Screening and breeding for insect resistance in pea, lentil, faba bean and chickpea

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Abstract

Although grain legumes are considered to be particularly susceptible to insect damage, few studies have quantified these losses in farmers' fields. Insecticides can protect each of the legumes from pest damage, but plant resistance appears to be an attractive alternative, particularly for developing countries. Large differences in susceptibility to the major insect pests have been detected in the germplasm of each of pea, faba bean, lentil and chickpea, but there are no reports of successful exploitation of genotypes bred for resistance. Methods of screening and breeding for resistance are described, with particular reference to *Heliothis armigera* on chickpea. The dangers of breeding crops under protected conditions, for subsequent use in farmers' fields where protection is not afforded, are emphasised.

Introduction

Pea, lentil, faba bean and chickpea not only provide food for man and his domestic animals, but also for a wide range of insects. Some of these insects cause substantial losses of yield and therefore merit research attention and action to reduce those losses. Unfortunately, there is a dearth of published information on the quantitative losses caused by various pests. There have been few attempts to measure losses and those reports that do exist show substantial variability. For example, Schwarz and Klassen (1981) reported a 48% loss when pea was unprotected from aphids in the USA, but Pimentel

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et al. (1981), in the same publication, estimated a 7% average loss to all insects on this crop in the same country.

All four of these food legume crops are grown across a wide range of geographic and economic environments. The range covers many developed countries, where the crops are grown commercially using insecticides and other inputs, and many developing countries, where much of the production is from crops given few, if any, inputs. Over 70% of world chickpea production is from India, where surveys show that less than 10% of farmers use pesticides on this crop (Bhatnagar *et al.*, 1982). Over 70% of world lentil production is shared by India and Turkey; China is responsible for more than 50% of world faba bean production; and the USSR produces more than 50% of the world pea crop (FAO, 1985) — but we could find no statistics for insecticide use on these three crops in these four countries. However, it is probable that most of the world production of all four legumes is from crops grown without pesticide protection. For these circumstances, the exploitation of host plant resistance (HPR) to pests would appear to merit priority and to have great potential.

The potential for resistance

Breeding crop plants for resistance to a large range of abiotic and biotic stresses has proved to be very profitable. In particular, breeding for resistance to diseases has been extremely successful in the grain legumes and other crops. In contrast, resistance to insect pests has been much less exploited. There have been great successes (for example phylloxera resistance in grapes, Hessian fly resistance in wheat and jassid resistance in cotton) but breeding for resistance was neglected until Painter (1951) published his book on the subject. Since then, there has been increased interest and action, particularly in the USA. But, resistance breeding continues to be undervalued and underfunded!

Lukefahr (1982), when reviewing the prospects for plant resistance to *Heliothis* spp., wrote: "Progress in host-plant resistance research is a long-term proposition and requires considerable resources. With the limited financial resources available today, many host-plant resistance projects have suffered. Unfortunately, funding is available only when a crisis is looming, and with the availability of the synthetic pyrethroids, there is no crisis on the horizon. An effective pesticide makes control of the pests very easy and also insures stability of yields. Very little management is required, and even if the number of applications is excessive, the grower has minimized the risk at very little extra cost. Therefore, in crops that have a low damage threshold, or that have a number of different pest species, population suppression will probably rely on conventional pesticides. When pest resistance to the synthetic pyrethroids becomes widespread, the dosages can be markedly increased and still require only relatively small amounts."

"However, there are many crops where pesticide use is not part of the production system. These are usually crops that have a low cash value per unit of land, or crops grown in regions where growers do not have access to chemicals or the equipment to apply them. It is in these situations that host-plant resistance will have its potential impact". Although Lukefahr's comments were specifically directed towards research on *Heliothis* spp., they are equally applicable to the other pests of the grain legumes. In the developed world, most consumers now expect damage-free produce; a single insect-damaged pea or bean in a can or packet is likely to provoke immediate complaint. Insecticide use, rather than plant resistance, is the easy, short-term route to damage-free produce.

Breeding for insect resistance may be diminishing in the developed countries. For example, the Plant Breeding Institute at Cambridge, UK, has recently foresaken such work (H. J. B. Lowe, personal communication). Seed production and supply is largely controlled by commercial companies in several developed countries. Some of these companies provide a complete package to farmers, including insecticides. Under these sorts of circumstances the outlook for breeding for insect resistance is bleak.

Although the farming systems of the developing world appear to offer the greatest opportunities for insect resistant crop plants, there are obstacles to progress. Breeding for resistance requires persistent, long-term research. But, in most developing countries, research scientists and assured funding are often scarce, and so the emphasis gravitates towards short-term research. The setting up of the Consultative Group on International Agricultural Research (CGIAR) Centres has provided an ideal opportunity for the merits and benefits of resistance breeding to be evaluated. Rice genotypes that are resistant to insect pests are already in widespread cultivation in farmers' fields in many developing countries; genotypes that originated from one of the oldest Centres, the International Rice Research Institute in The Philippines. Teams of plant breeders, entomologists and other scientists at ICRISAT (see p. 39) and ICARDA (see p. 25) have insect pest resistance breeding as one of their primary objectives, and it is expected that these newer Centres will soon have comparable impacts to those of IRRI on rice.

However, grain legumes of the developing world are still land-races, sown by farmers using seed saved from the previous year's crop. Unless there is a well developed seed production and distribution system available, resistant cultivars will not reach the majority of farmers.

Host plant resistance in the cool season food legumes

There are very many published reports of pea and faba bean genotypes that have shown resistance to insect pests. Horber (1978) reviewed some of the then recent literature and found reports of resistance to almost all of the major field pests, including *Bruchus pisorum, Cydia nigricana, Sitona lineatus,* and *Acyrthosiphon pisum* in pea, and to *Aphis fabae, Empoasca fabae* and *Epilachna varivestis* in faba bean. Most of these reports were from scientists working in the USA in the 1950s and 1960s, but reports of varieties of pea being resistant to aphids date back more than 50 years (Searls, 1983).

However, we can find no reports that such resistance is being utilized today. Farmers in the Americas and Europe may be sowing pea and faba bean genotypes that have been bred for resistance to insect pests but, if they are, this achievement is very poorly publicized!

The available literature gives no clear indication of extensive resistance breeding in the grain legumes in either the USSR or China. However, isolated reports, such as that by Vilkova and Kolesnichenko (1973) who stated that pea with resistance to *B. pisorum* are available in the USSR, indicate that greater exchange of information and germplasm might provide mutual benefits.

There appear to have been very few reports of resistance to any of the field pests of lentil. This may reflect a lack of research on the crop, partly because of its relatively small importance in the developed countries, but could also indicate that lentil suffers relatively few pest problems. There are several reports that the seeds of some chickpea genotypes are resistant to stored product pests (Schalk *et al.*, 1973), and Parsons *et al.* (1938) reported considerable genotypic differences in susceptibility to *Heliothis armigera* in this crop in Africa.

Screening for resistance

The first essential in any programme designed to breed for resistance to insect pests is to develop a practicable screening method that will result in the reliable selection of resistant genotypes. Dahms (1972) provided a useful list of selection criteria for resistance to insect pests. For some crop stages and some pests, such screening can best be done in a nethouse or in field cages, using inoculations of reared insects. This is by far the simplest and most practicable method. Unfortunately, in cannot be used for all crop stages and all pests, and in many cases there is no alternative to open field screening using natural pest populations.

The nethouse method, using inoculations of laboratory reared insects, is particularly suited to the screening of seedlings against aphids, which are major pests on all four of these food legumes. The aphids can be reared on susceptible host plants and then inoculation is easily and reliably accomplished by placing cut pieces of those plants into the plots of test seedlings. Care must be taken to ensure that all seedlings are treated equally. If genotypes, rather than progenies, are being screened, then adequate replication in restricted-randomization designs will limit the "escape" problem (escapes being plants that suffer little, or no, pest attack by chance rather than as a result of any intrinsic resistance). Resistance is relative, so infestation or damage on the test plants must be compared with that on control genotypes. Both resistant and susceptible control genotypes can be usefully employed in such screening.

If the insects are inoculated directly onto each test plant, the nonpreference type of resistance (Painter, 1951) may be missed. Nonpreference (which may be more usefully termed antixenosis; Kogan and Ortman, 1978) is often considered to be less valuable than antibiosis, but may be particularly useful against strong-flying, polyphagous pests such as *Heliothis* spp.

Tolerance, which was defined by Horber (1980) to include "all plant responses resulting in the ability to withstand infestation and to support insect populations that would severely damage susceptible plants", is usually identified by comparing the yields from test genotypes with those of appropriate controls. Nethouse tests are not well suited to screening for tolerance, partly because the yields obtained may not be typical of those produced in open field conditions.

Open-field screening, although often misused, can be efficient, particularly for pests that tend to distribute themselves evenly across large areas. Such screening is more suitable for insects (such as *Heliothis* spp.) that lay their eggs singly, than it is for insects (such as *Spodoptera* spp.) that lay their eggs in clusters from which the larvae disperse, so resulting in clumped distributions.

Open-field screening can also be very successful where there are adequate natural populations of the target pest and where other pests do not complicate the screening process. The major problem in open-field screening is that of frequent escapes. A good example of the escape problem is provided by data from an open-field, screening block intended to screen chickpea germplasm for resistance to *H. armigera* (at ICRISAT Center in 1976/77). Of the 8629 germplasm accessions tested, 11.1% had no infestation. Evidence that many of these were escapes was provided by data from the 450 plots of two control cultivars that were replicated at regular intervals throughout the field; 19.5 and 27.9% of these plots had no infestations either.

All of those accessions that had more damage and less yield than the adjacent controls were rejected and the remainder were rescreened in replicated trails in subsequent seasons. Most of the accessions that were damage-free in 1976/77 were found to be susceptible in the subsequent season — they were simply escapes in the original screening. Unfortunately, there are many reports in the literature of "resistant genotypes" identified in unreplicated, single-season tests; almost all of these genotypes are later found to be susceptible!

The work at ICRISAT also discovered that the populations of *H. armigera* were very variable across time in any season. Thus, genotypes of different crop durations face very different pest populations during their vulnerable flowering and podding stages. In most of the trials at ICRISAT, short-duration genotypes are more severely attacked than long-duration ones; the former flower early and when *H. armigera* populations are at a peak. Thus, differences in damage and infestation among genotypes may be caused by differences in phenology, rather than differences in susceptibility (ICRISAT, 1981).

Based on these observations, the screening of chickpea genotypes at ICRISAT has been through replicated trials, each containing genotypes of a narrow range of maturity durations. By screening the world germplasm of more than 12 000 accessions over a period of 10 years, several genotypes with substantial resistance to *H. armigera* have been identified. Oviposition nonpreference, antibiosis and tolerance types of resistance have been identified (ICRISAT, 1981; Lateef, 1985).

As in nethouse testing, inoculation with reared insects will reduce the escape problem in open-field screening but, again, this approach has the disadvantage of concealing the nonpreference type of resistance.

Similar field screening at ICARDA has identified chickpea genotypes that have some resistance to the leaf miner (*Liriomyza cicerina*), which is the major insect pest of the crop in most countries in the Mediterranean region. But, attempts to screen lentil for resistance to *Sitona* spp. were not successful (ICARDA, 1985).

Pesho *et al.* (1977) have identified sources of resistance to pea weevil, *Bruchus pisorum*, in their field screening programme of pea introductions in the USA.

In Egypt, faba bean have been screened for resistance to *Bruchus rufimanis* and *Aphis craccivora* in field and laboratory trials. In the field trials natural populations of *A. craccivora* were augmented with inoculations of laboratory reared aphids. Such replicated trials have identified substantial differences in susceptibility among genotypes (Bishara, unpublished).

Breeding for resistance

It is unlikely that an insect resistant selection from the available germplasm will possess all of the traits required for immediate release as a cultivar to farmers. For example, almost all of the chickpea genotypes that were selected for resistance to *H. armigera* at ICRISAT were found to be susceptible to Fusarium wilt (*Fusarium oxysporum* f. sp. *ciceri*). It is, therefore, necessary to make crosses that will combine the desired traits and then to screen the segregating progenies for plants that possess the required combinations.

A primary task for the breeder is to determine the inheritance of the resistant character. Diallel tests at ICRISAT, using chickpea genotypes that were resistant or susceptible to *H. armigera*, showed that the resistance was additive and so can be handled using the conventional breeding (pedigree method) already in use (ICRISAT, 1983; Gowda *et al.*, 1985). Crosses between resistant genotypes have given rise to progenies with increased resistance and better yields (ICRISAT, 1986).

Single-plant selection for resistance to insects from segregating progenies of crosses that involve a resistant parent leads to special problems. For example, the variances produced by uneven distributions of *H. armigera* populations, and plant to plant dispersal of larvae, preclude single-plant selection with any degree of confidence. However, by using a wide spacing (60 cm × 60 cm), the differences between resistant and susceptible plants can be increased; the plants are larger and so provide a larger pod sample, and plant to plant dispersal of larvae is reduced (ICRISAT, 1986).

Stability of resistance

There are several examples of plant resistance to insects breaking down as a result of a change in the pest population, resulting in biotypes that overcome the resistant character. Gallun and Khush (1980) gave examples from several crops, in their review of the genetic factors affecting the expression and stability of resistance. Robinson (1976) and others have stressed the stability of polygenic resistance.

Resistance to aphids in the grain legumes would appear to be particularly precarious since the existence of several biotypes of *Acyrthosiphon pisum* has long been known (Harrington, 1945). Fortunately, resistance to *H. armigera* in chickpea is likely to be stable; not only is the resistance polygenic, but also there is very little selection pressure on a polyphagous pest when resistance is introduced into only one of its many host species.

Problems with antibiosis

The risks of consuming persistant insecticides if these are used on our food crops have been well publicised. There has been a tendency to generalise that synthetic chemicals are damaging to health whereas plant-made chemicals are not! There are, of course, many plant chemicals that are extremely toxic to animals and there is an obvious risk that plants, selected for antibiosis to insects, may also be deleterious to other animals, including man. Norris and Kogan (1980) have reviewed the research on the biochemical basis of plant resistance to insects; they listed many chemicals involved in antibiosis to insects that would be unwelcome in a human diet. Some grain legumes already contain anti-nutritional or toxic factors, for example those in faba bean that cause Favism (Nowacki, 1980). There is an obvious need to investigate the biochemistry of genotypes that have been bred for insect resistance before they are used extensively as food or feed.

Host plant resistance to storage pests

There are many reports of considerable differences in the susceptibility of seed of different grain legume species and genotypes to storage pests, particularly to *Callosobruchus* spp. In the case of chickpea, resistant seeds are usually small with rough seed coats (Raina, 1971; Schalk *et al.*, 1973). Such characters will also promote human consumer resistance!

The storage pests do not attack chickpea crops in the field, and so if seed is placed into clean, insect-proof stores, there should be no storage pest problem. Where a potential problem can be routinely prevented by adequate storage, there is little point in embarking upon a resistance screening and breeding programme; the cost: return ratio would probably not be a favourable one.

However, there may be situations where field to storage pests are a major problem in the legumes. If so, breeding for resistance to these may be profitable. Screening for resistance to storage pests appears to be easier than for resistance to field pests, for several reasons. Problems posed by crop growth differences, weather and competing pests, can be avoided. Simple exposure of replicated samples of seeds from different genotypes to standard inoculations of the pest, with counts of pest populations and damage at determined intervals, will distinguish differences in susceptibility. However, although there have been many reports of such screening activities, we know of no examples where they have led to the breeding of a resistant cultivar that has been used commercially.

Tolerance

Even when it may not be profitable to embark upon an extensive insect resistance programme, there will be benefits from ensuring that new genotypes emerging from breeding programmes are not "super susceptible" to pests. In all such programmes, promising genotypes must be compared with established cultivars in pesticide-free trials. Those which yield less than the controls should be rejected. With this simple precaution, some tolerance will be retained in new genotypes. This precaution is very necessary, for although most breeders grow their selections under pesticide umbrellas many farmers, and especially those growing pulse crops, do not!

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