The role of phenology in adaptation of chickpea to drought

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Abstract

Chickpea is grown from autumn to early summer in both Mediterranean-type climates with winter dominant rainfall and on stored soil moisture in sub-tropical climates with summer-dominant rainfall. In both types of environment, water shortages can occur at any time during the growing season, but terminal drought predominates. A study conducted over a 2-year period with a common set of 73 genotypes showed that high-yielding genotypes flowered early, podded early and had a relatively long flowering period at most, but not all, low-yielding sites. Thus drought escape was an important phenological characteristic at sites with terminal drought. However, these characteristics did not predominate at a site in which the drought was severe throughout the growth period. Studies under rainfed conditions at a dry site in Western Australia have shown that a high degree of biomass redistribution from leaves to stems to the pod is associated with high yield, suggesting that physiological mechanisms in addition to rapid phenological development play a role in the adaptation of chickpea to water-limited environments.

Keywords

Cicer arietinum, adaptation, drought resistance, phenology, osmotic adjustment, assimilate redistribution

Introduction

Chickpea (*Cicer arietinum* L.) is grown from south-western Australia with a Mediterranean-type climate and winter-dominant rainfall to central Queensland with a subtropical summer-dominant rainfall. In all environments except in northern Western Australia, it is grown through the winter and spring as a rainfed crop and suffers from water shortage during seed development in spring (1). Despite this wide environmental range, there has been little development of specifically adapted varieties, and at this stage the same cultivar may be seen in farmer's fields from Queensland to Australia. The basis of the wide adaptation in chickpea is important as new cultivars are developed. The possibility that higher yields could be achieved if chickpea cultivars were more specifically adapted to a particular environment needs to be explored. The present study evaluated the phenological adaptation to terminal drought in chickpea germplasm.

Materials and Methods

A diverse group of 73 genotypes of chickpea (*Cicer arietinum* L.), dominated by drought-resistant genotypes from India, but also including Australian lines, was grown under rainfed conditions in a randomized complete block design at the Minnipa Research Station, South Australia, in 1999 and at the Merredin Research Station in 2000. The experiments were sown with a cone-seeder using seed inoculated immediately prior to seeding with Group N *Bradyrhizobium*. 75 kg/ha DAP (starter N) was drilled with the seed. Weeds were controlled with a range of herbicides, and ascochyta blight by prophylactic spraying with Bravo. In 2000, as there was very little rainfall prior to sowing, the seed was virtually dry-sown (Fig. 1). The time of emergence, first, 50% and final flowering, first, 50% and final podding, and maturity were recorded. The length of the vegetative phase (50% flowering – emergence), flowering phase (end flowering – 50% flowering) and total growing season (maturity – emergence) were calculated from this data. Early vigour was estimated by removing all above-ground biomass from $1m^2$ (2 x $0.5m^2$ quadrats) at 600 degree-days after sowing. Plant density was measured from $1m^2$ at weekly intervals until 600 degree-days, and then again at maturity. Seed and biological yield was estimated at maturity using 2 x 0.5m^2 quadrats. Seeds per pod, pods per plant, and their respective oven-dry weights were measured in duplicate 5 plant subsamples from each plot.

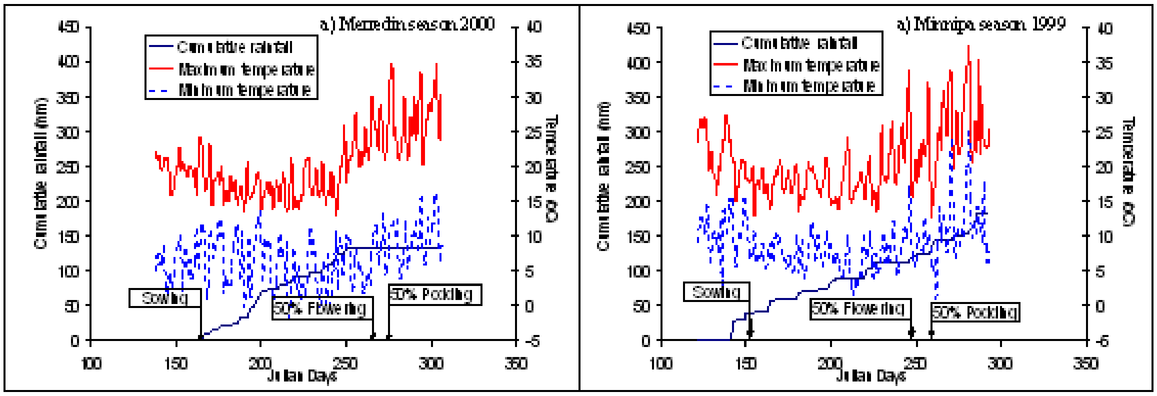

Fig. 1. Growing season climates at the Merredin Research Station, WA in 2000 (a), and at the Minnipa Agricultural Centre, SA in 1999 (b).

Results

As a result of the extremely dry season experienced during 2000 (Fig. 1a: 123.4 mm from sowing to harvest), seed yields at Merredin were very low, with a mean of 0.66 t/ha. Nevertheless, a very wide range in seed yield (0.04-1.31 t/ha) was recorded. Principal components analysis (Fig. 2a) revealed that seed yield was positively associated with biomass, harvest index, the length of the flowering phase, and productivity per plant (r=0.53-0.88, P<0.001), and negatively associated with the date of flowering and podding, and the amount of time taken to fully set pods (r = -0.50 to –0.59, P<0.001). In other words, yields were higher in those genotypes that were early flowering, early podding and rapidly set pods. The length of the vegetative phase, and time taken to maturity were also negatively associated with seed yield (r = -0.33 to –0.38, P<0.005), but not as strongly as the characters listed above. Interestingly, plant density and early vigour were unrelated to productivity (r = 0.01 to 0.03, P>0.78).

Genotypes were split into low, intermediate and high yielding categories on the basis of their seed yield Z score. Fig. 2a shows these categories arranged along the X-axis (PC1) in order of productivity: from the low yielding group on the left to the high yielding group on the right. This is a reflection of the strong positive correlation between seed yield and PC1 (r = 0.86). Given that PC1 was dominated by phenological variables, it is not surprising to find significant differences in phenology between the three productivity groups. Table 1 shows strong linear trends among the productivity groups; as seed yield increased, genotypes became consistently earlier, with a concomitant increase and decrease in the lengths of the post-anthesis and vegetative phases, respectively.

Table 1. Phenology (days after sowing) of low, intermediate, and high yielding chickpea genotypes at Merredin in 2000. (Pod development = days between 1st and 100% podding).

Productivity group	50% emergence	50% flowering	50% podding	Maturity	Vegetative phase	Flowering phase	Pod filling phase	Pod development
Low yield (n=12)	34.9	100.2	108.8	139.7	65.3	15.4	31.0	13.7

Medium yield (n=51)	33.5	96.8	105.7	138.2	63.3	17.3	32.5	7.8
High yield (n=13)	32.8	93.5	103.6	137.0	60.8	20.4	33.4	7.0
P linear trend	0.091	0.000	0.000	0.002	0.009	0.000	0.003	0.000

At Minnipa (1999), the total season rainfall (144 mm) was similar to that at Merredin in 2000, but was more evenly spread throughout the growing season (Fig 1b). Although yields were very similar to those at Merredin in 2000, the role of phenology was far reduced. Biplot vectors in Fig. 2b show that yield at Minnipa was closely associated with fecundity and harvest index. While phenological descriptors were heavily loaded on PC1, and closely linked to seed size, early vigour, and vegetative dry matter production per plant, they had little influence on yield. Fig 2b shows that at Minnipa in 1999 the three yield categories separated along PC2, rather than PC1. Thus genotypes in both high, or low yielding categories, could either be early (-ve PC1 scores) or late (+ve PC1 scores) (Fig. 2b). Table 2 confirms that there were only minimal phenological differences between the productivity categories on average.

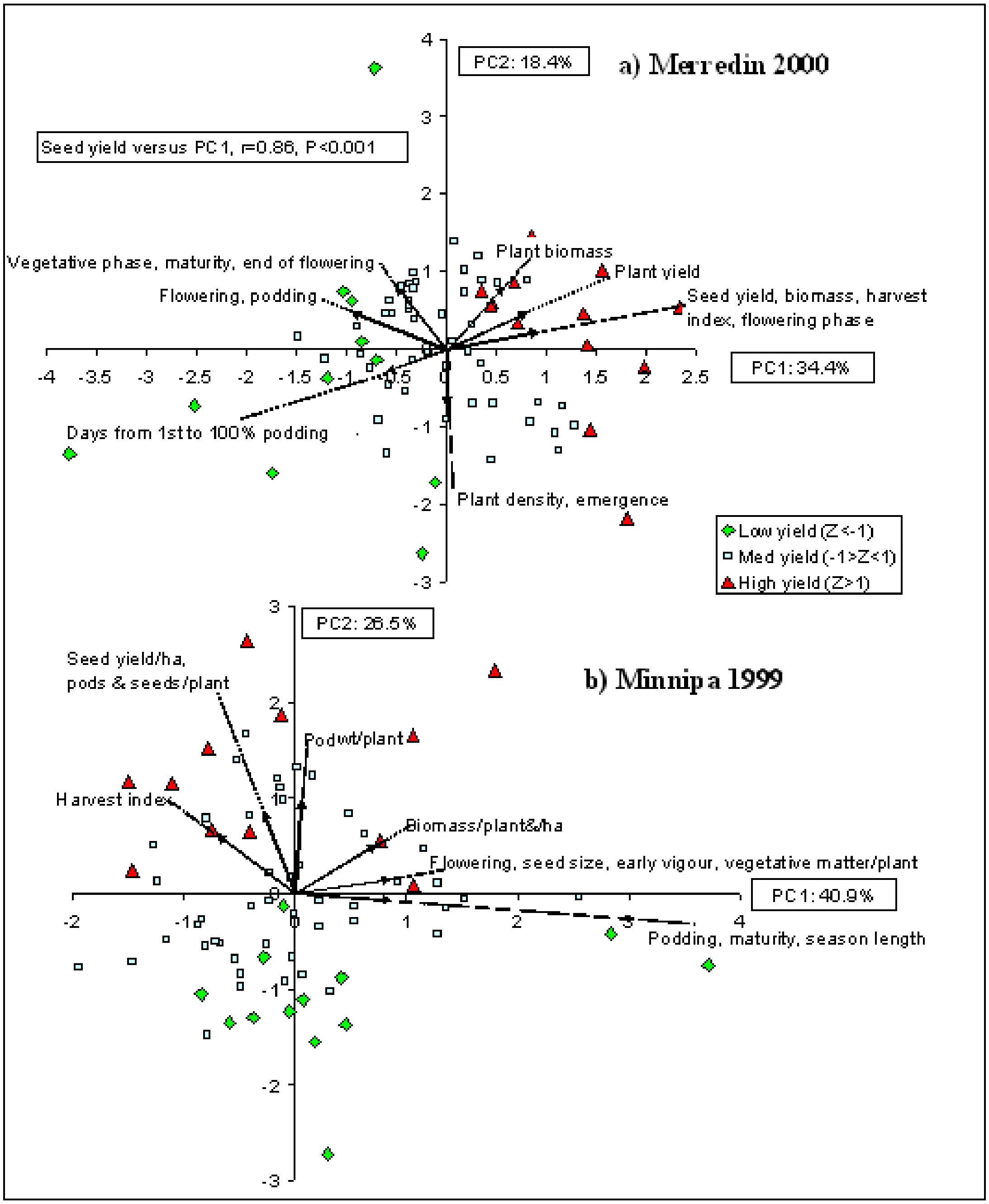

Fig. 2. Principal components analysis of continuous traits recorded in chickpeas grown in: a) Merredin in 2000, b) Minnipa in 1999. Accessions were grouped on productivity using the normal distribution: low (z<-1), intermediate (-1<x<1), and high (z>1) yield. Factor loadings for PC1 and PC2 are presented as biplot vectors (arrows).

Table 2. Phenology (days after sowing) of low, intermediate, and high yielding chickpea genotypes at Minnipa in 1999.

Productivity group	50% emergence	50% flowering	50% podding	Maturity	Vegetative phase	Pod filling phase

Low yield (n=14)	21.0	95.5	111.2	142.2	74.4	31.1
Med yield (n=46)	20.8	96.2	106.4	140.7	75.6	34.3
High yield (n=12)	20.9	93.1	103.5	139.4	75.3	35.9
P linear trend	0.646	0.307	0.000	0.023	0.686	0.001

Discussion

Studies conducted with the same set of genotypes at 7 sites in India and 5 sites in Australia have shown that seed yield of chickpea is closely associated with phenology in India, where the sites varied from warm short-season locations in the south to cooler northerly location. Genotypes that were early flowering and podding had high yields in the south whereas longer season genotypes were higher yielding in the north. Under these conditions, drought escape though early flowering and podding is clearly an important trait for higher yield. However, in Australia, the picture is not as clear. Low-rainfall sites with similar yields and similar growing-season rainfall, such as Minnipa in 1999 and Merredin in 2000, were associated with early flowering at Merredin, but not at Minnipa. As has been shown in wheat, where within-season distribution of rainfall was important in determining yield and water and nitrogen use efficiency (1), the low, but even distribution at Minnipa resulted in phenology playing a much lesser a role in determining productivity. It is conceivable that under these conditions, traits associated with drought tolerance are more important for high yield. While further analysis and experimentation is required, it appears that traits associated with assimilate redistribution are important in determining yield under drought, while the role of osmotic adjustment is equivocal (2).

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