Yield formation of canola (*Brassica napus* L) and associated traits in the high rainfall zone

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ABSTRACT

A wide range of canola genotypes (triazine tolerant (TT), hybrid conventional (HC), hybrid Clearfield (HCL), hybrid TT (HTT), Clearfield, and Conventional) were examined to evaluate the relationship between yield and phenology, crop growth, and yield components in the high rainfall zone of south-western Australia in 2009 and 2010. In the average rainfall year (2009), HC and HCL canola outperformed HTT, TT, Clearfield canola by 22% and the genotypes with mid and late maturity yielded significantly (P < 0.01) higher than early maturity ones. In the dry year (2010), the genotype with early maturity produced similar seed yield to the ones with late maturity, but higher than ones with mid maturity. Principle components analysis revealed that seed yield was strongly correlated to above ground dry matter at maturity, the number of pods/m^2 and the number of seeds/m^2, but was not related to harvest index, seeds/pod, and 1000 seed weight in both years despite of significant differences in the growing season conditions. The high yielding genotypes in average rainfall season were characterised by late phenology, high dry matter accumulation with early vigour and more pods m^{-2}.

INTRODUCTION

Canola (*Brassica napus. L*) is one of the major oilseed crops grown worldwide, occupying 27 million ha in 2005 (FAOSTAT, 2006). In Australia, canola is the third-largest broadacre crop (after wheat and barley) and is widely grown across south-east Australia and in Western Australia. From 1970 to 2000, Australia canola breeders successfully improved yield, adaption, blackleg resistance and seed quality (Cowling, 2007). The availability of better varieties and crop agronomy packages and good prices made canola really attractive to growers and led to rapid expansion. The area sown to canola in Australia rose from 150,000 ha in 1991 to 1.6 million ha in 1999 (Colton and Potter, 1999). However, the canola industry in 2000 was predominately located in regions with average annual rainfall >450 mm and canola was almost absent from areas averaging less than 325 mm average annual rainfall because of less successful breeding for this region (Cowling, 2007). Despite of the importance of canola as a major oilseed crop in Australia, limited research has been carried out on yield formation and associated traits for high yielding. The major objective of this study is to quantify the relationship between seed yield and yield components of canola and identify high yielding agronomic traits.

MATERIALS AND METHODS

The experiments were conducted in Kojonup, southwestern Australia in 2009 and 2010. The average annual rainfall at Kojonup is 540 mm. Soil is a duplex soil with 0-40 cm of gritty loamy sand overlaying clay. Seventeen and 20 commercial cultivars and breeding lines were sown at a targeted plant density of 60 plants m^{-2} in 2009 and 2010, respectively. The cultivars and breeding lines were classified as five groups, namely triazine tolerant (TT), hybrid conventional (HC), hybrid TT (HTT), Clearfield (CL) and Hybrid Clearfield (HCL). The selection of commercial cultivars aims to cover a range of maturity (early, medium, and late) and different herbicide resistance (TT, IM and conventional). A randomized complete block design was used with four replicates. Each plot was 30 m by 1.44 m (8 rows).The canola crops in both years were supplied with 120 kg N/ha split as follow: 20 kg/ha at sowing in the form of Agras, 50 kg/ha at the 4 leave stage and 50 kg/ha at the stem elongation stage in the form of urea. Seventeen kg P/ha was drilled at seeding in form of Agras and 50 kg K/ha in form of muriate of potash was top-dressed along with N at 4 leave stage. Phenology of the crop was recorded using a decimal code. Each year, the crop was sampled using a quadrate of 0.54 m^2 covering the mid 6 rows to determine above-ground dry matter at critical growth stages (6 leave stage, flowering, pod filling and maturity). At maturity, all plants from a 1.08 m^2 (1 m of six inner rows) quadrate were harvested to determine seed yield. The plant samples were dried in a forced draught oven at 60°C for 78 hours, weighed, and threshed. Seed yield was calculated by dividing seed weight by the harvested area. Harvest index was calculated by dividing seed yield by the above-ground dry matter. At maturity, 3 plants were harvested with care and the number of pods each plant was counted. These 3 plants were separated into stem, pods, and seed and dried in a forced draught oven at 60°C for 78 hours and weighed. The pods were threshed by hand and seed were collected. The number of seeds was counted. The number of pods m^{-2} and seed m^{-2} was calculated by multiplying the above ground dry matter by the number of pods g^{-1} dry matter and seed g^{-1} dry matter from the 3 plant samples. The score of blackleg infection was recorded visually by assigning a percentage of the stem section infested by blackleg of randomly selected 10 plants at maturity. Principle components analysis (PCA) based on the correlation matrix was used to construct a biplot of genotypes (PC scores) and associated traits (PC factors loadings, shown as biplot vectors). The correlation matrix-based PCA standardizes each trait by subtracting its mean and dividing by its standard deviation so that the traits share a common scale of variation.

RESULTS

The annual rainfall in 2009 was 540 mm with 455 mm falling during the growing season, representing an average year in the region. In contrast, Year 2010 was a dry one with the growing season rainfall of 250 mm, representing 1 in 4 years. In both years, there was a dry spell during seed filling.

Table 1. Dry matter and seed yield of Triazine tolerant (TT), Hybrid conventional (HC), Hybrid TT (HTT), Clearfield (CL) and Hybrid Clearfield (HCL) canola genotypes and yield components at Kojonup, Western Australia in 2009 and 2010.

Type	No of genotype	Dry matter ($g\ m^{-2}$)	Yield ($g\ m^{-2}$)	HI	Pods m^{-2}	Seeds m^{-2} ($\times10^3$)	1000 seed weight (mg)	Seeds pod^{-1}
2009								
CL	3	1130	294	0.26	5257	92	3.25	17.4
Con	1	1060	241	0.23	6999	76	3.15	12.0
HCL	4	1337	360	0.27	6908	119	3.05	17.4
HC	2	1269	360	0.28	7459	110	3.29	14.8
HTT	2	1053	295	0.28	4949	96	3.09	19.4
TT	5	934	253	0.27	5125	88	2.92	18.1
lsd (P < 0.05)		87	44	0.02	734	12	0.21	1.3
2010								
CL	2	960	270	0.28	4916	76	3.6	15.5
HCL	4	1000	249	0.25	5459	76	3.4	14.1
HC	2	905	255	0.28	4997	75	3.6	15.0
HTT	3	842	242	0.29	4575	74	3.5	16.2
TT	8	821	243	0.30	4529	75	3.3	16.9
lsd (P < 0.05)		76.7	ns	0.01	587	ns	ns	2.3

Seed yield differed significantly between the seasons as a result of difference in the growing season rainfall. The average seed yield was 302 g m^{-2} for 17 genotypes in 2009 and 248 g m^{-2} for 20 genotypes in 2010. HC and HCL canola yielded significantly higher (P < 0.01) than CL, HTT and TT canola in 2009 while no significant yield difference was detected between the types in 2010 (Table 1). In 2009, the canola with early maturity produced significantly ($P < 0.05$) lower yield than the ones with mid and late maturity (Fig. 1a). In 2010, the canola with early maturity produced similar seed yield to the ones with late maturity, but higher than the one with mid maturity (Fig. 1b). This is probably because lack of rainfall in 2010 restrained the mid and late maturity from expressing their potential. Seed yield across the two years was significantly ($r^2 = 0.80$, $P < 0.001$) related to dry matter at maturity (Fig.2a) but not to harvest index (Fig. 1f). Seed yield increased with increasing number of pods m^{-2} ($r^2 = 0.49$, $P < 0.001$) (Fig. 2b) and seed m^{-2} ($r^2 = 0.78$, $P < 0.001$) (Fig. 2c). No clear relationship was observed between seed yield and 1000 seed weight (Fig. 1e) and between seed yield and seeds per pod (Fig. 2d). The number of pods m^{-2} ($r^2 = 0.54$, $P < 0.001$) and seed m^{-2} ($r^2 = 0.67$, $P < 0.001$) were significantly correlated to dry matter at maturity (data not shown).

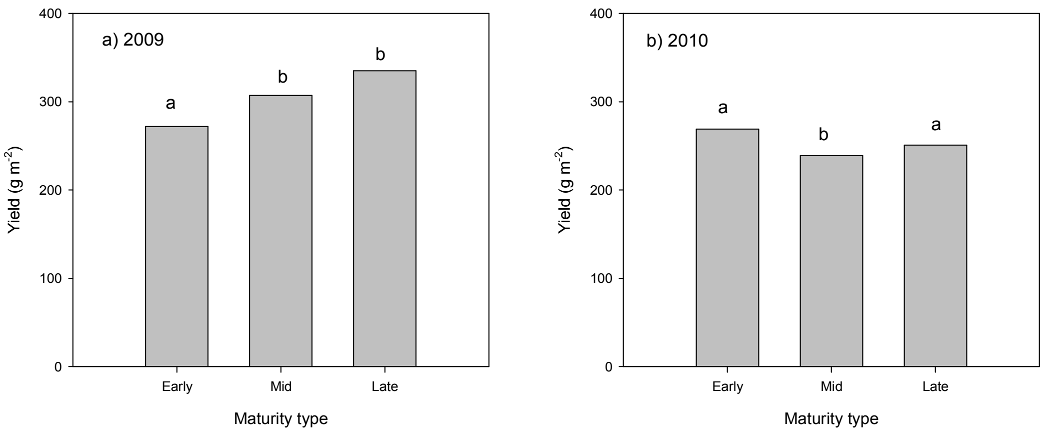

Fig. 1 The effect of maturity types (Early, Mid and Late) on seed yield at Kojonup, Western Australia in a) 2009 and b) 2010. The different letters above the bars indicate a significant ($P < 0.05$) difference in yield compared to Early.

Figure 3 showed the relationship between seed yield and phenological and agronomic traits. PCA reveals that seed yield was positively correlated with dry matter at maturity ($P < 0.001$ in 2009 and $P < 0.006$ in 2010), the number of seed m^{-2} ($P < 0.001$ in 2009 and $P < 0.001$ in 2010), pods m^{-2} ($P < 0.01$ in 2009 and $P < 0.001$ in 2010) but not correlated with 1000 seed weight, seed per pod and HI. The correlation of seed yield with the days to flowering was different between the two years. A negative ($P < 0.01$) correlation between seed yield and the days to flowering was observed in the drought year 2009 while a weak positive ($P = 0.13$) correlation in the average year 2009. Seed yield was not affected by blackleg disease in both years because of low infection rates. The flower abortion rates were negatively but not significantly ($P = 0.07$) related to seed yield in 2009 and not related to seed yield in 2010. The response of seed yield to early vigor represented by dry matter at six leave stage differed between the years. In 2009, seed yield was positively ($P < 0.01$) correlated with early vigor while no significant correlation was observed in 2010. In 2009, the high yielding genotypes (Pioneer 46Y78, Hyola 50, Hyola 76, Pioneer 06N7851, Pioneer 06N7881, and Hyola 571CL) are located on the positive PC1 and low yield genotypes (all TT canola) on the negative PC1. The PCA reveals that hybrid canola with medium to long season genotypes produced higher dry matter, more pods m^{-2} and higher yields and that TT canola produced low dry matter, fewer pods m^{-2} with high abortion rates of flowers. In 2010, high yielding genotypes were associated with early maturity (Surpass 400, Pioneer 44C79 CL), or high dry matter (Pioneer 06N7861 and Pioneer 06N7881).

DISCUSSION

This study showed that high dry matter is the key to high seed yield because no difference in harvest index was found between five different types of canola. High dry matter determined the number of pods m^{-2}, and seed m^{-2}, and seed yield. This is in agreement with other studies (Mendham et al., 1981a; Mendham et al., 1981b; Robertson et al., 2002). However, many of these studies derived the relationships from agronomic management manipulation such as different sowing dates (Mendham et al., 1981a; Mendham et al., 1981b), different N rates, or across a wide range of environments (Robertson et al., 2002). The relationships established in this study are based on variation in yield of different genotypes under the same two environments and therefore these relationships are genetically determined and represent genetic differences.

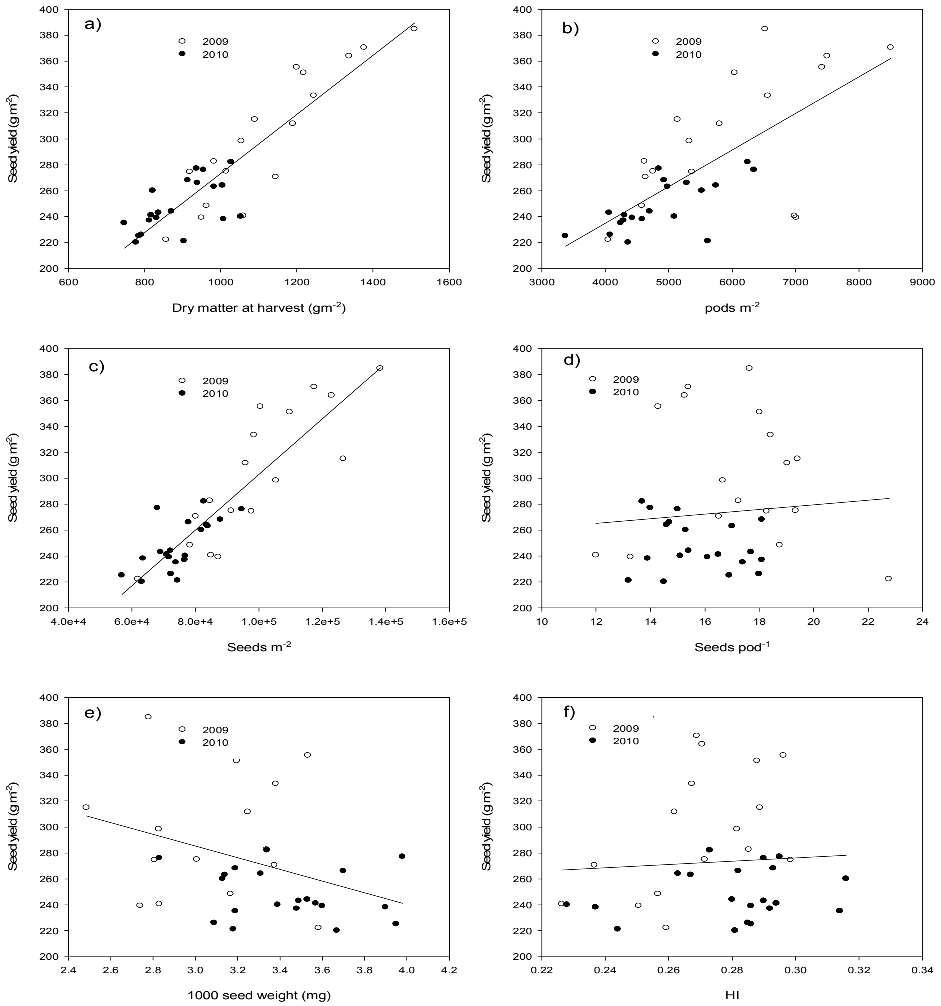

Fig. 2 Relationships between seed yield and (a) dry matter at maturity, (b) pod m-2, (c) seeds m-2, (d) seeds pod-1, (e) seed weight, and (f) harvest index (HI) of canola genotypes in 2009 (●) and 2010 (○).

TT canola produced up to 40% less yield than HCL and HC canola but similar yield to HTT and CL canola in 2009. All five types of canola produced similar yield in 2010. This suggests that there were strong genotype × environment interactions as suggested by (Zhang et al., 2011). The yield penalty associated with TT trait has been reported in Australia (Potter and Salisbury, 1993; Robertson et al., 2002). Low yield of TT canola was mainly due to less dry matter produced because no difference in HI was observed. TT canola has been showed to have low radiation use efficiency compared with non-TT canola (Robertson et al., 2002). This reduced radiation use efficiency translated into 10-15% less dry matter at maturity in the drought year 2010 and 30-40% in the average year 2009. No better performance of yield in the HC and HCL canola than TT ones in 2010 was probably related to the growing season condition. Lack of rainfall in 2010 prevented HC and HCL canola from achieving their potential as a result of significantly ($P < 0.01$) high abortion rates compared to TT canola.

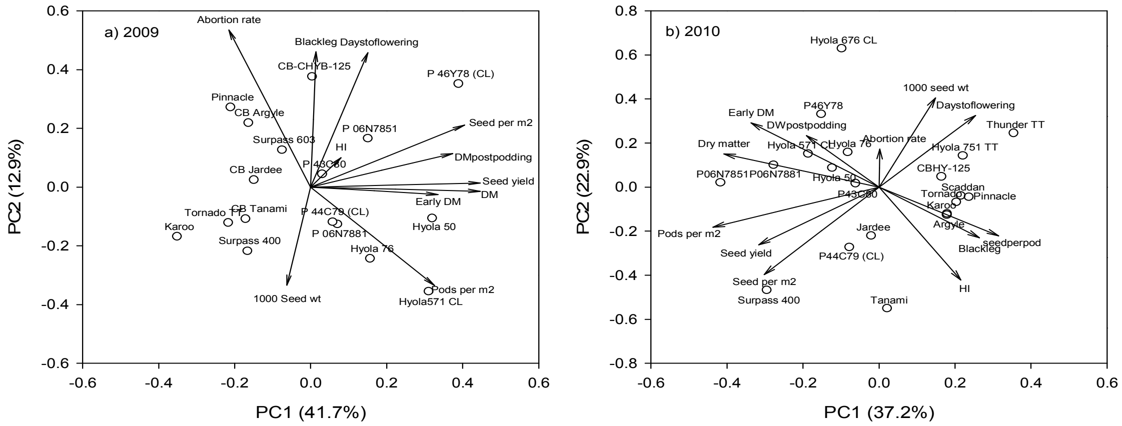

Fig. 3 The principle components analysis of plant traits of canola genotypes (○) in (a) 2009 and (b) 2010. Biplot vectors are trait factor loadings. The name of genotypes are placed next the open red circles.

This study showed that seed yield is more related to the number of pods m^{-2} than seed weight and seeds pod^{-1}. The number of pods for high yield was in a range of 7000-7500 m^{-2}, in consistent with an optimum pod number of between 6000 and 8000 pods m^{-2} in Europe (Berry and Spink, 2006). It is clear that all canola produced more than enough flowers because about 40-60% of flowers were aborted. This probably suggests that source of assimilate supply at pod formation period was limited and warrant a further study. The significant correlations between the number pods m-2 and dry matter in both years reinforce the importance of high dry matter. There was a close relationship between dry matter at six leave stage and dry matter at maturity, suggesting that early vigor is an important trait for high yielding.

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REFERENCES

Berry, P.M., Spink, J.H., 2006. A physiological analysis of oilseed rape yields: Past and future. Journal of Agricultural Science 144, 381-392.

Colton, B., Potter, T.D., 1999. History canola in Australia: the first 30 years. In: Salisbury, P.A., Potter, T.D., McDonald, G., Green, A.G. (Eds.), Proceedings of the 10th International Rapeseed Congress, Canberra, Australia, pp. 1-4.

Cowling, W.A., 2007. Genetic diversity in Australian canola and implications for crop breeding for changing future environments. Field Crops Research 104, 103-111.

FAOSTAT, 2006. FAOSTAT Data. www.faostat.fao.org.

Mendham, N.J., Shipway, P.A., Scott, R.K., 1981a. The effects of delayed sowing and weather on growth, development and yield of winter oil-seed rape (Brassica-napus). Journal of Agricultural Science 96, 389-416.

Mendham, N.J., Shipway, P.A., Scott, R.K., 1981b. The effects of seed size, autumn nitrogen and plant-population density on the response to delayed sowing in winter oil-seed rape (Brassica-napus). Journal of Agricultural Science 96, 417-428.
Potter, T.D., Salisbury, P.A., 1993. Triazine resistant canola in southern Australia. Proceedings of the 7th Australian Agronomy Conference, Adelaide, pp. 80-82.
Robertson, M.J., Holland, J.F., Cawley, S., Potter, T.D., Burton, W., Walton, G.H., Thomas, G., 2002. Growth and yield differences between triazine-tolerant and non-triazine-tolerant cultivars of canola. Australian Journal of Agricultural Research 53, 643-651.
Zhang, H.P., Berger, J.D., Milroy, S., 2011. Genotype × environment interaction of canola (*Brassica napus* L) in multi-environment trials. 17th Australian Research Assmbley on Brassicas, Wagga Wagga, New South Wales, Australia.