Growth, Dry Matter Production and Seed Yield of Indian Mustard (*Brassica juncea* L.) in the Mediterranean Environment of South Western Australia

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ABSTRACT

The effects of genotype, environment and their interaction on phenology, dry matter production and yield of Indian Mustard (*Brassica juncea* L.) and canola (*B. napus* L.) were studied in a field experiment at Northam (31^0 43'S, 116^0 38'E) in the medium rainfall (461 mm/annum) central grainbelt of Western Australia in 1999. Six mustard varieties/breeding lines varying in height, maturity and oil quality, together with three commercial canola varieties were sown at four times (mid May to mid July). The effects of genotype, environment (time of sowing) and their interaction on phenology, seed yield and final biomass were highly significant. Shorter, early and mid maturing mustard lines gave higher yields when sown early and yield decreased progressively when sowing was delayed. This study demonstrates that given a suitable genotype, Indian mustard is adapted to short season Mediterranean environments although early sowing is critical for the production of greater biomass and seed yields.

KEY WORDS

Adaptation, Indian mustard, canola, Mediterranean environment, genotype x environment interaction.

INTRODUCTION

Canola (*Brassica napus* L.) has become an integral component of the cropping systems of the Western Australian grainbelt during the past eight years. However, its adoption in the low rainfall regions of the grainbelt is hindered by its low and variable yields, high input cost and the relative high risk of crop failure due to drought and blackleg fungal disease (5). More recently Indian mustard (*Brassica juncea* L.) has shown potential for the commercial production particularly in the low rainfall cropping regions of Australia (2, 10) due to greater tolerance to heat and water stress, (7, 16) and several agronomic advantages over canola (2, 10).

Although mustard exhibits several desirable agronomic characteristics, the potential of mustard oil to be interchangeable with canola oil has been hindered by low oil content, high glucosinolate level in seed meal, high erucic acid and low oleic acid content in the oil (2). The Australian mustard breeding program based at Horsham, Victoria, has developed a range of lines with double low quality (i.e. <2% erucic acid in the oil and <20 µmol/g of seed meal of glucosinolate), large seeds, early vigour, early flowering and maturity, high yield and improved agronomic characteristics (1, 9). Limited yield trials that have been carried out in the northern and central grainbelt of Western Australia suggests that mustard has a higher yield potential in the medium and low rainfall regions of Western Australia (8). However, considerable varietal development and agronomic research on mustard is required in Western Australia before this crop can be recommended as an alternate to canola to growers.

The climate of South Western Australia is of a Mediterranean type and is characterised by hot, dry summers and mild and wet winters. The time of sowing has a large effect on seed yield of crops grown in this environment. Adaptation of a crop to such an environment depends on its ability to escape or tolerate drought and efficiently use resources to produce biomass and partition it in favour of seed yield. One approach to this problem is to select crops with rapid canopy development, early flowering and rapid grain filling that complete their life cycle before terminal drought sets in. The overall aim of this study was to examine the adaptation of Indian Mustard to dryland Mediterranean type environments by investigating the effects of genotype (variety), environment (time of sowing), and their interaction on the phenology, growth, yield and oil content and quality. Phenology, canopy development, radiation absorption, biomass production and partitioning and yield components of Indian Mustard has been examined in detail to explain its morphological and physiological basis of adaptation and yield improvement in the short season Mediterranean type environment of the Western Australian grainbelt.

MATERIAL AND METHODS

Experimental design and trial management

A field experiment was conducted on the Research Farm, Muresk Institute of Agriculture, Northam, Western Australia (31^0 43'S, 116^0 38'E, mean annual rainfall of 461mm) in 1999. The effects of time of sowing was studied in the main plots and included four levels; Very early sowing (12 May), Early sowing (2 June), Late sowing (23 June) and Very Late sowing (14 July). The effects of genotype was studied in sub-plots and consisted of six mustard genotypes varying in height and maturity, and canola quality and three canola varieties varying in maturity (Table 1). All the treatment combinations were arranged in a split plot design with three replicates. Plots were sown with a cone seeder at the seeding rate of 6 Kg/ha and were 1.44 m wide (8 rows, 18 cm apart) and 20 m long. Double Superphosphate was direct drilled at the rate of 114.2 Kg/ha at sowing. Urea was applied at the rate of 65 and 87 Kg/ha at sowing and four to five weeks after sowing respectively. Weeds and pests were controlled using recommended herbicides and insecticides where necessary.

Measurements

Daily maximum and minimum temperatures and daily rainfall were recorded at the nearby Muresk weather station. Date of emergence (when 90% of the plants are visible at the soil surface) and date on which 50% of plants commenced stem elongation, produced flower buds, produced their first open flower, ceased the flowering on the terminal raceme and reached physiological maturity (when seeds in the two lowest pods were dark brown colour) were recorded. Two representative mustard genotypes (82 No 22-98 and JM 33) and one representative canola genotype (Oscar) were selected for detailed dry matter partitioning and canopy development studies. Plant samples were collected every four weeks commencing from six weeks after emergence. The area of green leaves was measured using a Leaf area meter and Photosynthetically Active Radiation (PAR) interception was measured using a Sunfleck Ceptometer (data not presented). Plots were machine harvested at maturity and seed yield, final above ground biomass, Harvest Index (HI) and yield components were determined. All measurements were statistically analysed using analysis of variance using GENSTAT statistical software.

RESULTS

Phenology

The effect of genotype and genotype x environment interaction on all phenological stages were highly significant. The duration of vegetative phase (ie., days from sowing to stem elongation) was consistent across times of sowing. Days to first flower, last flower and maturity decreased significantly with delayed sowing (Table 1). However, all mustard genotypes and Charlton when sown last took slightly longer duration to mature than third sowing as plants have been rejuvenated after a severe diamond back moth attack by late rains. Early and mid season mustard genotypes produced their first open flower well before the early canola variety, Monty. Mustard lines, 82 NO 22-98 and JM 29, were the first and last lines to flower respectively in all times of sowing. Duration between flowering to maturity decreased with delayed sowing. Moreover, genotypes which were late to commence flowering had a short reproductive phase and its duration was progressively shortened with the delayed sowing. Though canola varieties flowered later than early and mid mustard lines, the difference between the date of the first flower and maturity was small as mustard lines matured relatively early.

Table 1. Description of nine genotypes of mustard and canola sown at four different times (S1-12 May, S2- 2nd June, S3- 23 June and S4- 14 July) and their duration (days after sowing) to first flower and maturity.

Genotype	Description	Days to first open flower (DAS)					Days to maturity (DAS)				
		S1	S2	S3	S4	X	S1	S2	S3	S4	X
887.1.6.1	Early, short, near canola quality mustard	82	84	78	92	84	160	154	131	141	147
JM 25	Early to mid, tall , near canola quality mustard	93	89	85	92	90	162	154	130	137	146
JM 33	Mid, tall , near canola quality mustard	90	89	82	93	89	184	167	142	145	159
JM 29	Late, tall , near canola quality mustard	130	114	100	104	113	187	170	146	147	162
Muscon, M-973	Early to mid, short , condiment mustard	78	78	78	90	81	155	149	125	139	142
82 NO 22-98	Early to mid, short , condiment mustard	76	74	74	74	75	154	149	124	135	141
Monty	Early maturing canola	90	86	85	82	86	160	153	131	133	144
Oscar	Mid maturing canola	107	102	94	106	102	183	163	143	140	157
Charlton	Mid to late maturing canola	104	94	94	100	98	181	161	142	141	157
Mean (X)		94	90	86	93	91	170	158	135	140	152
l.s.d. ($P < 0.05$)		Compare means of TOS = 9 Compare means of VAR = 4 Compare means of TOS X VAR = 11					Compare means of TOS = 5 Compare means of VAR = 2 Compare means of TOS X VAR = 6				

Seed yield and dry matter production

As the seed yield and the final above ground biomass production was significantly affected by the significant variation in plant density at harvest, it has been used as the covariate to adjust means and the adjusted means are given in the Table 2.

Seed yield and final above ground dry matter production differed significantly ($P<0.05$) among times of sowing and genotypes and were greatest in the early sowing (2 June) (Table 2). Significantly lower seed yields and final above ground dry matter production of some genotypes in the first sowing than second sowing was due to low plant density resulting from the poor germination in first sowing due to low soil moisture at sowing. Seed yield and final dry matter production was significantly and progressively reduced in third and last sowing. Early to mid season mustard lines yielded greater than late mustard line, JM 29, in all times of sowing. In general, seed yield of canola varieties were significantly greater than that of mustard lines when sown early, but these differences disappeared progressively with delay in sowing.

There was no significant difference between final dry matter production of mustard and canola genotypes in the first three sowings except in early to mid mustard line, JM 25, which recorded significantly lower final dry matter production when sown early. However, very late sowing significantly reduced the final dry matter yield. The Harvest Index (HI), was greater in canola varieties than in mustard lines when sown very early. With late sowing mustard lines recorded slightly higher HI than canola varieties. These differences were enhanced with very late sowing. Mustard line 82 NO 22-98, recorded the highest and JM 29 the lowest HI. Seed yield was significantly ($P< 0.01$) correlated with the final above ground biomass production ($r^2 = 0.93$) and harvest index ($r^2 = 0.74$).

Table 2. Seed yield, Final above ground biomass production and Harvest Indices of nine genotypes of mustard and canola sown at four different times (S1-12th May, S2- 2nd June, S3- 23rd June and S4- 14th July).

Genotype	Seed yield (t/ha)					Final above ground biomass (t/ha)					Harvest Index (%)				
	S1	S2	S3	S4	X	S1	S2	S3	S4	X	S1	S2	S3	S4	X
887.1.6.1	1.72	2.80	2.11	0.66	1.59	7.35	10.9	7.46	2.81	6.38	24	23	27	20	24
JM 25	0.90	3.10	1.84	0.56	1.35	4.23	11.8	7.39	3.05	5.80	21	24	22	17	21
JM 33	3.08	2.95	2.49	0.30	1.99	14.9	13.1	10.4	1.75	9.40	21	19	21	16	19
JM 29	1.63	2.22	1.55	0.31	1.21	9.81	8.12	7.50	1.85	6.11	17	16	15	15	16
Muscon M-973	1.63	2.60	1.84	0.44	1.34	8.73	10.9	7.44	1.96	6.49	20	22	24	22	22
82 NO 22-98	2.28	3.14	2.48	0.51	1.84	7.77	11.1	8.68	3.01	6.77	31	26	28	16	25
Monty	2.25	3.17	2.69	0.64	1.91	8.27	11.1	9.14	4.20	7.24	31	27	19	14	25
Oscar	3.35	3.03	2.52	0.07	1.93	10.8	11.0	8.95	2.30	7.14	30	26	27	2	22

Charlton	2.97	3.02	2.28	0.29	1.87	11.2	11.5	9.96	2.87	7.93	25	24	21	10	20
Mean (X)	2.20	2.89	2.19	0.59	1.68	9.23	11.1	8.55	0.72	7.03	25	23	24	15	21
l.s.d. (P < 0.05)	Compare means of TOS = 2.72 Compare means of VAR = 0.42 Compare means of TOS X VAR = 1.41					Compare means of TOS = 7.14 Compare means of VAR = 1.70 Compare means of TOS X VAR = 4.75					Compare means of TOS = 6 Compare means of VAR = 3 Compare means of TOS X VAR = 7				

Yield components

The total number of pods per plant and the number of seeds per pod differed significantly among genotypes and times of sowing whereas 1000 seed weight was not affected by the times of sowing but significantly differed among genotypes (Table 3). Mustard lines had significantly higher number of pods per plant than canola varieties, whereas canola varieties had significantly higher number of seeds per pod and higher 1000 seed weight than mustard lines.

Table 3. Yield components [total number of pods / plant, number of seeds / pod and 1000 seed weight] of nine genotypes of mustard and canola sown at four different times (S1-12 May, S2- 2 June, S3- 23 June and S4- 14 July).

Genotype	Total number of pods/ plant					Number of seeds / pod					1000 seed weight (g)				
	S1	S2	S3	S4	X	S1	S2	S3	S4	X	S1	S2	S3	S4	X
887.1.6.1	390	181	181	89	210	14.9	13.6	14.3	11.4	13.5	3.21	3.15	3.07	3.44	3.21
JM 25	312	247	222	95	219	13.0	13.3	13.1	13.5	13.2	3.51	3.20	3.22	3.44	3.34
JM 33	450	407	321	144	331	10.3	9.9	10.4	12.4	10.7	3.22	3.16	3.03	3.38	3.19
JM 29	386	322	171	139	254	10.1	10.9	11.0	12.1	11.0	2.88	3.08	2.94	3.52	3.10
Muscon M-973	364	188	189	53	198	12.6	11.7	13.4	11.6	12.3	3.55	3.81	3.78	3.63	3.69
82 NO 22-98	298	209	194	86	196	11.2	12.1	12.9	10.2	11.6	3.82	4.09	3.91	3.69	3.88
Monty	147	154	114	70	121	23.5	24.9	19.0	20.3	21.9	4.06	4.11	3.82	3.93	3.98

Oscar	178	137	45	11	78	24.6	23.1	18.6	15.4	20.4	3.58	3.67	3.57	3.72	3.64
Charlton	167	132	95	34	98	25.4	23.0	18.7	17.3	21.1	3.93	4.04	3.64	3.84	3.86
Mean (X)	299	220	170	69	190	16.2	15.8	14.6	13.8	15.1	3.53	3.59	3.44	3.62	3.55
l.s.d. (P < 0.05)	Compare means of TOS = 182 Compare means of VAR = 48 Compare means of TOS X VAR = 135					Compare means of TOS = 0.9 Compare means of VAR = 0.9 Compare means of TOS X VAR = 1.9					Compare means of TOS = 0.36 Compare means of VAR = 0.15 Compare means of TOS X VAR = 0.34				

DISCUSSION

Results from this single season study demonstrates that shorter, early and mid maturing mustard lines are well adapted to short season Mediterranean environment of the medium rainfall regions of the West Australian grainbelt when they are sown early in the season. Vigorous seedling growth, early stem elongation, rapid ground covering ability and early flowering shown by these lines under low temperatures and radiation levels early in the season are important yield determinant traits. This is in turn allowed the accumulation of greater biomass by the crop before flowering to support the seed development and the completion of seed development before the onset of drought stress at the end of the growing season. Late mustard lines produced lower seed yields and had lower harvest indices as they were taller, flowered late, had shorter reproductive phase and matured late in the season. Similarly, phenological characteristics such as, growth prior to flowering and an optimal time for the commencement of flowering have been identified as important criteria of selection for higher yield in rapeseed (3, 14), cereals (11) and grain legumes (4, 6, 13).

As have been reported in previous studies (3, 12, 13, 15), we found that high seed yield is strongly correlated with higher biological yield. Shorter, early and mid maturing mustard lines when sown early, produced more leaves and branches and therefore had greater leaf area indices which in turn allowed the crop to absorb more photosynthetically active radiation (data not presented) than when sowing was delayed. Further to that, longer reproductive phases of those lines have produced higher post anthesis dry matter production and resulted in higher final biomass than late lines. Though the final biomass production was not significantly different between mustard lines and canola varieties studied, the relative inefficiency of mustard lines to partition dry matter into seeds (lower HI), may have resulted in significantly greater difference in seed yields of canola varieties than some mustard lines.

The role of yield components is crucial in determining seed yield differences of mustard and canola. Despite the fact that mustard lines had significantly more primary, secondary and tertiary pods, the relatively higher yields produced by canola varieties than some mustard lines could be attributed to greater 1000 seed weight of canola seeds and the production of more seeds per pod.

CONCLUSION

This study demonstrates that the selection of phenologically adapted cultivars with appropriate sowing times improve the adaptation of Indian mustard in the short season Mediterranean environment of South Western Australia. Further studies are in progress at a number of contrasting locations in WA to understand the environmental responses of mustard when compared to canola.

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REFERENCES

1. Burton, W.A., Robson, D.J., Wright, C.L., Greenwood, C.F., Salisbary, P.A. and Oram, R.N. 1997. *11th Australian Research Assembly of Brassicas*. Perth, Western Australia, p 84-87.

2. Kirk, J.T.O. and Oram, R.N. 1978. *The Journal of Australian Institute of Agricultural Science*. **44**, 143-156.

3. Lewis, G.J and Turling, N. 1994. *Aust. J. Exp. Agric*. **34**, 93-103.

4. Loss, S.P. and Siddique, K.H.M. 1997. *Field Crops Research*. **52**, 17-28.

5. Marcroft, S. 1997. *11th Australian Research Assembly of Brassicas*. Perth, Western Australia, p 124-127.

6. Mwanamwenge, J., Loss, S.P., Siddique, K.H.M. and Cocks, P.S. 1998. *Aust. J. Exp. Agric*. **38**, 171-180.

7. Nicknam, S.R. and Turner, D.W. 1999. *Oilseed Crop Updates*. Northam, Western Australia, p 14-15.

8. Oram, R.N. and Kirk, J.T.O. 1995. *10th Australian Research Assembly of Brassicas*. Struan, South Australia, p 90-93.

9. Oram, R.N., Walton, G., Marcroft, S., Potter, T.D., Salisbury, P.A., Burton, W.A., Robson, D.J., Castleman, G.H., Easton, A.A., and Kirk, J.T.O. 1997. *11th Australian Research Assembly of Brassicas*. Perth, p 79-83.

10. Parker, P. 1999. *Oilseed Crop Updates*. Northam, Western Australia, p 12-13.

11. Perry, M.W., Siddique, K.H.M. and Wallace, J.F. 1987. *Aust. J. Agric. Res*. **38**, 809-819.

12. Richards, R.A. and Thurling, N. 1978. *Aust. J. Agric. Res*. **29**, 469-477.

13. Siddique, K.H.M., Loss, S.P., Regan, K.L. and Jettner, R.L. 1999. *Aust. J. Agric. Res*. **50**, 375-387.

14. Thurling, N. 1991. *Field Crops Research*. **26**, 201-219.

15. Thurling, N. 1974. *Aust. J. Agric. Sci.* **25**, 697-710.

16. Wright, P.R., Morgan, J.M. and Jessop, R.S. 1996. *Field Crops Research*. **49**, 51-64.