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Growth interactions of navy bean varieties with sowing date and season

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Summary. Five navy bean (*Phaseolus vulgaris* L.) varieties were sown monthly from December to February at Kingaroy in 1991–94, plus a November planting in 1993 and 1994, to investigate how varietal differences may be affected by time of sowing.

For grain yield there were seasonal interactions with both sowing date and variety, with maximums for a December sowing in 1991 and 1994 but a minimum in 1993 for November and December sowings due to infection with grey mould (*Macrophomina* spp.). Yields were least with the February sowing in 2 years and for mean yield over years. The early maturing varieties, Actolac and Pan 12, maximised yield with a January sowing, and the late varieties, Sirius, Rainbird and Spearfelt, with a December sowing.

Time to flowering and maturity was greatest for November plantings, while minimum time to flowering and maturity was subject to marked interactions with varieties and season.

Determinate varieties Rainbird, Spearfelt and Actolac were non-viny across sowing dates, while semi-determinate Sirius and Pan 12 were less viny with later sowing.

Canopy height, pod height and lodging were affected by interactions amongst varieties, seasons and sowing dates, with lodging tending to increase with canopy height and yield gains. Pod height was correlated with canopy height and was greatest for varieties Sirius and Rainbird. Spearfelt consistently had low lodging.

December–January sowing is recommended for Sirius, Rainbird and Spearfelt, and a January sowing is recommended for Actolac and Pan 12.

Introduction

In subtropical Queensland, navy bean (*Phaseolus vulgaris* L.) crops can be grown over a wide range of sowing dates—October–February in the south, March–August in the north. With the release of new varieties with increased yield potential and different growth habits from traditional varieties (Redden 1993), the benefits of new varieties could be affected by differential growth responses to dates of sowing. Currently in south Queensland, January is the recommended month for sowing (Bean News 1995). Any new recommendations would need to be based on trials over a number of years to average out the possible influences of seasonal climatic variation.

Sowing date trials with *Vigna* spp. indicated that optimum sowing dates for grain yield varied from November for green gram, December for black gram and December–January for adzuki beans (Lawn 1979). Grain yields of *Phaseolus vulgaris* have shown different optimal sowing dates by variety in Brazil (Ramalho *et al*. 1993), India (Vyas *et al*. 1990), Mexico (Valenzuela-Lagarda 1985), and Italy (Ranalli *et al*. 1984). But such variety x sowing date interactions are not always found (Iglesius *et al.* 1984 in Cuba, Lozano *et al.* 1983 in Puerto Rico, Grafton and Schnieder 1985 in the USA, Sharma *et al.* 1990 and Sekhon *et al.* 1992 in India). The occurrence of optimal sowing dates is common in most cropping regions variously affected by disease incidence (Siviero *et al.* 1985; Azmi and Rathi 1992; Tu 1993) and climate (Iglesias *et al*. 1984; Heyer *et al*. 1988; Dodd 1991; Scheunemann 1991; Vieira 1991).

Different sowing dates result in different photoperiod and temperature regimes which affect both phenology and various growth parameters in *Vigna* spp. (Lawn 1979*a*, 1979*b*) and *P. vulgaris* (Wallace 1985). For mechanised harvesting in Australia, potential sowing date influences on phenology as well as upon canopy height, pod height and lodging (Redden *et al.* 1985) may be relevant to sowing time recommendations for new navy bean varieties. Wallace (1985) hypothesised that yield expression will be maximised at the minimum time to flowering. Newly released varieties have higher pods and more erect growth habit than traditional varieties, enabling direct harvesting instead of the traditional cutting and windrowing (Redden 1993). Any changes in sowing date recommendations must take into account effects on both harvestability and grain yield.

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This study examines whether recommendations for time of sowing in southern Queensland from November to February might be affected by differences among 5 varieties in phenology, grain yield and growth traits relevant to crop management.

Materials and methods

The trials were located at the Queensland Department of Primary Industries J. Bjelke-Petersen Research Station, Kingaroy, over 4 summer–autumn growing seasons from 1991 to 1994.

December, January and February mid-month sowing dates were used in each season, with the addition of a mid November sowing date for the last 2 seasons (Table 1). Actual sowing dates varied by up to 6 days around the intended mid-month target due to logistic and incident rainfall influences. Mean monthly maximum and minimum temperatures did not vary more than 2–3ºC each season, however, critical temperatures affecting abortion of reproductive organs above 35ºC before, during and after flowering (Agtunong *et al*. 1992), were exceeded in a low but erratic frequency, especially in December and January and the 1991 and 1994 seasons (Table 1). Seasonal rainfall varied widely, with 1993 being relatively dry (Table 1).

Five navy bean varieties were sown, 4 at each date

Table 1. Date of sowing and climatic data for the growing seasons, 1990–94

Year	November	December	January	February	March	April	May	Seasonal mean
				1991				
Mean max. temp.	30.2	31.6	30.1	29.5	29.5	26.9	23.7	24.5
Mean min. temp.	9	19	7	1	4	—	—	—
No. of days >32ºC	9	19	7	1	4	—	—	
No. of days >35ºC	2	5	1	—	1	—	—	
Rainfall (mm)	49	97	150	88	49	1	36	
Sowing date	—	17	17	18				
				1992				
Mean max. temp.	29.7	29.6	31.5	28.7	27.1	24.2	21	27.4
Mean min. temp.	15.5	16.3	17.9	18.8	15.7	13.4	10.1	15.4
No. of days >32ºC	8	8	15	6	—	—	—	
No. of days >35ºC	1	—	1	—	—	—	—	
Rainfall (mm)	55	149	68	113	155	29	62	
Sowing date	—	18	13	14				
				1993				
Mean max. temp.	28.4	29.6	30.2	30.7	28.9	27.6	23.7	28.4
Mean min. temp.	14	16.5	17.6	17.8	14.6	11.3	9.6	14.5
No. of days >32ºC	4	9	5	9	1	—	—	
No. of days >35ºC	1	2	—	3	—	—	—	
Rainfall (mm)	93	53	133	76	20	0	34	
Sowing date	13	11	9	15				
				1994				
Mean max. temp.	28.5	28.9	32.5	27.2	25.7	24.9	23.6	27.3
Mean min. temp.	14.7	15.3	18.7	17.5	14.6	11.3	5.0	13.9
No. of days >32ºC	4	7	19	—	—	—	—	
No. of days >35ºC	1	1	7	—	—	—	—	
Rainfall (mm)	98	130	51	96	121	6	25	
Sowing date	16	15	12	9				
				Solar radiation (MJ/m^2. day)				
1991	23.6	19.9	18.9	19.8	16.7	15.3	10.9	
1992	15.2	—	—					
1993	22.2	20.9	22.2	20.3	18.5	16	11.1	
1994	19.1	20.2	15.6	16.1	15.1	11.2	10.2	
				Mean evaporation by month and year (mm/day)				
1991	6.7	6.7	5.3	5.2	5.2	3.8	2.5	
1992	6.5	6.6	7.1	4.7	4.2	3.2	2.1	
1993	6.7	6.3	6.5	5.9	5.5	4.5	2.7	
1994	5.9	6.6	7.2	4.4	3.9	3.7	2.7	

and a fifth (Pan 12) for 3 seasons, 1991–93, along with unreported new selections. The varieties ranged from the early maturing Actolac and Pan 12 to the late maturing Sirius, Rainbird and Spearfelt which were 3 new varieties bred in Queensland (Redden 1993) (Pan 12 was under consideration but never released).

A randomised split-plot design with 3 replicates was used each year with sowing date as the main plot and varieties as subplots. Plots consisted of 4 rows, 90 cm apart, of harvested length 6–7 m, with the 2 centre datum rows used for direct mechanical harvesting. The trial was fully spray irrigated according to an evaporation pan water deficit schedule for full replacement of water lost through evapotranspiration to a soil depth of 30 cm. Fertiliser was applied at sowing each year at a rate of 60–80 kg/ha of nitrogen and 20–30 kg/ha of phosphate and potassium. Seeding rate was 250 000 seeds/ha. A standard pesticide application regime controlled various insect pests, and weeds were controlled pre-emergence by Tri-flurilan and post-emergence by cultivation and hoeing.

Data were collected on: (i) stand establishment; (ii) days from sowing to flowering (50% of plants with first flower); (iii) days from sowing to physiological maturity at about 60 days after sowing (pods 80% yellow); (iv) canopy height of upper leaf surface (excluding apical vines) (cm); (v) vining (scale: 1, determinate to 4, indeterminate); (vi) lodging percentage at maturity (20% near erect, 30% inverse pyramid shape, 40% umbrella shape, 50% with branches dragging on the ground to 90% prostrate); (vii) pod height index (3, 50% of pods on the ground; 5, tips of lowest pods touching the ground; 7, lower pods >3 cm above the ground; 9, lower pods >5 cm above the ground); and (viii) harvested grain yield at assumed 12% moisture. In 1993, a 1 m subsample from a plot guard row, sown within 1 month of the adjacent plot, also provided total vegetative dry matter estimates at about 60 days after sowing. Canopy height, vining, lodging and pod height all describe plant type and in aggregate determine suitability for direct heading.

Results

Mean growth responses by sowing date and season

A November sowing date was included in only the last 2 years of the 4-year trial. The interpretation of results concentrates on the December, January and February sowing dates.

Grain yield was dramatically affected by the November and December sowings in 1993 by heavy infestations of grey mould (*Macrophomina* spp.) which devastated growth and pod set during the reproductive growth phase (Fig. 1*a*). Infestation of grey mould is associated with a combination of hot and dry conditions as illustrated by the relatively low rainfall in December 1993 (Table 1).

Seasonal trends for grain yield, with a 2-fold range even under irrigated conditions, interacted very strongly with date of sowing. In 2 seasons, a December sowing resulted in much greater yields than at other dates, with the reverse effect in 1993, and no clear difference between December and January sowings in 1992. In general, yields were depressed by a February sowing, although in 1991 the February sowing tended to outyield the January sowing. Temperature, heat stress or other climatic factors were not associated with these seasonal differences (Table 1).

Grain yield with a January sowing, though usually lower than for a December sowing, was more consistent and less risky in regard to grey mould.

Flowering responses to date of sowing were for earliness to be associated with January and February sowings with the exception of 1991 with earliest flowering in a December sowing (Fig. 1*b*). Maximum and minimum temperatures for December in the 1991 seasons were higher than in other years (Table 1). In 1993, the November sowing resulted in delayed flowering; this result may reflect the influence of grey mould infection in 1993. Except for 1991, the minimum time to flowering tended to occur following a January sowing, although it was not dissimilar from February sowing in 3 years.

Maturity data showed very large interactions between season and date of sowing, a larger range than for time to flowering (Fig. 1*c*). Maturity showed a significant correlation of 0.46 with time to flowering.

Maturity was shortest with a January sowing in 3 years, the exception being 1993 where the disease-affected November sowing was earliest. In 3 years, maturity was delayed with a February sowing. Maturity was also delayed by a December sowing in all years except 1991. An extraordinary delay in maturity occurred with a November sowing in the 1994 season, which was not affected by grey mould infection.

Maturity showed a weak negative correlation of –0.2 with grain yield, whereas there was no significant correlation of grain yield with time to flowering.

Mean canopy height was variable, depressed from 55 to 50 cm with late sowing dates in 1991, peaking at 60 cm with a January sowing in 1992, depressed to 47 cm with December and January sowings in 1993, and unchanging in 1994 except for reduced height (from 52 to 40 cm) in the February sowing [(P = 0.05) = 3.7]. Overall there was an inconsistent trend for reduced height with a February sowing. Canopy height was positively correlated (0.4) with grain yield.

Vineyness or tendency to be indeterminate showed a broadly consistent trend over seasons to decrease with later sowing dates and to be maximised at the early sowing dates (from 2.1 scale of determinency in December to 1.5 in January–February 1991 and 1992,

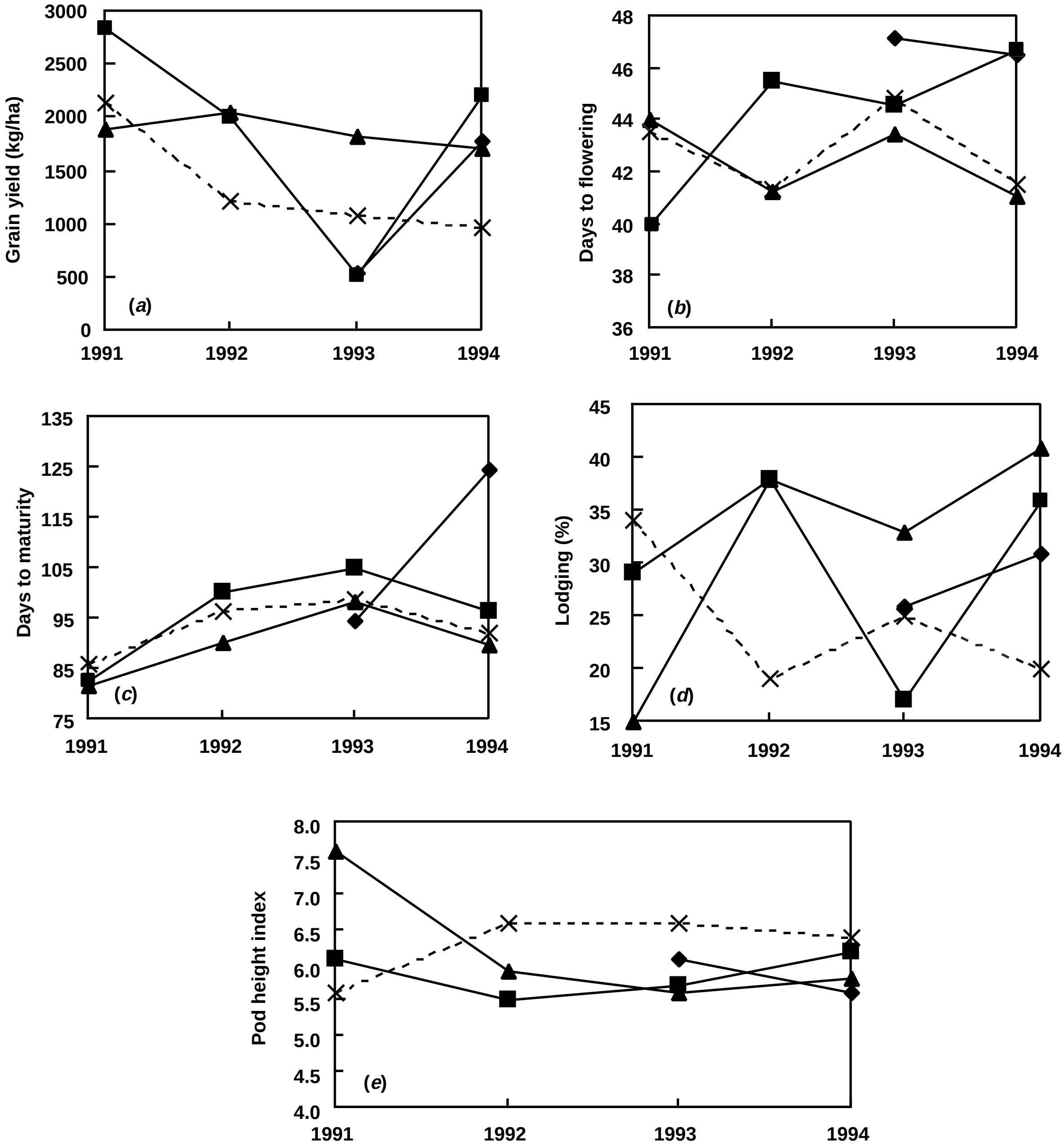

Figure 1. Monthly mean responses over years. (*a*) Grain yield: year x date l.s.d. (P = 0.05) = 480; years, date l.s.d. (P = 0.05) for each = 240. (*b*) Days to flowering: year x date l.s.d. (P = 0.05) = 1.1; years, date l.s.d. (P = 0.05) for each = 0.5. (*c*) Days to maturity: year x date l.s.d. (P = 0.05) = 2.4; years, date l.s.d. (P = 0.05) for each = 1.2. (*d*) Lodging: year x date l.s.d. (P = 0.05) = 8.7. (*e*) Pod height index: year x date l.s.d. (P = 0.05) = 0.76; years, date l.s.d. (P = 0.05) for each = 0.36. ◆ , November; ■ December; ▲ , January; **x** , February.

or from 1.7 in November to 1.1 in February 1994 [(P = 0.05) = 0.2].

Lodging levels during pod fill tended to be least with a February sowing, except in 1991 and the exceptional 1993 season with grey mould infection of the early dates (Fig. 1*d*). Lodging was positively correlated (0.45) with grain yield, and weakly correlated (0.26) with canopy height. Higher yielding taller crops tend to lodge. However, in 1994 the high yielding December sowing tended to lodge less than for the January sowing with an equally tall canopy, and in 1991 the December sowing, though higher yielding and taller than the February sowing, tended to lodge less. As expected, lodging was negatively correlated (–0.35) with pod height at harvest.

Pod height increased with a February sowing and the associated reduced lodging and yield (except in 1991), and was highest in the 1991 January sowing (Fig. 1*e*). There was a positive correlation (0.38) between pod height and canopy height. There was little interaction between seasons and dates of sowing upon expression of pod height. Amongst years, pod height varied slightly, above 6 (just above the ground) in 1991 and mainly below 6 in other years.

Stand establishment was generally close to 20 plants/m (200 000 plants/ha), although it was significantly low for December 1991 (175 000 plants/ha) and January 1993 (120 000 plants/ha) sowing dates and the 1992 season (about 170 000 plants/ha).

There was no significant response of total dry weight to either sowing date or variety in 1993, the only season in which this was monitored.

Overall, date of sowing effects were strongly influenced by seasonal effects. Grain yield and lodging were greatest at intermediate sowing dates; both days to flowering and maturity decreased with later sowing dates, although with a February sowing, maturity occurred later than for a January sowing; vineyness decreased and pod height increased at later sowing dates while canopy height, although least with a February sowing, was inconsistent.

Varietal interactions with sowing date and season

Variety x year interactions were significant ($P<0.05$) for all traits except grain yield and lodging. Variety x sowing date interactions were significant for all traits measured, although only at $P<0.06$ for pod height (Fig. 2*a* and *b*).

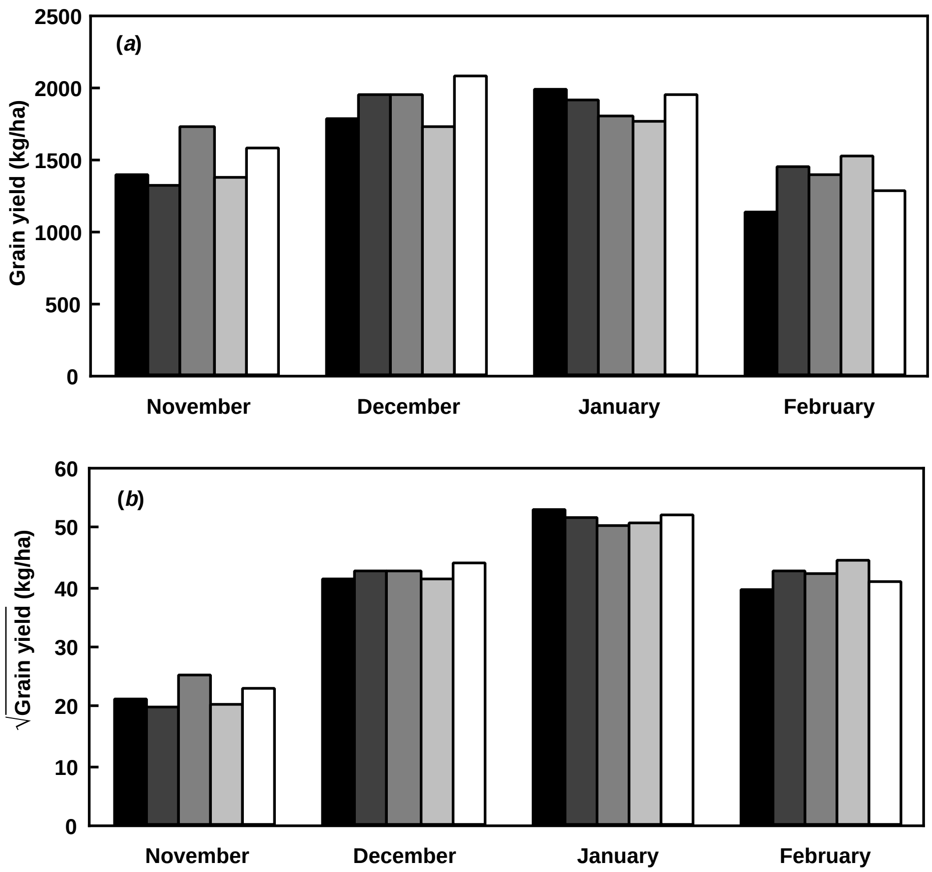

Figure 2. Grain yield (kg/ha) over years for varieties at respective sowing dates, as original and as transformed data. (*a*) Original data: date x variety l.s.d. ($P = 0.05$) = 325, within months = 246; years, date l.s.d. ($P = 0.05$) for each = 124. (*b*) Yield covariate with maturity, with square root transformation: date x variety l.s.d. ($P = 0.05$) = 5.6, within months = 5.0; years, date l.s.d. ($P = 0.05$) for each = 2.0. Solid bars, Actolac; heavily stippled bars, Rainbird; mediumly stippled bars, Sirius; lightly stippled bars, Pan 12; open bars, Spearfelt.

Sowing in January maximised yield for the early maturing varieties Actolac and Pan 12, and for the late maturing varieties, sowing in December maximised yield (Fig. 2*a*), although differences between December and January sowings were not significant. When adjusted for maturity on square-root-transformed yield data, yield was maximum for all varieties with a January sowing and minimum with a November sowing (Fig. 2*b*). Efficiency of yield production over time was maximised with a January sowing although optimum sowing dates for yield expression were affected by varietal differences in maturity.

Variety x year x sowing date interactions were significant. Maximum yield was equally associated with December and January sowings for the early maturing Actolac and Pan 12 varieties, but with a December sowing for the late maturing Rainbird, Sirius and Spearfelt varieties. The exception was 1993 with grey mould infection associated with sharply reduced yield in the December sowing.

The longest time to flowering occurred with the November sowing for all varieties (Fig. 3), but not significantly later than the December sowing in 1994 except for Actolac. For all varieties, the minimum time to flowering in 1991 occurred with the December sowing, and this recurred in 1993 with Actolac, but in other years the least time to flowering was observed for the January and February sowings.

For Pan 12, February sowing gave the earliest flowering on average but for the other varieties this occurred with a January sowing. For Rainbird and Spearfelt, the differences between January and February sowings were not significant in 3 of the 4 years.

Maturity occurred 10–14 days earlier in 1991 for all varieties compared with other seasons. Actolac and Spearfelt, although early and late in maturity respectively, were each earliest over the January–February sowing dates with seasonal variation (November 1993). Pan 12 clearly reached maturity the earliest following a January sowing, while Rainbird and Sirius were very inconsistent over seasons for expression of earliest maturity in January [85, 91, 107, 92 days (Rainbird) and 83, 92, 109, 93 days (Sirius) from 1991 to 1994] (Fig. 3). Specific expressions included the relative lateness by 5–10 days of Actolac in the 1993 December and January sowings, and the relative earliness of Rainbird, Sirius and Spearfelt in the January 1992 sowing.

Canopy height trends (53, 52, 52 and 46 cm for November–February sowings) showed consistency amongst varieties with mean values (cm): 45 Actolac, 53 Spearfelt, 46 Pan 12, 54 Rainbird, 56.5 Sirius. Height was maximised with the November sowing in 1993 for all varieties except Actolac (February), the December sowing in 1991, the January sowing in 1992 and the December and January sowings in 1994 except Sirius

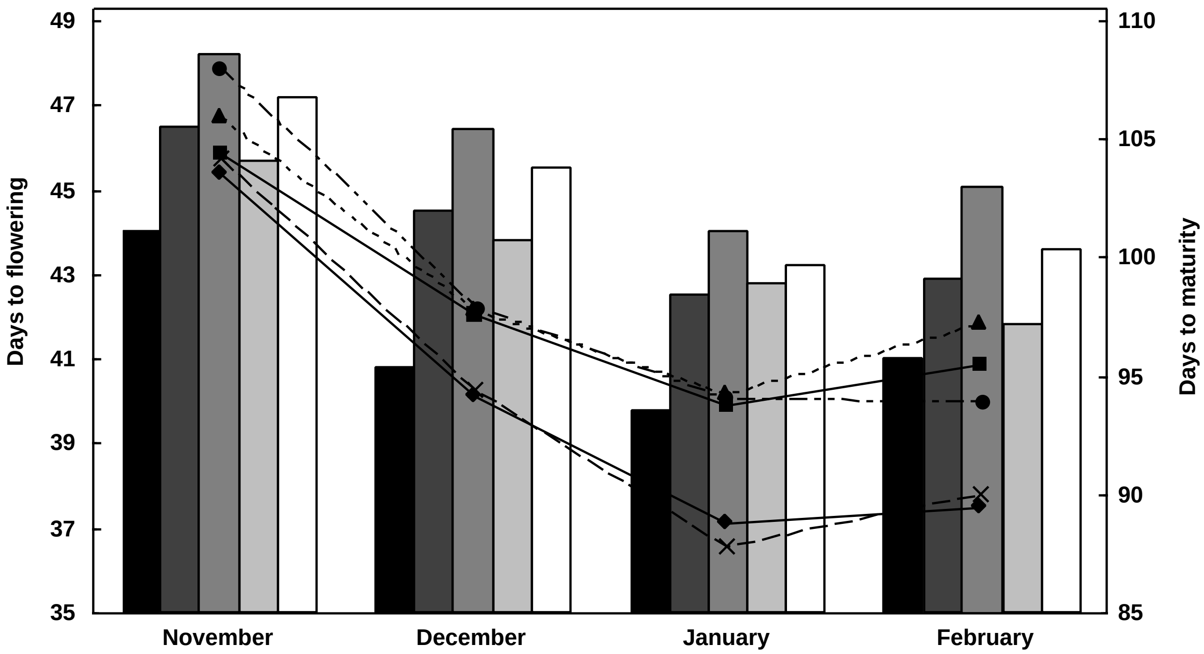

Figure 3. Varietal means for days to flowering (solid bars, Actolac; heavily stippled bars, Rainbird; mediumly stippled bars, Sirius; lightly stippled bars, Pan 12; open bars, Spearfelt) and maturity (◆ Actolac; ■ Rainbird; ▲ Sirius; x Pan 12;

(January). The new varieties, Rainbird and Sirius, were both tall and late, giving a small positive correlation (0.22) between these traits.

Vining trends by season and sowing date were absent for the determinate varieties Rainbird (score 1.1) and Spearfelt (1.0) or just tending to indeterminacy for Actolac (1.3–1.5) in the November and December sowings. Pan 12 tended to change from semi-determinate (2–3) over November–January sowings to fully determinate (1) in the February sowing, while Sirius showed a consistent response from an indeterminate (4) toward a semi-determinate (1.5) habit from November to February sowings.

Lodging responses to season and sowing date were highly variety-specific (Fig. 4). The greatest reduction in lodging occurred with the February sowing. Spearfelt consistently lodged least (10–37%) followed by Pan 12 (10–42%), with levels mainly 30–45% for the other varieties. For all varieties, the January 1991 sowing had the least lodging, this coincided with the lowest yield of the 1991 sowing dates. Lodging was greatest for Rainbird and Actolac with January and February sowings, for Spearfelt with January sowing, and for Sirius and Pan 12 with December and January sowings. There was a positive correlation of 0.45 for lodging with grain yield.

Pod height responses generally differed more by variety than by season or sowing date (mean scores were: Actolac 5.3, Pan 12 5.5, Sirius 6.5, Rainbird 6.8, Spearfelt 6.2). Being positively correlated (0.38) with canopy height and negatively correlated (–0.35) with lodging no trends with sowing date or season emerged. Pod height was maximised for all varieties in the 1991 January sowing, which also had low lodging, early maturity and relatively low yields. A small pod height response to sowing date was found for 2 of the determinate varieties, Actolac and Rainbird, which tended to have highest pods in January and February sowings, while for Sirius a score of 4.0 in the 1992 December sowing was associated with high lodging (Fig. 4).

Overall, the indeterminate varieties Sirius and Pan 12 tended to be most sensitive to date of sowing responses especially for vining, lodging and pod height. Thus the maximum yields for Sirius in December sowings were associated with maximum lodging and lowest pod heights. Maturity and canopy height tended to be maximum in November sowings and least in January–February sowings with varietal differences. Responses of flowering time to date of sowing tended to be similar to that for maturity but with a smaller delay effect of November sowing and a clearer trend for earliness to occur with a January sowing. Grain yield responses to sowing date were strongly affected by season and variety, and by grey mould infection in 1993. Generally early maturing Pan 12 and Actolac yielded best over the December and January sowings, while later maturing varieties clearly favoured a December sowing.

Over sowing dates, yield tended to be positively associated with height in November and December

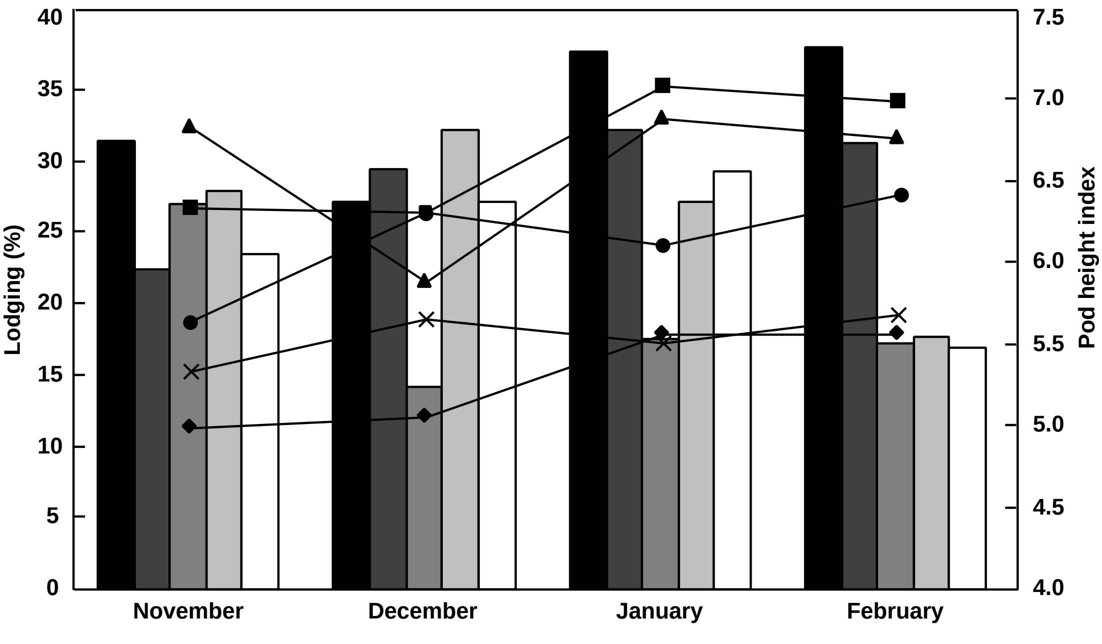

Figure 4. Mean pod height (◆ Actolac; ■ Rainbird; ▲ Sirius; x Pan 12; ● Spearfelt) and lodging percentage (solid bars, Actolac; heavily stippled bars, Rainbird; mediumly stippled bars, Sirius; lightly stippled bars, Pan 12; open bars, Spearfelt) over years for variety x date of sowing.

sowings, but not in January and February sowings. Similarly, yield was positively associated with flowering and maturity in November only, but negatively associated with a December sowing. The maturity trends were partly due to seasonal ‘clumping’ of data, hence seasonal rather than varietal effects were dominant.

Discussion

Grain yield can be increased by sowing late maturing varieties in December, rather than in January which is the recommendation for the traditional early maturing variety Actolac. Grey mould, however, may be more likely to occur with an earlier sowing date although in a related row spacing trial serious grey mould infestation occurred with a January sowing in 1991 (R. J. Redden unpublished data). In the present study, there were significant varietal differences in grey mould infection from maximum values as low as 2.7 for Sirius to 5 for Spearfelt on a 1–9 scale of increasing severity. Further evaluation of varietal differences in disease reaction (R. Redden unpublished data) may enable certain new late maturing varieties to be recommended for a December sowing to optimise their yield potential.

Wallace (1985) hypothesised for *Phaseolus vulgaris* that maximum yields and highest harvest index would be associated with each variety's minimum time to flowering and maturity, over both temperate and tropical environments. This coincidence was found for all varieties in 1991 with the December sowing, and for Actolac with a January 1992 sowing but not for other variety x season combinations where equivalent yields between December and January sowings were accompanied by time to flowering differences (Actolac 1994; Rainbird 1992, 1994; Sirius 1992; Pan 12 1992; Spearfelt 1992). In some cases, maximum yields occurred with a December sowing with minimum time to flowering in January and February (Sirius 1994, Spearfelt 1994, Pan 12 1994). Maturity had even less association with maximisation of yield by variety, tending to be latest with a November sowing and earliest with a January sowing for all varieties if 1993 comparisons are excluded. These results provide evidence supportive of the Wallace hypothesis only for 1991, and are inconsistent or contradictory in other years. The photoperiod regime by date of sowing was broadly similar between years, with a maximum of 9 days variation. Temperature differences were marginal between years, mean maximums 1–2°C higher in November and December 1991, and 2–3°C lower in February and March 1994. Agtunong *et al.* (1992), and Redden *et al.* (1993) found different varietal optimum temperatures over a much wider 10°C range, and the small temperature differences in this study do not appear to be sufficient to account for genotype x sowing date variation in yield and phenology.

The varieties least responsive or most stable in grain yield to date of sowing were Sirius and Pan 12, while the most responsive or unstable were Actolac and Spearfelt. Except for Sirius, yield expression was less variable with a January sowing. No varietal differences in sensitivity of phenologic responses to date of sowing were evident.

Pod height was maximised for all varieties in 1991 in the January sowing which was also low yielding and associated with low lodging scores. Similarly, increased pod height in the February sowings, 1992–94, was associated with low yields and reduced lodging scores. Seasonal variation in pod height occurred least for Actolac and most for Sirius, Rainbird and Spearfelt which have the greatest heights for both canopies and pods. Thus mechanised harvesting is facilitated more by choice of variety than by sowing date. Similarly, reduced lodging is strongly affected by choice of variety, but with lodging associated with yield maximisation. Provided that harvesting is not unduly affected by either vining or lodging, sowing time is best chosen for yield maximisation according to varietal choice. Besides greater yield potential, the new varieties are also more erect, with pod height apparently adequate (score ≥6) for direct heading at all dates.

Actolac, Rainbird and Spearfelt were unusually all semi-determinate in the 1991 December sowing. Although vining tended to be greater at earlier sowing dates, there was no simple relationship between vining and lodging (correlation not significant). Insufficient information was available to relate date of sowing interactions to possible varietal differences in canopy cover and hence interception of solar energy.

The yield results justify a recommendation for southern Queensland to plant the late maturing new varieties in the December–January period for which harvestability in terms of canopy height, pod height and lodging are acceptable and differentiated by variety from the traditional Actolac which tends to yield best with a January sowing. These results are consistent for adjusting sowing dates by varietal maturity, assuming that the optimum reproductive growth period for yield production under irrigation is in the February–March period, after the summer heat but before low temperatures (below 15°C) occur in late autumn.

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