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An Evaluation of Growth Characteristics of Faba Bean Cultivars

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Abstract: Resistance to herbicides and the lack of new herbicide options have led researchers to explore alternate methods to manage weed populations in large-scale cropping systems. Crop competition is an effective weed management approach that can reduce the pressure on herbicides. Faba bean (*Vicia faba* L.) is an important winter legume crop in Australia. Crop traits such as, height, biomass, growth rate, tillering capacity, leaf area, and root growth have been suggested as indicators of the competitive ability of crops against weeds. Based on pot studies at Narrabri and Toowoomba, we assessed the growth traits (biomass, height, leaf area, relative growth rate, and branch number) of six faba bean cultivars and ranked them for their potential ability to compete with weeds. PBA Marne and PBA Zahra were identified as highly competitive faba bean cultivars based on their higher overall ranking score achieved at both locations. PBA Nasma and PBA Samira were ranked highly and moderately competitive at Narrabri and Toowoomba sites, respectively. At Narrabri, PBA Nanu was ranked poorly competitive based on its lower biomass, height, and leaf area than the other cultivars. The weed suppressive ability of these cultivars needs to be assessed in the presence of weeds under field conditions.

Keywords: crop competition; weed-suppressive ability; faba beans; *Vicia faba* var. major

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1. Introduction

Over the past four decades, conservation cropping systems based on reduced tillage and residue retention, have largely replaced intensive tillage-based systems in many agricultural regions globally, including Australia [1,2]. This shift in cropping systems was made possible through the availability of highly effective herbicides for in-crop and fallow weed control. However, the absence of alternate weed control methods suited to routine use in conservation cropping systems, has resulted in growers relying on herbicides. Consequently, this has led to the widespread evolution of herbicide resistance in several weed species that are prevalent in Australian cropping regions [3–5]. For instance, more than 70% of populations of annual ryegrass (*Lolium rigidum* L.) are herbicide resistant [6]. Herbicide resistance prevents effective use of herbicides and is therefore, a major threat to the sustainability of conservation cropping systems. For this reason, it is necessary to explore alternate weed control methods that can complement herbicide use to manage resistant weed populations.

Crop competition is an effective, non-chemical strategy used for suppressing weed growth and development. Crop competition can be increased using agronomic approaches such as increased sowing rates [7,8], reduced row spacing [9,10], altered sowing time [11,12] and selection of competitive crops and/or cultivars [13,14].

Faba bean (*Vicia faba* L. var. *major*), is a winter legume crop and in Australia, it is valued for its role as a break crop in rotations and its ability to improve soil fertility by establishing a symbiotic association with nitrogen-fixing bacteria [15,16]. Faba bean was first grown in Australia in the early 1980s and since then the total production has increased

steadily from less than 0.1 million tons (Mt) in 1985 to 0.4 Mt in 2017 [17]. This crop has been traditionally grown in the Mediterranean climates of South Australia, Victoria, and Western Australia, but its area of production has now expanded into the northern grains region areas of Queensland and northern New South Wales. Faba bean is more competitive against weeds than other winter legumes such as chickpea and field peas [18–20]. However, this crop is still considered a poor competitor against weeds, owing to its slower initial growth and lack of early-season ground cover compared to cereals [14].

Crop cultivars and genotypes can differ in their competitiveness with weeds [21,22]. Plant traits such as increased crop height, early vigour, higher biomass, tillering capacity, leaf number and angle, leaf area, and branching/tiller production have been shown to be indicators of competitiveness against weeds [23,24]. Early biomass accumulation is an important trait that is directly related to the competitiveness of a crop against weeds [25]. Based on growth traits of six faba bean cultivars (PBA Nasma, PBA Samira, PBA Zahra, PBA Nanu, PBA Warda, PBA Marne), this study aims to identify the most competitive cultivars for the northern grains region of northern NSW and southeast Queensland.

2. Materials and Methods

Two pot experiments, one at the Leslie Research Centre Toowoomba, QLD (27°32′4.21″ S; 151°56′12.08″ E; 605 m a.s.l.) and the other at the I. A. Watson International Wheat Research Centre, Narrabri, NSW (30°16′15.38″ S 149°48′23.78″ E; 215 m a.s.l.) were conducted during the winter growing season (May to August) of 2018 to compare the growth and potential competitive ability of six commercial cultivars of faba bean. The climatic data (mean monthly, and daily minimum and maximum temperature) for both sites was obtained from nearby weather stations (Figure 1) [26]. At both sites, experiments were conducted in an outdoor bird-netted area to allow for comparisons of location effect. The six faba bean cultivars chosen for this study were PBA Marne, PBA Nanu, PBA Nasma, PBA Samira, PBA Warda and PBA Zahra (Table 1). These cultivars were selected following consultation with faba bean breeders and a review of a recommended variety guide for Australia [27].

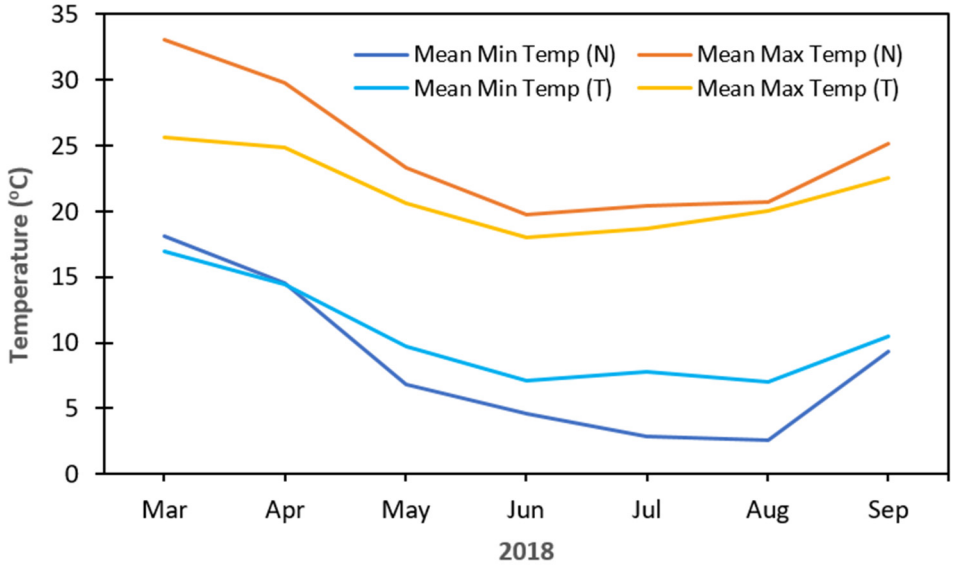

Figure 1. The mean monthly minimum and maximum temperatures (°C) of Narrabri (N), NSW and Toowoomba (T), Queensland sites recorded from the nearest weather station [26].

Table 1. Faba bean cultivars characteristics and source of seed used in pot studies conducted at Narrabri and Toowoomba.

Cultivar	Year Released	Maturity (Season)	Seed Source
PBA Warda	2012	early	trial seed
PBA Nasma	2015	early	commercial
PBA Samira	2015	late	trial seed
PBA Zahra	2016	mid to late	trial seed
PBA Nanu	2018	early	commercial
PBA Marne	2018	mid to late	trial seed

To determine average seed weight of each cultivar three replicates of five hundred seed lots were weighed. The average weight (g) of 100 seed lots was then calculated for each cultivar. The seed of these cultivars was acquired from plant breeders (PBA Nasma, PBA Samira, PBA Zahra) or commercial seed suppliers (PBA Nanu, PBA Warda, PBA Marne).

At both sites, plants from each of the six cultivars were subjected to destructive harvests at four growth stages. At each site, there were 6 cultivars × 4 sampling times × 6 replicates (Table 2). At both locations similar procedures were used for planting, watering, and fertilizing pots. Faba bean plants (one in each pot) were established by planting a single seed at a depth of 3 cm in the centre of 30 cm diameter plastic pots filled with a commercial potting mix (UltraGrow, Centenary Landscaping Supplies, Darra, QLD, Australia). After planting, the pots were placed on benches in a bird netted area where they were watered regularly throughout the experiment to maintain them at or near field capacity. The timing of seedling emergence (when the cotyledons are fully emerged) was recorded. The growing plants were fertilized regularly with an aqueous solution of a commercial fertilizer (Yates Thrive® NPK 25:5:8.8 plus S 4.6, Mg 0.5, Fe 0.18, B 0.005, Cu 0.005, Zn 0.004, Mo 0.001).

Table 2. Operations, date performed, and accumulation of growing degrees days (GDD) for faba bean cultivar pot experiments at Toowoomba, QLD and Narrabri, NSW 2018.

Operations	Growth Stage/BBCH Code	Site			
		Toowoomba	GDD $^{\alpha}$	Narrabri	GDD
Planting date		30 May		30 May	
Emergence date		14 June		13 June	
Sampling time 1	early growth/20	12 July (28) *	361.3	9 July (26)	322.4
Sampling time 2	early growth/22	19 July (35)	443.5	16 July (33)	378.6
Sampling time 3	late growth/30	26 July (42)	534.7	23 July (40)	453.6
Sampling time 4	flowering/50	16 August (63)	882.5	13 August (61)	713.6

* Values in parentheses are the number of days after emergence (DAE); α GDD = growing degrees days.

At each sampling time plant height, branching, leaf area, and dry weight biomass were determined. The leaf area was measured using a leaf area meter LI-3100C (LI-COR Inc., Lincoln, NE, USA). Leaves of freshly harvested individual plants were separated from their stems by cutting them at the petiole and then passing them individually through a leaf area meter. After the completion of leaf area measurements, all leaves of individual plants along with their respective stems were placed in paper bags which were then oven-dried at 70 ± 2 °C for 72 h before dry weights were recorded.

The relative growth rate (RGR) is an indirect measure of resource acquisition with higher rates associated with increased weed suppression. RGR was calculated using the formula of Hunt [28].

$$RGR = \ln(W_2) - \ln(W_1)/(t_2 - t_1) \quad (1)$$

where W_1 and W_2 are plant dry weights at times t_1 and t_2, t is the time (in days), and the subscript refers to the sampling time.

The growing degree days (GDD) or thermal time for faba bean plants grown at both locations (Narrabri and Toowoomba) were calculated by using the formula:

$$\text{GDD} = \text{Ave. daily temp.} - \text{Base Temp.} = (\text{max.} + \text{min.})/2 - \text{Base temp} \quad (2)$$

the base temperature for faba bean was taken as 0 °C [29].

In Toowoomba, the trial design was a randomized block design with six replicates while in Narrabri, the design was completely randomized with six replicates. As the trials at each location had different designs with large differences observed on same growth traits measured across two different sites, the data from each site were analysed separately. A one-way ANOVA was performed using Genstat 19th Edition on the data for all growth traits (biomass, height, leaf area, branch number) with cultivar the main effect and sample time the secondary parameter. Treatment mean comparisons were assessed based on Fisher's Least Significant Differences (LSD) test at $p = 0.05$. The data for sampling times 1–3 did not show consistent and clear results for all the parameters measured. Further, to manage complex interactions amongst different traits and sampling times, one-way ANOVA was performed separately on the data for final sampling time (4th) for each site. The data for 4th sampling time is presented here. Tukey's HSD was used for multiple pairwise comparisons among means.

The sampling times 1 and 2 typically represent early growth stages (BBCH code 20 and 22, respectively) while 3 and 4 correspond to late growth (code 30) and flowering stages (code 50) of the faba bean (Table 2; Figure 1) [30].

For each trait, a percentage score and a colour code was assigned to each cultivar based on the relative value for each trait. A score of 100% was assigned to top rated cultivar and percentage score was calculated based on this for rest of cultivars. To visually capture the performance of the cultivars, one table for each site was developed and individual cells coloured to indicate likely competitiveness.

3. Results

3.1. Dry Weight Biomass

In Narrabri, all long season cultivars (PBA Marne, PBA Zahra, PBA Samira) and one short season cultivar (PBA Nasma) produced greater ($p < 0.001$) biomass than PBA Nanu (Tables 3 and 4). All of these cultivars produced 40% more biomass than PBA Nanu. PBA Nasma produced 27% greater biomass compared to PBA Warda. In Toowoomba, there was no difference in the biomass production of the six cultivars (Tables 3 and 4; Figure 2). PBA Nanu, a short season cultivar recommended for northern NSW and southern QLD performed better in Toowoomba (southern QLD), producing about 2.5 times more biomass as compared to Narrabri (northern NSW). Similarly, all other cultivars performed better at Toowoomba as compared to Narrabri. Overall, the average biomass of all cultivars grown in Toowoomba was 36% greater than those grown in Narrabri.

Table 3. Dry biomass (g) of different faba bean cultivars grown in Narrabri and Toowoomba. Means with a different letter are significantly different at *p*-value ($\alpha = 0.05$).

Cultivar	Biomass (g)	
	Narrabri	Toowoomba
PBA Nanu	6.22 a	15.80 a
PBA Warda	8.69 ab	16.53 a
PBA Samira	10.76 bc	13.62 a
PBA Zahra	10.93 bc	16.26 a
PBA Marne	11.14 bc	15.89 a
PBA Nasma	11.81 c	14.37 a
LSD	2.79	3.04

Table 4. Analysis of variance for 4 traits of faba bean cultivars tested at two locations.

Traits	d.f	Narrabri		Toowoomba	
		f-Values	*p*-Values	*f*-Values	*p*-Values
Biomass (g)	5	1.49	0.001	3.83	0.332
Height (cm)	5	1.46	0.001	0.89	0.003
Leaf area (cm^2)	5	1.44	0.001	2.37	0.499
Branch count	5	0.67	0.551	1.05	0.010

Figure 2. Growth comparison of cultivars PBA Nanu (top) and PBA Zahra (bottom) at four different sampling times at Toowoomba, QLD site. (DAE = Days after emergence).

3.2. Plant Height

In Narrabri, PBA Nasma grew 31% and 11% taller than PBA Nanu and PBA Zahra. PBA Marne, PBA Nasma, PBA Zahra, and PBA Samira all grew on average 27% taller ($p < 0.003$; Table 4) than PBA Nanu (Table 5). In Toowoomba, PBA Nasma, PBA Samira and PBA Warda grew on average 23% taller than PBA Nanu (Table 4). Overall, the height of all cultivars grown in Toowoomba was 25% greater than those grown in Narrabri.

Table 5. Plant height (cm) of different faba bean cultivars grown in Narrabri and Toowoomba. Means with a different letter are significantly different at *p*-value ($\alpha = 0.05$).

Cultivar	Height (cm)	
	Narrabri	Toowoomba
PBA Nanu	22.40 a	28.75 a
PBA Warda	26.43 ab	36.67 cd
PBA Samira	28.88 bc	35.17 bcd
PBA Zahra	28.07 b	33.17 abc
PBA Marne	28.75 bc	30.83 ab
PBA Nasma	32.35 c	39.75 d
LSD	3.98	5.33

3.3. Relative Growth Rate

There was an interaction ($p = 0.024$) between cultivar and sampling time at the Narrabri site. The relative growth rate declined with age for all cultivars at this site (Figure 3A). The RGR of all cultivars was on average 35% higher at sampling time 2 (26–33 DAE) compared to sampling time 3 (33–40 DAE) and 4 (40–61 DAE). At Toowoomba, the RGR did not

change over the life of the study and there was no difference in the RGR of individual cultivars at any of the sampling times. Further, there was no difference ($p > 0.05$) in RGR between sampling times (Figure 3B).

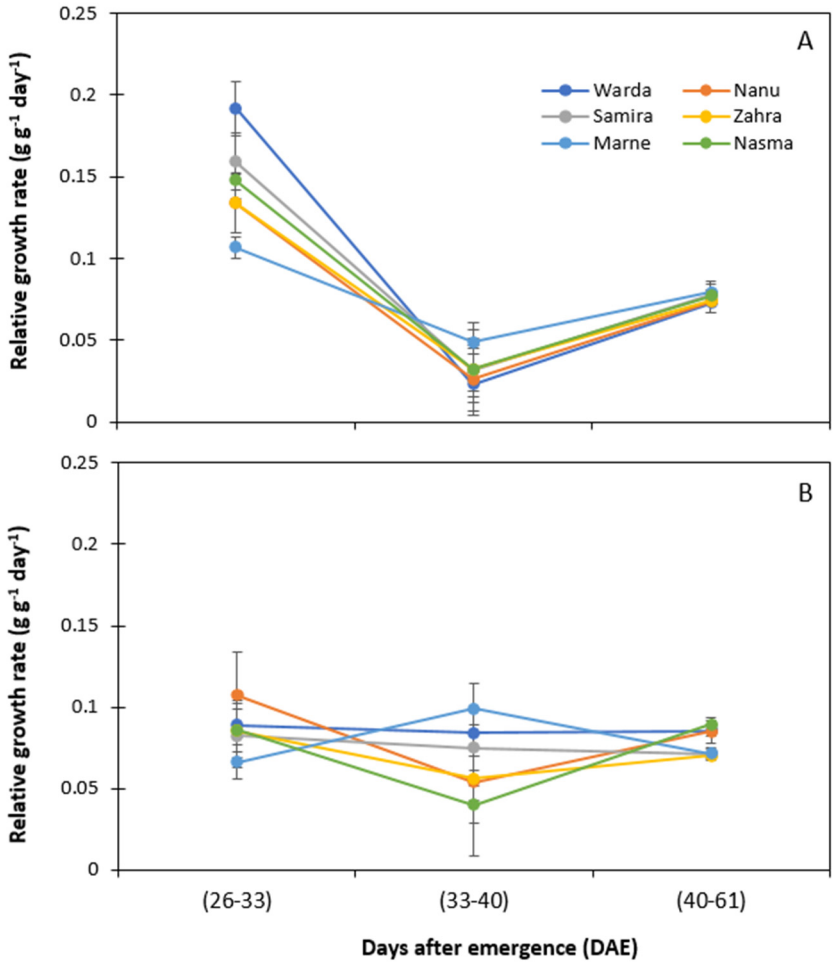

Figure 3. The relative growth rate (RGR) over time, days after emergence (DAE) of six cultivars of faba bean grown at Narrabri, NSW (**A**) and Toowoomba, QLD (**B**) in 2018 (LSD Narrabri: 0.035; Toowoomba: 0.046).

3.4. Leaf Area

The leaf area of each cultivar grown in Narrabri was smaller than those grown in Toowoomba (Table 6). On average, leaf area in Toowoomba was 38% greater than in Narrabri. However, cultivars performed differently across sites. For Narrabri, cultivar PBA Nanu had the least leaf area, on average 52% less ($p < 0.001$; Table 4) rest of cultivars. The leaf area of PBA Marne was 24% higher than PBA Warda. In Toowoomba, the leaf area of Zhara, was the highest and 15% greater ($p < 0.001$) than PBA Samira.

Table 6. Leaf area (cm^2) of different faba bean cultivars grown in Narrabri and Toowoomba. Means with a different letter are significantly different at *p*-value ($\alpha = 0.05$).

Cultivar	Leaf Area (cm^2)	
	Narrabri	Toowoomba
PBA Nanu	694 a	1819 ab
PBA Warda	1115 b	2011 ab
PBA Samira	1347 bc	1774 a
PBA Zahra	1323 bc	2086 b
PBA Marne	1453 c	1972 ab
PBA Nasma	1213 bc	1851 ab
LSD	283.6	293.7

3.5. Branch Count

Branching on faba bean cultivars was consistent across sites with no differences observed between Narrabri and Toowoomba (Table 7). At Narrabri, there was no difference in number of branches per plant produced by all six cultivars (Table 7). At Toowoomba, PBA Marne produced highest number of branches per plant and on average 34% greater ($p < 0.01$; Table 4) than PBA Warda, PBA Samira, and PBA Nasma (Table 7).

Table 7. Branch number ($plant^{-1}$) of different faba bean cultivars grown in Narrabri and Toowoomba. Means with a different letter are significantly different at *p* value ($\alpha = 0.05$).

Cultivar	Branch Number ($plant^{-1}$)	
	Narrabri	Toowoomba
PBA Nanu	5.00 a	6.33 ab
PBA Warda	5.00 a	5.50 a
PBA Samira	5.16 a	5.33 a
PBA Zahra	6.00 a	7.83 b
PBA Marne	5.83 a	8.00 b
PBA Nasma	5.16 a	5.16 a
LSD	1.42	1.53

3.6. Overall Ranking

At Toowoomba, the cultivars with the highest overall rankings for measured growth traits were PBA Zahra and PBA Marne (Table 8). PBA Warda, despite having good values, was heavily penalized by the smaller number of branches. PBA Warda, PBA Nasma, PBA Nanu and PBA Samira were all ranked as moderately competitive. PBA Zahra and PBA Marne are longer growing season cultivars and they performed better than all shorter season cultivars (PBA Warda, PBA Nasma, PBA Nanu) tested in this study. For Narrabri, the cultivars with the highest overall rankings for measured growth factors were PBA Marne, PBA Zahra, PBA Nasma and PBA Samira (Table 9). PBA Warda and PBA Nanu were ranked as moderately and poorly competitive, respectively. PBA Samira, a benchmark longer season cultivar, was ranked highly competitive at Narrabri.

Table 8. Comparison of growth measures of different faba bean cultivars grown in Toowoomba. For each trait, a percentage score and a colour code is assigned to each cultivar based on the relative value of trait attained. Cells are coloured to indicate likely competitiveness as follows <70 = red (poorly competitive), 71—80 = blue (moderately competitive), 81—90 = yellow (highly competitive), >90 = green (very highly competitive).

Cultivar	leaf Area (cm^2)	Branch Number	Height (cm)	Biomass (g)	Average Score
PBA Nanu	87.20	70.75	72.33	95.58	82.0
PBA Warda	96.40	68.75	92.25	100.00	89.0
PBA Samira	85.04	66.63	88.48	82.40	81.0
PBA Zahra	100.00	91.63	83.45	98.37	93.0
PBA Marne	94.53	100.00	77.56	96.13	92.0
PBA Nasma	88.73	64.50	100.00	86.93	85.0

Table 9. Comparison of growth measures of different faba bean cultivars grown in Narrabri. For each trait, a percentage score and a colour code is assigned to each cultivar based on the relative value of trait attained. Cells are coloured to indicate likely competitiveness as follows <70 = red (poorly competitive), 71—80 = blue (moderately competitive), 81—90 = yellow (highly competitive), >90 = green (very highly competitive).

Cultivar	Leaf Area (cm^2)	Branch Number	Height (cm)	Biomass (g)	Overall Score
PBA Nanu	47.76	83.33	69.24	52.67	63.0
PBA Warda	76.74	83.33	81.70	73.58	79.0
PBA Samira	92.70	86.00	89.27	91.11	90.0
PBA Zahra	91.05	100.00	86.77	92.55	93.0
PBA Marne	100.00	97.17	88.87	94.33	95.0
PBA Nasma	83.48	86.00	100.00	100.00	92.0

There were consistencies between the two sites with PBA Zahra and PBA Marne being ranked highly competitive based on measured growth traits. Our results suggest PBA Zahra and PBA Marne may be more competitive against weeds at a range of environments based on results obtained at both Narrabri and Toowoomba.

4. Discussion

Based on measured growth traits, we found consistencies between the two locations with PBA Zahra and PBA Marne both being ranked highly and suggested to be highly competitive (Tables 8 and 9). Both PBA Zahra and PBA Marne had greater biomass, more branches and greater leaf area than other cultivars, and all of these traits have been suggested to be correlated with competitive ability [31–33]. At both locations, PBA Nasma was ranked highest in terms of plant height, and based on overall traits score, this cultivar was ranked highly competitive at Narrabri. Tall genotypes of field pea (*Pisum sativum* L.) have reported to suppress the growth of annual ryegrass by 35% more than medium and short statured genotypes [14]. Aqtbouz and colleagues [34] evaluated the competitive ability of sixty landraces of Moroccan faba bean against a model weed, *Sinapis alba* L. The investigators found several landraces exhibiting high levels of weed tolerance and suppression. Likewise, the competitive ability of heterozygous faba bean genotypes was greater compared to inbred lines. The inbred lines suffered on average 30% more yield losses compared to heterozygous lines [35].

Both PBA Zahra and PBA Marne are longer season cultivars recommended for more southern environments (South Australia, Victoria and Southern NSW) while PBA Nanu and PBA Warda are shorter season cultivar adapted to the northern Australian grains region (Northern NSW and southern QLD). Despite being long season cultivars, both PBA Zahra and PBA Marne have shown better growth than most of the short season cultivars (PBA Nanu and PBA Warda). It is likely that these long season cultivars may be suitable

for the northern region, but this needs to be confirmed under field conditions. Further, this points to the potential opportunities for breeding more competitive faba bean cultivars suited to the northern environment. With the increasing reports of herbicide-resistant weed populations and potential impacts of herbicides on human health and environment, interest in breeding weed suppressive cultivars of crops is growing among research groups worldwide [24,36], with some commercial weed suppressive cultivars of crops (e.g., rice) available in the market [37].

The trait superiority of PBA Zahra, PBA Marne and PBA Nasma may also be due to their average larger seed weight (>60g/100-seed, Table 10) as compared to the rest of the cultivars tested. Our predictions for these faba bean cultivars agree with the findings of Place and colleagues [38] who compared the competitive ability of twenty-one soybean (*Glycine max* L.) genotypes with varying seed weight (6.2–24.9 g) against weeds and found that overall genotypes with large seed weight were positively correlated with weed suppression and soybean biomass accumulation. However, a range of characteristics, rather than a single trait are responsible for the competitive ability of crop cultivars in agroecosystems [23]. To test if the competitive ability could be predicted from plant traits, Gaudet and Keddy [31] studied the traits of 44 wetland plants and found a strong predictive relationship between plant biomass, height, and canopy and weed suppression.

Table 10. The seed weight (g) of six faba bean cultivars.

Cultivar	Seed Weight (g/100 Seeds) *
PBA Warda	51.94 (±2.16) a
PBA Nasma	74.87 (±3.01) e
PBA Samira	56.06 (±1.35) c
PBA Zahra	63.65 (±2.06) d
PBA Nanu	54.27 (±5.32) b
PBA Marne	62.08 (±1.36) d

* values shown in parentheses are standard errors for the three replicate samples. Values with a different letter are significantly different ($p < 0.05$); LSD = 8.87.

There were consistencies between the Narrabri and Toowoomba sites with PBA Zahra and PBA Marne both being ranked highly for measured growth factors. Nevertheless, there were some inconsistencies across both sites with PBA Nasma, PBA Warda and PBA Samira ranked lower at Toowoomba compared to the Narrabri site. The cultivar PBA Nanu was considered poorly competitive at Narrabri based on the lowest overall ranking score achieved, however it ranked higher in Toowoomba. These inconsistencies across two sites may be due to climatic differences between the two sites (Figure 1).

Rapid early growth is an important trait associated strongly to the competitive ability of a species [39]. In our study, no differences were observed among early biomass accumulation as assessed by comparing the relative growth rate values of all six varieties tested at Toowoomba. However, there was a significant cultivar × sampling time interaction found at Narrabri site. The higher relative growth rate of faba bean cultivars at early growth stages indicate their competitiveness at Narrabri.

Overall, plants of all cultivars at the Toowoomba site grew taller, produced more biomass and leaf area compared to the Narrabri site. These differences in growth traits across sites could have been due to differences in growing degree days (GDD), with Toowoomba site recording 135 more GDD than Narrabri (Table 2). In agroecosystems, the competitive advantage of crop cultivars may not just be due to specific trait superiority but may also be influenced by the environment × genotype interactions [40]. In a study conducted across multiple sites in southeastern Australia, Lemerle and colleagues [40] evaluated twelve competitive wheat genotypes for their weed suppressive ability. They found a significant genotype × environment interaction. No single wheat cultivar produced the highest level of annual ryegrass (*Lolium rigidum*) suppression at all sites suggesting local adaptation is important for a crop or cultivar competitiveness.

To confirm the suppressive ability and tolerance against weeds, these faba bean cultivars should be grown and assessed in the presence of weeds in field where other interacting biotic and abiotic factors are also present. Nevertheless, this pot-scale study, based on the ranking of different growth traits of cultivars at two locations, indicates the most competitive cultivars, PBA Zahra and PBA Marne would likely retain their trait-based competitive superiority in the field against weeds.

5. Conclusions

Crop competition is an effective and affordable weed control strategy that growers need consider in Australian cropping systems. Marne and Zahra are promoted as being highly competitive cultivars based on their growth traits.

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