or systemic action are effective against *Helicoverpa* spp. during the flowering stage. Finally, the development of transgenic plants with different insecticidal genes, molecular marker-assisted selection, and exploitation of the wild species of *Cicer* and *Lens* should be pursued to develop comprehensive programs for management of *Helicoverpa* spp. on chickpea and lentil.

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(Prepared by H. C. Sharma, T. J. Ridsdill-Smith, and S. L. Clement)

Thrips

Several species of thrips, including *Frankliniella occidentalis*, *Kakothrips robustus*, *Thrips angusticeps*, and *T. tabaci* (Thysanoptera: Thripidae), damage grain legumes, including lentil.

Geographic Distribution

F. occidentalis (Fig. 235) is commonly known as western flower thrips. The majority of the species in the genus *Frankliniella* are present in either North or South America, but a few are cosmopolitan. *F. schultzei* is known as cotton bud thrip and is important in Asia as a vector of *Tomato spotted wilt virus* (TSWV). *K. robustus* is known as pea thrips and is widely distributed in Europe. It attacks several crops such as horse bean, lathyrus, lucerne, and mustard in Bulgaria, the Czech Republic, Hungary, Poland, Romania, and Slovakia. *T. tabaci* and *T. angusticeps* are commonly known as onion or potato thrips. The genus *Thrips* comprises several hundred species, which are polyphagous and cosmopolitan in distribution. *T. tabaci* and *T. angusticeps* have been reported as key pests of lentil in central Spain.

Host Range

F. occidentalis is a polyphagous pest and has a wide host range including cereals, legumes, ornamentals, and fruit trees (citrus, grape, peach, plum, raspberry, strawberry, and others). This species is of worldwide importance as a vector of TSWV in a number of crops. *K. robustus* is polyphagous and infests a number of cultivated and weed hosts. *T. tabaci* and *T. angusticeps* infest banana, brassicas, cotton, cucurbits, gladiolus, mango, oil palm, onion, pea, tobacco, watermelon, and others. Besides infesting cultivated crops, these species also feed on several weed hosts. *T. tabaci* and *T. angusticeps* affect the productivity and quality of lentil seed in central Spain.

Nature of Damage

Most *Frankliniella* spp. prefer flowers (Fig. 236), but in the absence of flowers, they also feed on foliage (Fig. 237). When the populations of thrips are high, the growing points of the plants may blacken and wither. Feeding by thrips on young leaves results in silvery streaks on the opened leaves and distortion or curling of leaves. When infestation is severe, the leaf area is reduced, which indirectly affects photosynthesis and grain yield.

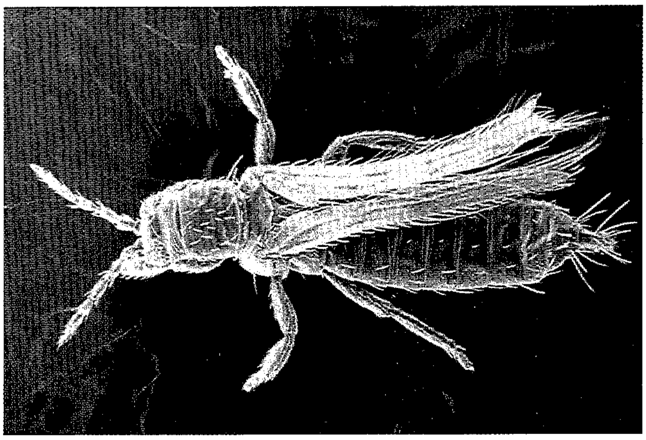

Fig. 235. *Frankliniella occidentalis* adult. (Courtesy ICRISAT)

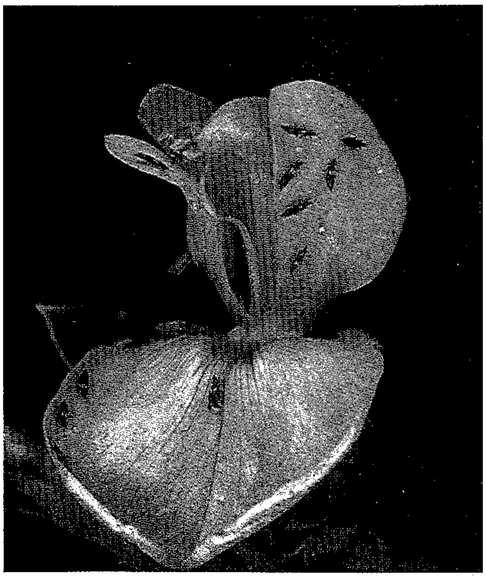

Fig. 236. *Frankliniella occidentalis* feeding on flowers. (Courtesy ICRISAT)