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Selection for drought and salinity tolerance in cool-season food legumes

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The increasing demand for food is compelling farmers to cultivate land in unfavourable climatic and edaphic environments. This applies particularly to food legumes which often have secondary status to more productive, higher income crops such as cereals. In addition, human encroachment upon both productive and marginal agricultural areas is exacerbating abiotic stresses such as salinity. The use of irrigation to overcome drought effects has often led to salinization of once productive land. Examples abound in the Indo-Gangetic Plain of South Asia (Sharma and Gupta, 1986), West Asia (Gelburd, 1985), western USA (Backlund and Hoppes, 1984) and Australia (McWilliam, 1986).

Before considering ways of alleviating drought and salinity stresses, it is necessary to define the magnitude, severity and nature of these problems. It is also necessary to realize that both genetic and management options are available to tackle them, and careful assessment of their relative merits in particular situations is required. This chapter focuses on genetic options, which involve modifying plants to cope better with these stresses. Although such options are less costly, it is important to emphasize that they can only ever be partial solutions. Immunity to drought and salinity is not possible and the crop improvement goal should be a modest enhancement of yield potential and yield stability in defined stress environments. These yield targets may be well below what can be expected for the crop under optimum growth conditions; furthermore, the traits required for genotypes to cope with stress may inhibit their yield potential in constraint-free environments (Rosielle and Hamblin, 1981). We elaborate on these ideas and describe approaches we consider appropriate for the genetic improvement of drought and salinity resistance in chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), lentil (*Lens culinaris* Medik.) and pea (*Pisum sativum* L.).

DROUGHT TOLERANCE

Drought is one of the most important factors limiting the productivity of rainfed chickpea, faba bean, lentil and pea in the Mediterranean environments of West Asia and North Africa (WANA) (Smith and

Harris, 1981) and of chickpea in the semi-arid tropics (Virmani et al., 1980). These legumes can experience two types of drought stress, depending on the season of cultivation.

Types of drought stress and plant response

The types of drought stress which affect cool-season food legumes are: intermittent drought stress caused by breaks in winter rainfall; and terminal drought stress, resulting from receding soil moisture. Autumn- or winter-sown crops in Mediterranean environments are likely to experience intermittent drought during vegetative stages of growth and terminal drought in the reproductive period. Spring-sown crops in Mediterranean environments and winter-sown crops in the semi-arid tropics, grown on residual soil moisture, experience progressively increasing terminal drought stress.

The severity of terminal drought stress depends not only on moisture input by precipitation, but also on the capacity of the soil to store moisture and the evaporative demand of the atmosphere. For example, the differences in drought severity between two contrasting chickpea environments in India — a cool winter site at Hisar in northern India and a warm winter site at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in peninsular India — are primarily because of a greater evaporative demand at the latter site (Saxena, 1987a). Terminal drought stress is more quantifiable, and predictable, than intermittent stress because of the low probability of precipitation during the later growth period. Post-rainy season yields of chickpea can be reasonably predicted from knowledge of available soil moisture at the beginning of the growing season (Huda and Virmani, 1987; Piara Singh et al., 1990).

The two main mechanisms by which plants adapt to drought environments are drought escape (completing the plant growth cycle before water becomes a limiting factor) or drought resistance (Levitt, 1980). The latter term has two components: dehydration avoidance, which involves retaining tissue turgor and volume by maintenance of water uptake or reduced water loss; and dehydration tolerance which refers to the protoplasmic tolerance of desiccation (Levitt, 1980). From a practical crop improvement point of view, drought resistance can be defined as the ability of one plant variety to produce a higher yield than another, at a given limiting level of water availability (Quisenberry, 1982).

Yield losses

Table 1 (*page 248*) provides an idea of the extent of yield loss due to inadequate soil moisture availability in the four crops in their major growing regions. For chickpea, yield loss can vary between 30% and 60%, depending on geographic location and climatic conditions during the crop season. Similar losses have been reported from other warm winter sites in India (Palled et al., 1985). Drought may not be a serious constraint in areas with low evaporative demand, a good pre-planting rainfall or a well-distributed rainfall pattern during the crop season. Irrigating crops under these conditions may indeed reduce yield by inducing excessive vegetative growth and lodging, as happens for chickpea at Hisar (*see* Table 1). Winter-sown chickpea in Mediterranean environments, although better suited to a more favourable moisture and thermal regime compared to spring-sown chickpea (Saxena, 1984), can still suffer yield losses due to terminal drought.

Faba bean is very sensitive to drought (Day and Legg, 1983) and highly responsive to irrigation. As shown in Table 1, losses in potential yield of up to 66% occurred when the amount of water applied was reduced from 700 mm to 100 mm. At Pantnagar in northern India, faba bean yield losses due to drought are about 34%.

Lentil is considered as relatively tolerant to drought and heat (Muehlbauer et al., 1985) but it produces low yields when grown as a rainfed winter crop in India (Jeswani, 1988). Potential losses in yield can range between 6% and 54% in the WANA region and the semi-arid tropics (*see* Table 1).

Pea, being a cool-season temperate legume, is particularly sensitive to high temperature and drought stress (Davies et al., 1985). Recorded yield losses are 21-54% in the semi-arid tropics of India and about 45% at Tel Hadya in northern Syria, the site of the International Center for Agricultural Research in the Dry Areas (ICARDA) (*see* Table 1). Under temperate conditions in New Zealand, yield losses computed using a model of yield response to drought (Wilson et al., 1985) were about 24% under severe water deficit.

Effects of drought on plant growth

There are two major effects of drought on agricultural productivity: failure to establish the desired plant stand; and reduction in growth and yield due to sub-optimal soil-available water.

Effects on plant establishment. Although poor plant stand can result from a host of biotic and abiotic stress factors, there are indications that lack of adequate soil moisture in the seedbed is an important constraint. In the case of chickpea in Syria, plant stand differs between years and between winter and spring (Brown et al., 1989; Saxena et al., 1990). Data are not available to determine whether variations in plant stand are due primarily to deficient soil moisture or other climatic factors, such as frost, or biotic factors. In northern Syria, Keatinge and Cooper (1983) reported that rains after seed germination contribute not only to adequate soil moisture reserves but also are important in establishing uniform and vigorous plant stands. They concluded that the risk of this transient drought, though small, would be significant, particularly when crops are sown early. The adverse effects of sub-optimal seedbed moisture content on plant stand establishment have been reported for chickpea, both from pot and field experiments (Saxena et al., 1983; Sharma, 1985). It is considered an important yield reducer for rainfed chickpea in the semi-arid tropics in India (Saxena, 1987a) and Syria (Saxena, 1987), and also for pea (Davies et al., 1985). Delaying the planting of spring chickpea to late March at ICARDA, when seedbed moisture was sub-optimal, resulted in a very poor establishment, contributing to failure of the crop (Saxena, 1980).

Effects on growth and yield. For all four crops, growth-inhibitive effects of drought are evident from the large yield reductions in rainfed treatments (*see* Table 1). The question of whether crop growth stages differ in relative sensitivity to drought is important in deciding genetic and agronomic management strategies to alleviate drought effects. Drought stress during vegetative stages of growth alone does not appear to cause a significant loss in chickpea and pea yields (Davies et al., 1985; Chandrasekharaiah et al., 1986). Summarizing data for the four legume crops, Farah et al. (1988) concluded that flowering is the most sensitive stage to drought. It is probable that high sensitivity to drought during the reproductive stage is due to the lack of new root growth, as reported for pea (Davies

Table 1   Yield and yield loss attributable to drought in irrigated (I) and non-irrigated (NI) chickpea, faba bean, lentil and pea in the West Asia and North Africa (WANA) region and in the semi-arid tropics

Chickpea	West Asia/North Africa							Semi-arid tropics		
	Yield (t/ha)				Yield increase over spring (%)			Yield (t/ha)		
	Autumn		Spring				Source[a]			
	1985-86	1986-87	1985-86	1986-87	1985-86	1986-87		ICRISAT	Hisar	Source
NI	1.56	2.04	0.88	1.48	77	38	(1, 2)	1.35	2.62	(3)
I	2.43	3.22	1.52	2.47	60	30		3.04	2.30	
Loss (%)	36	37	42	40				56	-14	

Faba bean	West Asia/North Africa			Semi-arid tropics			
	Yield (t/ha)	Yield loss (%)	Source		Yield (t/ha)	Yield loss (%)	Source
NI	4.10	18.5	(10)	NI	2.56	34	(13)
I	5.03			I	3.90		
100 mm	1.65	67	(11)				
700 mm	5.61						
I fortnightly	0.59	56	(12)				
I weekly	1.35						
I fortnightly	1.79	45	(13)				
I weekly	3.27						

Lentil	West Asia/North Africa			Semi-arid tropics			
	Yield (t/ha)	Yield loss (%)	Source		Yield (t/ha)	Yield loss (%)	Source
Rainfall + I							
273 mm	1.23	54	(4)	NI	0.95	52	(5)
340 mm	1.47	45		I	1.97		
525 mm	2.70			NI	1.48	6	(6)
				I	1.58		
				NI	0.87	45	(7)
				I	1.59		

Pea	West Asia/North Africa			Semi-arid tropics			
	Yield (t/ha)	Yield loss (%)	Source		Yield (t/ha)	Yield loss (%)	Source
NI	0.66	45	(8)	NI	0.88	54	(6)
I	1.19			I	1.81		
				100 mm	1.39	21	(9)
				250 mm	1.77		

Note: a   (1) ICARDA (1987); (2) ICARDA (1988a); (3) Saxena, N.P. (1984); (4) ICARDA (1988b); (5) Saraf and Baltha (1985); (6) AICPIP (1984); (7) Neema et al. (1984); (8) ICARDA (1990b); (9) Behl et al. (1968); (10) ICARDA (1988c); (11) Hebblethwaite (1982);(12) Salih and Ageeb (1983); (13)Singh et al. (1987).

et al., 1985) and faba bean (Salter and Drew, 1965). Some of the early formed roots also begin to senesce by this time. The exponential period of root growth in these four crops coincides with the period of rapid shoot growth (Davies et al., 1985; Gregory, 1988). However, faba bean (French and Legg, 1979; Hebblethwaite, 1982; Day and Legg, 1983; Hussain et al., 1983) and pea (Wilson et al., 1985) can be equally sensitive to drought at all growth stages. In the past, most attention in drought research has been on the obviously important reproductive crop growth stages, which coincide with drought occurrence in receding soil moisture conditions. However, research on the effects of and responses to drought during early crop establishment phases remains neglected and requires greater attention.

Genotypic differences in drought resistance

Crop establishment

The critical moisture requirement level for seed germination differs between crops (Hadas and Stibbe, 1973). Compared to pea, lentil and faba bean, chickpea has a relatively high moisture requirement for seed germination (Hadas and Stibbe, 1973). Nonetheless, the critical soil moisture required for seed germination and seedling emergence in chickpea is well below field capacity (Saxena et al., 1983; Sharma, 1985). Lentil seeds absorb water equal to their weight in less than 36 hours and germinate soon afterwards, but germination is affected when dehydration occurs thereafter (Saxena, 1981). This makes lentil crops sensitive to early season drought, particularly when planted shallow, as required for microsperma lentils (Saint-Clair, 1972).

There are a few studies on genotypic differences in seed germination at different levels of soil moisture availability in these four legumes. Genotypic differences in seed germination have been identified in chickpea using osmotic solutions (Dutt and Sharma, 1982). However, the usefulness of the superior genotypes in obtaining better plant stands in the field under rainfed conditions remains to be proved. Genotypic differences in seedling emergence from sub-optimal seedbed moisture have been identified in chickpea (Saxena et al., 1983; Saxena, 1987a). The small-seeded microsperma lentils are reported to be better adapted to drought than macrospermus (Genova, 1969). This can be attributed partly to an escape effect because small-seededness is associated with early flowering (Summerfield, 1981), but it may also be due to the larger surface/volume ratio of small seeds causing greater water-imbibing ability and hence improved plant stands. Small-seeded varieties will also have more seeds than the large-seeded types at a constant seed application rate. The better plant stands in microsperma may thus be an artefact if this factor is not considered.

In studies with a limited number of chickpea genotypes, no close correlation was observed between seed size and germination and emergence from suboptimal available moisture within the graded seeds of a genotype (N.P. Saxena, unpubl.). In spite of this negative observation, the simplicity of assessing for this trait and its potential usefulness warrants a more extensive examination of it in the germplasm of the four crops before abandoning the concept.

Genotypic differences in crop plasticity (that is, a yield plateau over a wide range of plant populations) is another useful trait to overcome the effects of sparse plant establishment in areas where there is a more favourable moisture supply during the later part of the growing season. Genotypic differences in plasticity in chickpea (Sheldrake and Saxena, 1979) and lentil (Saxena, 1981) and freely

branching pea (Davies et al., 1985) in reducing yield losses at suboptimal plant densities is worth further exploration.

Growth and yield

It is well recognized that crops differ in their water requirement. In northern Syria there is a clear, but not rigid, association between diminishing rainfall and the place of each of the three legumes in the cropping system (Keatinge et al., 1985), faba bean being associated with wet areas, chickpea with intermediate rainfall areas and lentil with dry areas. Genotypic differences in drought resistance levels assume greater practical relevance once the choice of a crop and a cropping sequence has been made. Such differences in resistance levels have been reported in chickpea (Saxena, 1987a, ICARDA, 1988a, 1989, 1990a), faba bean (Bond et al., 1985), lentil (Silim et al., 1992) and pea (Bhardwaj et al., 1971). However, greater progress has been made in identifying useful variability for drought resistance in chickpea and lentil than in pea and faba bean.
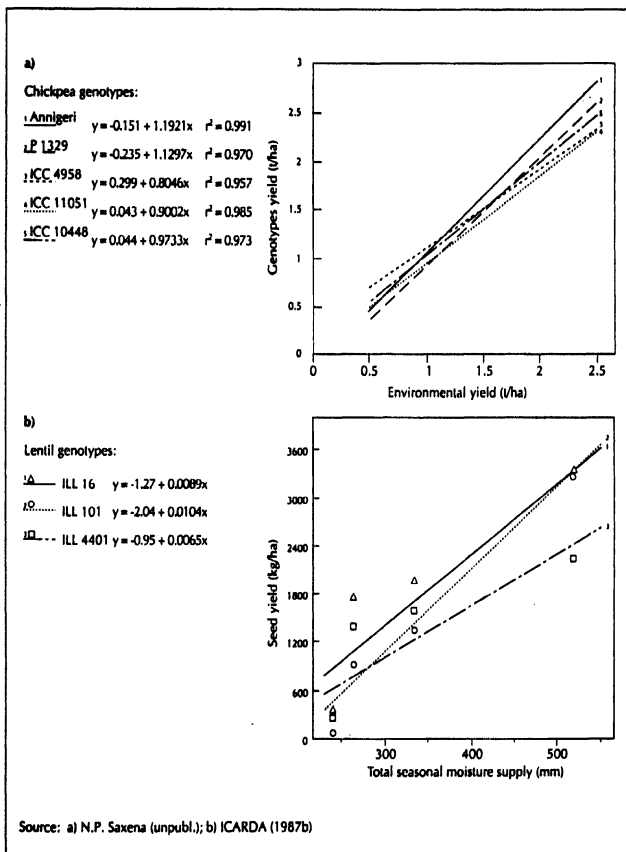
Drought-resistant genotypes are unlikely to be widely adapted because of the strong genotype x environment interactions to which they are subject (Byth et al., 1980). These are illustrated for chickpea and lentil in Figure 1, where genotypic rankings differ according to soil moisture status. However, if iso-drought environments can be characterized, then drought-resistant chickpea genotypes identified at one site may hold promise for other iso-drought sites. This is indicated for ICC 4958, a drought-resistant genotype identified at ICRISAT (Saxena, 1987a) which has been shown to perform particularly well in spring sowings at Tel Hadya in Syria (ICARDA, 1988a, 1989). Both these sites represent progressively increasing severe terminal drought environments. Similarly, the performance of early and late cultivars of pea in drought environments changes, depending on the severity of drought between years (Bhardwaj et al., 1971). These results suggest that specific adaptation to a given level of drought severity is an important consideration in attempts to maximize yield in drought-prone areas.

To date, the genotypic differences in water-use efficiency measured in chickpea are not large (Keatinge and Cooper, 1984; Aujla and Cheema, 1985; Sivakumar and Singh, 1987; Saxena, unpubl.), indicating that there is limited scope for selecting chickpea with substantially improved water-use efficiency. However, this aspect needs further evaluation, with more precise estimations of water-use efficiency across a greater range of genotypes. This now seems feasible using isotopic carbon discrimination techniques; in most plant species studied to date, discrimination of ^{13}C over ^{12}C in carbon assimilation in plant tissue is negatively related to water-use efficiency (Farquhar et al., 1989).

Mechanisms of drought resistance

There are a number of putatively important morpho-physiological traits that can improve the adaptation of crops to drought environments (Ludlow and Muchow, 1988). There is little direct evidence to show the usefulness of many of these traits in the genetic enhancement of drought resistance. However, two traits that seem of practical relevance in improving the adaptation of legume crops to drought are earliness, to escape from drought, and desiccation avoidance, through reduced transpiration loss and increased water uptake.

Figure 1   Yield of (a) five chickpea genotypes grown in a range of environments
                  on a Vertisol at ICRISAT, Patancheru, India in the 1984-85 post-rainy
                  season and (b) three lentil genotypes grown at different levels of soil
                  moisture on a calcic Luvisol at ICARDA, Tel Hadya, Syria in the
                  1986-87 winter season

a)

Chickpea genotypes:

Annigeri $y = -0.151 + 1.1921x$ $r^2 = 0.991$

LP 1329 $y = -0.235 + 1.1297x$ $r^2 = 0.970$

ICC 4958 $y = 0.299 + 0.8046x$ $r^2 = 0.957$

ICC 11051 $y = 0.043 + 0.9002x$ $r^2 = 0.985$

ICC 10448 $y = 0.044 + 0.9733x$ $r^2 = 0.973$

b)

Lentil genotypes:

△ —— ILL 16 $y = -1.27 + 0.0089x$

○ ······ ILL 101 $y = -2.04 + 0.0104x$

□ -·- ILL 4401 $y = -0.95 + 0.0065x$

Source: a) N.P. Saxena (unpubl.); b) ICARDA (1987b)

For stored soil moisture environments, most gains in yield and yield stability are likely to come from tailoring crop duration to the limit of available soil water in a growing season, thus exploiting the drought escape trait. A significant negative correlation between days-to-flowering and yield in rainfed chickpea at ICRISAT (Saxena, 1987a) is indicative of this. This approach, however, would lead to the development of short-duration cultivars which may suffer a yield reduction in years when soil moisture conditions are above average (Saxena, 1987a). Selection for strongly indeterminate habit in early flowering backgrounds would permit plants to flower and set pods early but also to continue growing, flowering and podding if the season extends.

Evidence to date indicates that the association of shoot parameters in conserving transpirational loss of water and increasing yields is very limited. Siddique and Sedgley (1985) have shown that, in a water-limited Mediterranean-type environment in Australia, altering patterns of ontogenic canopy development in chickpea through surgical treatment can indeed lead to a higher water-use efficiency during the reproductive period, high harvest index and high yield. This is an isolated but important piece of information which needs extensive validation through searching the germplasm for such plant types and testing their usefulness under field conditions. Studies on leafless pea in controlled environments (Harvey, 1980) also showed that these types, which had 49-63% less leaf area, consistently used 33-38% less water compared with the conventional leafy types. Contrary to the finding on chickpea (Siddique and Sedgley, 1985) the leafless pea types produced correspondingly low yield. Water-use in the two types of pea also did not differ when water was non-limiting. The leafless types had a lower water-use efficiency when the water deficit was severe because of a reduction in pod number.

The two contrary reports on chickpea and pea suggest that there could be a subtle balance between conservation of transpirational loss of water and maintenance of critical leaf area for photosynthesis. When this balance is not achieved, the benefits of water conserved are negated by decreased assimilate availability. Theoretically, reducing leaf area is an important adaptive mechanism because it is the first strategy a crop adopts when water becomes limiting (Hussain et al., 1990). This is apparent in faba bean where drought stress causes reduced shoot height and leaf area expansion, the development of leaves with a smaller area (thicker leaves) and leaf shedding (Hussain et al., 1990). By contrast, the rapid development of leaf area in early growth stages may be beneficial in terminal drought situations. This appears to be the case in lentil where early growth vigour and ground cover correlated well with drought response index (Silim et al., 1992). Changes in foliage colour in lentil, from dark to light green, in turn, correlate well with early growth vigour (Acevedo and Ceccarelli, 1989; Silim et al., 1992).

Significant genotypic differences in the frequency and dimensions of stomata have been measured in faba bean (Tanzarella et al., 1984) but the physiological significance of these traits in reducing water loss while maintaining gas exchange can only be speculated about at present (Ludlow and Muchow, 1988). Another commonly attributed mechanism of resistance to drought stress is accumulation of abscisic acid (ABA) under stress, as has been reported for faba bean and pea (Katrina and Zeevart, 1986). However, for these legumes, there is no information on genotypic differences in ABA accumulation, or if indeed this relates to yield under drought conditions.

As available water is the key limiting factor in drought-prone environments, most gains are likely to come from maximum extraction of the limited amount of water in the soil to make it available for transpiration (Summerfield, 1981; Hebblethwaite, 1982). This can be achieved only through adaptation mechanisms associated with the root system. In common bean (*Phaseolus vulgaris*, L.), using a reciprocal grafting technique, White and Castillo (1989) demonstrated that root traits are more

important than shoot traits in determining drought response of bean varieties. Reid (1990) also evaluated the different adaptation mechanisms for faba bean suggested by Hussain et al. (1990) and concluded that proportionately increased partitioning of assimilates to roots and reduced leaf area index was the most important adaptive mechanism when faba bean was subjected to drought. Whether greater relative partitioning of assimilates into roots reduces yield in drought and/or non-limiting water environments is not known. This information is required to select genotypes of appropriate root/shoot ratios and to understand their effects on yield formation in drought environments.

The importance of root traits in adaptation to drought environments is well recognized. Surprisingly, very little work has been done on this aspect for these legumes, probably because of the difficulties associated with root studies in the field. Even after very careful attention, there are large errors in root measurements. Such errors reduce the value of root data in making useful genotypic comparisons. Although these errors can be reduced to a minimum in pot experiments, the extrapolation of results from pots to the field is very tenuous.

Genotypic differences in the length and spread of root systems are reported for all four crops, from both pot and field experiments: faba bean (Looker, 1978; ICARDA, 1984), chickpea (Subramania Iyer and Saxena, 1975; Sheldrake and Saxena, 1979; Minchin et al., 1980; Nagarajarao et al., 1980; Singh et al., 1980; Vincent and Gregory, 1986; Singh et al., 1988; Brown et al., 1989), pea (Bhardwaj et al., 1971) and lentil (ICARDA, 1985). In planning genetic strategies to overcome drought effects, genotypic differences in root growth patterns should be considered within a given maturity duration group. Short-duration cultivars of chickpea (Minchin et al., 1980) and pea (Bhardwaj et al., 1971) have faster early root growth rate but are not able to sustain it during grain filling. This induces root senescence in short-duration cultivars, and they may lose 64-80% of their effective root length in this way (Minchin et al., 1980). Heat and drought stress and synchrony of podding aggravate the loss of active roots which coincides with the onset of reproductive growth (Summerfield, 1980). This relatively poor development of roots, and their deterioration during podding in short-duration cultivars compared with longer-duration ones, makes the escape mechanism of short-duration cultivars vulnerable.

Vincent and Gregory (1986) identified genotypic differences in root length and the root length/leaf surface area ratio in early stages of growth in chickpea cultivars grown in nutrient culture solutions. A large ratio signifies that water availability to plants, in relation to leaf surface area, is greater in such genotypes. Whether such differences will persist, as crop growth advances in water- and nutrient-limiting conditions, needs further investigation. If the differences are maintained in stress conditions, then the technique would be very useful in evaluating genotypic differences in rooting characteristics which are difficult to study under field conditions. Observations at ICRISAT on chickpea show that genotypic differences in root size are established early in the season. Genotypic differences in roots observed in rainfed field conditions were maintained in studies using sand culture systems (N.P. Saxena et al., unpubl.). These observations in chickpea are contrary to those observed in faba bean (Hussain et al., 1990), where the growth of roots may respond differently, depending upon drought stress. At this stage it is difficult to recommend for all four crops whether observations on root traits should be made under drought or well-watered conditions.

A major gap in drought research on legumes is inadequate knowledge of the effects of drought stress on symbiotic nitrogen fixation. Pronounced effects of soil moisture availability on nodule mass and activity have been observed in chickpea (Rupela and Kumar Rao, 1987) and faba bean (Sprent, 1972). It is unlikely that the effects of drought derive from an inability of rhizobia to survive under

drought; they are more likely to be due to interferences with infection by rhizobia and nodule initiation and formation (Rupela and Kumar Rao, 1987). A greater emphasis on quantifying these effects and identifying genotypic variability for enhanced symbiosis under drought conditions is required.

Knowledge of genetic control

There is very little definitive information published on drought resistance traits applicable to cool-season food legumes and still less on their genetic control. Among all the traits, roots have received most attention. In his summary of data on roots in chickpea, faba bean, lentil and pea, Gregory (1988) concluded that the depth of rooting is a genetically determined trait with a marked influence of environmental factors on its expression. On the basis of his data, the depth of root penetration in the four crops seems to be in the following order: chickpea > faba bean > lentil > pea. Comparing these crops at sites that differed markedly in rainfall, Hamblin and Hamblin (1985) also concluded that both rooting depth and fineness of root branching are genetically controlled traits. Heritability of cultivar differences in root traits seems to be very low in chickpea (Singh et al., 1988), indicative of a strong influence of environmental factors on expression. In lentil, a much-branched and shallow root system is associated with small seeds and a profusely branched shoot, and a deeper root system with large seeds and sparsely branched shoots (Nezamuddin, 1970). This character association has been implied in genetic control of expression of root traits in lentil.

The small leaf size (fewer leaflets) trait in chickpea has a simple inheritance in that it is governed by a pair of recessive genes (R.P.S. Pundir, pers. comm.). The usefulness of this trait in drought resistance is currently being investigated using empirical field screening methods at ICRISAT (ICRISAT, 1990).

A better understanding of the genetic inheritance of the traits associated with drought resistance is necessary to determine the breeding methods best suited to enhancing drought resistance. A simple genetic control would allow the use of backcrossing methods to introgress the desired trait into well-adapted agronomic backgrounds and a complex or polygenic control, such as that which applies for yield and biomass, would require selection and advancement in artificially created, reproducible drought environments.

Breeding for improved adaptation to drought environments

Action on breeding for drought resistance depends on the ability to screen germplasm and segregating material. This becomes practicable with the availability of simple criteria for selection and the development of simple and reproducible field screening methods.

Improvement of plant stand establishment

Genotypic differences in plant stand establishment would be applicable across environments because of the reduced genotype x environment effects associated with this character. Simple screening methods to detect genotypic differences in germination and emergence from marginal levels of

seedbed moisture exist for both laboratory (Sharma, 1985; Saxena, 1987a) and field (Saxena, 1987a) conditions. Genotypic differences detected using these methods, although consistent, were very small and tended towards greater susceptibility (ICRISAT, 1981). It would be desirable to systematically screen a large number of germplasm accessions for this trait, particularly those originating from regions prone to surface soil drying at sowing time.

Plasticity of yield over a wide range of plant populations should also be useful in overcoming the yield-reducing effects of sub-optimal and non-uniform plant stands. Genotypic differences in plant plasticity for chickpea have been observed in experiments conducted to determine population response functions (ICRISAT, 1977; Saxena and Sheldrake, 1980), but the relative advantage of more plastic genotypes in drought environments has so far not been evaluated.

Enhancement of drought resistance

Without knowledge of specific drought resistance traits, a breeding programme to enhance drought resistance can be attempted if a reasonably reproducible drought environment is available. A receding soil moisture situation in a post-rainy season provides a comparatively consistent terminal drought environment over years. This may be further standardized by irrigating prior to sowing to charge the soil profile to a predetermined level if rainy season rainfall is below normal. An important consideration is to ensure that the environment chosen for drought resistance breeding purposes is a reasonable reflection of the target environment in terms of soil moisture availability patterns. This is because of the strong genotype x environment interactions with respect to available soil moisture, as discussed earlier (*see* Figure 1).

Shoot mass and seed yield are effective parameters in characterizing genotypic differences in drought resistance in chickpea and lentil using empirical field screening methods in a receding soil moisture environment (Saxena, 1987a; ICARDA, 1988a, 1998b, 1989). These parameters integrate the total effects of soil and atmospheric drought over space and time. Progeny of crosses involving drought-resistant parents, as identified above, can be grown in the chosen receding soil moisture environment through the early generations (for example, F_2 to F_3) and selections made on the basis of yield assessment alone, or together with other desirable features such as seed characters. However, for these legumes it is usually necessary for early generations to pass through disease or insect screening nurseries also, presumably under 'optimum' soil moisture conditions. This can be accommodated for one or two generations provided that selection pressure under the defined drought environment is maintained in the other generations. After rigorous selection of progeny under drought in earlier generations their seed may be bulked through subsequent generations (for example, F_4 to F_7) for testing the genetic gain in drought resistance in replicated experiments with and without irrigation. Such tests will also allow assessment of yield potential of drought-resistant selections under well-watered conditions. As previously discussed, it cannot be expected that the yield of drought-resistant selections with irrigation will be able to match the yield of genotypes specifically selected in optimum moisture environments. Thus it is necessary to decide upon an appropriate trade-off between yield potential and genetic gain in drought tolerance.

If specific traits can be associated with drought resistance (that is, yield under stress), then selection for these traits can supplement or, if the association is very strong, even replace the yield-based selection procedure. For example, at ICRISAT it has been found that greater root growth and branching

in seedlings is associated with drought resistance in chickpea (ICRISAT, 1989). Thus, a sand culture technique has been used in screening the progeny of crosses involving resistant parents. Other such techniques of screening early generations for root characteristics have been reported (Singh et al., 1980; Vincent and Gregory, 1986). The efficiency of this approach is being tested at ICRISAT now that sufficient seed of these selections has been bulked. The feasibility of using small leaf traits to select for drought resistance is also being examined. A more comprehensive method of integrating drought resistance traits with the selection of progeny in drought environments is described by Acevedo and Ceccarelli (1989) for barley and wheat. This method could feasibly be extended to cool-season food legumes.

Once the genetic gains in drought resistance have been established in a particular drought environment it then becomes necessary to test the extent to which these hold true in different drought environments. Thus, multilocational trials, preferably involving rainfed and optimally irrigated treatments, are required.

SALINITY TOLERANCE

Yield losses

Like drought, salinity can manifest itself in many forms and, before any attempt is made at selecting plants for 'salinity resistance' (as defined by Levitt, 1980), the nature of salinity in the target area must be determined. The most widely accepted definition of a saline soil, as proposed by the Soil Science Society of America, is one in which the electrical conductivity (EC) of the saturated soil extract (ECe) is greater than 2 dS/m (Bresler et al., 1982). The EC is directly proportional to the salt concentration in solution. Similarly, a sodic soil is defined as a soil in which the sodium adsorption ratio (SAR = $[Na^+]/(([Ca^{2+}] + [Mg^{2+}])/2)^{1/2}$) is greater than 15 (Bresler et al., 1982). The sodic condition is often associated with a high pH (> 9.0 in 1:2 soil/water suspension; Sharma and Gupta, 1986) because of precipitation of Ca as $CaCO_3$ at a high pH. Thus sodic and alkali soils are usually considered to be synonymous. The ions which are involved in determining a plant's response to saline conditions include Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_4^- and CO_3^{2-}, and these ions can occur in a wide range of combinations in saline and sodic soils. In addition, the toxic accumulation of any nutrient element, whether through excess fertilizer application or naturally occurring soil toxicities such as manganese, can have similar effects on plant growth as classical salinity, which is associated mainly with excessive concentrations of Na^+ and/or Cl^-.

About 323 million ha of the world's soils are considered saline or sodic (Brinkman, 1980). These soils occur mainly in arid and semi-arid regions, where evaporation considerably exceeds precipitation, leading to salt accumulation in the soil surface. Such soils are particularly common in West and Central Asia and in Australia. However, saline soils can also occur in coastal regions of humid areas because of the ingress of seawater. It is notable that the major chickpea and lentil growing areas of the world (FAO, 1988) are regions with a high frequency of saline or sodic soils (Brinkman, 1980).

It is difficult to determine the extent of production loss attributable to salinity for the crops under consideration, for several reasons:

- it is usually not possible to find situations where crops are growing in adjacent salt-affected and non-saline areas so as to be able to estimate yield reduction due to salinity *per se* (c.f. the use of presence and absence of irrigation treatments to estimate losses due to drought)

- soil salinity varies markedly, both spatially and temporally, from the microsite to the regional level (Epstein and Rains, 1987)

- as cool-season legumes are relatively salt-sensitive plants, farmers usually do not consider growing them in salt-prone soils or stop growing them as salinity advances (as in north-western India and Pakistan's Punjab Province)

A preliminary indication of salinity damage to legume crops is the appearance of characteristic symptoms due to excess ion accumulation. Necrosis of the outer margins and yellowing of the older leaves are the first signs of salinity damage. As salinity intensifies, these symptoms progress to younger leaves and older leaves die and abscise. In desi chickpea, salinity intensifies anthocyanin pigmentation in leaves and stems but in kabuli chickpea these tissues become yellow. However, it is easy to confuse salinity symptoms in chickpea with symptoms of other nutrient disorders (Smith and Pieters, 1983) or even of disease (for example, chickpea stunt) and drought stress.

To quantify the effects of salinity on plant growth it is necessary to establish critical values, relating salt concentrations in either the rooting medium or plant tissue to reductions in growth or yield. Some examples of critical values determined for the four legumes are given in Table 2 (*overleaf*). It should be noted that these values are very experiment-specific because salinity response, and hence critical value, is much influenced by other growth factors such as soil water status (Saxena, 1987b), relative humidity (Salim, 1989), temperature (Ayoub, 1974) and nutrition (Kamel, 1986). Furthermore, there are several alternative methods of calculating critical values, including those described by Johansen et al. (1990) and Bresler et al. (1982).

In developing salinity screening techniques, it is necessary to establish which plant growth stage is most sensitive to salinity. As for most legumes, germination of chickpea is relatively less affected by salinity than subsequent seedling growth (Goel and Varshney, 1987; Yadav et al., 1989). Kumar (1985) indicated that later stages of chickpea growth were more sensitive than earlier stages and Siddiqui and Kumar (1985) reported that salinity effects increased over time. However, Maas and Poss (1989) pointed out that, in such studies, apparent sensitivity at later stages may be a result of salt accumulation over a longer period. For experiments in which salinity treatments were imposed at different growth stages, they showed that cowpea was most sensitive at the early (vegetative) growth stage. In a study with pea, Lal (1985) also found that earlier growth stages were more sensitive to salinity.

In establishing appropriate salinity screening techniques it is also necessary to understand which plant processes are most sensitive to salinity. For legumes, the first consideration is the symbiotic nitrogen-fixing process. Free-living rhizobia have a much higher salt tolerance than their host plants (Lauter et al., 1981; Sprent, 1984) and thus there is little point in screening free-living rhizobia for salt tolerance and expecting this to result in improved nitrogen fixation by symbiotic plants under saline conditions. There is, however, evidence that the symbiotic process itself is more sensitive to salinity than growth of the host plant *per se*. This is the case in pea (Siddiqui et al., 1985). Lauter et al. (1981) and Yousef and Sprent (1983) reported that chickpea and faba bean supplied with mineral nitrogen were more salt tolerant than symbiotically dependent plants. By contrast, Rabie et al. (1986) did not find that nitrogen fertilization alleviated salinity effects in faba bean. However, Sprent and Zahran (1988) pointed out that plant growth rate, and hence plant demand for nitrogen, could alter the relative sensitivity of the symbiosis to salinity; it would be more sensitive under environmental conditions permitting rapid plant growth. The greater salt sensitivity generally found

Table 2   Examples of critical values in the rooting medium for salinity damage in chickpea, faba bean, lentil and pea

Salinity parameter[a]	Critical value[b]	Plant measurement	Culture medium	Reference
Chickpea				
ESP	18-23%	Seed yield	Field	Kumar (1985)
ESP	19%	Seed yield	Field	Singh and Abrol (1987)
ECe	4.5 dS/m	Vegetative growth	Potted soil	Dravid and Goswami (1987)
ECe	7 dS/m	Vegetative growth	Potted soil	Yadav et al. (1989)
ECe-Cl	3-4 dS/m	Seed yield	Potted soil	Manchanda and
- SO₄	>7 dS/m			Sharma (1989)
ECe	2.0-3.5 dS/m	Vegetative growth	Potted soil	Johansen et al. (1990)
Faba bean				
ECe	6 dS/m	Seed yield	Soil in drums	Ayers and Eberhard (1960)
ECe	9 dS/m	Seed and dry-matter yield	Field	El Karouri (1979)
ECe	>15 dS/m	Seed and dry-matter yield	Potted soil	Abdel-Ghaffar et al. (1982)
ECe	11 dS/m	Seed yield	Field	Lockerman et al. (1983)
% (NaCl + CaCl₂) of dry soil	0.45%	Seed yield	Potted soil	Rabie et al. (1986)
Lentil				
ECe	4 dS/m	Seed yield		Ayoub (1977)
NaCl	0.5-1.1%	Vegetative growth	Sand culture	Rai (1983)
Pea				
ECe	9 dS/m	Vegetative growth	Sand culture at pH 7	Kumar and Garg (1981)
ECe	6-10 dS/m	Pod yield	Lysimeters in greenhouse	Cerda et al. (1982)
ESP	15%[3]	Seed yield	Field	Singh and Abrol (1983)
ECe	8 dS/m	Seed yield	Field	Lal (1985)
NaHCO₃	30 me/l	Dry-matter yield	Sand culture	Garg and Garg (1986)

Note: a   ESP = exchangeable sodium percent (as a percentage of total exchangeable cations).
b   Critical value defined as that causing a reduction in yield of about 50%.

in symbiotic plants would suggest that symbiotic plants, rather than nitrogen-fed ones, should be screened for salinity tolerance. However, symbioses of different *Rhizobium* strains with a particular host plant result in differences in salinity response (Lauter et al., 1981). In lentil grown in saline soil, there were large interactions between the *Rhizobium* strain inoculated and the lentil genotype, interactions which differed from those in normal soil (Rai, 1983; Rai et al., 1985). Thus, as Lauter et al. (1981) suggested, it may be necessary to screen for salinity response with both nitrogen-fed and symbiotic plants. Kumar and Garg (1981) showed that increasing salinity and alkalinity positively interact in depressing nitrogen fixation in pea, mainly by inhibiting the infection process.

The above discussion indicates that salinity can be a major constraint to these legumes. However, before resources are invested in the genetic improvement of their salinity resistance, several points need to be considered. Because of their relative sensitivity to salinity compared to other crop plants (Maas and Hoffman, 1977; Lauchli, 1984), they would rank low in crop choice for salt-prone areas. Rather than increasing the salinity tolerance of these legumes to levels comparable to salt-tolerant crops, such as barley, a more practical approach would be to attempt a reclamation programme that would eventually convert the salt-affected land to a state that would permit cultivation of salt-sensitive crops such as these legumes. Procedures for doing this, including a crop sequence from salt-tolerant species initially to salt-sensitive ones eventually, have been proven and documented (Meiri and Plaut, 1985; Sharma and Gupta, 1986).

For crops which are grown predominantly on residual soil moisture in a post-rainy season, such as lentil and chickpea, the salinity barrier to be overcome is particularly large. This is because of the concentration of salts in the soil surface as a result of evaporation of soil moisture under these conditions. For crops grown in a rainy season or with irrigation, salt concentrations near the soil surface would be diluted by leaching. Thus the level of improvement in salinity resistance needed to make a difference for lentil and chickpea is considerable as these crops are particularly salt sensitive even when compared to other legumes.

Thus, for the cool-season food legumes, the genetic enhancement of salinity resistance should be considered only as a supplement to management attempts to reclaim saline areas. For example, it would be desirable to be able to use these and other legumes earlier in the cropping sequence during a reclamation process. The level of resistance that we would be seeking to justify the genetic improvement of salinity resistance in these legumes would be an ability to produce more that 75% of maximum growth and yield at an ECe, or EC in solution culture, of greater than 10 dS/m.

Genetic differences in response to salinity

Among crop species, legumes are considered a relatively salt-sensitive group (Maas and Hoffman, 1977); within the legumes, chickpea, faba bean and pea are particularly salt sensitive (Maas and Hoffman, 1977; Lauchli, 1984). The data in Table 2 and those provided by Lockerman et al. (1983) indicate that faba bean may have greater salinity tolerance than the other cool-season food legumes. However, as Maas and Hoffman (1977) pointed out, species comparisons of salinity response between experiments are hazardous because this response is subtly affected by a range of environmental conditions which differ across experiments. It is therefore desirable to draw conclusions about species differences only when they are included in the same experiment. But even this is not foolproof because different species are likely to have different optima for the various environmental factors.

A prerequisite to genetic improvement of salinity resistance is the existence of genotypic variability, with at least some genotypes having critical values approaching the desired values. Genotypic variability has been demonstrated in chickpea but it occurs over a very narrow range of salinity levels (Lauter and Munns, 1986; Johansen et al., 1990). There were differences among four Iranian chickpea genotypes in their germination response to NaCl but these differences were relatively small (50% reduction at 0.5-0.7% NaCl) (Kheradnam and Ghorashy, 1973). In potted soil, critical ECe values, as assessed from ECe at half-maximal growth, only ever differed by 2 dS/m, whereas mean critical ECe values between different pot experiments under apparently similar growth conditions

differed by more than this (effects of environment considerably exceeding those of genotype) (Johansen et al., 1990). There was greater genotypic variability in the salinity response of wild species related to chickpea but this was because some species were much more salt sensitive than cultivated chickpea (Johansen et al., 1990). In field plots differing in exchangeable Na percentage (15-30%) but at a constant ECe (2.0-2.4 dS/m), Kumar (1985) found some genotypic differences in the response of nine chickpea genotypes but, again, critical values as estimated by half-maximal grain yield occurred over a narrow range of exchangeable Na percentages (18-23%).

For lentil grown in sand culture, Rai (1983) found that half-maximal yield of genotype L-9-12 was at 0.5% NaCl and that of Pant 639 at 1.1% NaCl. Genotypic differences in the salinity response of faba bean have also been reported (Salih, 1983; Knobel, 1987). Poljakoff-Mayber et al. (1981) found variation in salinity response, in terms of root extension rate, among three pea cultivars as well as in *P. elatius* and *P. fulvum*. Cerda et al. (1982) found useful variation in the salt tolerance of pea cultivars in that a half-maximal yield of SP-290 was obtained at 6 dS/m and of Durana at 10 dS/m.

Mechanisms of salinity resistance

An understanding of how a particular plant species reacts to toxic salt concentrations and the mechanisms at its disposal for alleviating toxic effects is fundamental to designing appropriate screening techniques (Johansen, 1987). All the possible different manifestations of salinity, including osmotic and specific ion effects, make this even more important. Among legumes studied, the ability to exclude Na and Cl from shoots distinguishes more resistant ones from sensitive genotypes (Lauchli, 1984; Keatinge and Fisher, 1985). Among 160 chickpea genotypes screened for salinity resistance in solution culture, the most resistant genotype, L 550, accumulated the least Na in shoots at yield-reducing salt levels (Lauter and Munns, 1986). This suggests that shoot Na concentration would be a good indicator of salinity resistance in chickpea.

It is important to consider the composition of the medium used for salinity resistance screening because the different ions involved have different uptake and translocation characteristics. For example, Cl uptake by plant roots usually greatly exceeds that of SO_4^{2-} and thus salt damage is greater when Cl rather than SO_4^{2-} is the dominant anion in isosmotic solutions. This applies in chickpea (Lauter and Munns, 1986; Manchanda and Sharma, 1989) and pea (Hasson-Porath et al., 1972). By contrast, Sheoran and Garg (1983) showed that Na_2SO_4 most adversely affected germination and early seedling growth of chickpea, compared with KCl, K_2SO_4 and NaCl. They attributed this to greater osmotic effects of Na_2SO_4 and the accumulation of Na. Kumar and Promila (1983) found that Cl and SO_4^{2-} salinity had different effects on different stages and processes of nitrogen fixation in chickpea. Nodule number increased but nodule weight decreased with Cl compared with SO_4^{2-} salinity.

There is much evidence to show that the regulation of salt accumulation by plants, and thus their reaction to salinity, can be controlled at different levels of cellular organization (Gorham et al., 1985; Cheeseman, 1988; Wyn Jones and Gorham, 1989). These include compartmentation in vacuoles and other organelles of root cells, control of translocation from root to shoot and compartmentation in and retranslocation from leaf cells.

The concentration of Ca in the medium considerably influences salinity response because of its effects on Na absorption *per se*, K/Na selectivity and membrane integrity (Lauchli, 1984; Cramer et al., 1985). Thus Ca levels in the screening medium need to be carefully set and maintained.

Knowledge of genetic control

Although genotypic differences in salinity resistance in the cool-season food legumes have been established, we could find no reports of studies on the genetics governing these differences. Such knowledge would be useful in designing appropriate breeding strategies and may also help in understanding the stability of genotypic performance (Tal, 1985). Abel (1963) found that Cl⁻ exclusion from shoots of soybean, a character which distinguished salt-resistant genotypes from susceptible ones, was controlled by a single gene pair with exclusion being dominant. This is rather a surprising finding when the various mechanisms, levels of organization, interactions and feedback systems are considered; most reviewers of the subject consider salinity resistance to be under polygenic control (Shannon, 1985; Tal, 1985; Epstein and Rains, 1987; Cheeseman, 1988; Wyn Jones and Gorham,1989). It would be interesting to determine whether the apparent simple genetic control of salinity tolerance held true under growth conditions other than those used by Abel (1963). Without definitive knowledge, it would be safe to assume that salinity tolerance in the cool-season food legumes is under polygenic control and therefore breeding procedures such as those used for increasing 'yield' would also be required for improving 'salinity resistance'.

However, it would seem a difficult task to combine high yield and salinity resistance, as stress resistance usually imposes a metabolic cost on the plant (Gale and Zeroni, 1985). Characters useful for salinity resistance are not conducive to high yield potential. Salt-resistant plants are more likely to be survivors than producers (Tal, 1985). They are likely to have higher rates of maintenance respiration to allow them to cope with the higher active ion transport duties required under saline conditions (Gale and Zeroni, 1985). Thus, in breeding for salt resistance it is necessary to acknowledge a yield penalty.

Before embarking upon a programme of genetic improvement, there are several criteria that should be addressed:

- the degree of improvement needed to make worthwhile yield improvements at farm level

- the extent of genotypic variability for salinity response currently existing in the crop species and the prospects of finding sources of increased resistance

- the practicality and repeatability of a technique to screen progeny for salinity resistance

Identifying sources of resistance

As explained earlier, for the cool-season legumes in general a large increase in the level of salinity resistance is required for any practical improvement but, to date, only limited variability for salinity response has been detected. Possible exceptions to this are the apparent higher levels of resistance in faba bean (*see* Table 2) and the pea cultivar Durana (Cerda et al., 1982). Thus the prime requirement for the genetic improvement of salinity resistance at this stage is to identify substantial sources of salinity resistance.

Field methods for such screening are not recommended because of the difficulty of separating environmental from genetic variation. More sophisticated field methods, such as growing rows of chickpea genotypes across natural salinity gradients and regressing chickpea growth and yield against

soil ECe in each sector (Saxena, 1987b), have proved of little practical value because of the large numbers of plant and soil measurements required. Screening therefore requires the creation of a growth environment as uniform and repeatable as possible; it is thus necessary to use solution or sand culture techniques in a glasshouse. Suitable screening techniques have been described, for example, by Sykes (1985).

In controlled screening it is important to:

• Ensure that the composition of the unsalinized nutrient solution and aerial environment are as optimum as can be achieved. These conditions should be regularly monitored and maintained throughout the experiment.   .

• Choose a test salt additive that best represents the salt composition of soil solutions of the target environment. This would rarely be NaCl alone; commonly, a mixture of salts is used (for example, Yadav et al., 1989).

• Test several levels of salinization (including the non-salinized control, comprising the optimum nutrient solution) so as to be able to measure differences in response curves, as their shapes are likely to differ between genotypes (Johansen et al., 1990).

• In using sand or soil culture, test symbiotic plants, ensuring maximum nodulation by supra-optimal inoculation of seeds. Nevertheless, it is desirable to compare the salinity response of some contrasting genotypes under nitrogen-fed conditions and with different strains of *Rhizobium* to check the universality of the genotypic differences. The uniform establishment of nodulated plants in solution culture is difficult and in this medium screening under nitrogen-fed conditions would be necessary. However, genotypic differences obtained in one system need to be confirmed in alternative systems.

Salt-tolerant callus tissues have been selected for chickpea (Gosal and Bajaj, 1984; Pandey and Ganapathy, 1984) and pea (Gosal and Bajaj, 1984) but it is yet to be demonstrated that whole plants regenerated from such tissue have significantly superior performance. It is difficult to conceive how improved tolerance at the cellular level will translate to the whole plant level considering the whole plant control and feedback mechanisms which govern salt transport in the plant. Sexual transmission of *in vitro* selected salt resistance is not always observed, although apparently stable both in culture and in regenerated plants in the absence of selection pressure (Dix et al., 1986). Nevertheless, success in selection at the cellular level in translating into improved salt resistance has been claimed for tobacco (Nabors et al., 1980). Flowers et al. (1985) also produced evidence that the basis of differences between a salt-resistant and salt-sensitive rice variety was at the cellular level. They showed that, at similar levels of salt in leaf tissue, there was greater disorganization of cellular structure and decreased net photosynthesis in the sensitive cultivar.

SUMMARY

In chickpea, faba bean, lentil and pea, the scope for the genetic enhancement of drought resistance s to be relatively greater than for salinity resistance. There has been some success in identifying

useful variability for drought resistance using empirical yield-based screening methods in chickpea and lentil in the semi-arid tropics and in the Mediterranean areas of the WANA region. If this thrust is maintained, more sources of drought resistance are likely to be identified for other drought environments in these two major areas. The same approach could also perhaps be extended to faba bean and pea.

Studies on the physiological basis of adaptation to drought in chickpea have received greater attention recently, and several simple, putatively important morphological traits have been identified. Such traits will enhance selection for drought resistance in segregating populations of crosses involving drought-resistant parents. However, causal relationships between these traits and yield advantage under drought or rainfed conditions need to be better demonstrated. Studies on the genetics of inheritance of the useful traits should proceed concurrently for developing breeding programmes for drought resistance on a more sound basis. Emphasis should also be given to refining current screening methods and developing more simple, rapid and reproducible methods.

In all four legumes, the major hindrance in initiating a breeding programme on the genetic enhancement of salinity resistance is the lack of the required variability in germplasm with desired levels of resistance. If it is indeed considered feasible to cultivate any of these relatively salt-sensitive legumes in defined saline soils, rather than approach the salinity problem through agronomic management or crop-type selection strategies, a priority would be systematic germplasm screening to identify useful levels of tolerance. Testing accessions of the cultivated types or wild relatives that have evolved in saline habitats is suggested as a more fruitful approach than some of the cell biological techniques currently in vogue. Further work is needed on adapting salinity screening methods specifically for these legumes, particularly to account for effects of salinity on symbiotic nitrogen fixation. A better understanding of the mechanisms of salinity resistance available to these legumes would assist in this respect. Thus a programme on the genetic enhancement of salinity resistance in these legumes must be conceived on a long-term basis, with greater emphasis being placed on basic research.

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