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Realized Yield Potential in Chickpea and Physiological Considerations for further Genetic Improvement

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Summary

The maximum harvested yields of chickpea have remained virtually static in India at least over the last two decades. Source-sink interrelationships at the current level of productivity indicate that any reduction in source size or activity during flowering may lead to yield reductions. These reductions, however, do not seem proportional to the degree of defoliation. The failure of flowers to set pods at low night temperatures and at high soil moisture is considered a waste of sink capacity, limiting expression of yield potentia' by inducing excessive vegetative growth. It is speculated whether this loss in sink potential could be an adaptive mechanism which stimulates vegetative growth and thus provides additional nodes/sites for subtending more flowers and pods, thereby ultimately increasing yield. Increasing the harvest index and grain yield seems feasible for chickpea in the winter environment of northern India through incorporation of tolerance to low temperature This would allow pod set to begin in the cooler months of December and January, as compared to mid-February which is now the case for conventional cultivars. In warmer chickpea growing environments, such as peninsular India, high yields under non-limiting conditions of water, nutrients and biotic stresses are accompanied by high harvest indices. Further yield improvements seem possible only by increasing biomass through selection for higher crop growth rates and greater tolerance to high temperatures both at the beginning and the end of the growing season.

Introduction

Chickpea (*Cicer arietinum* L) is a pulse crop of foremost importance in the Indian subcontinent (Saxena, N. P., 1984) but it is also cultivated in at least 32 other countries (Jodha & Subba Rao, 1987). It is one of the five mandate crops of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), which is headquartered in India. Work on Desi types is coordinated from here. Work on Kabuli types of chickpea, which are important in the Mediterranean region and parts of America, is carried out and coordinated by the International Centre for Agricultural Research in the Dry Areas (ICARDA), which is headquartered in Syria, in collaboration with ICRISAT.

Average yields of chickpea in the major growing regions are only around 0.5-0 7 t/ha (Jodha & Subba Rao, 1987). When the various biotic and abiotic stress factors are minimized yields in the range of 3-4 t/ha can be recorded (Jain, 1975; Laxman Singh, 1980; Pandya & Pandey, 1980; Saxena, N. P., 1984; Saxena, M. C., 1984). Exceptionally high yields of 5.0 t/ha (quoted by Lal & Tomer, 1980) and 5.9 t/ha (Khanna-Chopra & Sinha, 1987) have been reported from Iran and Lattakia (Syria), respectively, but these cases are rare.

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When biotic and abiotic stress factors are minimized yield in a given agroclimatic condition is essentially a function of the ability to produce dry matter and partition it efficiently into seed. In this paper we have examined some aspects of dry matter production and partitioning for chickpea in two contrasting environments in India, Hisar and Patancheru (Saxena, N. P., 1984) and the possibilities for exceeding the current ceiling yield levels.

Materials and Methods

All of the experiments referred to in this paper were conducted either on Vertisol fields at ICRISAT Center, Patancheru (18° N, 78° E, altitude 542 m), Andhra Pradesh, in peninsular India, or on Entisols at the Haryana Agricultural University (HAU)-ICRISAT Cooperative Center, Hisar (29° N, 76° E, altitude 221 m), Haryana. Crops were grown at the normal densities of 30 x 10 cm, generally on flat beds (unless specified), and sown during the latter half of October at Patancheru and during late October to early November at Hisar. Fields were kept fallow in the preceding rainy season at both sites. A pre-sowing irrigation at Hisar and a post-sowing irrigation at Patancheru was always applied to saturate the soil profile so as to ensure uniform crop establishment. The mean climatic conditions at the sites of these experiments are described by N. P. Saxena (1984).

Shoot Mass, Yield and Harvest Index

Patancheru—Three cultivars, Annigeri, K 850 and CPS 1, were each sown in three blocks of 25 x 9 m (225 m^2) to determine the maximum realizable yield of chickpea with irrigation. A basal dressing of 10 t/ha farm yard manure (FYM), 40 kg/ha N, 31 kg/ha P, and 50 kg/ha $ZnSO_4$ was applied. Sowing was done on 23 October, 1 -30. Seeds were treated with fungicide (0. 25% Benlate-T) and inoculated after sowing with the *Rhizobium* strain ICC 2002 by the soil drench method. In addition to the post-sowing irrigation, three irrigations of about 5 cm depth were applied at 27, 47 and 68 days after sowing. A plant sample was taken for growth analysis at 64 days after sowing from an area of 1.5 m^2 in each block. Harvesting was done during 12-17 February in subplots of 6 x 4.8 m (28.8 m^2), there were 19 subplots for each cultivar.

Hisar—This experiment was conducted using 16 genotypes grown in a randomized block design (RBD) with 4 replications. Plot size was 4 x 4 m and the harvested area was 4 x 1.2 m (4 rows). Single superphosphate (SSP) at 9 kg/ha P was applied as a basal dressing. The experiment was sown on 11 November 1986. An irrigation, additional to the presowing irrigation, was applied on 4 December, 1986. The crop was harvested on 29 April, 1987.

Effects of Partial Reductions in Source Size Through Defoliation

Patancheru—This experiment was laid out in a split plot design in three blocks with cultivars Annigeri and K 850 in the main plot and five defoliation treatments (expressed as percent leaf removal) in the subplots. The defoliation treatments were: control (no defoliation), 33% (first of three consecutive leaves), 50% (one of two), 67% (two of three) and 100% defoliation. The defoliation treatments were commenced at flowering and were maintained until maturity. A basal dressing of 22 kg/ha P (as SSP) and 25 kg/ha Aldrin (5%) was applied. Subplots comprised four rows 3.0 m long, but only the center rows were sampled. Sowing was done on ridges 75 cm apart, for convenience of effecting defoliation treatments from outside the border rows and also for irrigation. K 850 was sown on 15 October and Annigeri on 9 November, 1976. In addition to the post-sowing irrigation, further irrigations were given on 15 December, 1976, and 4 and 21 January, 1977. K 850 flowered on 12 December and Annigeri on 20 December and these cultivars were harvested on 14 and 17 March, 1977, respectively.

Hisar—This experiment was similar to the trial done at Patancheru but Annigeri was replaced with G 130 and one more defoliation treatment (25% defoliation, first of four consecutive leaves removed) was included A basal dressing of 17 5 kg/ha P (as SSP) and 40 kg/ha Aldrin (5%) was applied Sowing was done using a hand plough A heavy presowing irrigation was given on 5 October, 1977 and the experiment was sown on 29 October Subplots comprised six rows (including two border rows) each 5 m long K 850 flowered on 20 January and G 130 on 2 February, 1978 In both cultivars, pod set began on 3 March and maturity occurred around 18 April, 1978

Effects of Lowering Incident Solar Radiation by Shading

Shades made from white mosquito netting, thin cheese cloth and thick cloth, that obstructed different amounts of incident solar radiation, were used These were supported horizontally at 30-50 cm above the crop canopy The photosynthetically active radiation (PAR) transmitted through the shades was measured at noon using a Lambda quantum sensor, held 30-50 cm below the shades The amount of radiation transmitted, expressed as a percentage of PAR in full sunlight, was as follows. mosquito netting 77% transmission (this treatment at Hisar only), thin cloth 45% transmission, thick cloth 16% transmission

The design of the shade was such that there was a free circulation of air between the shade and the crop canopies Maximum air temperatures under the shades were 1-2° C lower than those outside, but the minimum temperatures were marginally higher or similar.

The trials were conducted in a split plot design at both the locations. Cultivars were in main plots and shading treatments in subplots.

Patancheru—Annigeri and K 850 were the cultivars used with the four shading treatments (including a non-shaded control). There were three replications and subplot size was 3.5 x 1 5 m Sowing was done in two rows on ridges 75 cm apart Dates of sowing, irrigations applied and flowering were the same as in the defoliation experiment at this site mentioned above Shading treatments were commenced at 50% flowering and continued until harvest, on 19 March, 1977

Hisar—Four cultivars (P 173, K 850, G 130 and L 550) were used in 1976/77 and two cultivars (K 850 and G 130) in 1977/78 Subplot sizes were 4 5 x 3.5 m in 1976/77 and 5 4 x 3 0 m in 1977/78 There were three replications Sowings were done on 30 October, 1976 and 29 October, 1977 Shading treatments in 1976/77 commenced on 5 February, 1977, at 50% flowering, and pod set commenced in the first week o. March In 1977/78, shading treatments were imposed on 26 March, when temperatures began to rise and after pod set had commenced (around 3 March) Shading treatments were continued until harvest, which was around 20 April in both the years

Sink Size at Successively More Apical Nodes

The details of these experiments and methodology followed have been described by Sheldrake & Saxena (1979) Experiments were conducted both at Patancheru and Hisar At the time of harvest (February-March, 1975), the main stems and primary, secondary and tertiary branches were separated from 20 plants per cultivar and the number of branches in each category recorded From each class of branch, the pods at the most basal pod-bearing node (node 1) were pooled, as were the pods from the second and succeeding nodes The oven-dry weight of the pods and the number and weight of seeds they contained were recorded Some pods contained no seeds and hence in some cases the average number of seeds per pod was less then one.

Flowering and Pod Set at Low Night Temperatures at Hisar

Details of the experiment on "the effect of low temperature on the failure of flowers to turn into pods at low night temperatures in conventional cultivars at Hisar" have been described (Saxena, 1980). Fifteen cultivars were grown in non-replicated plots of size 7.0 x 2 5 m. Sowing was done on 1 November, 1978. The first perfect flowers were tagged and the dates of flower initiation and pod set were noted for successive nodes

Another experiment on the effect of early pod set on shoot mass, yield and harvest index was conducted at Hisar with 120 genotypes. These genotypes were single plant selections made from the segregating F_3 population, provided by the ICRISAT chickpea breeders, from six crosses. Each cross had a low temperature tolerant breeders' experimental line as one of its parents. Single plant selections were made on the basis of flowering and pod set at low night temperatures in 1985/86. These were grown as nonreplicated single plant progenies in 1986/87 at a spacing of 60 x 30 cm. Progenies were divided into 12 groups based on the time of first pod set, between 50 and 110 days after sowing Those flowering and podding later than 110 days, the time of pod set in conventional cultivars adapted to the region, were discarded The mean of the top ten entries in each flowering group has been presented.

Results

Source Size

The maximum leaf area index recorded at Patancheru was 2 4-3 2 and at Hisar 6.6-7.0 (Table 1). The maximum ground cover by the crop was such that it intercepted >80% light at ICRISAT Center and >95% at Hisar. At such dense crop canopies, the lower leaves on the plants senesced but were retained on the plant during active podfill The active green canopy however, moved upwards with the increase in height of the crop.

Partial defoliations to alter the source size resulted in a decrease in seed yield both at Patancheru and Hisar (Fig 1) but the decrease in yield was not in proportion

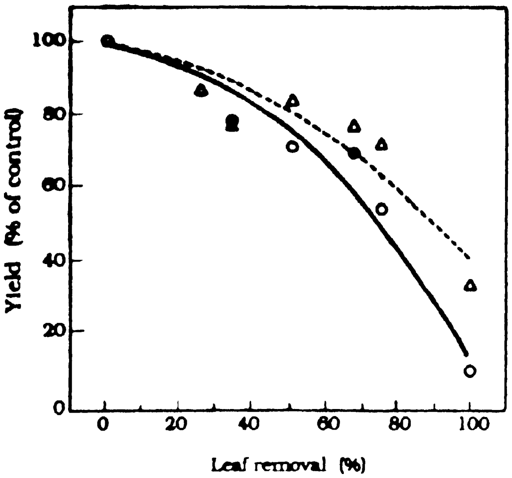

Fig.1 Effect of defoliation on yield (% of control) of chickpea cultivars Annigeri and K 850 on a Vertisol (O) at ICRISAT Center (Y = 100 0 16 x - 0 068 x^2, R^2 = 0 93) and cultivars G 130 and K 850 on an Entisol (Δ) at Hisar (Y = 100-0 098 x - 0 006 x^2, R^2 = 0 82) 1976/77

to the degree of defoliation. For example, 33 and 75% defoliations resulted in a mean decrease in yield of 22 and 46%, respectively, at Patancheru, and 23 and 28%, respectively, at Hisar

Effects of Light Intensity

Reduction in light intensity below full sunlight at Hisar at the time when flowering commenced but before pod set, caused large reductions in yield in 1976/77 (Table 2) However, such shading treatments imposed when podset had commenced had no significant effect on yield of Annigeri at 45% of incident solar radiation, when unshaded yield was around 3.0 t/ha at Patancheru (Table 2) and at Hisar (Table 2, 1977/78).

Sink Size on Successive Apical Nodes — The weight of the pods formed earlier on the more basal (proximal) nodes of the main stem was higher and declined progressively at the later-formed more apical (distal) nodes both at Patancheru and Hisar (Fig. 2). This pattern was repeated on the primary and secondary branches.

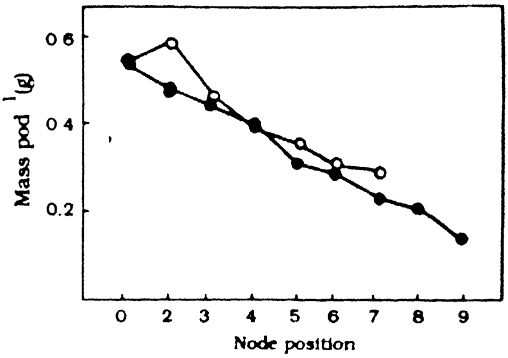

Fig. 2 Mean pod weight of chickpea cultivar K 850 at successive pod bearing nodes on main stems at ICRISAT Center, 1974/75 (O) and first primary branch at Hisar, 1976/77 (●).

Shoot Mass, Seed Yield and Harvest Index — The maximum shoot mass recorded at Patancheru did not exceed 6 2 t/ha and about half of it was partitioned into seed yield (Table 1). It was accumulated over a period of 105-120 days at a mean (for the three cultivars used) crop growth rate (CGR) of 52 kg/ha/day. Seed yield accumulated at a rate of 29 kg/ha/day

On the other hand at Hisar, nearly 10 t/ha of shoot was produced by some of the cultivars, with a mean of 8 3 t/ha (Table 1) Only one third of this biomass was partitioned into grain yield, with the exception of cultivars K 850 and S 26 which partitioned more. This resulted in a mean CGR of 56 kg/ha/day and seed yield increase of 18 kg/ha/day.

Table 1 Performance of chickpea cultivars grown under optimum conditions in India on a Vertisol, Patancheru 1980/81, and Entisol, Hisar 1986/87

Attribute	Patancheru[1]	SE (±)	Hisar[2] Mean	SE(±)	Maximum
Yield (t/ha)	3 18	0 118	2 68	0 338	3 35
Shoot mass (t/ha)	6 20	0 061	8.29	0 797	9 91
Harvest index(%)	51 7	1 57	33	5 4	42
Days to 50% flowering	43	-	87	1 1	102
Days to maturity	109	-	147	0 8	162
Leaf area index	2.4	-	-	-	7 0[3]
Light intercepted (%)	82	-	-		
CGR (kg/ha/day)	57		56	5 6	69
Yield accumulation (kg/ha/day)	29	-	18	2 3	25

[1] Annigeri only.
[2] Maximum and mean of 16 cultivars.
[3] 6.6-7.0 for only three cultivars determined.

Table 2. Effects of shading, using horizontal cloth shades varying in thickness, on chickpea yield (t/ha) at Patancheru (1976/77) and Hisar (1976/77 and 1977/78)

PAR reduction (%)	Patancheru Annigeri	K 850	Mean	Hisar 1976/77	1977/78
0	2.97	1.99	2.48	3.55	1.99
33	-	-	-	2.72	1.96
55	2.86	2.35	2.60	2.40	1.93
84	1.18	0.80	0.99	0.96	1.11
SE ±		0.144	0 101	0.066	0 082

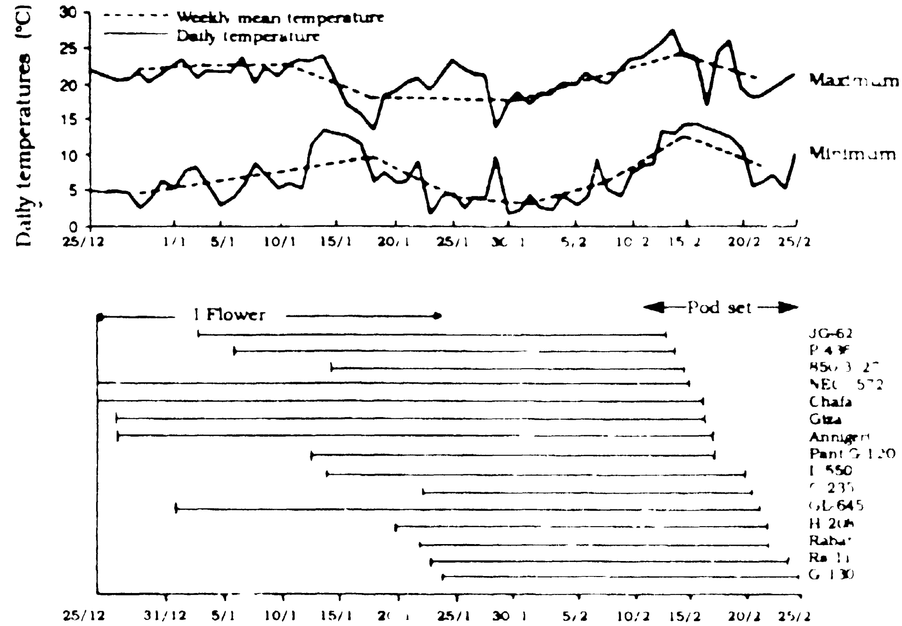

Fig 3 Date of first flower and pod set in 15 cultivars of chickpea and the daily and weekly mean temperatures during the period, Hisar 1978/79 (Source Saxena, 19..

Failure to Set Pods at Low Temperature and Excessive Soil Moisture. — At Hisar, flowers produced during the cooler months of December and January did not develop into pods in any of the cultivars studied (Fig 3) Pod set began when minimum night temperatures were greater than 8° C, usually by the second week of February Genotypes differed in their ability to commence pod set with the rise in night temperature during February.

At Patancheru, many flowers produced in irrigated plots failed to develop into pods, whereas most do in unirrigated treatments Instead, irrigation stimulates the development of branches on which more flowers can be borne. The commencement of pod set is thus delayed in irrigated treatments.

Effect of Early Podset on Shoot Mass, Yield and Harvest Index at Hisar — Cold tolerant lines that flowered at about 40 days after sowing were able to set pods at 50-52 days after sowing (Fig 4) Minimum temperatures during this period were 0-2° C (Fig 4) Genotypes that commenced pod set between 60-70 days produced relatively larger shoot mass and yield, compared to those that initiated pod set later in the season (Fig 4) There appeared to be two peaks in the accumulation of shoot mass yield and partitioning of dry matter into seed (i e , harvest index in relation to time of pod set)

Discussion

Yield in chickpea seems to be limited largely by the supply of photoassimilates to the later formed pods at the more apical (distal) nodes (Fig 2) Reductions in all components of yield (e g seeds per pod, 100-seed weight) in chickpea, an indeterminate crop, are known to occur at the more apical nodes (Sheldrake & Saxena, 1979) The predominant supply of assimilates to the more basal nodes can also be

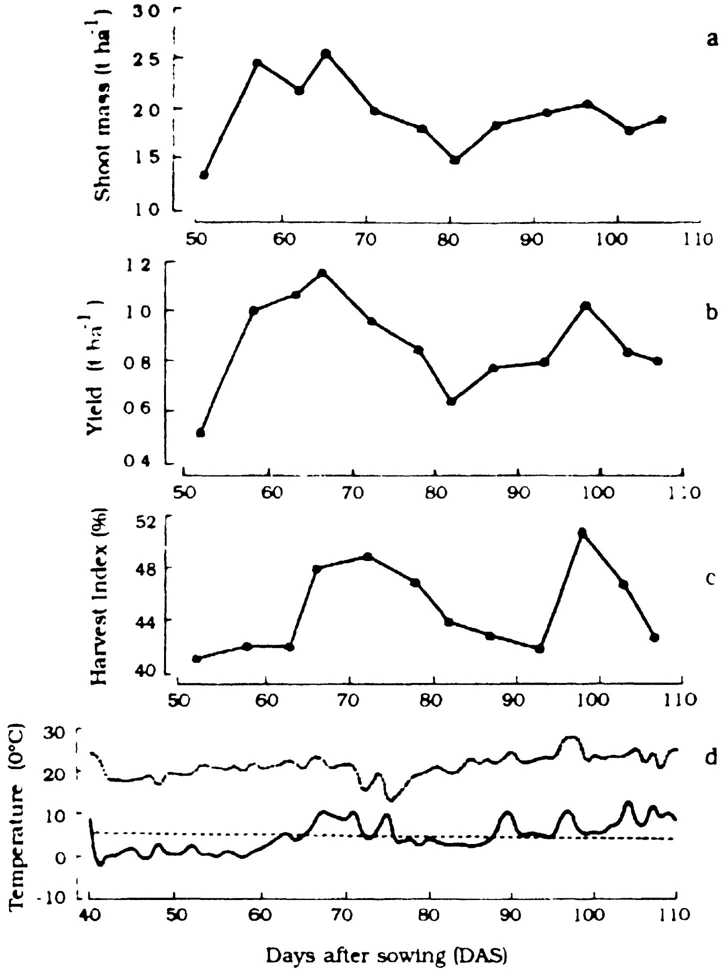

Fig. 4 Effects of time of pod set on (a) shoot mass (t /ha), (b) seed yield (t/ha) and (c) harvest index (%) in relation to (d) maximum and minimum temperatures at Hisar 1986/87 Each point in a, b, c is a mean of 10 genotypes

seen in the development of branches from the axils subtending pods at these nodes. Such branches diminish towards the more apical nodes.

The limitations to yield because of lack of assimilate supply were also seen in experiments on partial defoliation (Fig. 1) and lowering of solar radiation by shading during flowering at Hisar (Table 2), which resulted in yield reductions This suggests that during flowering any decrease in source size below that achieved at a given yield level or reduction of incident radiation below full sunlight, causing reduced source activity, would result in limitations to yield. During podfill a greater reduction of source activity, at 16% of incident radiation, was required to cause significant yield reductions (Table 2).

Responses to favourable growing conditions, whether due to good management (such as with irrigation at Patancheru) or because of site selection (Hisar vs Patancheru), resulted in larger LAIs

(Saxena *et al.*, 1983). However, because of the indeterminate habit of chickpea, the number of potential sink sites also increases as source size increases. This suggests a yield potential beyond that which is currently realized for chickpea under non-limiting growth conditions. To break presently recorded ceiling yield levels for particular environments research should thus be focussed on two main aspects: firstly, factors constraining biomass accumulation and how they may be alleviated and, secondly, factors preventing optimum partitioning of biomass into grain yield and their alleviation.

In the Patancheru environment, harvest indices are high by the standards of any crop (viz. above 50%, Table 1). Thus there seems to be little scope for increasing partitioning efficiency in this environment and any increases in grain yield must come through increased biomass production. The higher CGRs achieved in some cultivars at Hisar than at Patancheru (69 vs 57 kg/ha/day; Table 1) suggest some scope for selection of genotypes for greater biomass production at Patancheru, in the absence of a moisture limitation. For example, if total biomass accumulation could be pushed to 8 t/ha then yields exceeding 4 t/ha could be expected. We have noted that, in this environment, harvest indices remain constant at around 50% over a wide range of yield levels, to above 3 t/ha at least.

At Patancheru, if optimum irrigation can be provided, the length of the growing season for chickpea is defined by the high maximum temperatures (>30°C) at the beginning (October) and end (February) of the season. Thus a search should be made for genotypes with maximum CGR at different growth stages throughout the present growing season, as well as for high temperature tolerance before the beginning (seedling emergence and establishment) and after the end (pod-fill) of the presently defined growing season.

At Hisar, the prime limitation to yield of present cultivars does not seem to be biomass production. A shoot mass of nearly 10 t/ha could be produced (eg. C 104) but only a small fraction of it (33%) was partitioned into the seed. Thus, research on how to breach existing ceiling yield levels in this environment should focus on improvement of harvest index. If similar harvest indices as to what are achieved at Patancheru could be obtained at Hisar, then grain yields of 5 t/ha become feasible.

Flower and pod shedding is one of the possible reasons for the poor harvest indices and low realized yields in chickpea in the cooler environments of northern India and Pakistan. On an average, a 20% flower drop and a further 20-30% pod drop has been reported for chickpea from Hisar; this was primarily associated with rainfall (Varma & Kumari, 1978). Low pod set due to cloudy weather has been suggested to be another reason for low yields and harvest indices in chickpea (Chandrashekaran & Parthasarathy, 1963). In studies carried out at Hisar (Saxena, 1980), low night temperatures have also been implicated as a reason why early-appearing flowers fail to set pods (Fig. 3). Differences between genotypes in tolerance to low temperature stress during flowering and pod set have been found in chickpea (ICRISAT, 1988). This has enabled selection of single plant progenies with a range in time of first pod set, from late December through to February, when night temperatures at Hisar are <5°C (Fig. 4). This is a temperature regime which is not conductive to pod set in conventional cultivars (Fig. 3). A shift in time of first pod set, from 80-90 days after sowing in conventional cultivars to 60-70 days after sowing in the cold tolerant geonotypes appears to have resulted in an increase in biomass, yield and harvest index (Fig. 4). This is probably because partitioning of dry matter into pods commences sooner in the low temperature tolerant genotypes than in the conventional cultivars (Fig. 5) and pod set occurs under a more favourable soil moisture (Saxena, 1987) and temperature regime (Fig.4). An added benefit of the low temperature tolerant genotypes could be that they would not proliferate into excessive vegetative growth resulting in lodging and susceptibility to foliar diseases. Further, the reproductive growth phase would be lengthened but maturity reached earlier, before the rapid rise in temperature during March. Studies are continuing to identify genotypes that can maintain a high level of biomass production but have an extended period of reproductive growth before high temperatures limit podfill (Summerfield *et al.*, 1984).

The physiological approaches outlined above for improvement of chickpea yield should be applicable to chickpea improvement programs elsewhere. For example, the strategies suggested for Patancheru

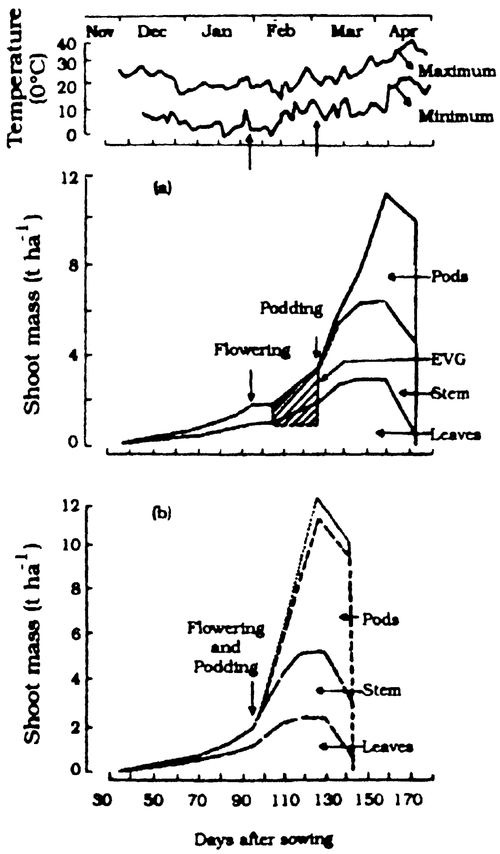

Fig. 5. Dry matter accumulation and partitioning into different components with time in (a) cultivar G 130 and (b) G 130 improved for cold tolerance. Above: maximum and minimum temperatures at Hisar during the experimental period.

may well apply to Spring plantings in West Asia and the strategies for Hisar applicable to Pakistan and Winter plantings in West Asia. However, a prerequisite to such analyses for any site is a thorough understanding of the existing environmental limitations to chickpea performance.

It could be argued that flower drop, whether it is due to excessive soil moisture in irrigated treatments such as at Patancheru or due to low night temperature and possibly also high soil moisture at Hisar (Fig. 3), may result in potentially higher yields. Death of flowers or very young pods remove potential sinks for accumulation of assimilates before sufficient biomass (source) has accumulated. The assimilates not partitioned to these sinks at an early stage are therefore invested in root and shoot growth and development of a larger canopy structure with more leaves, branches and axils (site for sinks) than would otherwise be the case. Further work is required to define the optimum time for the onset of sink activity in different environments.

Conclusions

Ceiling yield levels, under conditions where abiotic and biotic stress factors are minimized, have remained more or less static in chickpea over recent decades. However, it seems practical to breach the present upper limits in defined environments. For example, by introducing low temperature tolerance during flowering in the adapted genetic background for the cooler environments such as in northern India and selecting for higher CGRs and greater tolerance to high temperature in warmer chickpea growing environments such as peninsular India. A fundamental requirement for progress is a detailed analysis of the environmental and physiological constraints to biomass production and partitioning to grain in specific environments. A more systematic definition and identification of the traits required to break existing ceiling yield levels can then be achieved.

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