1257 CP055

Research on *Heliothis* at ICRISAT

V.S. Bhatnagar, S.S. Lateef, S. Sithanantham, C.S. Pawar, and W. Reed

Abstract

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has a mandate to improve the production of sorghum, pearl millet, groundnut, pigeonpea, and chickpea. All of these crops are susceptible to Heliothis *spp. and survey data show that both pigeonpea and chickpea suffer crop loss to these pests in almost all the areas of the world where they are grown. The recent progress in research on various aspects of the ecology and management of* Heliothis armigera *at the ICRISAT Center in India is reviewed: population studies using light and pheromone traps; pesticide use; natural control elements, including parasites, predators, and diseases; cultural and cropping practices, including mono- and inter-crop comparisons; and host-plant resistance screening and breeding, including mechanisms of resistance. The potential for the development of integrated pest management that will be of practical benefit in farmers' fields is also discussed.*

Résumé

*Recherche sur l'*Heliothis *faite à l'ICRISAT: L'Institut international de recherche sur les cultures des zones tropicales semi-arides (ICRISAT) a pour mandat d'augmenter la production de sorgho, de petit mil, d'arachide, de pois d'Angole et de pois chiche. Toutes ces cultures sont sensibles à* Heliothis *spp. Des données d'enquêtes montrent qu'il y a chez le pois d'Angole et le pois chiche des pertes culturales imputables à ces ravageurs dans presque toutes les parties du monde où ces plantes sont cultivées. Les progrès récents de la recherche faite au Centre ICRISAT, en Inde, sur les divers aspects de l'écologie et de la lutte contre* Heliothis armigera *sont présentés: études des populations à l'aide de pièges lumineux et à phéromone; utilisation d'insecticides; éléments de lutte naturelle, dont les parasites, les prédateurs et les maladies; pratiques culturales, dont une comparaison entre les cultures pures et associées; criblage et amélioration de la résistance de la plante-hôte, incluant les mécanismes de résistance. Le potentiel de développement d'une lutte intégrée, offrant des avantages pratiques en champs paysans, est également discuté.*

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has the mandate to improve the production of five crops: sorghum, pearl millet, groundnut, pigeonpea, and chickpea. The small farmers with very limited resources, who form the great majority of the farmers in the semi-arid tropics, are our special target. Our clients are the agricultural research and development workers of the national and regional programs, to whom we supply information and materials, particularly new germplasm, which can be locally adapted and developed for the benefit of the farmers.

All five of ICRISAT's mandate crops are susceptible to *Heliothis* spp. At ICRISAT Center, *Heliothis armigera* damages all of these crops and has also been recorded on more than 100 other plant species in this area. This pest causes greatest losses on pigeonpea and chickpea, so our major efforts in *Heliothis* research have been concentrated upon these two crops.

Although chickpea and pigeonpea are not very well known in the world's food markets, they are of enormous importance in some parts of the semi-arid tropics, particularly in the Indian subcontinent, where 80% of the world's chickpea and 90% of the world's pigeonpea crops are grown. They are the two major pulse crops of the region, providing a valuable protein supplement to the diets of the predominantly vegetarian human population.

On pigeonpea, as on most other hosts, *Heliothis* spp larvae are mainly pests of the flowering and fruiting stages of the crop. On chickpea, however, the plants are attractive to egg laying by *Heliothis*

*International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.

International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India.

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Surveys of Pest Damage in Chickpea and Pigeonpea

Crop Damage in India

As there were no wide-scale survey data of losses caused by pests in farmers' crops of pigeonpea and chickpea, ICRISAT embarked upon one, starting in 1975, in cooperation with national entomologists. This survey has been particularly active in India, where we have visited and assessed the pest damage in 1297 fields of pigeonpea and 645 fields of chickpea in the major producing areas of the country.

Pigeonpea suffers damage from a large complex of insect pests including several species of lepidopteran larvae, which feed upon the flowers and pods, but *H. armigera* is by far the most important of these. Our surveys are timed to collect samples of pods from the crop at the maturity stage. These samples are brought to our laboratory, where a skilled team assesses the percentage of pods that have been damaged by the various pest groups. The data that were recorded from these surveys across India are shown in Table 1.

It can be seen that damage caused by lepidopteran larvae (mostly *H. armigera*) tends to decrease in the north where the crop matures after the at a time when these pests have had insu time to build up to large populations. In the west, however, there is substantial crop early-maturing pigeonpeas, which are ha before the winter, and these are often s damaged by *Heliothis*. The second most da pest of pigeonpea in India is the podfly, *M gromyza obtusa*, which tends to be of most tance in the central and northern areas late-maturing crops.

In southern India, more than one-third pods on average, but much more in some and years, are damaged by *H. armigera*. I we are aware that *H. armigera* not only da the large pods, which are retained on the pl so can be counted in our survey samples, bu destroys large numbers of buds, flowe young pods, which are shed, so our surv can grossly underestimate the damage cau this pest.

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Table 1. Pigeonpea pod damage by insects in samples from farmers' fields in India, 1975-1981.

	Northwest zone Early-maturing	North zone Late-maturing	Central zone Mid- and late maturing	Sou zo Early m matu
Fields sampled (no.)	49	359	446	443
Pods damaged by lepidopteran borers (%)	29.7	13.2	24.3	36
Pods damaged by podfly (%)	14.5	20.8	22.3	11
Total pods damaged by insect pests (%)	44.0	33.8	48.0	49

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In southern India, more than one-third of the pods on average, but much more in some areas and years, are damaged by *H. armigera*. Further, we are aware that *H. armigera* not only damages the large pods, which are retained on the plant and so can be counted in our survey samples, but it also destroys large numbers of buds, flowers, and young pods, which are shed, so our survey data can grossly underestimate the damage caused by this pest.

Chickpea has a relatively small number of insect pests of which *Heliothis* spp are dominant in all the major production areas of the world. In India we have collected pod samples from more than 600 farmers' fields and found an average of 7.5% of pods damaged by *H. armigera*. Here again, this grossly underestimates the actual losses caused, for there can be severe vegetative and flower feeding, particularly in central and southern India. This crop grows through the winter, and in most years in northern India it is harvested before *H. armigera* populations build up to damaging levels. In some years and areas, however, the crop is hit by mas-

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Fields sampled (no.)	49	359	446	443
Pods damaged by lepidopteran borers (%)	29.7	13.2	24.3	36.4
Pods damaged by podfly (%)	14.5	20.8	22.3	11.1
Total pods damaged by insect pests (%)	44.0	33.8	48.0	49.9

sive populations of this pest, perhaps as a result of migration, and the crop can be completely destroyed.

Crop Damage in Other Countries

In line with our international mandate, we also take every opportunity to collect data on the pests and the losses that they cause in other countries where these crops are of importance. We collect such data by visits and through correspondence with local entomologists. In all areas of the world where pigeonpea is of importance, *Heliothis* spp are the dominant pests. In eastern Africa, *H. armigera* severely damages the crop. In the Caribbean, both *H. zea* and *H. virescens* are common pests of pigeonpea pods. In our cooperative studies with ICARDA on the pests of chickpea in Syria, we have found that *H. armigera* and *H. viriplaca* (syn *H. dipsacea*) cause major damage, in addition to the leaf miner, *Liriomyza cicerina*, which can cause crop loss in most of the Mediterranean and west Asian chickpea-producing countries. In Mexico and other American countries, both *H. zea* and *H. virescens* are known to cause substantial crop loss in chickpea.

Monitoring and Forecasting *Heliothis* Populations

We are now monitoring the populations of *H. armigera* across areas and seasons in the hope that we will eventually understand the major factors influencing these populations and so be able to forecast the incidence of damaging populations in any area.

Egg and Larvae Counts

The polyphagous habit of *Heliothis* spp complicates the estimation of populations by direct counts of eggs and larvae, for there are so many hosts. At ICRISAT Center our pest surveillance team counts *H. armigera* eggs and larvae on sample areas of all our crops on the pesticide-treated areas. The summarized data from these counts are illustrated in Figure 1. Here it can be seen that our crops provide food for *Heliothis* from late July until April, when a closed season of 2 months, during which no crops may be grown, begins. We adopted this closed season in an attempt to reduce our pest problems, which had become particularly severe, partly because there was continuous availability of crops at all stages of growth throughout the year. In the past 2 years we have reduced *H. armigera* populations within the ICRISAT boundaries virtually to nil during this closed season. Outside our boundaries however, *H. armigera* can be found through the hot and dry April to June period in reduced but substantial populations on a variety of weed hosts and on irrigated tomatoes.

Light- and Pheromone-Trap Catches

We also monitor *H. armigera* populations through catches of moths in light and pheromone traps.

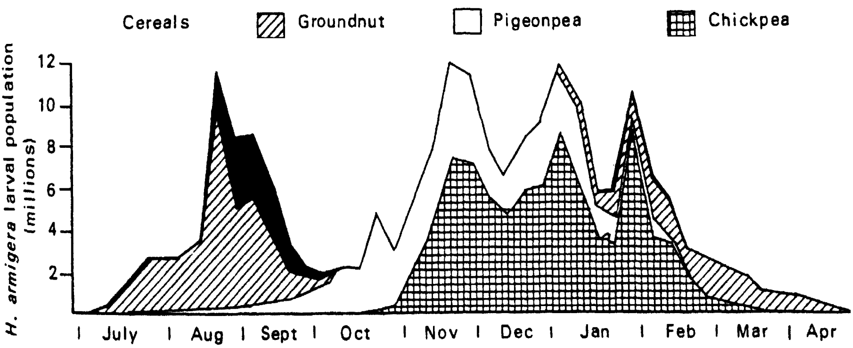

Figure 1. Populations of Heliothis armigera *larvae on crops in the pesticide-treated areas of ICRISAT Center, mean data of 1979-80 and 1980-81 seasons.*

Three light traps have been operated at ICRISAT Center since 1977, the first having been commissioned in 1975. We intend to analyze the catch data in combination with climatic data in an attempt to determine the factors that are of importance in inducing the large fluctuations in populations. We think that there is a probability that there are large-scale migrations of *H. armigera* moths across India. To gain evidence for this, we have joined the Indian Council of Agricultural Research in a project in which light traps have been set up to monitor *H. armigera* in several centers throughout the country. Some centers have found the maintenance of light traps difficult or impossible where no electric power is available, and sorting light-trap catches is a skilled and time-consuming process. We have also initiated a network of pheromone traps, baited with rubber septa impregnated with the synthetic *H. armigera* pheromone, developed and supplied by the Tropical Products Institute (Nesbitt et al. 1979, 1980) with whom we are in active cooperation. These pheromone traps have obvious advantages over light traps for they are relatively cheap, require no power source, and almost all catches are of *H. armigera* male moths, so little time is wasted in sorting the catches.

We are now well into a project comparing the two types of trap catches with each other and with counts of eggs and larvae from the plant hosts across ICRISAT Center. If we find that the trap catches can give reasonable estimates of pest populations we should be able to help the Indian national entomologists who are participating in the trap network to identify the factors, including migration, that determine the populations of this pest in their areas. Pheromone traps may also be of use as indicators of the need for pesticide use against *H. armigera* on crops in a district. We also intend to investigate the possible role of pheromones in reducing *H. armigera* populations in an area using either a mass trapping or a confusion technique.

Work on *Heliothis* Control

Pesticide Use

Our surveys of farmers' fields revealed that only 5.9% of pigeonpea fields and 7.3% of chickpea fields were treated with pesticides. Intensive work by the All India Coordinated Pulse Improvement Project has shown that several pesticides can give adequate control of *H. armigera* and good profits. Endosulfan sprayed at 0.07% concentration in 600 liters of spray liquid per hectare is the most widespread recommendation. In our surveys, however, we found that of the few farmers who used pesticides, almost all used DDT and/or BHC, usually as dusts.

The failure to utilize the widely recommended endosulfan sprays can be largely attributed to the cost and nonavailability of this pesticide and a shortage of water during the flowering and podding period. Moreover, most genotypes of pigeonpeas that are grown by farmers reach a height of more than 1.5 m at the time of flowering, and the application of pesticides to such crops is difficult, particularly with the applicators that are available to farmers in India at this time. There appear to be two ways of dealing with this problem: to reduce crop height or to develop spraying methods with machinery that can give adequate coverage to tall, dense crops. Our breeders are now attempting to develop genotypes that are small but productive. We are also looking at alternative methods of pesticide application, including the use of controlled droplet applicators (CDA) and have found marked improvement in pest control by using these sprayers. At present neither the CDA equipment nor the low volatile pesticide formulations required for this method are readily obtainable in India.

The application of pesticides to chickpea is relatively easy, but the profits from pesticide use in most areas and years appear to be much lower than those from pesticide use in pigeonpea. Replicated comparisons of pesticide-protected and pesticide-free chickpea plots from 1977 to 1981 showed yield increases ranging from 8.7% to 50%, with a mean increase of 28%. This is in sharp contrast to the benefits obtainable from the use of pesticide on pigeonea, on which we often record gains of more than 200%. The average yield increase produced by pesticide use on pigeonpea at ICRISAT over all seasons, maturities. and fields has been more than 100%.

Natural Control Elements

We have been monitoring the natural control elements of *H. armigera* and other pests on pigeonpea, chickpea, and other crops and plants throughout each year, both at ICRISAT Center and in farmers' fields. Although no virus particles could be detected in samples of dead larvae collected

Table 3. Parasitism levels recorded from eggs and larvae of *Heliothis armigera* on sorghum (CSH-6) and pigeonpea (ICP-1) in cropping systems trials at ICRISAT, 1978-81.

Pest stage	Collection periods	Crop	No. of *H. armigera* examined	Parasitism (%) Diptera	Hymenoptera
Eggs	Aug-Oct	Sorghum	11 846	0.0	26.4
	Sept-Feb	Pigeonpea	9 250	0.0	0.1
Larvae	Aug-Oct	Sorghum	6 098	2.1	24.9
	Sept-Feb	Pigeonpea	14 052	10.2	1.1

ral control elements of *H. armigera*, at and around ICRISAT, has been an interesting exercise. However, it is of no direct value in furthering our aim of enabling the small farmer of limited means to produce more food from his land. But we regard such surveys as prerequisites to augmenting natural control levels and to minimizing damage to natural control agents where pesticides are used.

Effect of Pesticides on *Heliothis* and on Natural Control Elements

At ICRISAT Center we normally use endosulfan to reduce *H. armigera* populations, for this pesticide is generally considered to be less damaging to the Diptera and Hymenoptera, which form the bulk of the natural enemy complex. In comparisons of *H. armigera* collected from pigeonpea and chickpea from the pesticide-free area of ICRISAT Center and those from pesticide-protected fields, we have found no great or consistent effects on the percentages of larvae containing parasites. However, collections of *H. armigera* larvae from farmers' pigeonpea in the Tandoor region of Andhra Pradesh, where farmers have used pesticides, particularly DDT, for several years on this crop, revealed a very low incidence of parasitism. In addition, there are complaints that such pesticides no longer give adequate control of the *H. armigera* larvae. There are suspicions that populations of this pest may have developed resistance to some pesticides in some areas, but there appears to be no recorded evidence to support this. We are hoping to cooperate with the Indian Agricultural Research Institute in Delhi in a study of the susceptibility of *H. armigera* larvae, collected from various areas, to pesticides. This project could also give evidence to confirm or deny the importance of migration in this species.

Augmentation of Natural Control

Our research on augmentation of natural enemies is still in its preliminary stages. We will examine the potential for augmentation of the natural control elements both native and exotic. From 1979 we have been gaining experience in the handling, breeding, and release of the tachinid fly, *Eucelatoria* sp, which was imported from the United States by the Plant Protection Directorate of the Government of India. We have found that the laboratory breeding of this parasite, using both laboratory-bred and field-collected *H. armigera* as hosts, has been relatively easy. Field-cage releases have shown that it parasitizes *H. armigera* larvae feeding on pigeonpea more readily than those on chickpea. We suspect, however, that this parasite might not be able to survive the hot dry season at ICRISAT, when maximum shade temperatures exceed 40°C and unshaded soil surface temperatures exceed 50°C, for this fly has not survived temperatures exceeding 35°C in our laboratory tests. We are now examining the potential of selecting for temperature tolerance in this insect. We also expect to examine the potential of other exotic parasites in cooperation with scientists within the national programs and with the Commonwealth Institute of Biological Control. We will also be looking for natural enemies of this pest in India that may be of value if introduced into other areas, such as eastern Africa. The economics of laboratory or "factory" production of parasites that may be candidates for inundative release projects will have to be carefully assessed. In most developing countries the labor costs are relatively low compared with the USA and Australia, so this may benefit such projects.

reports distributed by the Cropping Entomology unit of the Farming Systems Research Program at ICRISAT.

In addition to the intercropping studies, we have also experimented with cultural practices in monocrop pigeonpea and chickpea by varying spacings and times of sowings, with cultivars of differing maturities. All of these studies indicate greater populations of *H. armigera* larvae per unit area with greater plant densities in both crops, but with no obvious increase in the percentage damage in the pods. Typical data are shown in Table 5.

Our physiologists find marked yield advantages in close spacing for both these crops, but their results are from pesticide-protected trials. Our spacing trials in the pesticide-free areas often show a reduction of yield when pigeonpea is planted closer than five plants/m² and chickpea is planted closer than 16 plants/m².

We have found that sowing dates and/or the use of genotypes with differing maturities can have a major effect on the *H. armigera* infestations attacking any particular pigeonpea plot. Here at ICRISAT, pigeonpea flowering in November has a severe infestation of *H. armigera* larvae in most years. Pigeonpea flowering in February has relatively little attack by *H. armigera*, but other pests, including the podfly and a plume moth larva, *Exelastis atomosa* are more damaging at that time.

Screening for Resistance

For both pigeonpea and chickpea, which are still grown without pesticide use in most farmers' fields, the development of selections with reduced susceptibility or tolerance to attacks by *Heliothis* spp could lead to enormous benefits. ICRISAT is ideally situated for open-field screening of genotypes against *H. armigera*, for in recent years this pest has appeared in sufficient numbers for screening, during the pigeonpea and chickpea seasons. We also have unique advantages in this work, for ICRISAT has the responsibility of maintaining the world's germplasm of both crops and has been provided with sufficient funds and staffing to carry out intensive and sustained screening programs.

The problems of screening for resistance to *Heliothis* spp are obvious. The pest itself is polyphagous and so is unlikely to be susceptible to small changes in the chemical or physical composition of any particular host. Plants are not normally attacked until the flowering or fruiting stage so the screening of large numbers of seedlings, which has provided quick results in many other pest- and disease-screening programs, is of little or no utility for *H. armigera*. We entered into our screening programs with a full awareness of the problems involved and a knowledge that the search for resistance to *Heliothis* spp in other crops had met with only limited success. However, we are also aware that most breeding and improvement programs involving these crops are carried out in environments where pesticides are used to protect the trials. Such programs are likely to produce materials that will be of no use in the real world, where few farmers protect their crops with pesticides.

Pigeonpea and chickpea are markedly different in many aspects, and these differences have affected the progress in screening for resistance. Pigeonpea is a slow-growing but large plant that is susceptible to many pests and can have a high percentage of outcrossing. Thus, relatively few plants can be grown per unit area and no more than one generation of the mid- and late-maturity types can be grown per year. In open-field screening we

Table 5. *Heliothis armigera* larvae recorded per m² and percent pod damage in plant-density trials at ICRISAT Center, 1978-1979.

Pigeonpea			Chickpea		
Plants/m²	Mean no. *H. armigera*/m²	Pods damaged (%)	Plants/m²	Mean total *H. armigera*/m²	Pods damaged (%)
1.4	2.6	24	3.3	13.5	18
4.4	4.0	30	8.0	20.3	19
10.7	5.2	25	33.0	48.7	19
			67.0	51.4	24
SE (m) ±0.17		± 1.2		± 0.98	± 0.3

cannot determine whether any line or plant has any resistance until the podding stage, and even then resistance to *H. armigera* may be masked by the damage caused by other pests. The seed from selected plants is likely to have been outcrossed, so that we are dealing with a segregating mess in subsequent generations. Attempts to utilize field cages in which the infestations of *Heliothis* can be controlled, as used by Lukefahr et al. (1975), have not been successful at ICRISAT.

In spite of all these problems, we have made some progress in screening for resistance within the available germplasm. We have developed a methodology (Lateef and Reed 1980) that first rejects the most obviously susceptible materials in unreplicated screening and then progresses to replicated testing of materials, against appropriate checks, within trials that each contain a narrow range of maturities. This is essential, for the inclusion of plants with differing maturities in any trial will simply result in the selection of plants that happen to flower and pod during a dip in the pest population pressure!

We have tested over 10 000 germplasm accessions and breeding lines and have selected materials in each maturity group that have shown more, and less, resistance, and also those that are tolerant to *H. armigera* and other pests. Some pigeonpea plants have an outstanding ability to compensate for losses to pests; all of the first flush of flowers or pods may be lost, but the plant can quickly replace these with a second flush that can give an equal or greater yield. This complicates our testing, for we now routinely record both the first- and second-flush yields, and the pod damage in these, from each of our many trials. Data from one such trial are shown in Table 6.

In this trial we used balanced lattice squares, a design that we have found to give substantial advantage in efficiency for such testing, when compared with randomized block designs. We have found several lines that show consistent differences in their susceptibility to pest attacks and some that consistently give reasonable yields in spite of heavy pest attacks. However, we have not yet selected any plants that are outstandingly resistant to *H. armigera* attacks, and two or three pesticide sprays during the flowering period will usually result in very large increases in yield from all of our early and mid-maturity selections.

We have found that some of the *Atylosia* spp, which are close relatives of pigeonpea, have considerable resistance to *H. armigera* and other pests. Feeding tests have shown that *A.scarabaeoides* has marked antibiosis, for *H. armigera* reared on this plant show increased mortality, prolonged larval periods, low pupal weights, and reduced fecundity. This plant can be crossed with pigeonpea, and, in cooperation with our breeders, we now have several selections from the derivatives of such crosses that are of some interest, including entries 6 and 7 in Table 6.

Table 6. Percentage of pods bored (mainly by *H. armigera*) and yields from a balanced lattice-square design trial of pigeonpea selections in the pesticide-free area of ICRISAT Center, 1980-81.

		First pick		Second pick		Total
Entry	Genotype	Bored pods (%)	Plot[a] yield (g)	Bored pods (%)	Plot yield (g)	yield (kg/ha)
1	PPE-45-E2	17.2	551	14.2	115	800
2	Sehore 197	29.1	858	35.0	109	1160
3	T-21 (Check)	33.7	706	18.9	122	993
4	ICP-7349-1-S4	30.1	697	17.5	145	1011
5	ICP-7203-E1	26.9	941	18.7	258	1438
6	1914(IG)-E2	15.5	607	20.6	150	909
7	1925(IG)-E2	26.6	817	10.1	155	1166
8	ICPL-100	22.0	585	22.4	164	900
9	ICP-1903-E1	13.0	802	14.9	156	1150
	SE (m) ±	3.0	48.2	4.25	29.3	92.1
	CV (%)	25.6	13.2	42.5	38.5	17.2

a. Net plot harvested = 8.33 m^2.

In cooperation with our biochemistry unit and with the Max-Planck Institute for Biochemistry in Munich, we have initiated studies of the factors involved in resistance or susceptibility to pests in this crop. This work is in an early stage, but several interesting chemical and physical differences have been observed.

Chickpea is a rapidly growing, but small, plant that is almost invariably self-pollinated and has a remarkably restricted range of insect pests. However, this crop is particularly attractive to *H. armigera* from the seedling stage. This is illustrated in Table 7, which summarizes the egg laying on both chickpea and pigeonpea grown in pots and exposed to *H. armigera* moths in field cages. These data show that although pigeonpea is more attractive from the flowering stage, chickpea is outstandingly attractive to egg laying during the vegetative stage.

Chickpea can be eaten down to bare stalks by *H. armigera* larvae during the vegetative stage, but will usually recover to give a crop, provided there is sufficient moisture in the soil and the temperatures are not too high.

Although the chickpea plant differs considerably from pigeonpea, we have found that the general methodology developed for the field screening of the latter is equally effective for the former. On chickpea we record the damage at the seedling stage, the percentage pod damage, and the yields, and use all three criteria in our selection.

Our initial screening is in unreplicated small plots. Here the major problem is with uneven distribution of populations of *H. armigera* larvae in space and time, which allows chance escapes from damage. In this initial screening we discard the entries that appear to be very susceptible. Subsequent tests are with increasing replication of the entries, which are grouped into narrow maturity categories, with appropriate checks. In this way we have screened all of the available germplasm and the breeders' and pathologists' materials, making a total tested of more than 12 000 lines.

Early-maturing chickpeas yield better than those of later maturity at ICRISAT Center but generally suffer from the heaviest *H. armigera* attacks, particularly at the podding stage. It is within this group that we have had our greatest success, for we have been able to select lines that are consistently less attacked than the commonly grown cultivars, and also yield more in pesticide-free conditions. Data from a 1980-81 balanced lattice square design trial, which was carried out in cooperation with our breeders, are shown in Table 8.

Here we grew four of our best selections together with four entries that the breeders had selected in their pesticide-protected trials, and a well-known cultivar as a check. It can be seen that the entries previously selected as being less susceptible to *H. armigera* showed less damage and greater yields than the other entries. There was a similar trial under pesticide protection, but there we had a heavy incidence of fusarium wilt, and the best of our selections were susceptible to this disease. Our breeders have been crossing our selections with wilt-resistant materials and the progenies of these are being selected in wilt-sick plots in this season. The seed of our best selections has been made available to the national scientists, and the preliminary results from tests in southern India are promising.

We have not been so successful in selecting for resistance to *H. armigera* in the later maturing chickpeas which yield well in the major chickpea-growing tracts of northern India. We have recently transferred much of our selection and testing of this group to the farm of the Haryana Agricultural University at Hissar, where the later maturing chickpeas yield well and are also subject to heavy *H armigera* attacks.

Table 7. Mean numbers of eggs laid on chickpea and pigeonpea plants grown in pots and exposed to *H. armigera* moths in field cages at ICRISAT, 1978-79.

Stage	Mean no. of eggs laid/plant	
	Chickpea	Pigeonpea
Seedling	12.5 (120)[a]	2.3 (134)
Flowering	1.2 (113)	18.5 (105)

a. Figures in parentheses are number of plants examined.

Mechanisms of Resistance

In cooperation with our biochemistry unit and with the Max-Planck Institute of Biochemistry in Munich, we are studying the mechanisms of resistance or susceptibility of pigeonpeas and chickpeas to *H. armigera* attacks. The green tissues of chickpea plants are densely covered with glandular hairs that exude very acidic (pH 1.3) droplets this very acid exudate is probably what deters mos

Table 8. Comparison of entomologists' and breeders' selections of early-maturing chickpeas in pesticide-free conditions at ICRISAT Center, 1980-81.

Genotype	Selected	Mean pod damage (%)	Yield (kg/ha)
IC-7394-18-12-1P	Ent[a]	14.6	2223
ICC-506	Ent	5.1	2001
IC-738-8-1-1P	Ent	9.9	1963
IC-73103-10-2-1P	Ent	14.9	1900
ICCCC-9	Br[b]	18.0	1876
Annigeri-1 (check)	-	20.0	1828
ICCC-6	Br	17.8	1726
ICCC-8	Br	14.9	1685
ICCC-1	Br	28.0	1297
SE (m) ±		1.70	47.0
CV %		21.3	5.1

a. Ent = Selected by entomologists in pesticide-free fields in previous seasons.
b. Br = Selected by breeders in pesticide-treated fields in previous seasons.

insect pests from feeding upon this crop. It has been shown that some of our more resistant selections tend to have greater concentrations of malic acid in their exudates (Rembold and Winter, these Proceedings). In addition, the seed of ICC-506, one of the most resistant selections, has a higher concentration of polyphenols in its seed coat than has any other seed so far tested (Umaid Singh, unpublished). There is a possibility that some of our selections may have differing mechanisms of resistance; our breeders have been crossing the selections, hoping to produce progeny that have multifactor and increased resistance.

We are particularly interested in finding out what stimulates *H. armigera* to lay eggs on chickpea during the seedling stage, for on most other hosts egg laying is mainly restricted to the flowering stage. One possibility is that the moths are primarily attracted to plants to feed, usually upon nectar. This would explain why there is some egg laying on cotton before flowering, for on that crop the extrafloral nectaries on the leaves could provide food. On chickpea there is a possibility that the moths can feed upon the acid exudate. We have been conducting laboratory tests comparing the oviposition of moths that are allowed access to honey, differing concentrations of malic acid, and water. These tests have given variable results, but it does appear that the moths can feed upon malic acid solutions.

Integrated Management

Trials combining some of the elements of integrated management of *H. armigera* are already being field tested at ICRISAT Center. For example, we are testing the utility of the more and less susceptible chickpea selections in pesticide-protected and pesticide-free plots, and include parasite release and protection from predators in some of these. However, the major elements of any pest management program cannot be adequately tested at a center such as ICRISAT, where combinations of crops, sowing dates, and pesticide use all result in an atypical pest situation. We must carry our experimentation to farmers' fields where we can encourage the synchronous sowing of crops that will limit the buildup of *H. armigera* in the area and also dilute the populations that will occur. The use of pesticides and natural enemy augmentation will also be controlled over the area. We anticipate that we will be in a position to suggest such experimentation within the next 3 years, in cooperation with national agencies.

Summary

Research towards the effective and economic management of insect pests, but particularly *H. armigera*, has been in progress at ICRISAT for the last 7 years. Our early work was largely concerned with determining the basic data of the incidence of the pests and their natural enemies on the crops, with investigating the biology and ecology of the insects, and with developing the methodology of sampling and screening for resistance to the pests in pigeonpea and chickpea. We are now well into the action phase of our research, where we are investigating the possibility of improving the elements of pest management on these crops, including economic pesticide use, natural enemy augmentation, and the use of less susceptible and more tolerant plants. We soon hope to test our findings in farmers' fields, through the national agencies.

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