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Plant Breeding Abstracts

Chickpea breeding — progress and prospects

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ABSTRACT

Chickpea (*Cicer arietinum*), grown on about 10 million ha annually, is the world's third most important pulse crop. Although its breeding history is short, considerable progress has been made in cultivar improvement. Breeding cultivars with resistance to freezing, *Fusarium oxysporum* f.sp. *ciceris*, *Ascochyta rabiei* and *Helicoverpa armigera*, and for short duration are examples of successes. Yield stability has increased and yield gains of 1.6% per annum have been achieved. In the West Asia and Mediterranean region, drought avoidance by winter sowing has been achieved by incorporating disease resistance and changing the sowing date. This has resulted in a 75% yield increase. A 20% yield increase was recorded in peninsular India because of the extra-short duration.

The prospects for additional gains from breeding are good. Desirable traits include resistance to high temperature, salinity, *Botrytis cinerea*, *Sclerotium*[*Corticium*] *rolfsii*, *Liriomyza cicerina* and stunt caused by bean leaf roll luteovirus. Attention should also be given to the problems of chilling and lodging in the most productive chickpea-growing areas. The possibilities of applying new biotechnological methods for genetic improvement, particularly the use of interspecific crossing, micropropagation, somaclonal variation, and isoenzyme and restriction fragment length polymorphism (RFLP) mapping, are discussed.

INTRODUCTION

Chickpea, after dry bean and dry pea, is the third most important pulse crop in the world. It is grown annually on about 10 million ha, and produces on average 650 kg/ha. It is an ancient crop; its oldest remains, found at Hacilar in Turkey, date back to 5450 BC. No other pulse is used in as many ways as chickpea. The leaves may be eaten as a vegetable, a refreshing drink can be prepared from the plant exudates, the green seeds may be consumed raw, roasted or boiled, and the dried seeds can be used to prepare an amazing array of different dishes. Most of the seed is used for human consumption, but some is fed to animals (to pigs, for instance, in Mexico). Animals also like chickpea hay. No other crop is covered on all its surfaces with an acid exudate and few have, possibly as a consequence, so few insect problems.

Two types are usually distinguished within the species *C. arietinum*: the small- and brown-seeded desi, and the large- and white-seeded kabuli, the garbanzo blanco bean of international commerce, and a favourite component of salads.

Chickpeas, mainly desi, are widely cultivated in the Indian subcontinent. However, West Asia is also an important producer, of kabuli mainly, and Turkey is the top producer in the region. The Mediterranean countries of Asia, North Africa and Europe have been famous for their kabuli chickpea from ancient times, but in Europe the production has dwindled over the past 25 years. Attempts, however, are now being made to revive it. In some parts of the world, chickpea production has shown rapid and unexpected increases within the past 10 years. For instance, the area under chickpea in Australia has increased from 6000 ha in 1985 to an estimated 150 000 ha in 1990. The largest producer of chickpea in Africa is Ethiopia, where there are approximately 180 000 ha of the crop, mainly desi. In the Americas, Mexico is the top producer and grows an estimated 140 000 ha of chickpea annually, with equal amounts of desi and kabuli.

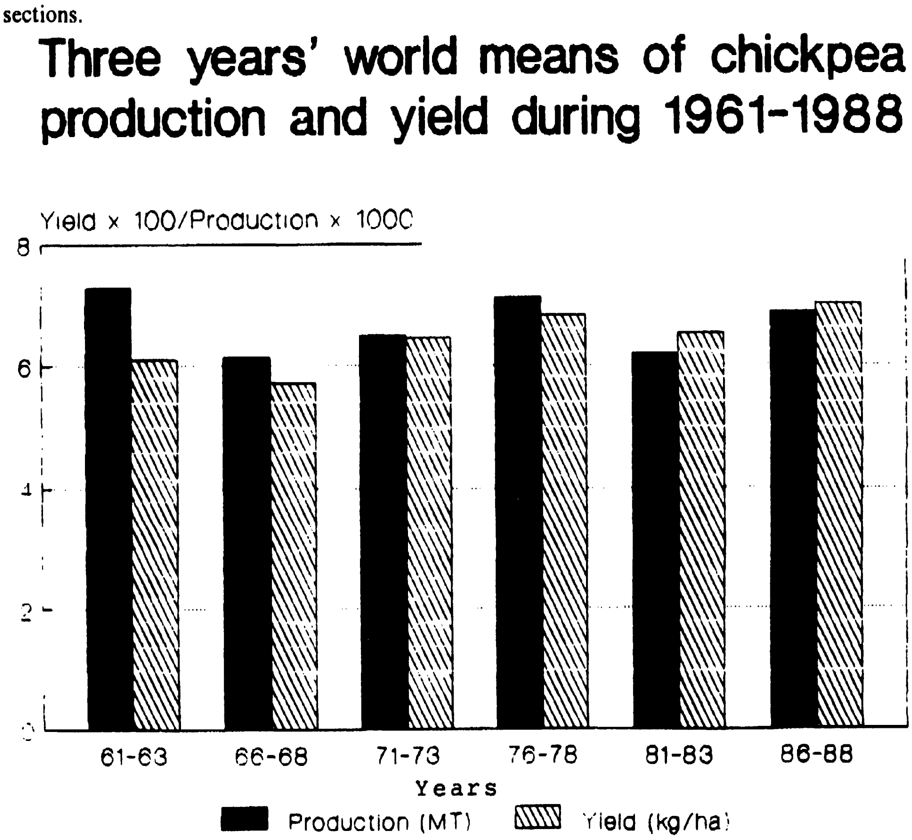
The fact that mean world chickpea yields over the years 1961-63, 1976-78 and 1986-88 were a rather steady 613, 682 and 700 kg/ha leads one to question what progress research on chickpea, breeding included, has made. Before answering, it must be realized that the history of chickpea breeding is relatively short (Singh, 1987).

Early in the 20th century, a modest beginning was made to breed chickpea in India, but only from 1966, when the All India Coordinated Pulses Improvement Project (AICPIP) was initiated, has there been a concerted national effort to improve chickpea. Morocco, Tunisia, Spain, Greece, Turkey and Italy began chickpea improvement before the forties, but the scope of their programmes remained small. In Mexico, the history of chickpea breeding goes back to 1958; it was the first country to develop a wilt-sick plot to screen chickpea for resistance to fusarium wilt. Ethiopia initiated its chickpea breeding in 1967. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Patancheru, India, became involved in chickpea research in 1972 and the International Centre for Agricultural Research in Dry Areas (ICARDA) at Tel Hadya, Syria in 1977. Recent work reported from Canada and the USA involves analysis of isoenzyme and RFLP for chickpea breeding, and the development of high density gene maps has begun.

Much of the chickpea breeding research literature is in Indian journals, but significant reports have appeared in other international journals. The International Chickpea Newsletter, issued from ICRISAT since 1979, informs readers twice a year about the latest developments in chickpea improvement. CAB International (formerly the Commonwealth Agricultural Bureaux), in association with ICRISAT, began publishing in March 1988 the quarterly CAB prompts series for chickpea and pigeonpea as a current awareness publication for timely dissemination of research findings.

PROGRESS IN CHICKPEA BREEDING

Smithson *et al.* (1985) described the breeding advances made in chickpea research at ICRISAT and suggested that the main reason for the stagnation in chickpea production (Fig. 1) was its yield instability. Since then, the constraints leading to yield instability have been further analysed and ranked to obtain a global picture of major problems and their distribution (Table 1)). Breeding efforts have been directed towards the alleviation of these constraints, both abiotic and biotic, to help achieve the main objectives of stable high yield and quality. This work is discussed in the following sections.



Source: FAO Production Yearbook 1962–89

Fig. 1. World production and yield of chickpea from 1961–63 to 1986–88.

Table 1. Ranking of desirable characters for chickpea in different zones of the world.

	Zones (degrees latitude)				
	A	B	C	D	
Desirable characteristics	0–20	20–25	25–30	30–45	
Stable, high yield	+	+	+	+	
Good seed quality	+	+	+	+	
Resistance to stresses					
Biotic					
Fusarium wilt	2–1	2–1	2–1	3	
Ascochyta blight	–	–	6*	1	
Botrytis grey mold	–	5	3	–	
Root rots	3	3	5	4	
Stunt	4	4	4	5	
Helicoverpa	1–2	1–2	1–2	6	
Leaf miner	–	–	–	2	
Nematodes	?	?	7?	7?	
Abiotic				*Spring*	*Winter*
Drought	1	1	1	1	–
Salinity	3	3	2	–	–
Excessive moisture	–	4	5	–	2
High temperature	2	2	4	2	–
Low temperature	–	–	3	–	1

* in case of epidemics, the crop damage is severe.
\+ required.
– not required.
? uncertain.
Source: van Rheenen (1991)

First, the abiotic constraints. van Rheenen *et al.* (1990) distinguished between abiotic stresses, where cultural practices have little effect, such as temperature extremes, and those where cultural practices can be effective in alleviating the stress, for instance drought, and they discussed these accordingly. In this review, the ranking shown in Table 1 is followed, and a more holistic approach adopted.

1. Drought

Chickpea is commonly grown on residual moisture, and this practice is probably the main reason for the world's low and variable yield (Fig 1). The mean yield and its CV from 1961-88 were 642 kg/ha and 11%. For rainfed chickpea, the following options seem to be open to alleviate drought stress:

1. sowing during the rainy season,
2. growing short-duration cultivars,
3. using drought-resistant cultivars.

These options will be discussed in detail, since they are concerned with the foremost problem: drought.

(a) Chickpea as a rainy season crop

In West Asia and the Mediterranean region (zone D in Table 1), chickpea is usually sown in the spring and grows on residual moisture from winter rains. In regions of zones A, B and C, chickpea is commonly sown in the autumn on residual moisture from the summer rains. To grow a rainy-season crop, zone D needs to change from spring to autumn sowing, and zones A and B from autumn to summer sowing. Transition zone C is the highest in production, and requires no change. The 2 situations have similarities, but also differ considerably as will become apparent.

(b) From spring to autumn sowing

(zone D in Table 1)

The idea of sowing chickpea in the autumn to use the scarce winter rains must have occurred to farmers in zone D as it did to ICARDA's scientists. However, a disease of little significance for a spring-sown crop posed a serious threat to an autumn-sown crop. The disease is ascochyta blight, caused by the fungus *Ascochyta rabiei*.

In a search for resistance to this disease, more than 13 000 germplasm accessions were screened at ICARDA and 17 genotypes identified as resistant. These have been used in breeding programmes and the resulting cultivars have helped to stabilize production and increase yield by about 75%, a spectacular success indeed (Nene and Reddy, 1987). Apart from ascochyta blight, winter cold also endangered the autumn-sown crop. An extensive screening, breeding and research programme resulted in the development of freezing resistant lines (Singh, *et al.*, 1989). One need only see the dramatic differences in resistance to ascochyta blight and to frost damage to appreciate this breeding achievement (Fig. 2).

(c) From autumn to summer sowing

(zones A and B in Table 1)

The idea of sowing chickpea in summer to use the summer rains must also have occurred to farmers in zones A and B. Here again, a disease of little significance for an autumn-sown crop threatened the summer-sown chickpea. The disease is colletotrichum blight, caused by *Colletotrichum dematium*.

Apart from colletotrichum blight, waterlogging and high temperatures may also exert adverse effects on summer-sown chickpea. Research at ICRISAT has shown that rain as such does not harm the vegetative growth of a well-drained chickpea crop; that genotypic differences for resistance to colletotrichum blight exist; and that advancing the sowing date by 1 month can increase the yield by 25%. Under low-fertility conditions and without insect control, a yield of 1.5 t/ha was recorded when the sowing date was advanced by 1.5 months in 1989 (Singh *et al.*, 1990b; van Rheenen, 1991).

(d) Short-duration chickpea

The maturation period for chickpea, growing on residual moisture, is closely related to the number of days from sowing to flowering. The earliest-flowering chickpea cultivar in the International Chickpea Germplasm Collection of approximately 16 000 accessions maintained at ICRISAT is ICCV2, a kabuli cultivar (Fig. 3). It was released in 1989 in the state of Andhra Pradesh, India, as Swetha, and has proved popular elsewhere, e.g. in Myanmar. Swetha was selected from a cross involving 5 parents, and combines the desirable traits of extra-short duration, resistance to fusarium wilt and relatively large seed size, the most important being the extra-short duration as it enables the plants to escape drought. In non-irrigated on-farm trials in the state of Maharashtra, India, Swetha flowered about 2 weeks earlier than the control varieties, outyielded these by 20% in 1988/89 and gave a mean yield of 860 kg/ha (Fig. 3). This cultivar represents a significant contribution to the crop's stability through its flexibility in sowing date, its potential for crop rotation, and its short duration of 75 days in which time it can produce 1 t of seed per ha. Subsequent efforts to develop desi varieties of similar duration have produced the varieties ICCV88201 and ICCV88202, and work in this direction has been further intensified.

(e) Drought-resistant chickpea

Screening of germplasm accessions under irrigated and non-irrigated conditions enabled Saxena (1987) to identify 2 drought-resistant lines, ICC4958 and ICC10448. An interesting observation was that ICC4958 exceeded the well-established cultivar of peninsular India, Annigeri, by 30% in root volume and yielded 360 kg/ha (72%) more than Annigeri's yield of 500 kg/ha. At 1700 kg/ha the varieties were at par in yield, and beyond this Annigeri began to exceed ICC4958 in productivity. A diversified bulk population breeding method is being followed for cross populations, with ICC4958 as one of the parents, to widen the adaptation of drought-resistant selections.

2. Temperature constraints

Three different temperature regimes are harmful to chickpea. The temperature can be too low (0°C) and freeze the crop; it can be over 0°C, but still so low (0-5°C) that it causes chilling of the plant and, consequently, flower drop and pod abortion (Buddenhagen and Richards, 1988). Finally, it can become too warm (>30°C) for optimal growth and development. I will discuss these 3 cases separately.

(a) Freezing temperatures

Chickpea sown in the autumn in West Asia and the Mediterranean region may encounter severe winter cold. Monthly minimum temperatures at Tel Hadya, Syria, for instance, may be as low as about −10°C. Under such conditions, Singh *et al.* (1989) identified 73 germplasm lines from a collection of 2526 that were tolerant of such temperatures. Percentage-wise, Morocco, India and Chile had more resistance in their collections than other contributing countries such as Afghanistan, Algeria, Turkey and the USSR. Inheritance studies revealed that resistance to freezing was dominant, and that it was controlled by at least 5 genes with both additive and non-additive effects and high heritability estimates (Singh *et al*, 1989). In the breeding programme at Tel Hadya, segregating populations and progenies are sown in advance of the recommended date, and plants or lines that suffer cold injury are rejected. This procedure has resulted in the selection and release of several low-temperature resistant cultivars (Fig. 2).

(b) Chilling temperatures

Chickpea in zone C (Table 1) is usually autumn-sown, and temperatures below 0°C are rare. However, minimum temperatures do reach from 0 to 5°C and can cause flower abortion. Chickpea breeders and physiologists searched for germplasm lines that could retain flowers and set pods under these conditions. Eventually, in 1980/81 at the ICRISAT Cooperative Research Station at Hissar, in northern India, a few plants were observed in F_1 segregating populations that showed pod formation at low temperature. Breeding, using this material, has progressed well and the lines produced hold promise not only for chilling resistance but also for earliness, and therefore have the potential to escape foliar disease and pod-borer (*H. armigera*) attack. In addition, the plants show less profuse vegetative growth than normal types and are less liable to lodge under good growing conditions (Saxena *et al.*, 1988; ICRISAT, 1989 and 1990). This may lead to a breakthrough in chickpea production in a zone where the crop seems to be very well adapted.

(c) High temperatures

It is generally agreed that temperatures above 30°C are harmful to the crop, especially during the reproductive stage. However, the literature contains little of practical relevance in this area and information on screening for heat resistance is almost non-existent. At ICRISAT, some screening for heat resistance is being done by sowing chickpea in January to expose plants to high temperatures (range daily maximum temperature 33-39°C) in the March-April period. In 1990, one trial entry gave a yield as high as 1.7 t/ha in such a screening test. This type of work deserves more attention, as chickpea is a cool-season crop, but often has to cope with above optimal temperatures.

3. Other abiotic constraints

Chickpea is very sensitive to salinity, and although genotypic differences have been observed, the levels of resistance have been low. Some screening work is being conducted at a few places but only on a small scale. Other soil factors, such as low pH and iron deficiency can affect crop growth. For the latter, chickpea varieties have shown marked differences in susceptibility, and during the course of breeding programmes lines showing severe iron chlorosis symptoms are discarded.

Regarding biotic constraints, 47 diseases and 54 insect pests have been reported from chickpea (Singh *et al.*, 1990a). Fortunately, only 6 diseases are of major importance, and 2 insect pests are of serious concern. I will discuss in more detail those for which progress has been made in breeding.

4. Chickpea diseases

(a) Fusarium wilt

Fusarium wilt, caused by *F. oxysporum* f.sp. *ciceris*, is probably the most widespread disease of chickpea. Wilting of chickpea can be caused by many organisms, and chickpea wilt was earlier referred to as the wilt complex. The unravelling of this complex to its component parts, of which *F. oxysporum* is of major importance (Nene *et al.*, 1978), is a significant success story. Inheritance studies of resistance to this pathogen (Singh *et al.*, 1987) have contributed considerably to current success in breeding resistant varieties. Resistance to race 1 is controlled by 2 recessive and 1 partially dominant gene, which in any combination of 2 confer resistance. Many varieties now being released are resistant to fusarium wilt.

(b) Ascochyta blight

The blight caused by *A. rabiei* can be devastating in certain regions, but may be of little or no significance in others. For example, autumn-sown chickpea in northern Pakistan, north-western India, West Asia, northern Africa and southern Europe can be severely damaged by the disease, but in Mexico, Ethiopia and South Asia it poses no problems. Extensive screening and breeding for ascochyta blight resistance has helped to alleviate the disease stress in West Asia, the Mediterranean region, Pakistan and northern India (Reddy *et al.*, 1990; Singh *et al.*, 1990a; Malik *et al.*, 1988). Studies of the inheritance of ascochyta-blight resistance report dominant and recessive single gene control (Singh and Reddy, 1989) but genetic control of resistance is probably much more complex than suggested in current literature (Gowen *et al.*, 1989; Malik, B.A., 1990: personal communication).

(c) Other diseases

There are several other fungal diseases such as botrytis grey mould, caused by *B. cinerea*; dry root rot (*Rhizoctonia bataticola*[*Macrophomina phaseolina*] and collar rot (*Sclerotium*[*Corticium*] *rolfsii*) that can seriously damage chickpea in some locations in some seasons. Resistance breeding has been initiated and results are forthcoming, but the work is still in its infancy. The same applies to nematode and viral diseases (Greco and Sharma, 1990; Kaiser *et al.*, 1990). For instance, screening and breeding for resistance to chickpea stunt has resulted in the development of resistant lines (Nene, 1988), but more needs to be known of the causal agent(s) and their mode of transmission (D.V.R. Reddy, 1990: personal communication).

5. Insect pests

There are 2 major chickpea pests, the pod borer *H. armigera* and the leaf miner *L. cicerina*. The former has a world-wide distribution while the latter is restricted to areas in zone D (Table 1).

(a) *Helicoverpa* pod borer

This pest attacks chickpea from the seedling stage to near maturity and can cause severe damage. At ICRISAT, insecticide sprays gave mean values over 8 years of 12% less pod damage and 21% more yield in large chickpea plots. The story of the search for host-plant resistance against the pod borer is fascinating. ICRISAT's entomologists screened more than 14 800 germplasm accessions from 1984-90 in unsprayed areas. The first success came when young plants were noticed which retained part of their foliage when others were completely stripped of leaves by *Helicoverpa*. The best such accession was ICC506. Over 6 years, ICC506 showed a mean of 8.6% pod borer damage and yielded an average of 1.2 t/ha. Over the same period, the popular cultivar Annigeri suffered 29.9% damage and gave a yield of 1.0 t/ha (Reed *et al.*, 1987; Lateef and Pimbert, 1990). The national chickpea research programme in India identified many resistant lines, and recommended some for use as parents in crossing programmes (Sachan, 1990). One problem now overcome was the linkage between pod-borer resistance and susceptiblity to fusarium wilt. The line ICCL86102 combines the 2 resistances. Although biochemical factors are being studied for their contribution to insect resistance, results so far have not found practical application in breeding programmes (Rembold *et al.*, 1990)

(b) *Liriomyza* leaf miner

In West Asia, northern Africa and southern Europe, *L. cicerina* is the most important insect pest of chickpea. Resistance screening at ICARDA of 6800 chickpea lines yielded 10 with consistently low leaf miner damage scores (Weigand and Tehhan, 1990). However, within the breeding programmes, resistance screening has still to be established as a routine practice.

(c) Other insects

Other insect pests harmful to chickpea include aphids and white grubs, but no breeding efforts have bee: undertaken so far to control these. As for storage pests, *Callosobruchus* spp. are the most harmful. Screening 6697 kabuli chickpea lines failed to detect useful resistance to this pest, but the wild species *Cicer echinospermum* was found to be free from seed infestation (Weigand and Tahhan, 1990). A fortunate recent development is the successful crossing of *C. arietinum* × *C. echinospermum* (ICARDA, 1990).

6. Stable yield and high quality

Chickpea breeding for yield and quality has utilized the various methods usually applied to self-pollinated crops. In addition to pure line and mass selection, breeders have used pedigree, bulk population and backcross breeding methods and combinations of these. Population improvement by recurrent selection is exceptional, but mutation breeding for yield has had an impact (Kharkwal, 1989). Smithson (1985) mentioned that because of the ineffectiveness of visual selection for yield, and the magnitude of the genotype × environment interaction, ICRISAT changed from pedigree to bulk methods of breeding from 1978. The approach of multilocational early generation bulk yield testing was adopted and applied to F_2 and F_3 populations. Some other breeding programmes have followed the same method (Dahiya *et al.*, 1984). However, Geletu (1987) from his study of F_2-F_6 generations of 9 crosses, concluded that the yield correlations between generations was low, not justifying continuation of the elaborate method of multilocational F_2/F_3 yield testing. van Rheenen *et al.* (1991) proposed a method called polygon breeding, whereby segregating populations and selections are shared and exchanged between breeders.

Saxena and Johansen (1990) believe that despite intensive breeding efforts, there has been no significant enhancement of yield potential of chickpea over the last 2 decades, and they recommend an ideotype approach for yield improvement. Others have estimated yield increases of 1.6% annually from breeding efforts (ICRISAT, 1990, unpublished report). Let us focus on one recent case of yield improvement for a variety listed by ICRISAT as ICCV10 and yield tested multilocationally in 2 zones of peninsular India for 4 years: 1986/87 to 1989/90 (Fig. 4). This variety ranked first each year in both the Central and South zone trials; its mean yield increase over the control varieties in the 2 zones being estimated at 21% in the Central zone and 16% in the South zone trials; average yields were 2.0 t/ha in the Central zone and 1.8 t/ha in the South zone. The variety was developed from a cross between P2559 and the line F_5 (BN10 × NP34) in 1976, and the annual yield increase may therefore be estimated at 1.3%. This is only one example, but similar progress can be quoted from the national breeding programmes of India and other countries. Several avenues have been followed to achieve yield increase, such as breeding tall or mid-tall types, desi × kabuli introgression, and employment of the double-podded and multiseeded characters, but such work may have to be pursued to bring forth the expected results (Bahl *et al.*, 1990).

On quality I may be brief. Much research has been conducted and continues on the quality aspects of chickpea (ICRISAT, 1991), but for practical breeding purposes it is mainly the seed appearance that is taken into account during the breeding process, while such quality factors as cooking time and protein content are tested on the elite material.

7. Synthesis and summary

Major yield increases have been reported, resulting from agronomic practices such as irrigation and weed control, and from the use of pesticides, discussion of which is beyond the scope of this mini-review.

Chickpea breeding has been largely defensive in that it has aimed at incorporating factors that alleviate stresses. This has been and still is important as yield stability is the top requirement. Many cultivars have been bred over the years, and the number is increasing rapidly. Singh (1987) has listed 159 cultivars, released from 1926 to 1984 from a range of countries. Several already have specific stability factors. A major increase in yield of about 75% has been reported from West Asian and Mediterranean countries by breeding for a combination of ascochyta blight and freezing resistance, and by changing the date of sowing from spring to autumn. The trend towards shorter-duration chickpea in peninsular India has been beneficial in that yield increases of about 20% have been achieved. There has been a steady yield improvement, exemplified by the variety ICCV10, with estimated 1.3% increase per annum. Several interesting and promising new approaches to chickpea improvement are being followed. I will discuss these in the section on prospects although some have been mentioned already.

PROSPECTS FOR CHICKPEA BREEDING

As we have seen, chickpea is subject to many stress factors, both abiotic and biotic; most of these have not been studied in depth, and many have received hardly any attention, for example, high temperature effects, salinity, collar rot and nematodes. It must be remembered that chickpea's breeding history spans only a short period and therefore the prospects seem promising. Breeding for resistance to adverse factors is likely to be a rewarding task. Germplasm enhancement will need to receive more emphasis in this context. The use of chilling resistance for a major chickpea-production belt is to be further probed, promoted and consolidated. For the same areas, lodging resistance may contribute much to maximizing yield. The breeding of extra-short duration chickpea has just started to bear fruit with the release of cv. ICCV2 in 1989. It is anticipated that advances in this area will be rapid. Taking the crop out of the critical period of residual moisture by changing sowing date has been successful in West Asia, North Africa and southern Europe. This approach may also succeed in regions of lower latitude, thus opening areas more promising for yield and resistance breeding than the marginal areas used at the present time. Mutation breeding as a tool to improve varieties for specific characteristics may contribute even more than it has done so far. The expected benefits from the application of biotechnology to chickpea have been described by van Rheenen *et al.* (1988). The main practical interests for the breeder are probably, at the moment, interspecific crossing, somaclonal variation and micropropagation, although transfer of desirable genes by recombinant DNA techniques is his dream. The recently initiated work based on isoenzyme and restriction fragment length polymorphisms is important, especially for the construction of saturated gene maps that show linkages with agronomically important characters that are hard to select for (Muehlbauer *et al.*, 1990). I conclude that the pathways leading to progress are many.

I return now briefly to the question asked in the introduction in connection with the steady yields over several years. Chickpea lacks the long breeding history and scientific input that some other crops, particularly cereals, have received. Competition with the latter has pushed chickpea onto the poorer land. However, signs of change are evident from the recent progress described, and given a little more time the prospects for this pulse crop, which is gaining popularity worldwide, seem hopeful and encouraging.

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Fig 2 Resistance (right) and susceptibility (left) to frost damage at ICARDA, Tel Hadya, Syria, 1989

Fig. 3. Chickpea variety ICCV2 growing in a farmer's field in Maharashtra, India Inset: seed

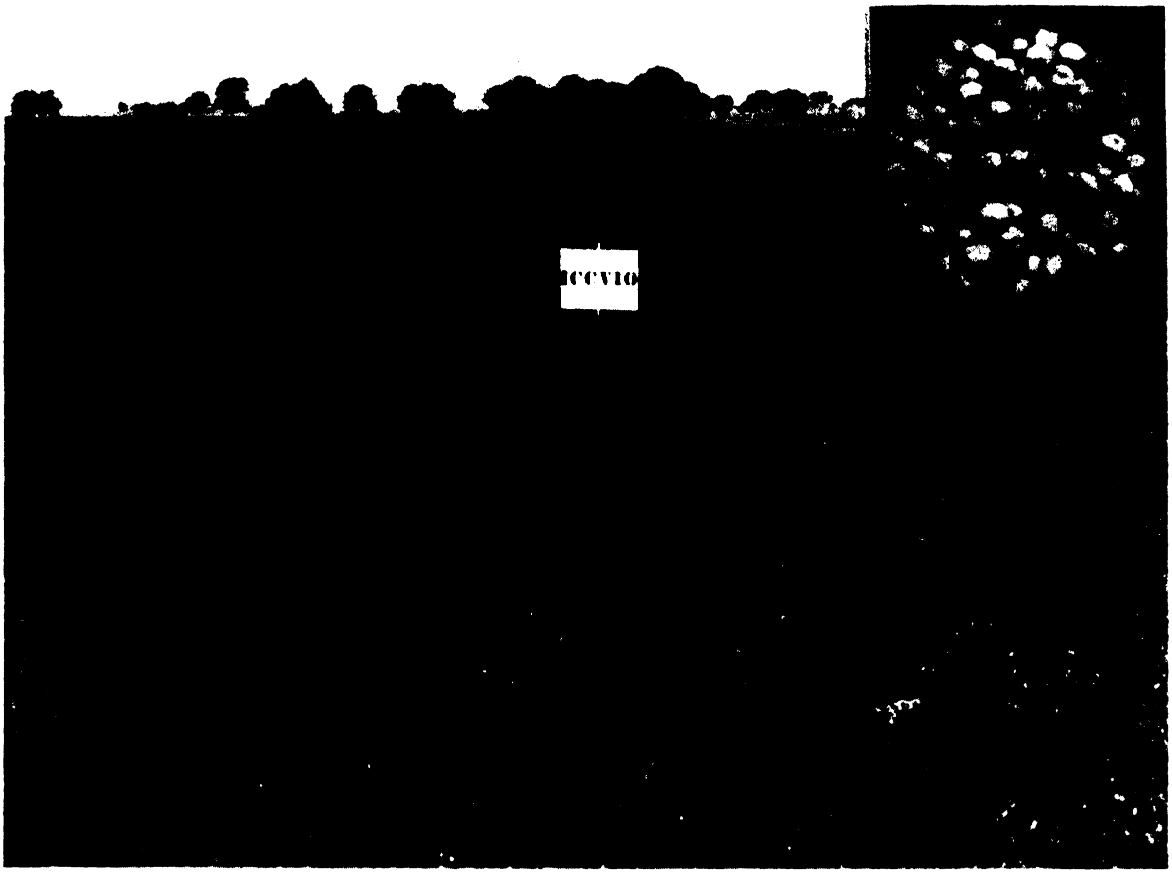

Fig. 4. Chickpea variety ICCV10. Insct: seed.