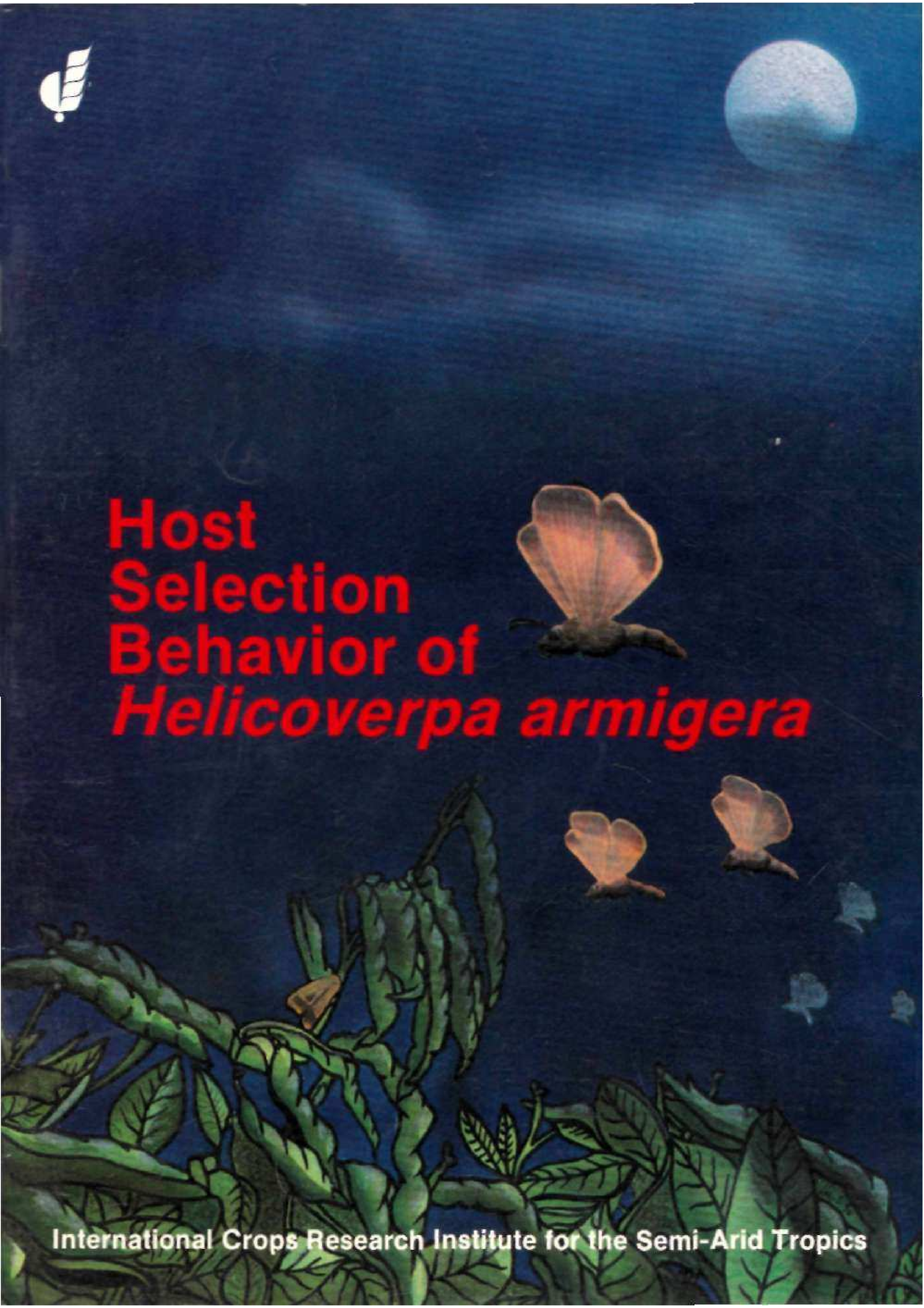
Host Selection Behavior of *Helicoverpa armigera*



International Crops Research Institute for the Semi-Arid Tropics

Abstract

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Helicoverpa (Heliothis) armigera Hubner (Lepidoptera: Noctuidae) is a major pest of several food and cash crops in the Old World semi-arid tropics. In this publication, scientists review research on the host selection behavior of *H. armigera* and on the mechanisms of host-plant resistance to this pest in pigeonpea *(Cajanus cajan* (L.) Millsp.) and chickpea *(Cicer arietinum* L.). Five technical papers cover host selection by lepidopteran insects, behavioral and electrophysiological studies of *H. armigera,* the identification of host-plant resistance in pigeonpea and chickpea, and the chemical basis of pest resistance in these pulse crops. Recommendations are made for further action to control *H. armigera* through a better understanding of its host selection behavior and the factors that interfere with this behavior.

Resume

Reference: ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1990. Comptes rendus de la Premiere reunion du groupe consultatif sur le comportement de recherche de la plante-hdte de *Helicoverpa armigera,* 5-7 mars 1990, Centre ICRISAT, Inde. Patancheru, A,P. 502 324, Inde: ICRISAT.

Heicoverpa (Heliothis) armigera Hubner (Lepidoptera: Noctuidae) est un insecte ravageur qui provoque des pertes importantes sur plusieurs cultures dans les regions du tropique semi-aride du Vieux Monde. Dans cette publication, des chercheurs presentent les informations disponibles sur le comportement de recherche de la plante-hote par *H. armigera.* Les mecanismes de resistance de la plante-hote vis-a-vis de cet insecte ravageur sont aussi presentes pour le pois d'Angole *(Cajanus cajan* (L.) Millsp.) et le pois chiche *(Cicer arietinum* L.). Les divers themes couverts par les cinq communications techniques sont: la recherche des plantes-hotes par les insectes lepidopteres, l'analyse du comportement et de l'electrophysiologie de *H. armigera,* l'identification de varietes de pois d'Angole et de pois chiche resistantes au ravageur, les bases chimiques de la resistance varietale chez ces legumineuses. Des mesures futures visant a contrdler ce ravageur sont proposers. El les p assent par une meilleure comprehensien du comportement de recherche de la plante-hdte par *H. armigera* et des facteurs qui perturbent ce comportement.

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Host Selection Behavior of *Helicoverpa armigera*

Summary Proceedings of the First Consultative Group Meeting 5-7 Mar 1990, ICRISAT Center

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics,
Patancheru, Andhra Pradesh 502 324, India

1990

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Contents

Objectives of the Meeting

The objectives of the meeting were to:

- bring together representatives of research groups studying the behavior of *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) and other lepidopteran pests;
- share existing knowledge on the host selection behavior of *Helicoverpa armigera* with special reference to pigeonpea and chickpea;
- summarize the present status of knowledge on the biochemical and biophysical characters that deter *Helicoverpa armigera* from ovipositing and feeding on pigeonpea/chickpea plants showing good levels of host-plant resistance i.e., resistance markers for plant breeding programs;
- list the research needs and priorities for future research on the host selection behavior of *Helicoverpa armigera* and on the mechanisms of host-plant resistance to this pest in pigeonpea and chickpea;
- identify responsibilities for the research, training, collaborative links, and necessary funding for this multi-disciplinary project.

Objectives de la Reunion

Cette reunion avait pour but de :

- rassembler les representants des groupes de recherche concernes par la lutte contre *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) et d'autres Lepidopteres;
- partager les connaissances acquises sur le comportement de selection de la plante-hote par *Helicoverpa armigera* avec mention speciale au pois d'Angole et au pois chiche;
- faire une synthese des connaissances actuelles sur les traits biochimiques et biophysiques qui empechent *Helicoverpa armigera* de pondre et de se nourrir sur les plantes de pois d'Angole et de pois chiche manifestant une bonne resistance varietale, a savoir des marqueurs de genes pour les programmes de selection;
- cerner les besoins et les priorites de recherche sur le comportement de selection de l'hote par *Helicoverpa armigera* ainsi que sur les mecanismes de la resistance varietale a ce ravageur dans le pois d'Angole et le pois chiche;
- identifier les responsabilites en matiere de recherche, de formation, de collaboration et de financement pour ce projet multidisciplinaire.

Welcome Address

D. McDonald

Director, Legumes Program, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh 502 324, India.

On behalf of ICRISAT's Management and on behalf of the Legumes Program I welcome you to ICRISAT and to the First Consultative Group Meeting on the host selection behavior of *Helicoverpa armigera.* To place our activities over the next few days in perspective, I will give a brief description of the Legumes Program and its activities.

ICRISAT's Legumes Program was formed in June 1986 by merging the previous Pulses and Groundnut Programs. We are now concerned with improvement of chickpea, pigeonpea, and groundnut. Our research is directed towards alleviating production constraints of chickpea, pigeonpea, and groundnut with particular emphasis on rainfed conditions and low-input farming systems. We are concerned with both abiotic and biotic constraints and, for all three crops, we are working on drought, nutritional problems, photoperiod, temperature and humidity effects, diseases, and pests. Our initial approach to solving these problems is to seek genetic resistance or tolerance to stress factors. We work closely with the Genetic Resources Unit which provides us with varieties and landraces of our crops, and genotypes of their wild relatives for use in germplasm enhancement and breeding programs.

We also closely cooperate with scientists of the Resource Management Program who find the best way of fitting ICRISAT legumes and cereals crops into improved and sustainable farming systems.

We are becoming increasingly involved in cooperative research with National Agricultural Research Systems (NARSs) in applied and adaptive research, and with mentor institutes in developed countries for strategic and basic research. In some cases we have taken the lead in initiating collaborative international research projects to bring together scientists from advanced institutes and from NARSs to concentrate their combined efforts in solving particularly difficult problems.

I should like to give an example of how ICRISAT's multilateral mandate can catalyse cooperative research between developed and developing countries. There is, in Africa, a serious disease of groundnut called groundnut rosette virus disease. It was first reported in 1907, and although some success had been achieved by the 1970s in breeding resistant varieties and in developing cultural control practices, we had no definite information as to the identity and nature of the causal agent(s). The disease is restricted to the African continent so that we could not carry out research on it here in India. What we could do was to harness the best of the world's virological expertise to help us unravel the complex story of the causal agents, the symptoms and the vectors. Starting in 1983, scientists from the USA, UK, the Federal Republic of Germany, Nigeria, and ICRISAT Center and SADCC/Malawi Groundnut Teams started to work on various aspects of the problem. Their activities were coordinated at Consultative Group Meetings such as the one you are now attending. This combined effort led, within a period of 6 years, to a comprehensive elucidation of the virus complex responsible for groundnut rosette disease, and to the development of effective methods for detecting the components of the complex.

We now have the necessary tools to investigate the epidemiology of the disease. Our breeders and cell biologists have a clear picture of the resistances needed in the cultivated groundnut and its wild relatives to the component viruses. Without this coordinated international effort the groundnut rosette disease situation would still be shrouded in mystery.

We should like to see similar coordinated international research applied to important insect pest problems. The understanding of the host-selection behavior of *Helicoverpa armigera* has been indicated as a suitable problem for such a united approach. This insect is a pest of all our ICRISAT crops and of many more important food and cash crops of the semi-arid tropics. The extent and seriousness of the *Helicoverpa* problem was well described in the International Workshop on *Heliothis* Management held here in ICRISAT in November 1981. If anything, *Helicoverpa armigera* now poses a more serious problem then it did in 1981. Even though a considerable amount of research has been conducted, much of the knowledge we need has still to be obtained. This applies particularly to the pest's behavior and the ways in which host-plant resistances operate. Such information is essential for the development of integrated pest management (IPM). The Technical Advisory Committee of the Consultative Group on International Agricultural Research has given its support to the involvement of international centers in IPM research, because this approach holds great promise for assisting farmers in developing countries to reduce damage to their crops from pests and diseases so as to ensure sustainability of production. Effective management systems for *Helicoverpa armigera* will be needed to achieve this goal.

The pest is particularly severe in pigeonpea which is one of its preferred host-plants. With the changing agricultural landscape and continued abuse of pesticides, the situation in South Asia is getting increasingly serious. We have had considerable success in identifying sources of resistance to *Helicoverpa* from the world collection of pigeonpea germplasm, and in incorporating appropriate genes into high-yielding varieties. This resistance has to be maintained and enhanced, and supplemented by other crop protection measures.

For this to be achieved we have to obtain much more information about the ecology of *Helicoverpa.* We need to access the considerable expertise available in research institutions in developed countries, and interface this with the requirements of the NARSs of the countries of the semi-arid tropics. It is with this in mind that we have invited you here.

I should like to stress that our intention is that this should be an informal meeting to explore the possibilities for research cooperation and, hopefully, to develop a research agenda. However, a plan for research will have no value if a funding strategy is not evolved to allow the planned work to materialise. The economic significance of *Helicoverpa* damage to crops, and the human misery that has resulted, are well documented and are paralleled only by the devasting locust plagues of Africa. This should be sufficient to support research proposals that are generated in this meeting. You have come here to discuss a very important problem and I am sure that we all wish you success in your deliberations.

The Asian Grain Legumes Network and *Helicoverpa armigera*

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Collaborative Agricultural Research Networks (CARNets)

CARNets are now extensively used to pool the research efforts of existing staff, facilities, and resources in a planned manner to deal more effectively with a common problem of those involved. To be effective a CARNet should have an important clearly defined problem and objective, a membership, a policy making and coordination mechanism, good communications, input from all members, ability to provide answers, and sufficient assets.

Asian Grain Legumes Network (AGLN)

The AGLN, which is a typical CARNet, was set up in 1986 on the recommendation of representatives from Asian Countries who asked ICRISAT to assist the national agricultural research systems (NARSs) in Asia strengthen their research on chickpea, pigeonpea, and groundnut through a network. The Coordination Unit and research backstopping for this network is provided by ICRISAT through its Legumes Program. The AGLN structure consists of a series of subnetworks involving ICRISAT, individual NARS, and sometimes other institutions. The country-AGLN subnetworks are based on individual country - ICRISAT formal Memoranda of Understanding (MOUs). Each country-AGLN subnetwork has a country-AGLN coordinator who coordinates the AGLN activities within a member country, and is the administrative link with the AGLN Coordination Unit at ICRISAT. This administrative framework facilitates direct contacts between network scientists within the country and between these scientists and member scientists at ICRISAT. All these scientists work directly with each other on collaborative research projects. Collaborative projects are planned and reviewed at regular review and planning meetings held in each country. These projects together with all network activities in the country form the country-AGLN Work Plan. AGLN's multilateral activities include workshops, monitoring tours, and coordinators' meetings. These activities bring together representatives from all AGLN countries to interact with each other.

Another important facet of the AGLN is its links with regional and mentor institutions such as those represented in this consultative group. All these institutions are considered AGLN members because they contribute to the collaborative research activities of the network. This contribution can be in association with the country-AGLN subnetworks, or in association with special working group subnetworks each of which is organized across countries to deal with an important common problem. A good example is the Working Group on Asia-Pacific Groundnut Viruses which is similar to the Groundnut Rosette Virus Group just described by Dr McDonald.

This working group started out in 1987 as the Working Group on Peanut Stripe Virus (PStV). In 1984 it was first recognized in the USA that PStV was a disease separate from other viruses that mottled groundnut leaves. By 1986 it was realized this disease was widespread in China, Indonesia, and Thailand where it caused a considerable reduction in groundnut production. Equally worrying was the fact that it was seedborne and could move with germplasm samples throughout the world if not detected. Therefore the AGLN organized the First Meeting to Coordinate Research on PStV at Malang, Indonesia that brought together all known experts on this disease to pool their knowledge and develop a plan to tackle this newly identified problem. This meeting was cosponsored by Indonesia's Agency for Agricultural Research and Development, Australian Centre for International Agricultural Research (ACIAR), Food and Agriculture Organization (FAQ), Peanut Collaborative Research Support Program (Peanut-CRSP), International Development Research Centre (IDRC), and the Dutch Agency for Technical Aid (ATA) Project at Malang. The working group successfully implemented all the recommendations made at the first meeting. The Second Coordinators' Meeting on PStV was held at ICRISAT Center in 1989. It reviewed the progress made since the first meeting, heard some very specialized technical papers, and produced a series of recommendations including broadening the mandate of the group to include all groundnut viruses in the Asia-Pacific region.

The PStV Working Group provides a good model for this *Helicoverpa* working group. *Helicoverpa armigera* is a very important problem on chickpea and pigeonpea in Asia and understanding its host selection behavior is essential to provide guidance for its control.

The objectives of the meeting are well thought out and if met, should lead to this working group providing very useful results. The members of this meeting can be thought of as an expert group and may consider forming a small steering committee to review the research results and provide direction for the group's activities between major meetings. For this group to have the greatest impact on *Helicoverpa* control in Asia it is essential to also identify cooperators from Asian countries as members of this working group. These country cooperators have an important role in defining the problem of *Helicoverpa* more exactly, in participating in the group's collaborative research, and in extending the research results to Asian countries and providing feedback. They are also indispensable for integrating the group's research results into IPM systems that are appropriate for each country.

The major asset of this working group is the scientific background and research capability of its members here today. Additional sources of funding will likely be necessary to support the networking activities of this consultative group. Funding will probably come for specific activities of the group, rather than an overall support from one source. For example, separate funding will be required for training, for screening material, and for meetings. Often donor funds are available to partially support these activities within individual countries. The following groups have indicated interest in links with, or in providing funds for this *Helicoverpa* working group: Asian Vegetable Research Development Center (AVRDC), FAO, IDRC, International Institute for Tropical Agriculture (IITA), Overseas Development Natural Resources Institute (now NR1), Peanut-CRSP, and various NARSs. I am sure there are others you can tell us about.

Understanding the host selection behavior of *Helicoverpa armigera* can have a massive effect on solving a universally devastating constraint on legume production and in particular pigeonpea and chickpea production in Asia. AGLN looks forward to facilitating the group's activities in Asia and wishes you every success in achieving the objectives of your meeting.

Summaries of Papers

Host Selection by Lepidopteran Insects: the Role of Plant Chemicals in Oviposition and Feeding Behavior

L.M. Schoonhoven

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Oviposition and feeding behavior in herbivorous insects is governed, to a large extent, by physical and chemical signals from plants. Although there is no example of a plant-insect relationship where all behavioral cues involved in host selection have been identified, most of our knowledge in this area is based on research with Lepidoptera.

Oviposition

Visual (color, shape, etc.) as well as chemical factors affect oviposition in butterflies and moths (e.g., Ma and Schoonhoven 1973; Rothschild and Schoonhoven 1977). Chemicals of plant origin, which stimulate landing on a plant and oviposition, are perceived by olfactory sensilla on the antennae and taste receptors on the tarsae, as has been concluded from ablation experiments and electrophysiological recordings (Van Loon and Frentz 1989; Ma and Schoonhoven 1973). At the same time oviposition behavior may be modified or even suppressed by plant-derived chemicals, as well as by oviposition-deterrent pheromones. Compounds that inhibit oviposition and promote insect dispersal stimulate chemoreceptors on antennae and tarsi (Rothschild et al. 1988; Schoonhoven et al. In press). It is evident that an insect's chemoreceptors can be stimulated by a variety of chemicals, and only when the right blend impinges on its sensory system will oviposition behavior be discharged. The fact that certain individuals of a host-plant species elicit egg laying, whereas others do not (Mitchell 1977) indicates the presence in the insect of a fairly delicate decision-making process. This conclusion is corroborated by the observation that, when employing an experimental set up with a wind tunnel and a locomotion-compensator, the oriented movements of the Colorado potato beetle to odor sources were blocked when the airstream also contained volatiles from other plant species (Thiery and Visser 1986).

Larval Feeding Behavior

Food acceptance behavior in lepidopteran larvae has been quite extensively studied. The chemosensory cues involved in food plant recognition have been analysed in detail for some species. From these studies, reviewed by Schoonhoven (1986), it can be concluded that different species have differently tuned chemoreceptors, and that the insects obtain fairly detailed information of a plant's chemical fingerprint. This allows an insect to distinguish between different plant cultivars, and to select certain parts of their hosts.

Food preferences are, to a certain degree, genetically determined. However, experience may modify preference behavior to a considerable extent (Jermy 1986). Apparently some kind of associative learning, based on the presence or absence of specific chemicals, affects food choice (Saxena and Schoonhoven 1978). Changes in the sensitivity of the chemoreceptory system can be recorded concomitantly with the induction of food preferences. It is concluded that behavioral changes are, to a certain extent, therefore due to modifications in the sensory message that is transmitted to the central nervous system (Schoonhoven et al. 1987).

The behavioral aspect of food plant induction has a physiological counterpart in the change of utilization parameters. There is some experimental evidence for the hypothesis that lepidopteran larvae show higher food conversion efficiencies on induced food plants (e.g., Schoonhoven and Meerman 1978). This is supposedly due to an adaptation of the digestive system to the particular food and/or changes in the enzyme system responsible for the detoxification of noxious allelochemics.

This summary of the role of plantborne chemicals (in addition to physical stimuli), in host recognition, oviposition, and feeding behavior in Lepidoptera, evinces that some general principles have been identified. This is because of sophisticated chemical analytical techniques, well-designed behavioral methods, and powerful physiological instrumentation are available. In combination these methods provide the means for analysing in detail the factors governing a particular insect-plant relationship. Understanding these factors is imperative when developing methods aimed to disrupt such a relationship.

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The Role of Chemicals from Legumes in Mediating Host Selection by Adults and Larvae of *Helicoverpa armigera:* A Behavioral and Electrophysiological Study

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Behavioral, electrophysiological, and biochemical techniques have been combined to study the factors that influence the host selection behavior of *Helicoverpa armigera.* Comparisons have been made between the chemicals in a range of crop legumes that affect larval feeding behavior, and those that affect adult oviposition and feeding behavior. We have studied cultivars and close wild relatives of the following crop legumes: *Cajanus cajan, Cicer arietinum, Glycine max, Phaseolus vulgaris, Vigna radiata,* and *Arachis hypogaea.* The host selection behavior of gravid female moths was found to be influenced by a range of volatiles present in some of the cultivars of the plants studied.

Our results indicate that moths usually selected plants with relatively high proportions of hexanal, beta-pinene, (Z)-3-hexen-l-ol acetate, limonene, alpha cedrene, methyl-cyclopentane, and 2,3,4-trimethylhexane. These volatiles, when applied to an inert substrate in the laboratory, stimulated adults to oviposit. However, the presence of these compounds does not always stimulate females to oviposit, as some of them are present in the non-preferred plants. Thus, our findings would suggest that adults may recognize a potential host-plant by the presence of the above compounds, but they may use very slight differences in other compounds to discriminate between genotypes. By a sychronous combination of behavioral and chemical techniques we hope to define the molecular criteria responsible for the observed host-plant preference. We need also to monitor the seasonal phenology of the volatile compounds present in the plants. It is possible that adults use variations in the profile of the volatiles to determine the growth stage in plants, and thus their suitability as hosts.

Females were also responsive to levels of less volatile allelochemicals, such as sesquiterpene lactones, phenolics, diterpenes, and acids, as well as to nutrients. Oviposition was negatively correlated with increasing concentrations of gallic acid, benzoic acid, vanillic acid, malic acid, and oleanolic acid. Feeding was positively correlated with increasing concentrations of sucrose, fructose, and glucose and with the presence of leucine, alanine, and proline.

Larval development and feeding behavior were inhibited by compounds present in chloroform extracts of leaf surfaces, and in ethanol extracts of whole leaves of approximately half the wild relatives studied. Due to the significant activity of these extracts, an exhaustive study is presently being undertaken to isolate and identify the active components in them. These active extracts are being prepared by grinding foliage, which is then added to boiling ethanol, and after approximately 5 min the mixture is cooled and homogenized. The homogenate is then filtered through glass wool, evaporated down, and the residue sequentially extracted with hexane and water.

Many of the water fractions have been found to decrease feeding and larval growth. Active water fractions are extracted with n-butanol and, after evaporating off the butanol, the residue is taken up in water for HPLC studies. Fractions are obtained with a C 18 reversed-phase column at a flow rate of 3 mL min^{-1} using a water-acetonitrile gradient. The active fractions are applied to thin-layer chromatography (TLC) plates (Whatman K6 silica gel 10 x 20 cm) and a range of solvent systems and reagents are used to visualize the components in the extracts. The majority of the components in the active extracts from wild relatives of *Cajanus* and *Cicer* have not, as yet, been identified, whereas those in the cultivars and wild relatives of *Phaseolus, Vigna, Glycine,* and *Arachis* have been identified as known compounds. Some of the ethanol extracts of *Phaseolus vulgaris* contained triterpenoid glucosides that increased mortality of 3rd instar larvae when incorporated into an agar-cellulose diet at concentrations greater than 0.5%.

In the early stages of the project, detailed observations were undertaken of host-selection behavior by neonate larvae. These larvae were deterred from feeding on the leaves of some cultivars of *Cicer, Cajanus,* and *Phaseolus.* The chloroform extracts obtained from the surface of these leaves contained a range of flavonoids which were, by themselves, not very active feeding deterrents, but in the presence of amino acids (alanine and leucine) and sugars (glucose and fructose) significantly influenced the feeding behavior of larvae in the 1st and 2nd instars. The larvae were observed to spend more time rasping the surface of glass fiber discs ((GFD) Whatman GF/A 2.1 cm diam) treated with 100-ML of the crude leaf extracts from these resistant leaves, or the flavonoid/amino acid or flavonoid/sugar combination present in these extracts, than they did on GFD treated with extracts from susceptible leaves. It would appear that flavonoids elicit, or do not inhibit, biting behavior but do inhibit swallowing.

Electrophysiological studies have been undertaken to further investigate this phenomenon. The gustatory sensilla on the maxillae are brought into play when the larvae initially contact a leaf. These sensilla are usually wiped on the surface of the leaf, where they are stimulated by surface compounds, and are therefore involved in the early stages of host selection. We have shown that they are responsive to the extracts and compounds described above all of which are associated with lack of feeding. However, the extracts stimulate neurones in these sensilla that usually respond to phagostimulants, and thus elicit biting behavior in the larvae, the behavior observed in the present study. The fact that sustained feeding does not follow the biting suggests that the chemicals stimulate other mouthparts in a way that inhibits feeding. The sensilla likely to be involved are located on the labium.

Overall, our results show that some compounds could be very important in attracting adults to select and oviposit on a plant, whereas other compounds deter larvae from feeding. However, we have no unequivocal proof that either of the observed effects could be modified by altering the concentration of a single compound in the plant. Therefore, it is not certain that altering the genome encoding for only one compound would significantly alter the resistance of a plant to attack by *H. armigera.* Our results suggest that the levels of a group of compounds would have to be altered to influence a plant's susceptibility or resistance to *H. armigera.*

Our overall approach to crop protection is to gain a thorough understanding of the basic mechanisms by which an insect selects a plant. This study on *H. armigera* has shown that a protective mechanism would have to be based on the differential levels of a range of compounds. Therefore, in order to modify the resistance of a plant to attack by *H. armigera* the active compounds must be known. The ability to isolate the genes encoding for these active compounds, and then engineer them into a crop plant, would depend in part on the types of compounds involved. This task is made easier if the active compound is a protein, but so far the compounds we have found to be involved in host selection by *H. armigera* have been either non-proteinaceous secondary metabolites, or simple nutrients. However, some plants that were intially accepted by larvae, but then caused high mortality, could contain anti-metabolic proteins as we have some evidence that the wild relatives of *Phaseolus* and *Vigna* contain high levels of a trypsin inhibitor.

The Search for Host-Plant Resistance to *Helicoverpa armigera* in Chickpea and Pigeonpea at ICRISAT

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Chickpea *(Cicer arietinum* L.) and pigeonpea *(Cajanus cajan* (L.) Millsp.) are two important food crops in many parts of the semi-arid tropics (SAT). Among the insect pests that feed on these crops, *Helicoverpa armigera* can be devastating on the buds, flowers, pods, and seeds of both grain legumes.

ICRISAT entomologists have focused on identifying chickpea and pigeonpea genotypes with characteristics that interfere with the host selection behavior of *H. armigera.* These insect-resistant genotypes are a key component of the integrated pest management (IPM) schemes developed for farmers who live in the risk-prone SAT.

Chickpea

From 1976, we have been screening the world germplasm collection of this crop, held in the gene bank at ICRISAT Center, for resistance to this pest. An open-field screening technique, using natural populations of *H. armigera* occasionally supplemented by laboratory-reared insects, was developed to identify resistance sources in pesticide-free conditions. Initial tests were unreplicated, and all the genotypes that were more damaged by the pest and yielded less than the standard control cultivars of the same duration were discarded. Promising genotypes were then tested in larger plots with increasing replications over the years, with advanced evaluation in balanced lattice design trials. So far, 14 800 germplasm accessions and many breeders' lines have been screened. We have selected several genotypes with consistent resistance to H. *armigera* (Lateef 1985). Some of these are listed in Table 1.

Our selections have been used in crosses by plant breeders to increase host-plant resistance and combine it with other traits, particularly with resistance to fusarium wilt {*Fusarium oxysporum* Schlecht.), since most of our selections have proved to be susceptible to this widespread disease. Inheritance studies have shown that resistance to *H. armigera* is additive (Gowda et al. 1985). One of our resistant selections ICCX 730008-8-1-IP-BP (ICCV 7) has been recommended for use as a parent in the Indian national chickpea breeding program.

Table 1. Chickpea genotypes identified as resistant to *Helicoverpa armigera* at ICRISAT Center, India.

Chickpea genotypes	Mean resistance rating[1]	Borer damage (%) range during 1979-89
Desi short-duration		
ICC 506	3.0 (9)[2]	1.1 - 12.8
ICC 10667	3.1 (9)	1.7-14.2
ICC 10619	3.4 (9)	2.7-21.0
ICC 6663	3.5 (10)	1.1-31.8
ICC 10817	3.6(10)	2.4 - 30.0
ICCV 7 (ICCX 730008-8)	3.8 (8)	3.8-11.8
Control		
Annigeri	6.0(10)	13.2-36.3
Desi medium-duration		
ICC 4935-E2793	2.8 (10)	2.3 - 11.9
ICCX 730041 -8- 1-B-BP-EB	3.8 (10)	1.7-38.2
ICCX 730094-18-2-1P-BP-EB	4.6(10)	3.8 - 20.0
Control		
K 850	6.0(10)	11.4-40.9
Desi/kabuli long-duration		
ICCX 730020-11-1	4.3 (10)	2.8 - 26.9
Control		
H 208	6.0(10)	3.8 - 44.3
ICC 10870	4.3 (9)	4.4 - 39.3
ICC5264-E10	3.8 (10)	2.5 - 28.3
Control		
I. 550	6.0(10)	2.8 - 39.4

1. Rated on a 1 -9 scale, where 1 = resistant and 9 = susceptible.
2. Figures in parentheses indicate number ol years tested.

Pigeonpea

About 200 insect species have been recorded as feeding on this crop (Lateef and Reed 1990). In India, where over 90% of the world's recorded production of pigeonpea is grown, and in several other countries, field losses are primarily caused by a pest complex that attacks the flowers and pods. *Helicoverpa armigera* is a major component of the pod-borer complex, being most damaging in southern and central India. The podfly, *Melanagromyza obtusa* (Mall.) causes equal or greater damage in northern India (Bhatnagar et al. 1982).

Since 1976, we have been screening the world collection of germplasm of this crop, held in the gene bank at ICRISAT Center, for resistance to *H. armigera* and *M. obtusa.* Because we found considerable variation in pest damage amongst cultivars of

Table 2. Pigeonpea genotypes identified as resistant to *Helicoverpa armigera* under pesticide-free conditions at two locations, 1979-90.

Pigeonpea genotypes	Mean resistance rating[1]	Borer damage (%) range during 1979-90
Short-duration (Hisar)		
ICPL 1	3.7 (7)2	5-32
ICPL 2	3.9 (8)	6-45
ICPL 269	4.7 (6)	11-29
ICPL 187-1	3.7 (7)	8-29
Control		
Pant A1	6.0 (9)	14-58
Medium and medium-long duration (ICRISAT)		
ICP 909-E3	4.5(11)	6-50
PPE 45-2	4.4(11)	4-37
ICP 1811-E3	4.1 (11)	9-50
ICP 1903-E1	3.8(11)	13-67
ICP 10466-E3	3.7(11)	3-67
Controls		
ICP1691(susceptible)	7.5(11)	11-100
BDN-1	6.0(11)	16-90
C-II	6.0(11)	18-76
ICP 3615	3.6(11)	14-50
ICP 5036	3.5(11)	7-61
PPE 37-3	4.4 (9)	10-29
ICP 8094-2-S2	3.5(11)	7-30
1CP8102-5-S1	4.7(11)	11-49

1. Rated on a 1-9 scale, where 1 = resistant and 9 = susceptible.
2. Figures in parentheses indicate number of years tested.

different maturities, screening was done in narrow maturity groups within which relevant genotypes were used as standard controls. To date, more than 10000germ-plasm accessions and breeding lines have been screened for resistance to *H. armigera* in *pesticide4ree* open-field plots over a period of 6-11 years per genotype (Table 2). Pigeonpea lines were identified not only for their resistance to pest attack and damage, but also for their ability to yield well and compensate for early losses.

We have not found any plants immune to *H. armigera.* But we now have several promising lines with tolerance to this pod borer that yield well under heavy pest attack in insecticide-free situations. These selections have been tested for several years at various locations in India and other Asian countries. More emphasis has recently been put on involving resource-poor farmers in the multilocational testing of lines identified as resistant on research stations. Farmer-designed and farmer-managed on-farm varietal trials enable us to evaluate genetic material not only in terms of insect resistance, but also in relation to other agronomically important traits under resource-poor conditions (Pimbert 1990). One of our borer-resistant selections ICP 1903-E1 (= ICPL 332) was released in 1989 for cultivation in the state of Andhra Pradesh, India.

Mechanisms of Host-Plant Resistance

Field and laboratory studies have shown that most of the resistant selections show oviposition non-preference. Low levels of antibiosis have been demonstrated in some chickpea selections and moderate to high levels of antibiosis have been detected in the seed coats of mature pigeonpea seed (Lateef et al. 1987). *Helicoverpa-resistant* chick-pea and pigeonpea genotypes showing oviposition non-preference and antibiosis are listed in Table 3.

Table 3. Chickpea and pigeonpea genotypes showing oviposition non-preference and antibiosis to *Helicoverpa armigera.*

Maturity groups	Chickpea	Pigeonpea
Short-duration	ICC 506	ICPL 2[1]
	ICCV 7	ICPL 187-1
	ICC 10619[1]	ICPL 2692
	ICC 10667[1]	ICPL 288[2]
	ICC 10817[1]	
	ICCL 86101[1]	
	ICCL 06102[1]	
	ICCL 86104	
	ICCL 86105	
Medium-duration	ICCX 730041	PPE 45-2
	ICC 4935-E 2793[1]	ICP 1903
	ICCL 79048	ICP 909
	ICCL 79022	ICP 10466
		ICP 3328
		ICP 1811
		ICPL 84060
		ICPL 87088
		ICPL 87089[1]
Medium-/ long-duration	ICCX 730020-11	ICP 5036[1]
	ICCX 730244	ICP 10531[1]
	ICCX 730185	
	ICCL 86111[1]	
	ICC 4856	
	ICC 5264-E9	
	ICC 10243	
	ICC 10870	

1 = tested for antibiosis only. 2 = tested for oviposition non-preference only.

Further elucidation of the biochemical basis of host-plant resistance in pigeonpea and chickpea is needed as are studies of the biophysical factors that may interfere with the host selection behavior of *H. armigera.* Understanding the pest's host selection behavior in relation to susceptible and resistant genotypes would not only help to identify resistance markers for plant breeders. It would also help to design other components of IPM, particularly if these studies consider the ecological factors that modulate insect behavior (either directly or indirectly via the changes they induce in the quality and quantity of the insect's food plants) (Pimbert 1990).

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Progress in Host-Plant Resistance Work in Chickpea and Pigeonpea against *Helicoverpa armigera* (Hubner) in India

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Host-plant resistance (HPR) in crop plants is a major component of integrated pest management. It is relatively stable, cheap, non-polluting and is compatible with other methods of pest control. The pod borer, *Helicoverpa armigera* (Hubn.) is an important insect pest of pigeonpea and chickpea crops that are primarily grown by poor and marginal farmers. The yield losses caused by this pest justify the development and adoption of resistant varieties. Research toward this goal in India was initiated by the Indian Council of Agricultural Research (ICAR) under the All India Coordinated Pulses Improvement Project (AICPIP) and at the Directorate of Pulses Research, Kanpur, and at the International Crops Research Institute for Semi-Arid Tropics

Table 1. Chickpea lines found to show resistance or tolerance to *Helicoverpa armigera* in different agroecological zones of India[1].

Agroecological zones	Chickpea lines resistant/ tolerant to *Helicoverpa*
South Zone (SZ)	ICCL 86101, ICCL 86104, ICCX 730179, ICC 3474, ICC 2553, ICC 2696
Central Zone (CZ)	N 37, ICCL 86101, ICCL 86104, ICCX 730185, ICCX 730179, ICCX 730020-11-1, ICC 3474, ICCX 730190, ICCX 730025, ICC 5800
North East Plain Zone (NEPZ)	ICCL 86101, C 10, DPR/CE-1-2, DPR/CE-2-3, DPR/CE-3-1, ICC 10156, ICCX 730179, ICCX 730025, S 76, N 37, ICCX 730020-11-1, ICC 10243, GL 1002, PDE 7, ICCX 730244, ICC 5264-E9, ICC 5264-E10 and ICC 3474
North West Plain Zone (NWPZ)	ICCX 730185, ICC 3474, S 76, ICC 5264-E10, ICC 7559, ICC 7966
West Zone (WZ)	ICCX 730185, ICCX 730179, ICCX 730190 AND ICC 2553

1. Source: Lateef and Sachan 1990.

(ICRISAT). Efforts in this direction have led to the identification of promising donors in the case of chickpea. However, to date only limited success has been achieved by the national program for pigeonpea. Reasonably good success in controlling *H. armigera* in pigeonpea has been achieved through the use of pseudoresistance (i.e., a host-avoidance phenomenon), particularly for late-maturing pigeonpea in northern India.

Many chickpea cultivars show good levels of resistance to *H. armigera* (Table 1). Selections ICC 506, ICCX 730008, ICC 6663, ICC 10817, ICCX 730020-11-2, ICCL 86102, ICCL 86103, PDE 2, and PDE 5 in the desi short-duration group, and ICC 4935-E-2793 and ICCX 730041 in the desi medium-duration group show consistent resistance to *H. armigera.* However, most of these resistant selections were found to be susceptible to such diseases *as fusarium* wilt *(Fusarium oxysporum* Schlecht.) and *ascochyta* blight *[Aschochyta rabeie* (Pass.) Labr.) and are therefore less useful. There is a need to incorporate disease resistance into these lines to ensure stable crop performance. Based on overall performance, chickpea selections ICCX 730008 (ICCV 7) and PDE 2 were recommended as donor parents for breeding *Helicoverpa-resistent* varieties during the 1986 annual AICPIP workshop at Srinagar. However, there is still a need to develop genotypes with stable resistance across the different agroecological zones of India. This could become possible by intensifying HPR work at five locations in India.

In India, over the last 8 years, HPR work in pigeonpea against pod borer in India has achieved limited success, but significant success in HPR has been achieved for podfly *(Melanagromyza obtusa).* A few pigeonpea selections with promising resistance to *H. armigera* have shown variable performance (Table 2) in AICPIP multilocational tests. However, ICPL 6 (extra-early), PPE 45-2 (early), ICP 1903 (medium), and MA 1 (late) have shown good overall performance against *H. armigera.*

Table 2. Pigeonpea selections showing resistance to *Heticoverpa armigera* under AICPIP multilocational testing.

	Season			
Location	1985/86	1986/87	1987/88	1988/89
Extra-early				
Pantnagar	ICPL2 TAT 10	-	ICPL 187-1 ICPL 187-1	Pant A-l
Badnapur	ICPL 1 ICPL 288	ICPL 6	ICPL 6	ICPL 2 ICPL 6
Hisar	ICPL 288	-	Tat 10 ICPL 187-1	ICPL 187-1 ICPL 6
Rahuri	-	-	Tat 10 ICPL 6	ICPL 2 ICPL 187-2
Puddukkotai	-	-	ICPL 288 Pant A-l	-

Continued

Table 2. *Continued*

Location	Season 1985/86	1986/87	1987/88	1988/89
ICRISAT Center	-	-	-	ICPL 6 ICPL 201 ICPL 187-1
Early				
Pantnagar	T21	Nil	ICP 7349-1	ICP 109BB
Rahuri	PPE 45-2	-	PPE 45-2	-
Badnapur	ICP 7349-1-5 PP E 45-2		ICP 909	PPE 45-2 ICP 7349-1
Hisar	ICP 909		ICP 909	PPE 45-2 GAUT82-1
Puddukkotai	-	-	PPE 45-2	-
Gulberga	-	-	T21	-
ICRISAT Center	-	-	-	ICPX 77303
Medium				
Badnapur	ICPL 84060 BDN 7	-	ICP 1903 ICP 3615	ICP I903-E ICP 10531
Sehore	-	ICP 4070	ICP 1903	ICPL 84060 ICPL 87089
Rahuri	-	ICP 1903	BDN 7 BSMR 1	-
Puddukkotai	-	-	ICP 10531	-
ICRISAT Center	-	-	-	Bahar ICPL 87088
S.K. Nagar	-	-	-	ICP 7946-E
Late				
Varanasi	DA 2, MA 2	-	_	MA 2
Dholi	-	MA 2	-	-
ICRISAT Center	-	-	-	ICP 9689 MA 2

1. = Data not available.

The major limitation in improving levels of HPR in pigeonpea has been the poor research base of pulse entomology. It is evident from Table 3 that except at DPR Kanpur and ICRISAT few efforts have been made in this direction within AICIPIP. There is an urgent need to substantially strengthen the HPR program in ways that are commensurate with the magnitude of the pest problem. The use of innovative tech-

Table 3. Chickpea and pigeonpea germplasm accessions screened by the AH India Coordinated Pulses Improvement Project (AK PIP), and at ICRISAT Center during 1981-89.

	No. of entries screened	
Locations	Pigeonpea	Chickpea
Akola	·	76
Badnapur	150	628
Coimbatore	171	103
Dholi	51	29
Faizabad	-	120
Gulberga	18	248
Hisar	87	456
Ludhiana	418	481
Lam	149	-
Puddukkotai	276	190
Rahuri	107	152
Ranchi	-	24
Vamban	62	-
Varanasi	72	-
DPR, Kanpur'	3500	3200
ICRISAT	10000	14000

1. DPR = Directorate of Pulses Research

niques involving tissue culture and genetic engineering may allow us to more fully exploit the resistance already present in wild types. The success achieved so far justifies strengthening the ongoing program.

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Semiochemicals and Host-Plant Selection by *Helicoverpa armigera:* Basic Studies in the Laboratory for the Field

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Thousands of chickpea and pigeonpea genotypes have already been screened for H. *armigera* tolerance in the field. Some of them have good levels of resistance that are maintained under the changing environmental conditions of different agroclimatic zones.

However, a severe drawback of this classical genetic approach, is the fact that very few quantitative resistance/tolerance markers are available under the open-field conditions that could directly guide the plant breeder. The reasons for this are obvious. The infestation pressure of the insect pest in a discrete plot is unpredictable because it depends on the insect's access to other host-plants, seasonal fluctuations in temperature, or moisture, or on previous climatic stresses and pesticide applications. The same holds true for the cultivars that are screened. They are exposed to changing environmental situations, including such agricultural practices as plant density and intercropping. Selection of H. *armigera* resistant lines is therefore extremely time-and labor-consuming. Some useful characters of a germplasm accession may even be missed by such a random screening strategy. After having selected for insect resistance, further field screening is often required to select insect-resistant lines with resistance to pathogens.

What can the chemist add to insect resistance breeding programs? One possibility is to identify characteristic phytochemicals whose concentrations correlate with insect resistance under field conditions. Another promising approach is to better understand the host-finding behavior of the insect pest. For the first approach highly susceptible or resistant genotypes that are the products of long-term field screening can be used. For the second approach the help of the biologist is required. From the beginning of our studies we have collaborated with entomologists at ICRISAT Center who provided us with the most recent resistance data and selections (Rembold and Winter 1982). This field material was then studied and analyzed in the laboratory by chemists and biologists with the intention of returning these basic studies to the field and to the plant breeder. Our activities concentrate on chickpea and pigeonpea, but we have recently added maize because it is also an economically important host-plant for *H. armigera.*

Kairomones are semiochemicals used by some insects as distance-perceivable signals to find their hosts. They can be used by larvae when they are searching for food, by the male in combination with the female sex pheromone, and by the egg-laying insect. An attractant that emanates from a certain plant is important for a polyphagous insect like *H. armigera.* Some of the volatile plant chemicals may just signal "green odor", whereas others convey important information on the trophic milieu that the ovipositing moth largely chooses for the larvae. Marker compounds can thus be used to increase (as trap plants), or reduce (by plant breeding) the attractiveness of a genotype. A synthetic kairomone can also be applied to lure larvae to toxic baits, or moths into field traps.

Our research concentrates on volatile compounds that, when released by the plant, strongly affect the insect pest's behavior. When tested in a simple flight tunnel we observed a strong positive response by H. *armigera* females to extracts from pigeonpea flowers, leaves, and the steam distillate of leaves. Further fractionation by vacuum distillation and column chromatography gave a fraction with high activity (Rembold and Tober 1985; 1987). The work on pigeonpea semiochemicals is continuing (Rembold 1988) and concentrates on purifying a group of sesquiterpenoids that elicit strong activity in larvae and adults. After we had found that chickpea seed flour attracted the larva of *H. armigera* (Saxena and Rembold 1984), and that a standardized olfactometer assay had been designed (Rembold et a l. 1989a), the search for the chemical basis of this attractiveness was possible using modern microannalytical techniques. Capillary gas chromatography showed that total chickpea flour aroma, was composed of 154 compounds, 132 of which were identified by GC-mass spectrometry. All substances comprising more than 0.5% of the total volatiles in the flour headspace have now been characterized. The dominant chemical classes are terpenoids (35%) - different from pigeonpea - alcohols (18%), and aliphatic hydrocarbons (Rembold et al. 1989b).

The 16 most prominent compounds were individually tested on 1st instar *H. armigera* larvae in an olfactometer bioassay. Significant positive orientation was evoked by pentan-1 -ol and by a mixture of the three terpenes, delta-3-carene, myrcene, and alpha-pinene. The highest attraction was obtained with a synthetic kairomone impregnated in a rubber septum, composed of the four compounds in the same proportion as the chickpea flour aroma, i.e., 2 parts of pentan-l-ol : 5 parts of delta-3-carene : I part of myrcene : 9 parts of alpha-pinene (Rembold et al. 1989a). A study with *H. armigera* adults also showed an interesting result: from a total of 24 egg-laying moths, individually tested in the flight tunnel, 17 (70%) showed a strong behavioral reaction, and each of the 24 moths showed some response to the kairomone. The moth's reaction was independent of the amount of kairomone applied. Interestingly, in a similar experiment with unmated females, only 3 (10%) of them showed this strong reaction, and the 24 males tested were completely indifferent (Kohne 1989). In a preliminary field experiment at ICRISAT, we used pheromone traps baited with a kairomone-impregnated rubber septum. Almost all insects caught were *H. armigera* females that continued egg-laying in the plastic bag in which they were trapped. Poor results were obtained with sticky delta-traps (unpublished results). These results highlight the value of observing insects under controlled conditions before going to the field. A flight cage is now being used to study flying moths with a video camera. All flight reactions around the kairomone source are computerized. Using the data obtained we hope to design a kairomone trap that can be used in the field to catch females when *H. armigera* populations begin to build up. After the insect has made contact with its host-plant by following distance-perceivable, volatile signals, other chemicals are involved in host recognition. An interesting example of a chemically based interaction involves the exudate of chickpea leaves, stems, and pods. The main component of this very acidic exudate is malic acid, whose concentration is correlated with *H. armigera* resistance (Rembold 1981). Malic acid seems to be the main resistance factor [if present in the exudate at a concentration >290 mg mL^{-1}]. Low to medium borer damage is observed in genotypes whose malic acid concentration ranges from 120-290 mg mL^{-1}. Susceptible cultivars have characteristically low malic acid concentration (60-120 mg mL^{-1}). However, a genotype with low borer damage was also found in the low malic acid group (Rembold 1990). This suggests that other compounds may also contribute to host-plant resistance. Analysis showed that the exudate was roughly made up of two thirds malic, and one third oxalic acids. Minor compounds identified were glucose-6-phosphate, citrate, and succinate. Glucose-6-phosphate and the acids are responsible for the low pH (almost 1.0) of all chickpea exudates. We are now examining the role these chemicals play in host-plant resistance against *H. armigera,* and the leafminer, *Liriomyza cicerina* (Rondomi) (Diptera: Agromyzidae).

To what extent can basic biochemical studies help design more insect-resistant crop plants? Besides the distance- and contact-perceivable semiochemicals, some phytochemicals interfere with the growth and development of the insect pests. Are such compounds present in the host-plants of *H. armigera?* We followed the development of *H. armigera* on artificial diets, containing chickpea, soybean, or maize powder ingredients. Although the larvae survived on all the offered diets, they passed through five successive instars on the chickpea and soybean diets, and six instars on the maize diet. There were significant differences in the developmental times and survival rates; 82% on chickpea, 53% on soybean, and 12% on maize diet. The growth index value of *H. armigera* was highest for chickpea, moderate for soybean, and very low for the maize diet (Singh and Rembold 1988). Understanding the biochemical basis of this effect could help identify another resistance marker for the plant breeder.

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Recommendations/Recommandations

Recommendations

1. The Group recognized that ICRISAT could help the NARS of India and other Asian countries overcome the constraints to pigeonpea and chickpea production represented by *Helicoverpa armigera* by reinforcing its continuing attempts to develop appropriate integrated pest management programs (IPM).
2. It was noted that H. armigera-resistant genotypes of both crops have been identified, and that a pigeonpea variety resistant to this pest has been released in the Indian State of Andhra Pradesh. As the provision of crop varieties with resistance to important pests is a key component of IPM schemes it was agreed that more efforts should be made to incorporate resistance to *H. armigera* into varieties adapted to other agroecological zones. In view of the fact that much of the world's pigeonpea and chickpea germplasm collection has been screened for resistance to this pest, it was considered necessary to make the best use of the resistant genotypes that have been identified. To do this, the Group recognized that a clear understanding of the biochemical and biophysical factors associated with host-plant resistance is required. Markers for use by plant breeders would be identified in this process.
3. The involvement of pathologists in such studies was recommended because of the need to remove apparent blockages in the development of multiple pest resistant varieties, and to determine the influence of pathogens on the degree of host-plant resistance to insects.
4. After reviewing the *H. armigera* situation and the results of insect behavioral and neurophysiological studies, the Group recommended that ICRISAT should seek help from, and work with, mentor institutions to carry out research on the host selection behavior of *H. armigera.* The Group agreed that this approach would provide a comprehensive understanding of the mechanisms of host-plant resistance in pigeonpea and chickpea, and would generate the basic knowledge required to develop other components of IPM schemes. Moreover, the research project as a whole should fit in with other existing and proposed IPM programs.

Research

5. The research areas that are of high priority are:

a. Studies of the short distance and contact orientation of moths with reference to oviposition behavior:
   - understanding short distance orientation and oviposition behavior,
   - identifying chemical and physical factors that influence the choice of oviposition sites. This study would encompass an investigation of the relevant sensory systems involved,
   - determining the identity of the plant surface chemicals and odors acting as behavioral cues,
   - studying variations in individuals, and within and between populations, including host effects,

- continuing the existing kairomone studies.

b. A study of the chemical and physical stimuli involved with the acceptance or rejection of a host-plant by adults and neonate larvae. The influence of secondary metabolites, nutritional and antibiosis factors on the development and survival of caterpillars require special attention.

c. Long-distance orientation was identified as an important area of investigation but the means of studying this topic need to be affirmed.

6. Steps should be taken to ensure that ICRISAT can supply an adequate quantity of disease-free *H. armigera* larvae from its insect-rearing unit.

7. There is a need for further Consultative Group Meetings to seek more effective ways of relying on existing natural control processes. The influence of host-plant characterstics, including resistance factors, on predators and parasites is an important, but neglected, issue that should be addressed at future meetings.

Information Flow

8. There is a need to consolidate available information on the pigeonpea and chickpea genotypes that have resistance to *H. armigera,* including an indication of the degree of acceptance of these genotypes across zones and by farmers.

   Research findings could be disseminated via the International Pigeonpea and Chickpea Newsletters for rapid transfer of information, and by conventional scientific publications. Holding Consultative Group Meetings at 2-year intervals would speed up the dispersal of innovative ideas and preliminary research findings. The publication of summary proceedings of these meetings would give recognition to the scientists and institutes involved.

9. It was recommended that the Indian Council of Agricultural Research (ICAR) should call a meeting of all relevant scientists (irrespective of their crop background) to discuss the *H. armigera* problem and methods of alleviating it. Such a meeting may include scientists from other national agricultural research organizations (NARSs) and international organizations.

Organizational Aspects

10. Projects should be subdivided to make them acceptable to donors and, where appropriate, of a size that can be handled by postgraduate students, postdoctoral fellows, visiting scientists, and scientists on sabbatical leave. Once projects are in progress, there will be scope to organize regular training courses on detecting mechanisms of host-plant resistance for scientists in Asian NARSs.

11. Other national and international institutions should be brought under the umbrella of this Group. This can be effected by initiating an IPM network, under the aegis of AGLN, and by bringing in scientists from other high-interest areas, such as Australia, Israel, France, and USA.

Recommandations

1. 11 a ete convenu que l'ICRISAT aiderait les Systemes nationaux de recherche agricole (NARS) en Inde et dans d'autres pays asiatiques a reduire les pertes causes par *Helicoverpa armigera* a la production du pois d'Angole et du pois chiche en intensifiant s e s recherches sur la mise au point des programmes appropries de lutte integree (IPM).
2. Il a ete signale que des genotypes des deux cultures resistants a *H. armigera* ont ete identifies, et qu'une variete de pois d'Angole resistante a ce ravageur a ete vulgarisee dans l'Etat indien d'Andhra Pradesh. Etant donne que la resistance varietale est un element clef dans les programmes IPM, une attention plus soutenue doit etre accordee a Incorporation de la resistance a *H. armigera* dans les varietes adaptees a d'autres zones agroecologiques. Puisque la plupart des collections des ressources genetiques de pois d'Angole et de pois chiche du monde ont ete criblees pour la resistance a ce ravageur, il faudrait tirer le meilleur parti possible des genotypes resistants qui ont ete identifies. A cette fin, le Groupe a reconnu qu'une meilleure comprehension des facteurs physico-chimiques associes a la resistance de plante-hote est necessaire. Les marqueurs pouvant etre utilises par les selectionneurs seraient ainsi identifies.
3. La participation des phytopathologistes dans ces etudes a ete recommandee afin de lever les contraintes evidentes dans la creation des varietes resistantes a differents ravageurs et de determiner Tinfluence des agents pathogenes sur le degre de resistance de plante-hote aux ravageurs.
4. Apres avoir fait le point des etudes sur *H. armigera* ainsi que les resultats des etudes neurophysiologiques et du comportement de Tinsecte, le Groupe a recommande que l'ICR1SAT devrait faire appel aux instituts guides et travailler en etroite collaboration avec eux pour les recherches sur le comportement de selection de *H. armigera.* Cette approche permettrait d'obtenir une connaissance plus globale des mecanismes de resistance de la plante-hote dans le pois d'Angole et le pois chiche et d'obtenir les informations necessaires au developpement des autres elements des programmes I P M . En plus, le projet de recherche devrait renforcer d'autres programmes IPM actuels ou prevus.

Recherche

5. Les domaines de recherche prioritaires sont:

a. Etudes des perceptions par contact et a courte distance liees au comportement de ponte du ravageur:
   - comprendre les comportements de recherche de la plante hote a courte distance et le comportement de ponte;
   - identification des facteurs physico-chimiques qui influent sur le choix du lieu de ponte. Cette etude comprendra egalement une enquete sur les systemes sensoriels concernes;

- identification des substances chimiques de la surface de la plante et des odeurs qui servent de signaux de comportement;
- etudes des variations dans les individus, entre et au sein des populations, y compris les effets des hotes;
- poursuite des etudes actuelles sur les kairomones.

b. Une etude des stimuli physico-chimiques associfcs a l'acceptation ou le rejet d'une plante-hote par des adultes et des larves neonates. L'attention doit etre particulierement mise sur l'influence des metabolites secondaires ainsi que sur l'effet des facteurs nutritionnels et d'antibiose sur le developpement et la survie des chenilles.

c. L'activite locomotrice a distance a ete identifiee comme un important domaine d'fetude, mais les moyens de realiser cette etude restent a affirmer.

6. L'ICRIS AT doit prendre les mesures necessaires pour fournir une quantite adequate de larves saines de *H. armigera* a partir de son unite d'elevage des insectes.

7. Il est necessaire d'organiser advantage de Reunions des groupes consultatifs afin de rechercher des moyens plus efficaces d'utiliser les processus actuels de lutte biologique. L'effet des caracteristiques de la plante-hote, y compris les facteurs de resistance, sur les predateurs et les parasites, quoiqu'un sujet important, a retenu peu d'attention; il doit etre aborde dans les reunions futures.

Echange d' Information

8. Il importe de recueillir des donnees disponibles sur les genotypes de pois d'Angole et de pois chiche resistants a *H. armigera* ainsi que sur le degre d'acceptation de ces gfcnotypes dans differentes zones ecologiques et par les paysans.

   Les resultats de recherche pourraient etre diffuses par l'intermediaire des bulletins "I nternational Pigeonpea Newsletter" et "I nternational Chickpea Newsletter" pour une transmission rapide de Information, et par des publications scientifiques conventionnelles. L'organisation des Reunions biennales des groupes consultatifs permettrait d'accelerer la dissemination de nouvelles idees et les resultats de recherches preliminaires. Il conviendrait de publier les comptes rendus de ces reunions en reconnaissance des chercheurs et les instituts concernes.

9. Il a ete convenu que le Conseil indien de recherche agricole (ICAR) devra tenir une reunion de tous les chercheurs concernes en vue d'examiner les problemes poses par *H. armigera* et les mesures a prendre pour les surmonter. La reunion pourrait etre assistee par des chercheurs provenant des autres Systemes nationaux de recherche agricole et des organisations internationales.

Aspects organisationnels

10. Les projets devront etre subdivises pour etre acceptables aux bailleurs de fonds, et si necessaire, d'une dimension appropriee pour etre etudies par les chercheurs (doctorat, post-doctorat, en detachement, et en conge sabbatique). Apres la mise en marche des projets, il y aurait des possibilites d'organiser regulierement des

stages de formation sur la determination des mecanismes de resistance de la plante-hote pour les chercheurs des programmes nationaux asiatiques.

11. D'autres instituts nationaux et internationaux doivent s'incorporer au sein de ce Groupe. Ceci pourrait etre effectue par le lancement d'un reseau de l'IPM, sous l'egide du Reseau asiatique sur les legumineuses a grains (AGLN), et par la participation des chercheurs provenant des divers pays interesses tels que l'Australie, l'Israel, la France et les Etats-Unis.

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