Response to competition and association with yield of chickpea

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Abstract

Donald's ideotype and empirical evidence in crops including rice, wheat and sunflower indicate high yield is associated with less competitive plants. In this study we investigate the response to competition (RC) of 20 chickpea lines in six environments to determine the associations between yield and competitive ability. RC was calculated as the trait value of border row plants (low competition) divided by the trait value of inner row plants (high competition). We calculated RC for yield and yield components including biomass, pod number, seed size, seed number, seed per pod and the derived traits harvest index and pod wall ratio. There was a negative correlation between yield and RC for all yield components except pod wall ratio, seed size and seeds per pod. The largest RC occurred with seed number and yield, with both trait values increasing an average of 1.5 times in low competition conditions compared to high competition. The largest RC for yield was 1.76 and 1.72 for seed number and the lowest was1.31 for yield and 1.27 for seed number.

Keywords

Competitive ability, yield components, breeding, communal behavior, population dynamics

Introduction

Plant-plant interactions include reciprocal negative interactions between neighbours arising from utilisation of a common resource or through interference that is not mediated by resources (e.g. light signals, allelopathy). Donald (1981) originally suggested breeding targeting the 'communal ideotype' which is based on the idea that introgressing traits that confer adaptation to monocultures (weak competitive ability) will result in higher yield. The communal ideotype has been documented in cereals (Jennings and Jesus, 1968, Hamblin and Donald, 1974, Reynolds et al., 1994, Romani et al., 1993, Thomas and Schaalje, 1997) and sunflower (Sadras et al., 2000). A secondary consequence of competition is the impact on yield and performance at the plant and plot level. Failure to recognise this impact may introduce confounded effects into trials which in turn may lead to identification of germplasm of limited value (Rebetzke et al., 2014).

Currently there is no information on the relationship between intraspecific competitive ability and yield for chickpea, or the underlying physiological determinants of this relationship. Understanding more about chickpea communal behaviour will enhance our understanding of chickpea physiology and the underpinnings of yield within chickpea production systems.

Methods

Plant material, environments and experimental design

A selection of 20 chickpea lines were chosen in consultation with the Australian national chickpea breeder (Dr Kristy Hobson), representing a broad range in adaptation and key traits. The lines varied in yield, phenology, disease resistance and seed type (kabuli or desi). Accessions were compared in six environments in South Australia that were a combination of locations, seasons and sowing dates. The six environments were Turretfield (34^{o}33'S, 138^{o}49'E) at recommended sowing time (TOS 1; 8th June 2013 and 6th June 2014) and late sowing time (TOS 2; 9th of July 2013 and 15th of July 2014), and Roseworthy (34^{o}52'S, 138^{o}69'E) at recommended sowing time (TOS 1 on 10th June 2014) and late sowing time (TOS 2 on 15th July 2014). Experimental plots were sown in a randomised complete block design with three replicates. Plot size was 7.25m2, comprised of six rows (spaced 23cm) of five meters length. Plots were spaced 55cm apart from each other (rather than the usual 30cm) for decreased competitive pressure in border rows (Rebetzke et al., 2014). The target plant density was 50 plants m-2. Diseases were controlled with preventive treatments.

Measurements

Phenology was scored on a weekly basis with stages recorded when reached by fifty percent of plants in a plot. Stages scored included the time to: flowering, pod emergence, end of flowering and maturity (yellowing pods). Phenology was expressed on a thermal time scale, calculated from daily mean temperature and base temperature of 0ºC. Yield and components were measured from two 50cm cuts taken from either border (low competition) or inner rows (normal competition). Yield and components were measured from outer rows and their associated RC expressed as a ratio of the control yield and components (Reynolds et al., 1994, Sadras et al., 2000). Yield components measured included biomass, seed weight, seed number, pod number, seed size, seeds per pod and the derived traits harvest index (seed yield/shoot biomass) and pod wall ratio (pod wall weight/whole pod weight).

Results

Yield

Across all environments and varieties, yield ranged from 138 g m-2 to 627 g m-2. The highest average yield for an environment was 390 g m-2 and the lowest average was 292 g m-2. The lowest average yielding line yielded 278 g m-2 with a range of 192 – 392 g m-2 and the highest average yielding line yielded 392 g m-2 with a range of 226 – 627 g m-2.

Phenology

The range of time to flowering was 946ºCd for Sonali up to 1224ºCd for Genesis Kalkee. Time to pod emergence ranged from 1110ºCd for Sonali to 1325ºCd for Genesis Kalkee, and end of flowering ranged from 1356ºCd for PBA Striker to 1510ºCd for Genesis Kalkee. The environment with the shortest season was Roseworthy late sown (2014), with 874ºCd to flowering, 979ºCd to pod emergence and 1233ºCd to end of flowering. The longest season was Turretfield normal sowing (2013), which had 1235ºCd to flowering, 1422ºCd to pod emergence and 1625ºCd to end of flowering. There was a positive relationship between yield and time to phenological stage, with the most significant relationship being between yield and maturity (r2 = 0.36, P = <0.0001).

Response to competition

The range for yield response to competition across environments was 1.40 to 1.87. The range between varieties was 1.31 to 1.76. A larger response to competition was associated with lower yield (Figure 1). Yield had a significant negative correlation with response to competition of yield, biomass, pod number, harvest index, seed number and seed per pod (Table 1). The relationship between yield and response to competition varied with sowing date as reflected in positive residuals for early and negative residuals for late sown crops (Figure 2). Time to maturity accounted for a significant part of the scatter in the relationship of yield and response to competition (Figure 3).

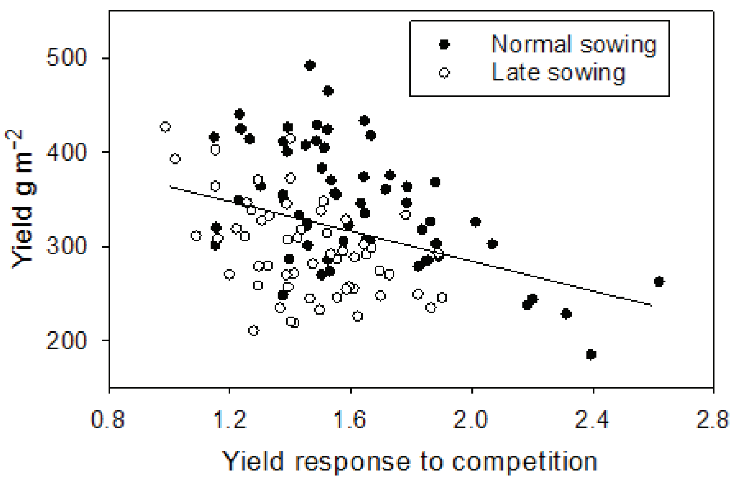

Figure 1: Effect of RC on yield. Data are based on the 20 lines and 6 environments. Data points are average of three replicates. Closed symbols are from normal sowing and open symbols are from late sowing. R^2 = 0.12 and *P* <0.0001.

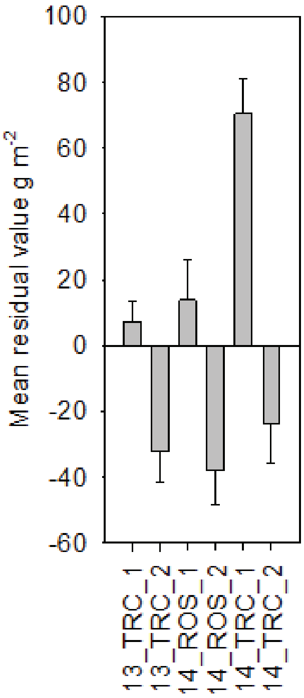

Figure 2: Average residual of the relationship between yield and response to competition (Fig. 1) for each environment. Abbreviations: 13 and 14 denote year, TRC = Turretfield, ROS = Roseworthy, 1 = normal sowing and 2 denotes late sowing. Error bars are one standard error. Differences between environments were significant (P <0.001).

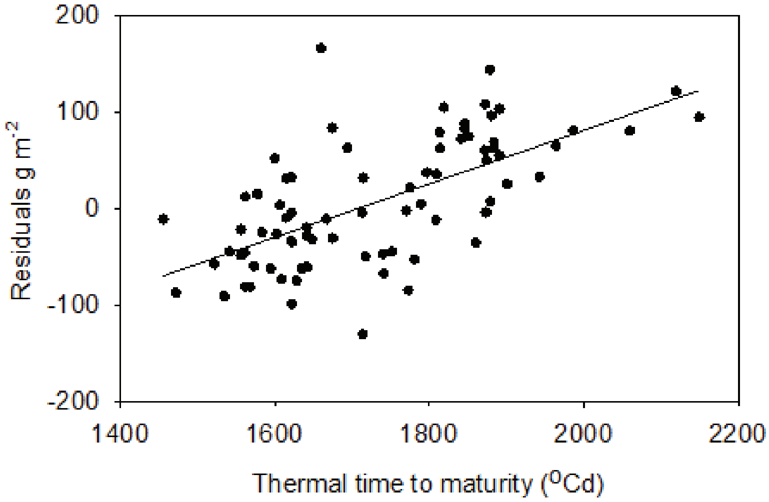

Figure 3: Residuals of the relationship between yield and response to competition (Figure 1) against thermal time from sowing to maturity. R2 = 0.41 and P <0.0001.

Table 1: Correlation matrix of response to competition (RC) for different traits and crop yield (measured in the inner row - normal competition). Significance is indicated as **P<0.0001 and P<0.05 according to Fischer's r to Z test.

	Response to competition **(RC)**							
	Pods	Yield	Seed size	Harvest index	Pod wall ratio	Seeds	Seed per pod	Yield (inner row)
Biomass (RC)	0.83**		0.23**	0.28**	-0.02		0.10	-0.41**
Pods (RC)			0.13*	0.44**	0.08		-0.26**	-0.42**
Yield (RC)			0.25**	0.60**	-0.10		0.19*	-0.45**
Seed size (RC)				0.18*	-0.05	-0.02	-0.26**	0.06
Harvest index (RC)					-0.21**		0.27**	-0.31**
Pod wall ratio (RC)						-0.09	-0.30**	-0.03
Seeds (RC)							0.27**	-0.47**
Seed per pod (RC)								-0.14*

Discussion

Previous studies in cereals and sunflower have confirmed the theory of "Donald's ideotype" with more competitive lines producing a lower yield in pure stands. This is the first study that investigates grain legumes. Our finding conforms to theory: lines that are more responsive to competition have a lower yield than their less responsive counterparts. Sadras et al. (2000) reported a yield response to competition of 0 to 84% in sunflower, while Reynolds reported differences of 25 to 40% in wheat, which compares with our observations of 31 to 76%. The responses to competition and associations with yield varied among environments and phenology. For the same response to competition, yield was higher in normal sowing environments and for lines with longer season. Although we had a significant effect of response to competition on yield, there was little difference between the response of varieties to competition, a result also reported by Romani et al. (1993).

Conclusions

This research has demonstrated that a less competitive chickpea phenotype is associated with higher yields and conforms to the idea of the 'communal ideotype'. It has also highlighted the potential risks of selection based on single plant performance or mass selection of highly competitive phenotypes as selection for yield will favour competitive phenotypes.

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