ABIOTIC FACTORS LIMITING CHICKPEA AND PIGEONPEA PRODUCTION

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Abstract

Abiotic stress factors contribute significantly to the generally low yields (< 0.8 t ha $^{-1}$) of chickpea (Cicer arietinum) and pigeonpea (Cajanus cajan) achieved in farmers' fields. Such factors include drought, waterlogging, nutrient deficiencies, soil chemical toxicities, extremes of temperature and sub-optimal solar radiation. Current research efforts have focused on exploration of both management and genetic means of alleviating these stresses. Various management options for overcoming problems of water deficit or excess have been evolved, such as irrigation scheduling and ensuring of appropriate drainage in fields. Development of short-duration genotypes of both chickpea and pigeonpea has increased options of escaping terminal drought stress. Further, recent studies have revealed substantial sources of drought tolerance in both the crops, thus improving the feasibility of breeding for drought tolerance. At this stage, nutrient deficiencies are best overcome by judicious use of fertilizers, except in the case of iron deficiency in chickpea which can be tackled by use of iron efficient genotypes. Substantial sources of salinity tolerance have been found in some of the wild relatives of pigeonpea, which opens the way for genetic enhancement of salinity tolerance in this crop. To better adapt chickpea to northern Indian environments, genotypes with ability to set pods at lower winter temperatures(< 5° C) have been identified. To allow wider adaptation of these crops, sources of heat tolerance(> 30° C) need to be identified for chickpea and sources of cold tolerance for pigeonpea.

Introduction

Chickpea and pigeonpea are the two most important pulse crops in India. The national average yields of both the pulses are very low, less than 0.8 t ha $^{-1}$ and yields are subject to considerable annual fluctuations. There has been relatively small improvement (N 10per cent) in the national yield of both the crops over the last two decades, even though we have witnessed a quantum jump in the yields of cereals such as wheat and rice. Due to economic non-competitiveness of chickpea with wheat in northern India, the area under chickpea is declining. Potential yield of most commonly used cultivars of both the pulses can be quite high, around 4 t ha $^{-1}$, in environments with minimal growth constraints. Biotic stress factors, due to diseases, insect pests and weeds, are readily identifiable as contributing to this yield gap but there is now increasing quantification and understanding of the role of abiotic stress factors in preventing realization of yield potential. Both crops are usually grown under rainfed conditions on soils generally considered marginal for crop production. Usually, farmers provide few of the inputs required to alleviate, at least to some extent, the known abiotic limitations. This paper sum-

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marizes our present knowledge of the major abiotic constraints for production of chickpea and pigeonpea in India and discusses strategies for their alleviation. Both genetic and management options are considered.

Chickpea

Chickpea, although a crop of temperate origin, can be grown successfully even in subtropical and tropical environments. The crop can be adapted in these zones by choosing appropriate crop growth patterns and by following cultural practices which satisfy the crop growth requirements within reasonable limits. In India, the crop is grown between 11° N and 31° N latitudes, ranging from warm peninsular Indian to cool northern Indian environments. Soils on which chickpea is grown in India are very diverse, including Vertisols, Inceptisols and Entisols. In spite of a decreasing trend in the area and production of the crop in the last two decades, chickpea remains the most important pulse crop in India.

When a cool season legume is introduced into warmer environments, the abiotic constraints of drought and heat become important in limiting the productivity of the crop. Introduction of input responsive varieties of wheat has pushed the cultivation of chickpea to less fertile lands. Further, the crop is disappearing from traditional areas of its cultivation which have become saline because of indiscriminate use of irrigation water (Johansen *et al.*, 1988).

Drought

Drought is a major abiotic constraint in chickpea, which is primarily grown as a Rabi (postrainy) season crop in India on residual soil moisture (Saxena, 1984). The nature and magnitude of drought experienced by chickpea in two contrasting environments, such as at Patancheru in the warmer winter region of peninsular India and at Hisar in the cooler winter environment of northern India, have been described (Saxena, 1987 a). Estimated losses of production due to drought appear to be much larger for chickpea than for pigeonpea, which is understandable because chickpea is a postrainy season crop dependent on residual soil moisture (Table 1).

Table 1. Estimated [1] losses in production of chickpea and pigeonpea crops due to drought stress in India and their possible recovery through genetic or management options.

Crop	Losses		Possible recovery (m Rs.)
	Production ('000 t)	Economic (m Rs.)	
Chickpea	1,151	4,840	1,240
Pigeonpea	455	1,740	350

[1]Calculated on the basis of known reduction in yield due to stress and the extent of genotypic variation.

Limiting seedbed moisture

A primary adverse effect of drought is on poor establishment resulting in non-uniform plant stands, which perhaps is the single most important factor responsible for the low yields of rainfed chickpea

(Saxena, 1987 a). Depending upon the time elapsed between cessation of rains and time of planting, the soil type and the moisture conservation practices adopted in the preceding rainy season, soil moisture could recede to different depths from the soil surface at the time of planting. If seeding can be done at depths where there is adequate soil moisture, a good stand establishment can be obtained. Evidence gathered at ICRISAT suggests that chickpea genotypes differ in their ability to germinate and emerge from sub-optimal and receding seed bed moisture (Saxena, 1987 a). Genotypes with superior ability to germinate and establish from sub-optimum seed bed moisture can contribute to improved plant stands in rainfed systems of chickpea cultivation. Laboratory and field screening methods have been developed (Saxena, 1987a) but this area of research requires greater emphasis in future.

Tolerance to drought

A generalization is often made that chickpea is a drought tolerant crop but there is little evidence to verify this (Saxena, 1984). Chickpea is known to proliferate its roots to soil depths of at least 120 cm in Vertisol (Sheldrake and Saxena, 1979) and can extract water from depths of up to 150 cm (ICRISAT, 1979). Even then rainfed chickpea suffers severely from drought as judged from the irrigation responses on these Vertisols, where yield can be doubled in peninsular Indian conditions (Saxena *et al.*, 1983). When supplementary irrigation is not feasible, another way to alleviate the effects of drought is to use varieties which can either escape or tolerate drought. Nevertheless employing escape strategies is a conservative approach because such genotypes are likely to suffer a penalty in potential yield due to the shorter time available for biomass accumulation. Using a field screening method, consistent genotypic differences in drought tolerance within the short-duration group(e.g. ICC 4958 and ICC10448) of chickpea have been identified at ICRISAT (Saxena, 1987a). ICC 4958 is now being used as a parent for genetic improvement of drought tolerance. Investigations on the physiological basis of drought tolerance are also in progress at ICRISAT.

There is an urgent need that research on drought tolerance for identification of useful variability and its use in breeding programs should be extended to all drought-prone environments in which chickpea is cultivated.

Temperature

Extremes of temperature can set limits to the growth and yield of chickpea.

High temperature stress

Under Indian conditions, chickpea can experience heat stress both at the time of seedling establishment and during the pod filling stages. Soil temperatures at the time of sowing often exceed an optimum of 30° C for the germination of chickpea seeds (Saxena *et al.*, 1988) and this can result in reduced plant stands, independent of the effects of drought. Soil temperatures of 30° C and above adversely affect the rhizobial infection and nitrogen fixation processes (Rupela and Saxena, 1987). This is of particular relevance when early plantings are recommended to capitalize on the good seed bed moisture soon after the cessation of rains, when temperatures are relatively higher(saxena and Sheldrake, 1980a). Effects of high temperature on early vegetative growth and genotypic differences in growth in response to combinations of day and night temperatures have also been reported in chickpea (van der Maesen, 1972). Using a field screening method, genotypic differences in heat tolerance at early seedling growth stages were studied and genotypes with higher growth rates at high temperatures were reported (Saxena and Sheldrake, 1980a). These data are encouraging and worth pursuing.

Temperatures above 35° C during reproductive stages have been shown to reduce seed yield in chickpea (Summerfield *et al.*, 1984). Alleviating heat stress on chickpea canopies by shading, which reduced incoming radiation by 50 per cent increased the yield of nonirrigated chickpea significantly in the warm environment of peninsular India (Sheldrake and Saxena, 1979). Studies on genotypic differences in heat tolerance during flowering and podfilling stages have not been reported so far and this is worthy of greater attention in future.

Low temperature stress

The effects of low temperature on pod set were recognized in chickpea growing at Hisar when flowers produced during the cooler months of December and January failed to produce pods (Saxena and Sheldrake, 1980a). The association of failure of pod set with low night temperature was verified using a diverse set of genotypes (Saxena, 1980). That low night temperatures are indeed involved in failure of podset was confirmed by using soil heating cables to raise ambient temperatures (ICRISAT, 1983). Flower and pod shedding at low temperatures is thus considered as one of the reasons for the poor harvest index and low yields realized by chickpea in cool-winter regions of northern India. Chickpea genotypes tolerant to low night temperatures have been identified and resultant increases in biomass and harvest index have been reported (Saxena *et al.*, 1988a). Possibilities of increasing yield, at the current levels of biomass production, through improvement of harvest index by using the cold tolerant lines recently identified at ICRISAT have been discussed by Saxena and Johansen (1990). With the availability of this new kind of variability in germplasm, research efforts need intensification to thoroughly explore the utility of the cold tolerant trait for genetic enhancement of yield potential in cooler environments of northern India.

Chickpea may also be exposed to low temperatures during early vegetative stages when planted late (in early December) after the harvest of paddy, or other rainy season crops, in the cooler region of northern India. Tolerance to low

temperature during early growth stages has been identified in chickpea at ICARDA(Singh *et al.*, 1989) and also observed in recent experiments at ICRISAT Cooperative center, Hisar. These sources of tolerance may be utilized in developing varieties specifically suited for late planting conditions.

Light intensity

In northern India, chickpea usually develops dense canopies which intercept nearly all of the incident solar radiation. Light penetration in such canopies may become a limiting factor as lower portions of the canopy do not receive adequate light. Work has just been begun on this aspect at ICRISAT. In peninsular India, by contrast, radiation appears to be excessive, particularly towards the reproductive stage, as it aggravates drought stress by increasing the heat load on the canopy (Sheldrake and Saxena, 1979).

Nutrient Limitations

Important deficiencies

Chickpea can fix atmospheric nitrogen symbiotically in most environments but responses to fertilizer nitrogen application are still obtained, indicating an inadequacy of the symbiosis in meeting the crop's N requirements (Saxena, 1987). Chickpea is particularly efficient in extracting soil P by being able to acidify the rhizosphere in calcareous soils (Marschner and Romheld, 1983; Ae et al., 1988). Strong mycorrhizal associations in chickpea also probably contribute to improved P uptake efficiency (Hirata *et al.*, 1988). Little evidence has so far been found of genotypic differences in P use efficiency in chickpea (Saxena et al., 1988 b). Responses to P application are variable and generally low even when biomass production is high and hence plant demand for P is also high (Saxena, 1984).

Iron deficiency is often observed on calcareous soils, either when the crop is irrigated or after persistent winter rains which may cause temporary waterlogging conditions. Losses in yield can vary considerably with location. In experiments at ICRISAT Center, a yield loss of nearly 40per cent due to iron deficiency was observed (Saxena and Sheldrake, 1980b). In chickpea, the deficiency can be easily overcome by a foliar application of 0.5per cent (w/w) aqueous solution of ferrous sulfate because of the presence of highly acidic exudates on the foliage(Saxena and Sheldrake, 1980b). The problem can also be alleviated through genetic improvement of efficiency of iron utilization as there are large genotypic differences in this regard (Gowda and Smithson, 1980).

On sandy loam soils in northern India, field deficiency of Zinc has also been observed which could be corrected by a soil application of 10-25 kg ha $^{-1}$ of zinc sulphate or a foliar spray at 0.5 per cent concentration mixed with 0.25 per cent lime (Saxena, 1987).

Salinity

The nature and magnitude of soil

salinity affecting crop plants, including chickpea, has been summarized by Chauhan (1987). Saxena (1987b) pointed out the limitations of using genotypic tolerance to salinity for increasing and stablizing chickpea productivity in salt-affected regions. This crop is very sensitive to soil salinity compared to other legume crops (Chandra, 1980). Genetic improvement for tolerance to soil salinity is not possible for chickpea at this stage because no useful variability has yet been identified in the germplasm, including the wild species of *Cicer* (Johansen *et al.*, 1990).

Pigeonpea

Drought

Pigeonpea forms an important component of dryland agriculture in the Indian sub-continent, Africa and the Caribbean region. In India, where most pigeonpea is grown, the cultivated area situated between 14° N and 28° N has been divided into three agroclimatic zones, comprising Agricultural Sub-division (AS) I-northern, AS II-central and AS III-peninsular regions (Reddy and Virmani, 1981). A significant relationship between moisture availability index (MAI), which is a measure of the dependability of rainfall in meeting crop water needs, in the different zones has been found (Chauhan, 1986). MAI is calculated by dividing annual dependable precipitation by potential evapotranspiration. MAI is generally lower in peninsular India than northern India and so are the yields. Indeed, the crop suffers most from increasing moisture stress in this region during the reproductive stage and towards maturity. In other regions also pigeonpea faces drought stress but less predictably than in peninsular India. Types of drought that affect pigeonpea production can be classified as seedling, intermittent and terminal.

Pigeonpea seedlings are vulnerable to drought stress due to their limited ability to access soil moisture. Genotypic differences in response to drought at the seedling stage have been observed but no special effort has been made to screen germplasm in this regard. Breaks in the monsoon rains can cause intermittent stress, which has been found to affect the productivity of short- duration pigeonpea (SDP), particularly when they occur during the preflowering and flowering stages (F.B. Lopez, C. Johansen and Y.S. Chauhan, unpublished results).

Terminal stress is the most predictable type of drought stress affecting growth and yield of pigeonpea. Possible annual losses due to this are given in Table 1. Both medium (MDP) and long-duration (LDP) pigeonpea genotypes begin flowering in the postrainy season. MDP suffers more from terminal stress as it is generally grown in warm winter environments where evaporative demand is high. In studies conducted at ICRISAT, we have estimated yield losses due to terminal drought stress of up to 50 per cent on Alfisol and 20-30 per cent on Vertisol even in a normal rainfall year. Elsewhere, up to a 300-560 per cent increase in seed yield has been reported when drought stress was relieved by irrigation (Singh and Das, 1987). This loss would be even more in low rainfall years. Since a considerable proportion of pigeonpea biomass is produced after flowering,

Table 2. The effect of terminal drought stress on mean yield, total dry matter, harvest index and yield components of 100 medium-duration pigeonpea genotypes, Alfisol ICRISAT Center, rainy season 1985/86.

	No stress	Stressed	SE
Mean seed yield (t^{-1})	1.89	1.27	±0.052
Mean total dry matter (t ha^{-1})	7.63	5.57	±0.213
Mean harvest index (%)	27.0	24.0	±0.15
Mean pods $plant^{-1}$	95.9	62.1	±1.99
Mean 100 seed mass (g)	8.6	8.7	±0.16
Mean seeds $pods^{-1}$	3.4	3.4	±0.04

the decline in yield due to terminal drought stress is primarily attributable to a reduction in total dry matter (TDM) and to a lesser extent to reduced partitioning into seed yield (Table 2).

The various mechanisms that are known to confer adaptation to drought in pigeonpea include leaf movement, senescence, its perennial nature and deep root system (Chauhan, 1992). Pigeonpea roots can proliferate as deep as 1.9 m and have a root length of more than 1500 m beneath every m^2 of soil surface, which enables the plant to exploit moisture from deeper soil layers (Singh and Russell, 1981).

Genetic enhancement of drought tolerance

The extent of genotypic variation in grain yield under terminal drought in case of MDP and intermittent drought in case of SDP have been examined at ICRISAT. In both the maturity groups significant differences among genotypes in response to drought have been recorded. For example, in MDP several germplasm lines, such as ICPL 83057, ICP 4595, ICP 4865, ICP 8744, and ICP 8754 with better performance under stress than the average performance of all genotypes have been identified. This also highlights the need for conducting breeding evaluations of MDP under terminal drought stress so as to guard against selecting more drought susceptible types. A set of promising genotypes from the terminal drought screening, which essentially involved empirical comparison of irrigated and unirrigated yields, has been constituted and is being tested in diverse environments.

Moisture responses of SDP breeding lines have been studied at ICRISAT using line-source sprinkler irrigation and genotypic differences recorded (ICRISAT, 1988). SDP hybrids tend to do well under stress as compared to the cultivars. Similarly, we have found that, in general, indeterminate genotypes do well under stress compared to determinate genotypes. More tolerant genotypes tend to have greater root mass (Onim, 1983) and capacity to retain leaf area, as in ICPL 87 (F.B. Lopez, C. Johansen and Y.S. Chauhan, unpublished). Probably due to phate application, at 4-8 kg Zn ha^{-1}. Enhancement of symbiotic nitrogen in fixing activity is considered the best way of overcoming N limitation (Kumar Rao, 1990).

Like other legumes, pigeonpea is adversely affected by soil salinity and acidity (Johansen, 1990). Pigeonpea growth is halved at soil electrical conductivities of 1.2 dS m^{-1} (1:2 soil water extract). Soil pH < 5.0 can also reduce growth of pigeonpea, probably primarily through an effect of Al toxicity and Ca deficiency (Johansen, 1990).

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