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Effect of emergence time on growth and fecundity of redroot pigweed (*Amaranthus retroflexus*) and slender amaranth (*Amaranthus viridis*): emerging problem weeds in Australian summer crops

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Abstract

Redroot pigweed (*Amaranthus retroflexus* L.) and slender amaranth (*Amaranthus viridis* L.) are considered emerging problematic weeds in summer crops in Australia. An outdoor pot experiment was conducted to examine the effects of planting time on two populations of *A. retroflexus* and *A. viridis* at the research farm of the University of Queensland, Australia. Both species were planted every month from October to January (2017 to 2018 and 2018 to 2019), and their growth and seed production were recorded. Although both weeds matured at a similar number of growing degree days (GDD), they required a different number of days to complete their life cycles depending on planting date. The growth period was reduced and flowering occurred sooner as both species experienced cooler temperatures and shorter daylight hours. Both species exhibited increased height, biomass, and seed production for the October-sown plants compared with other planting times, and these parameters were reduced by delaying the planting time. The shoot and root biomass of *A. retroflexus* and *A. viridis* (averaged over both populations) was reduced by more than 70% and 65%, respectively, when planted in January, in comparison to planting in October. When planted in October, *A. retroflexus* and *A. viridis* produced 11,350 and 5,780 seeds plant^{-1}, but these were reduced to 770 and 365 seeds plant^{-1} for the January planting date, respectively. Although the growth and fecundity of these species were dependent on planting time, these weeds could emerge throughout the late spring to summer growing season (October to March) in southeast Australia and could produce a significant number of seeds. The results showed that when these species emerged in the late spring (October), they grew vigorously and produced more biomass in comparison with the other planting dates. Therefore, any early weed management practice for these species could be beneficial for minimizing the subsequent cost and energy inputs toward their control.

Introduction

Redroot pigweed (*Amaranthus retroflexus* L.) and slender amaranth (*Amaranthus viridis* L.) are monoecious summer annuals of the Amaranthaceae family. Both species are widely distributed in temperate and warm temperate countries of the world, including countries in Africa, Asia, Europe, and North America (Holm et al. 1997; Uva et al. 1997; Waselkov and Olsen 2014). These species are also emerging problematic weeds on the continent of Australia, where they have infested many cropping systems across New South Wales, South Australia, and Tasmania (Manalil et al. 2017; Osten et al. 2007; Walker et al. 2005).

These weeds are common C_4 weed species in cultivated lands, in which their wide distribution, aggressive growth habits, and prolific seed production cause monetary losses to crop production globally (Ward et al. 2013). A single *A. retroflexus* plant can produce up to 300,000 seeds, while *A. viridis* (which can self-fertilize) can produce up to 7,000 seeds plant^{-1} (Costea et al. 2004; Holm et al. 1997; McLachlan et al. 1995). The spread of seeds from these species mainly occurs by rainwater, wind, farm equipment, cotton gin trash, livestock, and cover crop seeds (Farmer et al. 2017; Holm et al. 1997).

The high competitiveness of *A. retroflexus* and *A. viridis* for resources results in a significant yield loss in many crops (Carvalho and Christoffoleti 2008; Rajagopalan et al. 1993). For example, the presence of 12 plants m^{-2} of *A. viridis* reduced leaf area (25%), leaf biomass (72%), and stem biomass (74%) of red pepper (*Capsicum baccatum* L.) (Barbasso et al. 2018). Bensch et al. (2003) reported that soybean [*Glycine max* (L.) Merr.] yield could be reduced by 38% depending on *A. retroflexus* density and its emergence date. Overreliance on chemical weed management strategies has led to the evolution of acetolactate synthase– and photosystem II–inhibitor herbicide-resistant biotypes (Heap 2020). Although the presence of these species has been reported in Australia, there are no official reports on the level of infestation in summer crops, economic impact, herbicide-resistant biotypes, and other eco-biological weed management information for these species in Australia. Therefore, comprehensive studies on Australian populations of these weeds are required before these weeds become problematic across Australia.

Weed density, weed interference duration, and weed emergence time are major factors causing significant yield losses in crop fields (Estorninos et al. 2005; Hussain et al. 2015; Lindström and Kokko 2002). Emergence time has a significant effect on the growth and fecundity of weeds. Previous research showed that the potential peak growth and seed production of annual turnipweed [*Rapistrum rugosum* (L.) All.] and African mustard (*Brassica tournefortii* Gouan) occur when both weeds are grown in optimal environmental conditions (temperature and photoperiod) (Mobli et al. 2020). It has also been observed that when the emergence of these weeds was delayed from April to July, their biomass and seed production was reduced by more than 75%. It has also been reported that the seed production of Palmer amaranth (*Amaranthus palmeri* S. Watson) could vary between 100 and 250,000 seeds plant^{-1} depending on the time of emergence (Keeley et al. 1987; Sellers et al. 2003). Therefore, a better understanding of the effect of emergence time on weed growth and seed production may contribute to more efficient control of weeds with reduced cost and energy inputs.

Plant phenology is the study of the timing of plant growth stages in response to environmental factors (Hegazy et al. 2005). Weed phenology is an important factor in understanding weed–crop competition (Ghersa and Holt 1995). Temperature and photoperiod are the most influential factors impacting the phenological development of weeds (Hodges 1991; Patterson 1992). The knowledge of weed phenology is critical to understand weed growth, seed production, biomass production, and the level of potential competition with various crops (Grant 1989). Therefore, studies on growth and seed production of weeds under different emergence times may provide primary information for more effective management strategies. The main objectives of this study were to evaluate the growth and seed production of two populations of *A. retroflexus* and *A. viridis* in response to different planting dates.

Materials and Methods

Weed Populations and Seed Sources

Two populations of *A. retroflexus* and *A. viridis* were each collected in 2016 from Goondiwindi (28.41°S, 150.23°E; altitude 210 m) and Gatton (27.45°S, 152.21°E, altitude 90 m), located in the southeast region of Queensland, Australia. Maternal effects were minimized by growing both populations at Gatton, and mature seeds from these plants were used in the study (Mobli et al. 2019a). Seeds of both weeds exhibited sufficient germination, so no dormancy-breaking treatment was necessary.

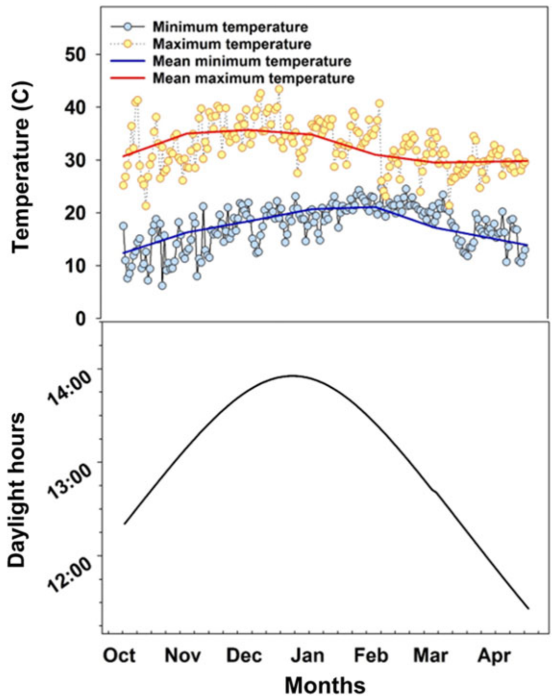

Figure 1. The mean thermal fluctuation and daylight hours of research site (Gatton, QLD, Australia) during the growth period in 2017–2019.

Experimental Approach

An outdoor pot experiment was conducted at the research facility of the University of Queensland, Gatton, during the late spring to summer seasons (October to March) of 2017 to 2018 to evaluate the effects of planting dates on two populations of *A. retroflexus* and *A. viridis*. The mean thermal fluctuation and photoperiod of the research site are provided in Figure 1. Seeds were sown on the third day of every month from October to January (four planting dates) in trays containing Platinum Potting Mix (Centenary Landscaping, Darra, QLD, Australia). The potting mix contained biological organic-based products and had a pH of 5.6 and an electrical conductivity of 1.6 dS m^{-1}. When seedlings reached the 5-leaf stage (4- to 6-cm height), they were transplanted uniformly in free-draining plastic pots (30-cm diameter, 40-cm height). The pots were filled with clay loam soil that had a pH of 6.7, electrical conductivity of 0.14 dS m^{-1}, and organic matter content of 2.8%. No nutritional deficiency symptoms were observed throughout the experiment, therefore no fertilizer was added. All the pots were supplied with adequate water through drip irrigation. The research site was kept weed-free by hand weeding. Plant height and number of leaves per plant were recorded at 14-d intervals until plant maturity. Plant height was measured from the soil surface to the tip of the uppermost reproductive structure. For each planting date, plants were considered mature when seed production had ceased and 10% of leaves had senesced. Shoot and root dry biomass, number of inflorescences per plant, and seed production were recorded at maturity. The shoot and root parts (washed to remove the soil particles) were bagged separately and oven-dried for 4 d at 70 C. All seeds were collected and weighed. The weight of 100 seeds was taken. These values were used to determine the total number of seeds per plant. For each planting date, plant development was recorded by calculating cumulative growing degree days (GDD) (Equation 1) as follows:

$$\mathrm{GDD}_{10} = \sum\left(\left(\frac{(\text{Maximum daily temperature} + \text{Minimum daily temperature})}{2}\right) - 10\right) \quad [1]$$

The flowering time was defined as the number of days required for 50% of flowering for five plants for each planting date. The experiment was repeated at the same location and experimental procedure in the summer (October to March) of 2018 to 2019.

Data Analysis

The experiment (factorial arrangement of species by population by planting date) was conducted in a randomized complete block design. For each planting date, there were 10 replicates for each population. The Shapiro-Wilk and Breusch-Pagan tests were performed to check the normality and homogeneity of data, and the original data were used for an ANOVA (GenStat 16th edition, VSN International, Hemel Hempstead, UK). Data were pooled over the experimental runs, as no significant differences were observed. Fisher's protected LSD mean comparison test was used with a probability value of 0.05. A three-parameter sigmoidal model was fit to the plant height and leaf number data (Equation 2) using SigmaPlot v. 14 (Systat Software, San Jose, CA, USA). The equation was of the form:

$$F = \frac{X_{\max}}{1 + e^{\frac{-(X - X_{50})}{b}}} \quad [2]$$

where F is plant height or number of leaves per plant at GDD X, $X_{\max}$ is the maximum plant height or number of leaves per plant, X_{50} is the GDD required to reach a 50% plant height or number of leaves per plant, and b is the slope.

Results and Discussion

Effect of Planting Date on *Amaranthus retroflexus* and *Amaranthus viridis* Flowering and Growth Period

The planting date had significant ($P < 0.001$) effects on the required number of days to plant maturity and flowering of both weeds (Table 1). Although both weeds reached maturity at a similar number of GDD, these weeds required a different number of days to complete their life cycles within each planting date. The growth period and flowering times of *A. retroflexus*, when planted in October, occurred at 121 and 52 d after planting, respectively. Similarly, for the October planting date, *A. viridis* required 123 and 48 d to complete the life cycle and flowering, respectively. When both weeds were planted in January, the growth period and flowering initiation time were reduced to 27 and 72 d, respectively. Similarly, in both species, the number of GDD required for flowering was reduced to 477 GDD when these weeds were planted in January. No significant differences in GDD and the number of days required for growth period and flowering were observed between planting in December and January.

The planting date was strongly associated with the growth and fecundity of weeds (Bosnic and Swanton 1997; Spaunhorst et al. 2018; Willenborg et al. 2005). Observations from this study suggest that the growth period and the flowering initiation of both species were reduced when planting was delayed. As a result of the delay, these species experienced lower temperatures and shorter daylight hours (Figure 1), which resulted in shorter growth periods and flowering times in comparison with the October planting date. A similar response to temperature and daylight hours (photoperiod) was also observed in *A. palmeri* and common waterhemp (*Amaranthus rudis* Sauer) (Spaunhorst et al. 2018; Wu and Owen 2014). In many weeds, temperature and photoperiod are the most influential factors in phenological stages (Hatfield et al. 2011; Hatfield and Prueger 2015). In the present study, when these species were planted in January, flowering was induced sooner, as plants experienced shorter daylight hours, and consequently, the growth period was significantly reduced. It has been reported that rapid flowering and the shortening of the growth period are associated with photoperiod, and these species are classified as short-day species (Huang et al. 2000).

Table 1. The effect of planting date on *Amaranthus retroflexus* and *Amaranthus viridis* flowering and growth period.[a]

	Days after sowing			
	Amaranthus retroflexus		*Amaranthus viridis*	
Planting date	Flowering	Growth period	Flowering	Growth period
October	52	121	48	123
November	37	96	41	92
December	29	76	29	72
January	27	72	27	72
LSD (0.05)	0.59	7.1	5.4	5.8
	Growing degree days			
October	664	1,474	642	1,490
November	622	1,510	654	1,474
December	494	1,460	494	1,448
January	477	1,488	477	1,488
LSD (0.05)	58.4	NS	54.3	NS

[a] Data were pooled over the populations and experimental runs ($n = 40$).NS, nonsignificant.

Effect of Planting Date on *Amaranthus retroflexus* and *Amaranthus viridis* Height

The interaction between population and planting date was significant ($P < 0.001$) for plant height for both species (Figure 2; Table 2). When both species were planted in October, they grew taller in comparison with cohorts from other planting dates. Any delay in planting date resulted in a reduction in plant height of both species. When the Gatton and Goondiwindi populations of *A. retroflexus* were planted in October, their mean plant height reached 106.7 and 87.4 cm, but the plant height was reduced to 50.0 and 52.4 cm when planted in January, respectively. Similarly, the plant height of Gatton and Goondiwindi populations of *A. viridis* was reduced from 87.4 to 46.7 cm and 74.3 to 46.5 cm, respectively, when planted in January. A three-parameter sigmoidal model estimated that Gatton and Goondiwindi populations of *A. retroflexus* required 801 to 990 GDD and 700 to 916 GDD, respectively, to attain 50% of their maximum plant height (X_{50} parameter) depending on planting date. Similarly, the Gatton and Goondiwindi populations of *A. viridis* required 665 to 780 GDD and 684 to 978 GDD, respectively, to reach 50% of their maximum plant height.

In the current study, later-emerged seedlings of these species (October) experienced warmer days and longer daylight hours than seedlings with other planting dates and consequently grew taller. This observation could be attributed to temperature, daylight hours, and growth period. Spaunhorst et al. (2018) reported that the plant height of *A. palmeri* was reduced significantly as a result of late emergence, which lowered its competitive ability.

Table 2. A three-parameter sigmoidal model fit to plant height of *Amaranthus retroflexus* and *Amaranthus viridis* when grown at different planting dates.

			Model parameters[a]			
Species	Populations	Planting date	X_{max}	b	X_{50}	R^2
			Plant height —cm			
Amaranthus retroflexus	Gatton	October	109.1 (4.2)	218 (20.4)	805 (28.0)	0.99
		November	77.7 (4.1)	244 (28.4)	801 (41.3)	0.99
		December	63.2 (7.6)	245 (61.3)	816 (101.2)	0.98
		January	59.6 (6.8)	323 (50.0)	990 (95.0)	0.98
	Goondiwindi	October	86.2 (2.3)	192 (16.1)	699 (9.7)	0.99
		November	70.2 (4.2)	216 (34.4)	722 (46.1)	0.99
		December	68.4 (13.7)	293 (83.8)	916 (166.6)	0.97
		January	56.7 (2.7)	245 (24.5)	866 (34.61)	0.99
Amaranthus viridis	Gatton	October	83.9 (5.2)	207 (37.7)	696 (46.7)	0.98
		November	58.5 (3.7)	229 (38.4)	665 (50.3)	0.99
		December	52.2 (4.2)	232 (46.3)	758 (68.8)	0.99
		January	47.6 (1.3)	211 (17.1)	780 (21.0)	0.97
	Goondiwindi	October	74.0 (2.2)	173 (3.1)	684 (20.8)	0.99
		November	65.2 (3.3)	258 (26.9)	812 (40.4)	0.99
		December	63.4 (10.2)	298 (59.8)	978 (128.4)	0.98
		January	50.9 (3.2)	259 (31.7)	906 (47.4)	0.99

[a] $F = X_{max}/\{1+ \exp[-(X-X_{50}/b)\}$, F is plant height at GDD X, X_{max} is the maximum plant height, X_{50} is the GDD required to reach a 50% plant height, and b is the slope. Values in parentheses are standard errors of means.

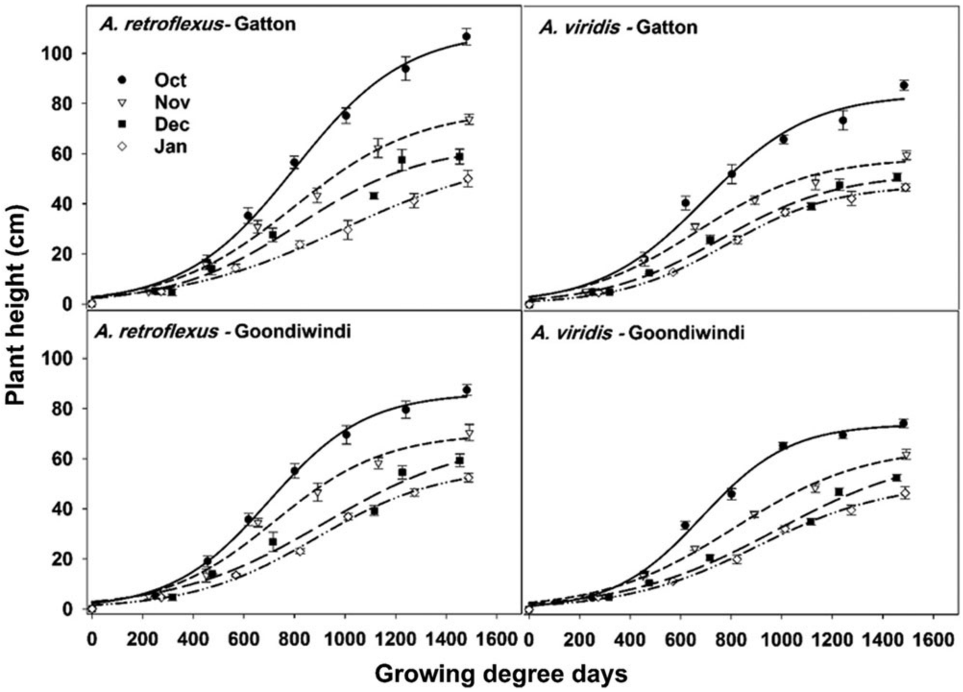

Figure 2. The effect of planting date on *Amaranthus retroflexus* and *Amaranthus viridis* height for populations collected at Gatton and Goondiwindi, QLD, Australia. Data were pooled over the experimental runs. Vertical bars show standard errors of means. Estimated parameters are presented in Table 1.

Effect of Planting Date on Amaranthus retroflexus *and* Amaranthus viridis *Number of Leaves*

The interaction effect of population and planting date was significant ($P < 0.001$) for the number of leaves per plant of both species (Figure 3; Table 3). The highest number of leaves of both species was produced in the plants planted in October, and the number of leaves of both species was reduced by delaying the planting date. When Gatton and Goondiwindi populations of *A. retroflexus* were planted in January, the number of leaves per plant was reduced by 48% and 49%, respectively, in comparison with the number of leaves produced in October. Similarly, the number of leaves of the Gatton and Goondiwindi populations of *A. viridis* was reduced by 58% and 54%, respectively, as a result of a delay in planting date from October to January. A three-parameter sigmoidal model showed that the Gatton and Goondiwindi populations of *A. retroflexus* required 598 to 680 GDD and 723 to 1,216 GDD to produce 50% of their leaves (X_{50} parameter), respectively. Similarly, the Gatton and Goondiwindi populations of *A. viridis* required 658 to 1,183 GDD and 801 to 1,120 GDD, respectively, to produce 50% of their maximum leaves per plant.

Similar to plant height, the number of leaves per plant was also reduced when the planting date was delayed. Huang et al. (2000)

Table 3. A three-parameter sigmoidal model fit to number of leaves of *Amaranthus retroflexus* and *Amaranthus viridis* when grown at different planting dates.

Species	Populations	Planting date	Model parameters[a] X_{max}	b	X_{50}	R^2
			Leaves —no. plant^{-1}			
Amaranthus retroflexus	Gatton	October	94.6 (3.7)	188 (20.4)	678 (28.5)	0.99
		November	74.9 (2.0)	215 (28.4)	739 (19.9)	0.99
		December	52.7 (3.4)	172 (61.3)	598 (56.5)	0.97
		January	49.1 (1.8)	197 (50.0)	680 (29.5)	0.99
	Goondiwindi	October	105.2 (11.2)	297 (43.5)	978 (84.3)	0.99
		November	77.7 (2.7)	181 (18.7)	723 (24.2)	0.99
		December	49.2 (9.4)	258 (82.1)	786 (149.0)	0.97
		January	65.4 (9.1)	305 (38.0)	1,216 (98.2)	0.99
Amaranthus viridis	Gatton	October	123.6 (7.3)	201 (36.4)	685 (44.4)	0.98
		November	105.4 (2.9)	209 (14.2)	833 (19.9)	0.99
		December	90.8 (13.0)	363 (38.8)	1,145 (391.5)	0.96
		January	73.4 (10.3)	300 (40.9)	1,183 (100.2)	0.99
	Goondiwindi	October	127.3 (5.9)	247 (20.9)	914 (33.9)	0.99
		November	105.8 (3.3)	210 (16.5)	801 (22.9)	0.99
		December	71.9 (13.3)	339 (55.2)	1,120 (147.2)	0.99
		January	59.8 (5.1)	237 (36.5)	998 (57.9)	0.99

[a] $F = X_{max}/\{1+\exp[-(X-X_{50}/b)]\}$, F is number of leaves at GDD X, X_{max} is the maximum number of leaves, X_{50} is the GDD required to reach a 50% number of leaves, and b is the slope. Values in parentheses are standard errors of means.

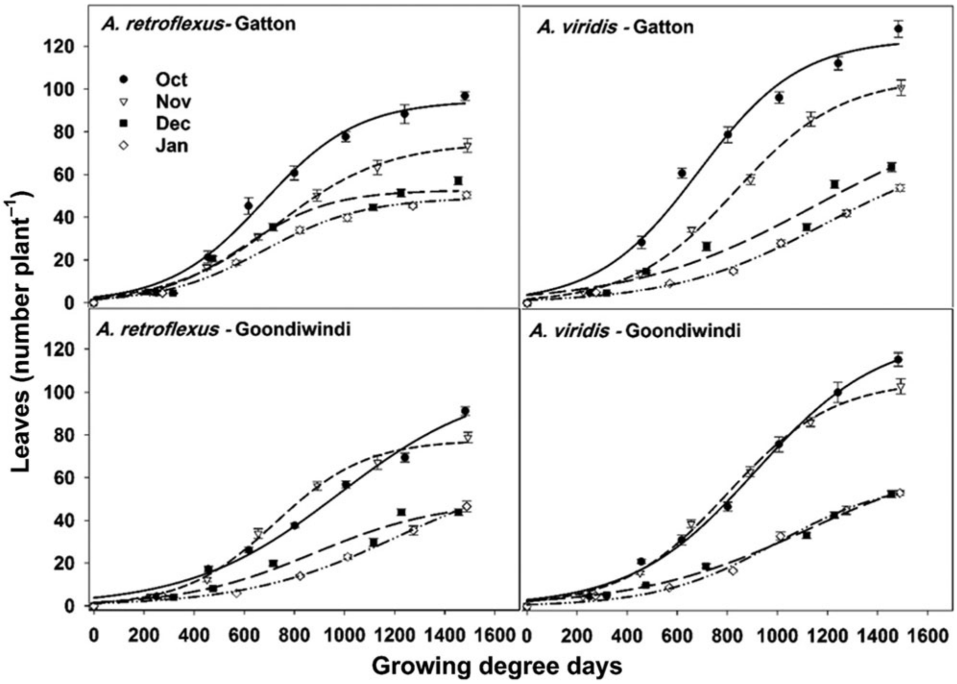

Figure 3. The effect of planting date on *Amaranthus retroflexus* and *Amaranthus viridis* number of leaves for populations collected at Gatton and Goondiwindi, QLD, Australia. Data were pooled over the experimental runs. Vertical bars show standard errors of mean. Estimated parameters are presented in Table 2.

reported that the number of leaves on the main stem of *A. retroflexus* was significantly reduced as the amount of daylight hours decreased. In the current study, significant differences were observed between the populations of both species in plant height and number of leaves per plant. Differences in the response of populations of a weed species to environmental conditions can be explained by genetic differences or maternal effects during plant growth and seed production (Bajwa et al. 2018; Mobli et al. 2019b). In the present study, the effect of maternal conditions was removed by growing both populations under the same conditions in Gatton. Therefore, it could be concluded that observed differences are likely due to genetic differences between populations. Spaunhorst et al. (2018) reported that *A. palmeri* populations that originated from different locations exhibited different biological characteristics, and the environmental plasticity of this species contributed to its survival and further distribution into new locations.

Effect of Planting Date on Amaranthus retroflexus *and* Amaranthus viridis *Shoot and Root Biomass*

The effect of population was significant ($P < 0.001$) for *A. retroflexus* shoot biomass and *A. viridis* root biomass (Figure 4). Delayed planting time resulted in shoot and root biomass

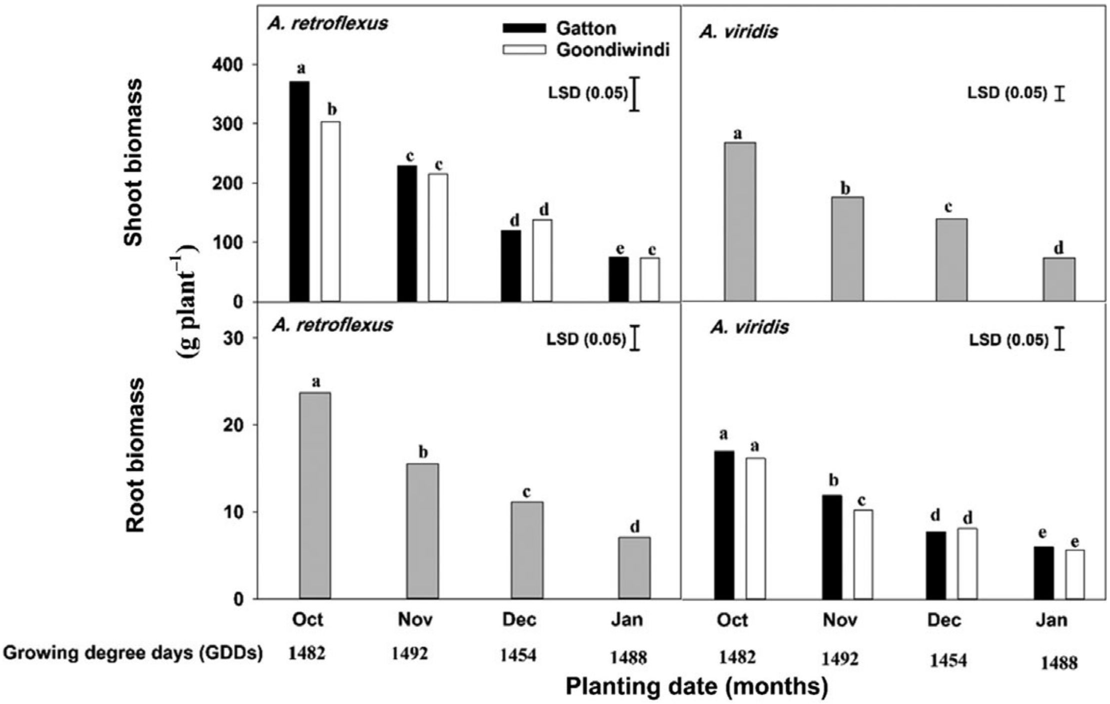

Figure 4. The effect of planting date on *Amaranthus retroflexus* and *Amaranthus viridis* shoot and root biomass for populations collected at Gatton and Goondiwindi, QLD, Australia. Data were pooled over the experimental runs and populations for shoot biomass of *A. viridis* and root biomass of *A. retroflexus*. Vertical bars are LSD values at the 5% level of probability, and letters above bars show grouping differences between means.

reduction in both species, with the maximum reduction being recorded from the January planting. The shoot biomass from the January-planted Gatton and Goondiwindi populations of *A. retroflexus* was reduced by 80% and 76%, respectively, when compared with the plants planted in October. Similarly, the shoot biomass of *A. viridis* was reduced by 73% as a result of a delay in the planting time from October to January. When *A. retroflexus* was planted in January, the root biomass was reduced by 70% in comparison with planting in October. Although the Gatton and Goondiwindi populations of *A. viridis* produced different amounts of root biomass in the November planting, the amount of root biomass for both populations was reduced by 65% as a result of delaying the planting from October to January.

In the current study, shoot and root biomass of both species was sharply reduced, followed by a reduction in plant height and the number of leaves as a result of a delay in planting date. Heneghan and Johnson (2017) reported that when waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] emerged in late spring (May), the mean biomass could reach 1,120 g plant^{-1}, but when the planting date was delayed to midsummer (July), the biomass was reduced to 266 g plant^{-1}.

Weed competition is strongly associated with weed biomass and phenological characteristics (Huang et al. 2001). The prediction of the phenological stages and potential competitiveness of weeds in different conditions is an integral part of integrated weed management strategies (Deen et al. 1998; Ghersa and Holt 1995). In this study, the competitiveness of *A. retroflexus* and *A. viridis* was not evaluated, but late spring–emerged seedlings of these species grew vigorously and produced a higher amount of biomass in comparison with other planting dates. It seems that any early weed management practice for these species could be beneficial to minimize the subsequent cost and energy inputs toward their control. Although the effect of planting date on the biomass of these weeds was evaluated in the current outdoor pot study, field studies should be conducted to confirm the results under natural conditions. Weed phenology also contributes to developing better weed management through accurate prediction of the beginning of the weed interference (Hegazy et al. 2005). Therefore, the identification of the most sensitive phenological stage of these weeds to weed management strategies and their competitiveness under different emergence times should be evaluated in future studies.

Effect of Planting Date on Amaranthus retroflexus *and* Amaranthus viridis *Inflorescence Number and Seed Production*

The interaction effect of population and planting time had a significant ($P < 0.001$) effect on the number of inflorescences of both species (Figure 5). The number of inflorescences and seed production of both species were reduced by a delay in planting time, and the reduction was highest in the plants planted in January. When Gatton and Goondiwindi populations of *A. retroflexus* were planted in January, the number of inflorescences was reduced by 75% and 62% compared with the October-planted plants, respectively. Similarly, the number of inflorescences of the Gatton and Goondiwindi populations of *A. viridis* was also reduced by 66% and 68%, respectively, in comparison with the October planting date. In the plants planted in October, *A. retroflexus* and *A. viridis* produced 11,350 and 5,780 seeds plant^{-1}, but this number dropped to 770 and 365 seeds plant^{-1} in the plants planted in January, respectively.

In the current study, it was observed that both species could germinate and complete their life cycles throughout the summer growing season (October to March). Although the growth and fecundity of these species was dependent on planting time, these weeds could emerge throughout the summer growing season

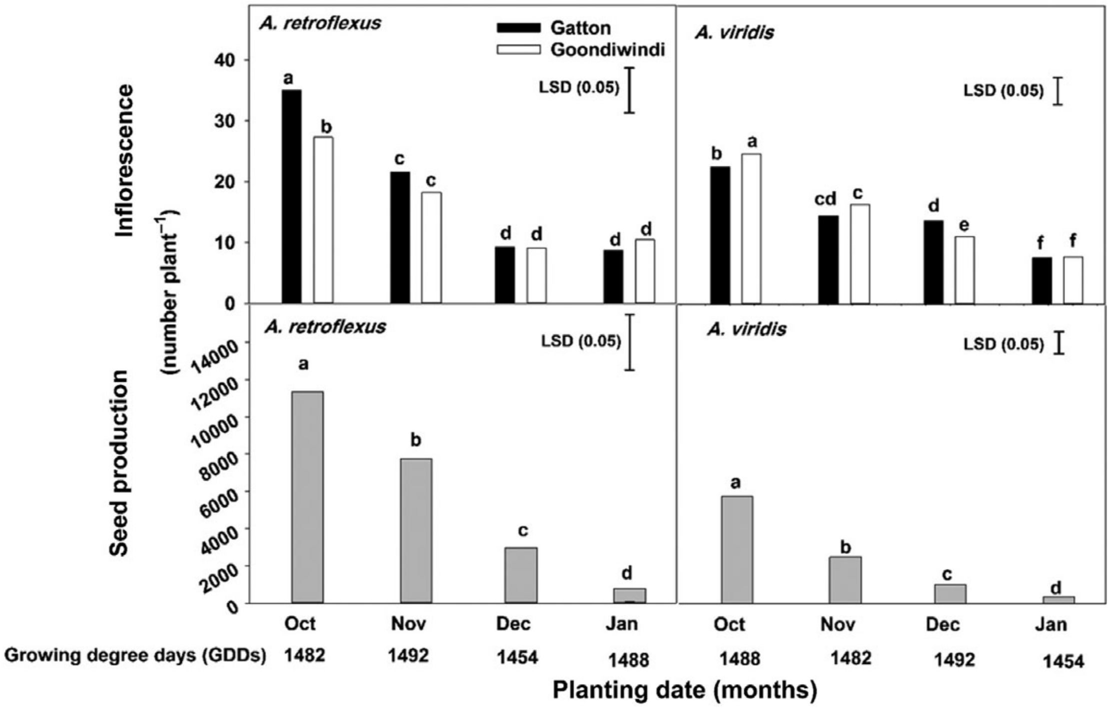

Figure 5. The effect of planting date on *Amaranthus retroflexus* and *Amaranthus viridis* number of inflorescences and seed production for populations collected at Gatton and Goondiwindi, QLD, Australia. Data were pooled over the experimental runs and populations (for root biomass). Vertical bars are LSD values at the 5% level of probability, and letters above bars show grouping differences between means.

under irrigation or sufficient rainfall and produce a significant number of seeds. Similar results were observed for *A. palmeri*, in which seed production was reduced as a result of late emergence (Spaunhorst et al. 2018). Heneghan and Johnson (2017) reported that when the emergence date of *A. tuberculatus* was delayed from late spring to midsummer (May to July), seed production was reduced by 70%, but late-emerging plants of this weed could produce more than 276,000 seeds plant^{-1}. It could be concluded that the seed control of these weeds should play an important role in their management, as late cohorts of these species could produce a significant number of seeds and enrich the soil seedbank. Although it has been reported that weed seed harvest control strategies are effective methods for managing *Amaranthus* species (Norsworthy et al. 2016; Schwartz et al. 2016), late-emerging plants of these species are shorter (below crop harvest height) and may escape this control practice. Therefore, more studies and consideration should be dedicated to the control of late cohorts of these species.

Amaranthus retroflexus and *A. viridis* germinated throughout the study period (October to January), and germination was not inhibited during the course of experiment; therefore, both species may predominate weeds in summer-season crops. It was observed that the growth and fecundity of both species were strongly associated with planting date (temperature and photoperiod). Plants had a tendency to flower earlier with decreasing daylight hours and temperature, which led to a shorter growth period and vegetative phase. When these weeds were planted in October, they grew vigorously and produced more seeds in comparison with other planting dates. The growth and seed production of both species were reduced as a result of the reduction in the growth period. Although the effect of planting date on crop competition of these species was not evaluated in the current study, it seems that a delay in planting date may result in a less competitive weed, as weed competition is highly associated with weed biomass and phenological characteristics. It could be concluded that any early weed management practice for these species could be beneficial to minimize the subsequent cost and energy inputs toward their control. However, preventing early-emergence cohorts of these weeds alone would not guarantee success in the management of these species, as a significant amount of seed was produced by late-emerged cohorts.

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