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Evaluation of *Helicoverpa* and drought resistance in desi and kabuli chickpea

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Abstract

A chickpea collection of 1600 desi and 1400 kabuli were evaluated for yield losses arising from pod borer (*Helicoverpa armigera*) infestation under rainfed conditions by spraying half the plots to prevent pod borer infestation and allowing the other half to be infested. From these lines, 82 were selected for further detailed evaluation of *Helicoverpa* resistance and drought resistance under irrigated and rainfed conditions. The yield losses from *Helicoverpa* damage varied from 10 to 33% depending on the chickpea type and the growing environment. Spreading types were more susceptible to *Helicoverpa* damage than erect types, as were kabuli types compared to desi types. Yield losses due to *Helicoverpa* infestation were always greater in the irrigated than in the rainfed materials. Terminal drought reduced yields by 13–37% depending on plant type. The yields in the kabuli chickpea lines were more severely reduced than were the desi types, due to a greater reduction in the number of branches and pods per plant in the kabuli compared to the desi lines. It appears that the extent of pod borer damage varies between the chickpea types, and that desi types have greater drought resistance than kabuli ones. These characteristics should be informative for the population improvement of chickpea for environments in which terminal drought and *Helicoverpa* damage occur frequently.

Keywords: *Cicer arietinum*; germplasm; *Helicoverpa armigera*; moisture stress; pod borer; seed yield; supplemental irrigation

Introduction

India has the largest acreage and production of pulses (grain legumes) of any country in the world, accounting for 37% of the area and 27% of global production. Among the range of cool-season and warm-season pulses grown, chickpea (*Cicer arietinum* L.) is the primary pulse. It is planted over more than 35% (6.5 million ha) of the pulse area and produces 40% (5.5 million t) of the total pulse production of India at an average yield of 0.8 t/ha, a yield that has been stable for about three decades. Cultivation of chickpea occurs during the winter season with planting starting in October in the south and harvesting finishing in April in the north. Thus chickpea is grown as a post-rainy season crop, relying primarily on stored soil moisture. More than 80% of plantings in India are rainfed. The reasons for the low productivity can be attributed to (i) damage by pod borer (*Helicoverpa armigera*), (ii) losses from terminal drought or moisture stress, and (iii) damage caused by soil-borne diseases. The damage by these three causes varies from year to year and area to area. When considered together, heavy losses occur each year and individually they can cause major losses in chickpea production at various growth stages.

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The intensity of *Helicoverpa* damage on chickpea has been reported by various workers (Reed *et al*., 1979; Sithanantham and Reed, 1979; Hariri, 1982; Tahhan *et al*., 1982). A large number of lines were evaluated for *Helicoverpa* resistance by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) who reportedly found that no resistance against *Helicoverpa* incidence was available (ICRISAT, 1984). However, Gowda *et al.* (1985) reported that the inheritance of *Helicoverpa* resistance in chickpea is controlled by additive genes. Drought in chickpea is also a worldwide problem and its impact on this crop has been studied and reported from different countries, namely in Australia by Turner (2003) and in India by Yadav *et al.* (2004). Therefore, addressing these causes of yield loss is a priority for pulse breeders in the Indian subcontinent. The incorporation of resistance against soil-borne diseases has been successful and several cultivars have been developed that possess resistance against several diseases (Yadav *et al*., 2004). Therefore, moisture stress and pod borer damage remain the unsolved limitations to chickpea yields.

The present investigation was aimed at assessing the range of variation for *Helicoverpa* and terminal drought tolerance in chickpeas. The overall goal was to identify types of chickpea with greater resistance to *Helicoverpa*, terminal drought, or possibly both, in order to define the characteristics required in a breeding programme. It was postulated that early flowering, small-seeded and erect types would be the least susceptible to *Helicoverpa* damage and that these same types may be more resistant to terminal drought. Approximately 3000 chickpea lines of diverse origin were evaluated for *Helicoverpa* damage and on the basis of this evaluation a core group of 90 lines was taken forward for assessment of both *Helicoverpa* and terminal drought resistance.

Materials and methods

Experiment 1: effect of Helicoverpa incidence on different chickpea types under rainfed conditions

A diverse set of 3000 kabuli and desi lines was evaluated at the Indian Agricultural Research Institute, New Delhi, during the 1996–97 growing season. Of the 3000 lines, 1600 were medium- and bold-seeded desi types and 1400 were bold- and extra-bold-seeded kabuli types. The lines were collected from various parts of India, from ICRISAT and from the International Centre for Agricultural Research in the Dry Areas (ICARDA). All the germplasm lines were hand planted in two-row plots without borders between the plots. Each plot was 6 m in length with 45 cm between rows and 20 cm between plants in an augmented design in which popular checks were included after each 20 lines. The experiment was given neither pre-irrigation nor any supplemental irrigation during the growing season. In each plot, three randomly chosen plants were marked at the vegetative stage in one row and in the other row three centrally located ones were covered with nylon netting to protect them from *Helicoverpa*. For complete protection from larval damage these plants were also given a protective spray of Endosulfan 35% EC at 2 l/ha at regular intervals during the vegetative and reproductive growth stages.

Single plant observations were recorded for pod borer damage and yield. For each line, observations of *Helicoverpa* damage were recorded for each selected plant throughout the season. At maturity, the three protected plants and three unprotected plants were harvested separately and the seed yield measured after air drying. Losses due to *Helicoverpa* damage for each genotype were calculated as the difference between the mean yields of the three protected (controls) and three unprotected plants. From these 3000 germplasm lines eight plant groups/types were identified on the basis of 100-seed weight and plant growth habit: desi medium-seeded spreading types, desi medium-seeded erect types, desi bold-seeded spreading types, desi bold-seeded erect types, kabuli bold-seeded spreading types, kabuli bold-seeded erect types, kabuli extra-bold-seeded spreading types and kabuli extra-bold-seeded erect types. The general mean of each plant group was used for statistical analysis using the SPAR-I® software.

Experiment 2: effect of Helicoverpa incidence and terminal drought on different chickpea types under rainfed and irrigated conditions

On the basis of the performance in Experiment 1, 82 selections, covering all eight groups of medium- and bold-seeded desi types and the bold- and extra-bold-seeded kabuli types, along with eight check cultivars were further evaluated in the growing seasons 1997–98, 1998–99 and 1999–2000 under both rainfed and irrigated conditions. Eight replicated blocks, four rainfed and four irrigated, were sown in each year in four-row plots (6 m in length with 45 cm between rows and 20 cm between plants) using a randomized complete block design. Two replicates were regularly treated with Endosulfan 35% EC at 2 l/ha and two replicates were left untreated. At the vegetative crop stage, *Helicoverpa* larvae were introduced into the two unsprayed replicates in the rainfed and irrigated plots. The irrigated blocks were flood irrigated when the plants were in the vegetative stage (about 65 days after sowing), and again at the pod-filling stage (about 110 days after sowing).

Each entry was visually scored for pod borer damage at weekly intervals during the crop season. Additionally, the number of days to both 50% flowering and to maturity were recorded on a plot basis. The number of branches, number of pods, total biomass, seed yield and 100-seed weight were measured on five randomly chosen plants in each replicate at maturity. Damage caused by *Helicoverpa* and yield losses due to moisture stress were calculated from the mean yield data of the five plants in each plot under rainfed and irrigated environments. Statistical analyses for yield and yield losses were carried out using the SPAR-I® software program.

Results

Effect of Helicoverpa incidence on different chickpea types

The presence of *Helicoverpa* larvae was first observed at the vegetative growth stage in all years. However, damage at this stage was insignificant in most of the lines due to low moth and larval activity during the cool temperatures prevalent in January. *Helicoverpa* damage increased at flowering as the temperatures rose in February and reached a peak during pod development.

The average seed yield (g per plant) of different plant types, both protected and unprotected from *Helicoverpa* under rainfed conditions, is presented in Table 1. Significant inter-entry differences in seed yield were observed in all years in both the protected and unprotected plants. The highest protected seed yield was observed in the desi bold-seeded erect types, whereas the lowest was observed in the kabuli bold-seeded spreading types in all years. A similar yield pattern was obtained when exposed to *Helicoverpa*, with the highest seed yield being recorded in the desi bold-seeded erect types and the lowest in the kabuli extra-bold-seeded spreading types. The yield losses due to *Helicoverpa* incidence on the 3000 germplasm lines in 1996–97 were greatest in the kabuli extra-bold-seeded spreading types (40%) followed by the kabuli bold-seeded spreading types (35%), desi bold-seeded spreading types (17%), kabuli extra-bold-seeded erect types (16%), kabuli bold-seeded erect types (15%), desi medium-seeded spreading types (11%), desi bold-seeded erect types (7%) and least (6%) in the desi medium-seeded erect types.

The seed yield of the 90 selections for the various plant types grown under irrigated conditions (Experiment 2) are given in Table 2. With supplemental irrigation and protection from *Helicoverpa*, the highest seed yield was recorded in the kabuli extra-bold-seeded erect types, and the lowest in the desi medium-seeded spreading types. When exposed to *Helicoverpa*, the highest seed yield was obtained from the irrigated kabuli extra-bold-seeded erect types and lowest from the irrigated kabuli extra-bold-seeded spreading types. Yield losses resulting from *Helicoverpa* damage under rainfed and irrigated conditions are presented in Table 3. These varied from 10 to 29% (under rainfed conditions), with greater damage affecting the kabuli types, and similarly for the spreading types compared to the erect types. The yield losses from *Helicoverpa* damage were higher (16–33%) in plots given supplemental irrigation during flowering and podding, but again the yield losses in the desi types were smaller than in the kabuli types, and in the erect types compared to the spreading types. Yield losses were also greater in large-seeded than in small-seeded types. In the desi types, yield losses from *Helicoverpa* damage were similar under irrigated and rainfed conditions, but in the kabuli types, the losses were much greater when irrigated. Yield losses due to *Helicoverpa* incidence in the other

Table 1. Seed yield (g per plant) of various chickpea types grown under rainfed conditions and protected (P) or unprotected (UP) against *Helicoverpa* in 1996–97 (Experiment 1; 3000 lines) and in 1997–2000 (Experiment 2; 90 lines)

	1996–97		1997–98		1998–99		1999–2000		Mean	
Plant type	P	UP	P	UP	P	UP	P	UP	P	UP
DMSS	27.2	23.5	28.8	24.5	26.3	22.6	24.6	22.0	26.7	18.1
DMSE	29.4	27.3	30.3	27.7	30.9	28.7	28.5	26.7	29.8	27.6
DBSS	31.6	25.5	32.5	25.1	31.8	25.4	30.2	25.9	31.5	25.5
DBSE	34.5	31.6	36.9	32.7	35.9	33.1	33.5	31.4	35.2	32.2
KBSS	19.4	13.4	22.3	15.3	23.7	16.9	22.8	17.7	22.0	15.8
KBSE	24.9	22.3	26.5	22.9	27.8	24.4	25.9	23.4	26.3	23.2
KEBSS	24.6	15.5	23.9	14.5	25.3	15.1	24.3	17.0	24.5	15.5
KEBSE	27.5	23.8	28.6	24.5	28.4	25.3	28.8	26.4	28.3	24.8
LSD ($P = 0.05$)	2.22	1.57	2.29	1.86	1.97	1.24	2.52	1.83	2.08	1.53

DMSS, desi medium-seeded spreading; DMSE, desi medium-seeded erect; DBSS, desi bold-seeded spreading; DBSE, desi bold-seeded erect; KBSS, kabuli bold-seeded spreading; KBSE, kabuli bold-seeded erect; KEBSS, kabuli extra-bold-seeded spreading; KEBSE, kabuli extra-bold-seeded erect.

Table 2. Seed yield (g per plant) of various chickpea types grown with supplemental irrigation, protected (P) or unprotected (UP) against *Helicoverpa* from 1997–98 to 1999–2000

	1997–98		1998–99		1999–2000		Mean	
Plant type	P	UP	P	UP	P	UP	P	UP
DMSS	31.7	26.2	29.9	24.9	32.4	27.6	31.3	26.2
DMSE	34.8	30.5	35.4	31.8	35.2	30.9	35.1	31.1
DBSS	36.3	25.6	34.8	25.9	33.5	26.7	34.9	26.1
DBSE	41.5	35.6	39.2	34.7	40.6	36.3	40.4	35.5
KBSS	36.9	20.4	35.7	20.5	36.3	23.3	36.3	21.4
KBSE	42.6	35.0	40.3	33.7	40.0	33.4	40.9	34.0
KEBSS	40.4	20.5	37.5	19.4	39.7	22.1	39.2	20.7
KEBSE	46.8	37.3	44.7	35.5	45.8	36.7	45.8	36.5
LSD ($P = 0.05$)	2.78	2.44	2.91	2.81	2.69	2.16	2.67	2.25

DMSS, desi medium-seeded spreading; DMSE, desi medium-seeded erect; DBSS, desi bold-seeded spreading; DBSE, desi bold-seeded erect; KBSS, kabuli bold-seeded spreading; KBSE, kabuli bold-seeded erect; KEBSS, kabuli extra-bold-seeded spreading; KEBSE, kabuli extra-bold-seeded erect.

groups were also higher under irrigated environments than in rainfed environments.

Effect of moisture stress

To understand the impact of terminal drought on the 90 selections, various quantitative traits were measured under both rainfed and irrigated conditions (Table 4). The relative yield performance under irrigated and rainfed environments fell by 14% in the desi medium-seeded types, 10% in desi bold-seeded types, 34% in the kabuli bold-seeded types and 38% in kabuli extra-bold-seeded types. Analysis by plant type showed that yield losses due to moisture stress were higher for the kabuli than for the desi types, but erectness had no effect on yield losses due to water shortage (Table 5). However, the larger-seeded types were less prone to yield loss than the smaller-seeded types. The impact of moisture stress was seen for all traits, but its greatest effect was on total biomass, number of branches and number of pods, particularly for the kabuli genotypes (Table 4). There was no effect of irrigation on seed size. The desi types flowered earlier than the kabuli ones under both irrigated and rainfed conditions, and terminal drought hastened the time to 50% flowering of the former by 10–12 days, but only by 5–6 days for the latter types.

Discussion

We have shown that *Helicoverpa* can cause considerable damage to chickpea, with yield losses varying from 10 to 33% depending on plant type. Spreading types were more vulnerable to *Helicoverpa* damage than erect types, possibly due to the greater protection from sunlight enjoyed by the larvae and/or because of the easier access to the pods in the spreading types. The kabuli types were more vulnerable to *Helicoverpa* damage than the desi types. Whether the fewer and larger pods in the kabuli chickpeas or their visibility or taste makes them more attractive to the larvae than the desi chickpeas is unknown, but the damage was greater in the large-seeded lines than in the small-seeded lines under both irrigated and rainfed environments. A small puncture of the pod wall appears to be sufficient to dehumidify the interior of the pod and

Table 3. Yields (g per plant) and yield losses (%) due to *Helicoverpa* incidence in various types of chickpea when protected (P) and unprotected (UP) and with supplemental irrigation (I) or under rainfed (R) conditions

	Irrigated				Rainfed					
Plant type	UP	P	UP/P	Loss (%)	UP	P	UP/P	Loss (%)	Mean loss (%)	R/I loss
Desi	29.7	34.4	0.86	16.1	25.9	30.8	0.84	15.9	16.0	0.98
Kabuli	28.2	40.6	0.69	30.5	19.8	25.3	0.78	21.7	26.1	0.71
Erect	34.3	40.6	0.84	15.5	27.0	30.0	0.90	10.0	12.8	0.65
Spreading	23.6	35.4	0.67	33.3	18.7	26.2	0.71	28.6	30.9	0.85
Small seed	28.2	35.9	0.79	21.4	21.2	26.2	0.81	19.1	20.2	0.89
Large seed	29.7	40.1	0.74	25.9	24.5	29.9	0.82	18.1	22.0	0.70
Overall	28.9	37.8	0.76	23.8	22.9	28.1	0.81	18.9	21.3	0.79
LSD ($P = 0.05$)	1.05	1.62	0.44	1.02	0.75	1.32	0.22	0.81	0.91	0.03

Table 4. Influence of terminal drought on quantitative and phenological traits

Traits	Desi medium-seeded	Desi bold-seeded	Kabuli bold-seeded	Kabuli extra-bold-seeded	LSD ($P = 0.05$)
Irrigated plots					
50% flowering (DAS)	97.2	97.7	101.2	99.8	1.95
Maturity (DAS)	157.3	158.5	164.0	162.7	3.29
Branch number per plant	35.2	36.6	36.2	38.6	1.29
Pod number per plant	98.4	110.1	115.9	108.9	3.13
100-seed weight (g)	16.3	25.7	24.9	33.4	0.75
Total biomass per plant (g)	91.6	123.8	106.0	129.7	3.67
Seed yield per plant (g)	27.5	34.3	35.9	40.5	1.44
Rainfed plots					
50% flowering (DAS)	87.2	85.4	95.6	94.5	1.74
Maturity (DAS)	148.5	147.2	156.4	154.3	5.02
Branch number per plant	28.6	30.5	22.8	22.2	0.85
Pod number per plant	90.3	104.0	76.7	72.5	3.51
100-seed weight (g)	16.3	25.6	24.1	31.6	0.82
Total biomass per plant (g)	62.7	72.6	55.9	59.3	2.55
Seed yield per plant (g)	23.5	30.8	23.9	25.2	3.65
Yield decreases due to drought (%)	14.5	10.2	33.5	37.9	

DAS, days after sowing.

prevent the seed developing (Shackel and Turner, 1998), which leads to pod abortion. Thus if the larvae puncture pod walls in the few pods per plant of the large-seeded kabuli cultivars, it will have a greater impact than the same number of pods damaged in a small-seeded genotype with a greater number of seeds.

It is generally held that there is no *Helicoverpa* resistance available in the chickpea germplasm (ICRISAT, 1984). Although this study concentrated on identifying variation among the types of chickpea, had a genotype with high resistance to *Helicoverpa* been identified, it would have been quickly adopted as a parent in breeding for *Helicoverpa* tolerance. Nevertheless, the study has shown that some types of chickpea are more vulnerable than others to *Helicoverpa* damage. Selection of erect desi types, and to a lesser extent erect kabuli types, will minimize the damage from *Helicoverpa*, but it may take the development of transgenic chickpea with insect resistance conferred by the *Bt* genes to markedly decrease yield losses from *Helicoverpa*, as has been demonstrated in cotton which is similarly vulnerable to *Helicoverpa* damage.

Table 5. Yields (g per plant) under irrigated (I) and rainfed (R) environments and yield losses (%) from lack of irrigation, under protection from *Helicoverpa* incidence

Plant type	Irrigated	Rainfed	R/I	Loss (%)
Desi	35.4	30.8	0.87	13.0
Kabuli	40.6	25.3	0.63	37.0
Erect	40.6	29.9	0.73	27.0
Spreading	35.4	26.2	0.74	26.0
Small seed	35.9	26.2	0.73	27.0
Large seed	40.1	29.9	0.57	25.0
Overall	38.0	28.0	0.74	26.0
LSD ($P = 0.05$)	1.34	1.05	0.03	1.04

Supplemental irrigation showed that yield losses from terminal drought are varible, but that kabuli types are more vulnerable. These losses are less than those in a study conducted in the Mediterranean-climatic region of Australia in which the yield loss in five rainfed desi chickpea genotypes reached 45% (Leport *et al.*, 1999), but emphasizes the limitations imposed by terminal drought in chickpeas grown both in the post-rainy season as in South Asia and on current rainfall in Mediterranean-type climates such as are found in parts of southern Australia. Early flowering is an important adaptation to rainfed environments for chickpea in both summer and winter rainfall regions of Australia (Berger *et al.*, 2004). In our experiments, desi chickpeas flowered earlier than the kabuli ones under both irrigated and rainfed conditions; but under rainfed conditions, terminal drought induced earlier flowering to a greater extent in the desi types. This may explain the commonly perceived advantage of desi over kabuli types. However, even when phenology was removed as a variable in a glasshouse study, water deficits early in seed filling reduced seed yield and induced a greater degree of pod abortion in kabuli than desi cultivars (Leport *et al.*, 2006). The major effect of the moisture stress on yield in the present study was the 38% reduction in extra-bold-seeded kabuli genotypes compared to the rather smaller reduction of 10% in the desi bold-seeded genotypes. This suggests that the desi genotypes possess a capacity to better withstand the impact of moisture stress, whereas the kabuli types are better adapted to irrigated or high soil moisture conditions, as has been previously suggested (Yadav *et al.*, 2004).

Conclusions

Chickpea is an important rainfed crop which is subject to the vagaries of both biotic and abiotic stresses. Yields in India are considerably reduced by exposure to *Helicoverpa* and terminal drought which occurs when the crop is grown in the post-rainy season on stored soil moisture. While progress is being made on the adaptation of chickpeas to water-limited environments (Berger *et al*., 2004, 2006; Yadav *et al*., 2004), the development of *Helicoverpa*-resistant genotypes is proving more difficult as genetic variation for *Helicoverpa* resistance has yet to be identified. However, it is clear that erect desi, and to a lesser extent, kabuli types suffer less yield loss from insect damage and should be preferred where pod borer damage is likely to be severe. A significant level of *Helicoverpa* resistance may in the end only be achievable by transgenic technology (the *Bt* gene) or via the introgression of resistance genes from wild progenitors, which appear to include useful genetic sources of increased disease resistance (Yadav *et al*., 2004). We would further suggest that chickpea breeders should deliberately select for superior-performing erect types, as this will help to control the yield losses due to *Helicoverpa* incidence. In relation to drought resistance, selection for desirable bold-seeded types would be desirable with a view to reducing yield losses due to moisture stress. This approach will be most beneficial for the development and identification of cultivars adapted to water-limiting environments.

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