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Research Article

Interference of turnipweed (*Rapistrum rugosum*) and Mexican pricklepoppy (*Argemone mexicana*) in wheat

Sudheesh Manalil[1] and Bhagirath Singh Chauhan[2]

[1]Honorary Associate Professor, Centre for Crop Science, Queensland Alliance for Agriculture and Food Innovation (QAAFI), University of Queensland, Gatton, QLD, Australia; Adjunct Lecturer, School of Agriculture and Environment, University of Western Australia, Perth, Crawley, WA, Australia; Professor, Amrita Vishwa Vidyapeetham, Coimbatore, India and [2]Associate Professor, Centre for Crop Science, Queensland Alliance for Agriculture and Food Innovation (QAAFI), University of Queensland, Gatton, QLD, Australia

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Author for correspondence:
Sudheesh Manalil, Centre for Crop Science, Queensland Alliance for Agriculture and Food Innovation, University of Queensland, Gatton, QLD 4343, Australia.
Email: s.manalil@uq.edu.au

Abstract

Turnipweed [*Rapistrum rugosum* (L.) All.] and Mexican pricklepoppy (*Argemone mexicana* L.) are increasingly prevalent in the northern cropping regions of Australia. The effect of different densities of these two weeds was examined for their potential to cause yield loss in wheat (*Triticum aestivum* L.) through field studies in 2016 and 2017. There was 72% to 78% yield reduction in wheat due to competition from *R. rugosum*. Based on the exponential decay model, 18.2 and 24.3 plants m^{-2} caused a yield reduction of 50% in 2016 and 2017, respectively. *Rapistrum rugosum* produced a maximum of 32,042 and 29,761 seeds m^{-2} in 2016 and 2017, respectively. There was 100% weed seed retention at crop harvest. Competition from *A. mexicana* resulted in a yield loss of 17% and 22% in 2016 and 2017, respectively; however, plants failed to set seeds due to intense competition from wheat. Among the yield components, panicles per square meter and grains per panicle were affected by weed competition. The studies indicate a superior competitiveness of *R. rugosum* in wheat and a suppressive effect of wheat on *A. mexicana*. The results indicate that a wheat crop can be included in crop rotation programs where crop fields are infested with *A. mexicana*. High seed retention in *R. rugosum* indicates the possibility to manage this weed through seed catching and harvest weed seed destruction.

Introduction

Turnipweed [*Rapistrum rugosum* (L.) All.] is a broadleaf weed from the Brassicaceae family with wide distribution in Australia, the United States, Iran, and Russia (Chauhan et al. 2006; Hatami et al. 2016; Manalil et al. 2018; Ohadi et al. 2011; Osten et al. 2007; Whish et al. 2002). Besides being an agricultural weed, it is an invasive species owing to its potential to invade fallow regions, railway tracks, and open forest areas (Cousens et al. 1994; Hani et al. 2017; Ohadi et al. 2011; Pipan et al. 2013). *Rapistrum rugosum* is well distributed throughout the Australian agricultural landscape and is becoming increasingly prevalent in the northern grain region of Australia (Chauhan et al. 2006; Manalil et al. 2018; Osten et al. 2007). Many biological attributes favor the emergence and establishment of this weed (Chauhan et al. 2006; Manalil et al. 2018). Abundant seed production, dormancy due to its seed pod, and the potential to emerge under diversified environmental conditions help this weed to emerge and establish at different phases of the crop-growing season (Chauhan et al. 2006; Wilson and Wilson 1981). Although *R. rugosum* is classified as a winter weed, its presence is not limited to winter crops; surveys have indicated the presence of this weed in cotton (*Gossypium hirsutum* L.) tracts and fallows (Manalil et al. 2017; Werth et al. 2013). Germination biology studies indicate the potential of *R. rugosum* to germinate in a broad range of temperature conditions (Manalil et al. 2018). In Australia, *R. rugosum* could produce around 13,000 seeds plant^{-1} under lack of competition when it emerged at the beginning of the winter season (April); however, plants that emerged in August were short and produced less than 2,000 seeds (A Mobli, personal communication).

As farming in the northern region is diversified, with the opportunity to grow both winter and summer crops, possibilities exist to vary crop management and weed control options (GRDC 2018), and for that reason, it is less likely that this weed would develop the herbicide resistance observed in many populations of wild radish (*Raphanus raphanistrum* L.) from Western Australia. In Western Australia, cropping is mostly confined to the winter season (Owen et al. 2015). However, when screening weeds for herbicide resistance, Adkins et al. (1997) observed resistance to the acetolactate synthase (ALS)-inhibiting herbicide chlorsulfuron in *R. rugosum*. Resistance to the ALS herbicide tribenuron-methyl was observed in Iran (Hatami et al. 2016), indicating the possibility for evolution of herbicide resistance in the absence of a diversified weed management program.

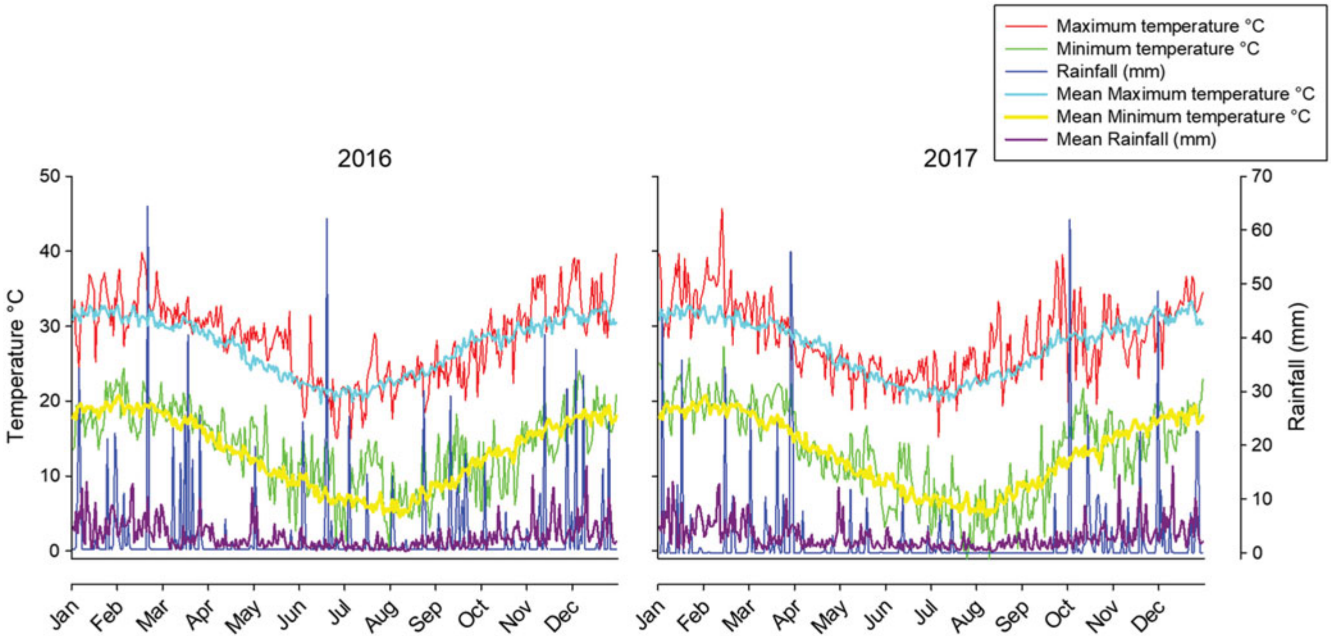

Figure 1. Weather data (2016 and 2017) for the experimental site.

Mexican pricklepoppy (*Argemone mexicana* L.) is an annual broadleaf weed from the Papaveraceae family and is rapidly emerging in the northern grain region of Australia (CottonInfo 2014; Manalil et al. 2017). Although this weed is poisonous to livestock and humans (CottonInfo 2014), no study has explored its biology or competitiveness. Field visits and communication with agronomists in the northern region indicated that this weed is a problem in fallow areas, chick pea (*Cicer arietinum* L.), and wheat (*Triticum aestivum* L.). It is characterized by a perennial seedbank with a potential to continue the infestation for many years if seed set and dispersal are not controlled (J Street, personal communication). In addition, periodic surveys in cotton indicated the presence of this weed (Manalil et al. 2017; Werth et al. 2013). *Argemone mexicana* flourishes under a moist environment (Manalil et al. 2017; Werth et al. 2013). A single *A. mexicana* plant can produce around 10,000 seeds plant^{-1} (CottonInfo 2014).

Knowledge of competitiveness and interference of weeds in crops provides valuable information for developing integrated weed management strategies and understanding the strengths and weaknesses of target weeds (Eslami et al. 2006; Lemerle et al. 2014; Reiss et al. 2018). Weeds vary in their potential to compete with crops (Korres et al. 2019; Soltani et al. 2018). Some crops and varieties could be used to suppress weeds (Mwendwa et al. 2018; Olsen et al. 2006). In addition, information on emergence, growth, maturity, and dispersal of weed seeds in comparison to crop maturity provides opportunities to frame management options aiming to reduce the enrichment of the weed seedbank (Walsh and Powles 2014). Information on weed seed retention offers the opportunity to employ nonchemical weed management options such as harvest weed seed control along with other weed management options (Walsh et al. 2018; Walsh and Powles 2014). The maturity of a weed in relation to a crop, timing of weed seed shattering, size of seeds, and crop chaff type and quantity in relation to target weeds are the major determinants affecting the success of harvest weed seed control (Schwartz et al. 2016; Walsh et al. 2012, 2013). Weed seed destruction using a Harrington seed destructor can vary depending on weed species (Walsh et al. 2012, 2013). There can be more than 90% control for major invasive weeds, including rigid ryegrass (*Lolium rigidum* Gaudin), *R. raphanistrum*, and wild oat (*Avena fatua* L.); however, seed destruction can be less than 50% for common lambsquarters (*Chenopodium album* L.) due to poor seed retention (Walsh et al. 2012, 2013). Knowledge gaps exist concerning the competitiveness and interference of *R. rugosum* and *A. mexicana* in winter crops that are grown in the northern region of Australia. Whish et al. (2002) examined the competitiveness of *R. rugosum* in chick pea; however, similar studies have not been conducted in wheat. Therefore, field trials were conducted in the winter seasons of 2016 and 2017 to examine the competitiveness of *R. rugosum* and *A. mexicana* in wheat.

Materials and Methods

Field experiments were conducted in 2016 and 2017 (from May to October) at the Research Farm of the University of Queensland, Gatton, Australia. The soil type of the experimental site was a heavy clay with pH 7.5 and an organic matter content of 2.7% (up to 20-cm depth). Nitrogen, phosphorus, and potassium concentrations were 62, 87, and 412 kg ha^{-1}, respectively. The site receives annual rainfall of 721 mm (30-yr climatic normal) and is characterized by high annual variation in total rainfall (Figure 1). For example, in 2016 and 2017, Gatton received an annual rainfall of 562 mm, out of which 218 mm was in the crop-growing months of the winter season (May to October) (Figure 1). In 2017, although 252 mm rainfall was received during the winter growing season, a major portion of the rainfall (170 mm) was received during the crop maturation phase (in the month of October).

Before seeding, the experimental field was cultivated two to three times using a rotory cultivator. The wheat cultivar 'Spitfire' was planted at 18-cm row spacing with a seeding rate of 60 kg ha^{-1}. Seeds of *R. rugosum* were collected from a chick pea field near St George, QLD (28.186°S, 148.634°E) in October 2015 and used in 2016 and 2017. Seeds of *A. mexicana* were collected in October 2015 from a chick pea field near St George, QLD (28.322°S, 148.518°E) and used in 2016 and 2017. *Rapistrum*

Table 1. Changes in wheat yield components due to competition from *Rapistrum rugosum* and *Argemone mexicana*.[a]

Weed	Weed density at anthesis[b]	Panicles 2016	Panicles 2017	Grains per panicle 2016	Grains per panicle 2017	1,000-grain weight 2016	1,000-grain weight 2017
Rapistrum rugosum		——no. m^{-2}——				——g——	
	Control (0.0, 0.0)*	304a	290a	45.2a	44.4a	47.7a	44.9a
	Low (10.2, 12.0)	159b	173b	41.7b	42.6a	47.4a	44.7a
	Medium (26.4, 28.7)	142c	138c	35.8c	36.8b	46.9ab	44.3a
	High (47.7, 46.8)	124d	132c	27.7d	27.2c	46.2ab	43.2a
Argemone mexicana	Control (0.0, 0.0)	305a	296a	44.4a	44.9a	47.8a	45.1a
	Low (14.8, 24.1)	284b	264b	43.3ab	43.9b	47.7a	44.3a
	Medium (43.5, 69.4)	271b	245c	42.5ab	41.6c	47.4a	44.4a
	High (73.6, 94.4)	243c	241c	41.8b	41.2c	47.1a	44.8a

[a] Mean separation was carried out by LSD. Within columns, means followed by different letters indicate significant difference ($P < 0.05$, $n = 3$).
[b] Values in parentheses are mean weed density (plants m^{-2}) in 2016 and 2017.

rugosum and *A. mexicana* were established at low, medium, and high density along with a control treatment (no weed plant; actual densities are presented in Table 1). The plot size was 5.0 by 2.3 m with three replications. Immediately after wheat sowing, weed seeds mixed with dry soil were broadcast applied. Weed seeding rates were adjusted based on the laboratory germination data to produce the required weed densities.

Plots were sprinkle irrigated on alternate days (four times) starting at the seeding stage to ensure good crop and weed emergence and then at the crop flowering stage in August (twice). Before the first irrigation, diammonium phosphate (18-20-0 N-P-K) was broadcast applied to supply 25 kg N ha^{-1} and 28 kg P ha^{-1}. Manual weeding was carried out to remove all other weeds except the target weeds. Crop and weed emergence and flowering were recorded (when 50% of plants emerged/flowered). Weed density and biomass were recorded with a quadrat (60 by 54 cm) at two places per experimental plot at the time of anthesis. The weed samples were oven-dried for 48 h at 72 C. Before harvest, the number of panicles per meter of crop row was counted in two places, the average number of grains was computed from 20 randomly picked panicles per plot, and 1,000-grain weight was recorded. Harvesting was carried out with a plot harvester, and grain yield was adjusted to 12% moisture content.

Six circular seed traps made of polyvinyl chloride pipe (12-cm diameter by 10-cm deep) lined with cloth at the bottom to hold seeds and to drain rainwater were randomly placed (4 wk before crop harvest) between crop rows in the high-density plots and monitored at weekly intervals to capture any seed dispersal. Weed seed production was computed by manually detaching pods (after oven-drying) from the quadrat plant sample collected at maturity. Seeds were cleaned and weighed, a subsample from each seed lot (around 10 g) was weighed, and the number of seeds was assessed. As *A. mexicana* did not grow well in 2016 in the wheat crop, in 2017, in addition to establishing four weed densities of *A. mexicana* in wheat, we grew 6 plants outside the experimental plot (without competition from wheat) until crop harvest to ensure there were no soil impediments preventing growth of *A. mexicana*. Emergence, flowering, and maturity of crop and weed were related to growing degree days base 5 (GDD_5) (Martin et al. 2014) as:

$$\mathrm{GDD}_5 = \sum\{[(\text{maximum daily temperature} + \text{minimum daily temperature})/2] - 5\} \quad [1]$$

A randomized complete block design was used in all the experiments with three replications (as fixed effects). Treatment differences were explored through ANOVA; means were separated using LSD at 5% level of significance (R Development Core Team 2018). Bartlett's test and the Shapiro-Wilk test were used to evaluate the homoscedasticity and normality assumptions before the analysis was performed. As there were significant differences between the experimental runs, data were analyzed separately for different years. Nonlinear regression analysis was performed to explore the relationship of [1] weed density to crop yield and [2] weed density to weed seed production. ANOVA was performed on yield parameters, including number of panicles (m^{-2}), grains per panicle, and 1,000-grain weight.

A two-parameter exponential decay regression model was fit to weed density and crop yield data:

$$G = a^{*}exp^{(-b^{*}x)} \quad [2]$$

where G is the crop yield, x is weed density, a is maximum crop yield, and b is a constant.

A two-parameter hyperbola model was fit on weed density and weed seed production data:

$$G = a^{*}x/(b + x) \quad [3]$$

where G is weed seed production, x is weed density, a is maximum weed seed production as estimated by the model, and b is a constant.

Results and Discussion

The emergence of the wheat crop was observed 9 ($GDD_5 = 125$) and 12 ($GDD_5 = 120$) d after seeding (DAS) in 2016 and 2017, respectively. *Rapistrum rugosum* emerged at 9 to 10 DAS. Emergence of *A. mexicana* was observed at 12 to 14 DAS. Anthesis in wheat was observed at 95 ($GDD_5 = 1{,}012$) and 102 ($GDD_5 = 1{,}030$) DAS in 2016 and 2017, respectively. *Rapistrum rugosum* flowered at 88 ($GDD_5 = 942$) and 93 ($GDD_5 = 925$) DAS in 2016 and 2017, respectively. *Argemone mexicana* did not progress to flowering, as this weed failed to grow well in wheat in both years. The wheat crop reached maturity at 136 ($GDD_5 = 1{,}523$) and 139 ($GDD_5 = 1{,}647$) DAS in 2016 and 2017, respectively.

In the experiment exploring the competitiveness of *R. rugosum*, 6,667 and 5,554 kg ha^{-1} of grain yield was produced in the control plots (weed free) in 2016 and 2017, respectively. The yield decreased exponentially with increasing competition from *R. rugosum* (Figure 2). In 2016, wheat yield reduction was 44%,

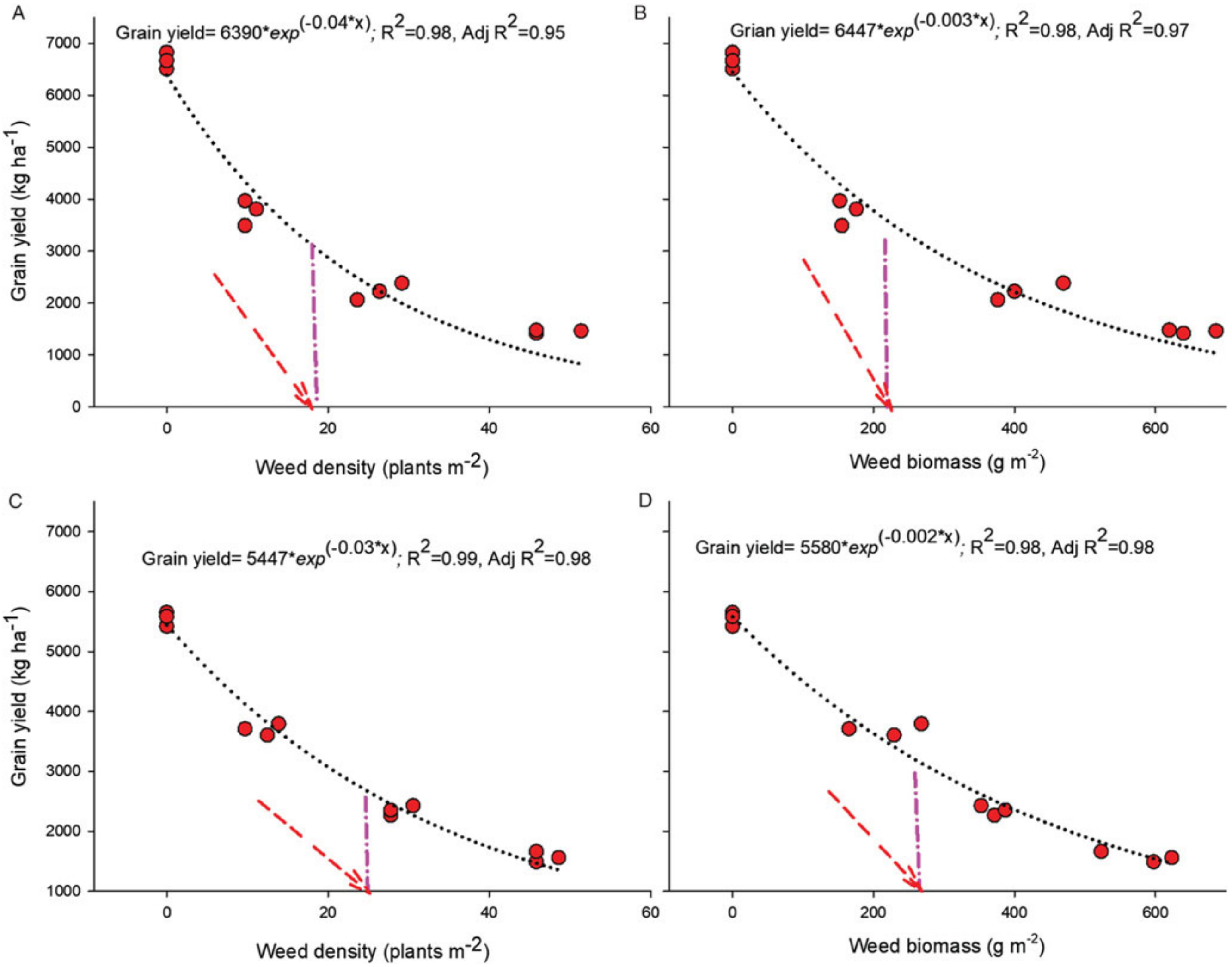

Figure 2. Effect of *Rapistrum rugosum* density and biomass on wheat yield in 2016 (A and B) and 2017 (C and D). The line represents an exponential decay regression model fit to the data, and the red arrows indicate density and biomass that caused 50% reduction in the crop yield.

67%, and 78% in low-, medium-, and high-density plots, respectively, and the corresponding reductions in 2017 were 33%, 58%, and 72%. Based on the regression model, weed densities at anthesis corresponding to the 50% yield reduction were 18.2 and 24.3 plants m^{-2} in 2016 and 2017, respectively; weed biomass corresponding to 50% yield reduction was 260 and 324 g m^{-2} in 2016 and 2017, respectively. The number of panicles per square meter and the number of grains per panicle were affected due to competition from *R. rugosum*; however, no difference was observed for 1,000-grain weight (Table 1). For *R. rugosum*, at low density, compared with the control, 40% to 47% and 4% to 8% reductions were observed in number of panicles per square meter and grains per panicle, respectively. At medium density, there were 52% to 53% and 17% to 21% reductions in number of panicles per square meter and grains per panicle, respectively. At high weed density, there were 54% to 59% and 39% reductions in number of panicles per square meter and grains per panicle, respectively. The impact on yield components due to competition were lower for *A. mexicana* compared with *R. rugosum*. At low density, compared with the control, 6% to 10% and 3% reductions were observed in number of panicles per square meter and grains per panicle, respectively. At medium density, there were 11% to 17% and 4% to 7% reductions in number of panicles per square meter and grains per panicle, respectively. At high weed density, there were 19% to 20% and 6% to 10% reductions in number of panicles per square meter and grains per panicle, respectively.

For *A. mexicana*, the grain yields recorded from control plots were 6,720 and 5,969 kg ha^{-1} in 2016 and 2017, respectively. The grain yield decreased exponentially due to weed competition (Figure 3). In 2016, there were yield reductions of 9%, 15%, and 17% in low-, medium-, and high-density plots, respectively, and the corresponding reductions in 2017 were 11%, 22%, and 23%. Among the yield components, significant reductions were observed for the number of panicles per unit area (m^{-2}) and the number of grains per panicle. However, no difference was observed for 1,000-grain weight (Table 1). Data for weed dry biomass were not used in the analysis, as plants were at the withering stage at crop anthesis and started to dry toward crop maturity. In 2017, all 6 plants close to the crop boundary were established, grew well, and progressed to maturity, indicating lack of establishment inside the crop (Figure 4) was not due to any soil impediments in the experimental location.

Without weed competition, the crop yield of more than 5,500 kg ha^{-1} in both years in the control plots represents a high-yielding

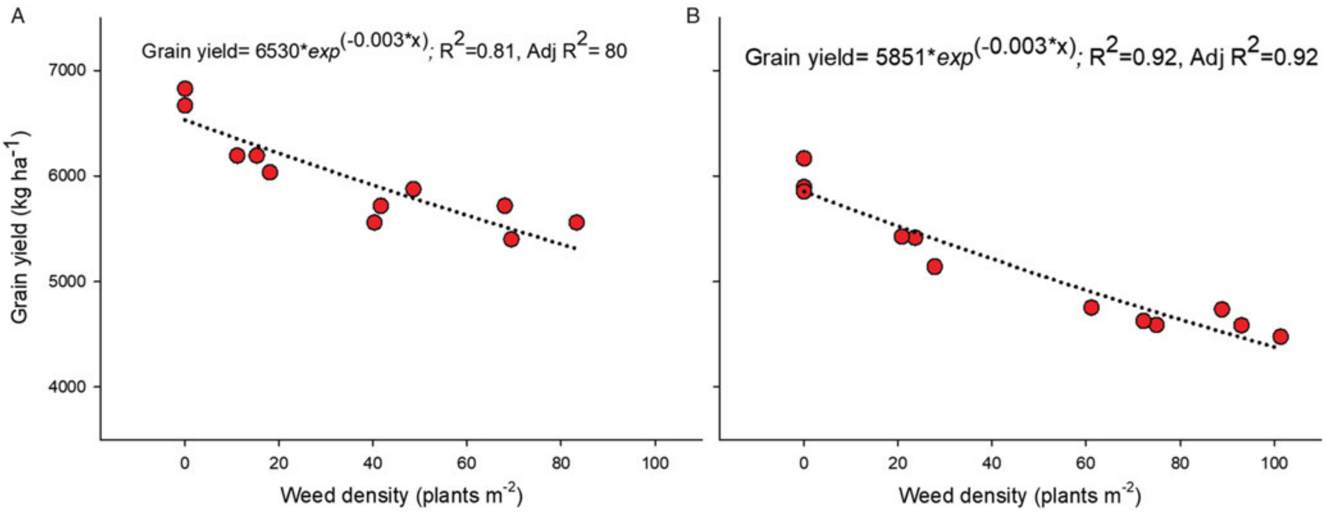

Figure 3. Effect of *Argemone mexicana* density on wheat yield in 2016 (A) and 2017 (B). The lines represent an exponential decay regression model fit to the data.

Figure 4. *Argemone mexicana* failing to establish in wheat crop.

wheat crop for the region. Although the seeding rate (60 kg ha^{-1}) and row spacing (18 cm) were selected to impart significant competition to any emerging weed, *R. rugosum* suppressed the wheat crop, leading to a yield loss of 72% to 78%. There are many reports available indicating the superior competitiveness of weeds from the Brassicaceae family over different crops (Blackshaw et al. 2002; Naderi and Ghadiri 2011; Whish et al. 2002). Wild mustard (*Sinapis arvensis* L.) exhibited a high level of competitiveness in canola (*Brassica napus* L.) (Naderi and Ghadiri 2011). At high *S. arvensis* densities (>20 plants m^{-2}), grain yield decreased even at 100 kg N ha^{-1} (Naderi and Ghadiri 2011). In another study, 4 *R. raphanistrum* plants m^{-2} reduced canola yield by 9% to 11%, and 64 *R. raphanistrum* plants m^{-2} reduced yield by 77% to 91% (Blackshaw et al. 2002). A study conducted in Australia indicated that 10 *R. rugosum*plants m^{-2} caused a yield reduction of around 50% in chick pea (Whish et al. 2002).

Conversely, the competition from *A. mexicana* was less compared with *R. rugosum*, and *A. mexicana* could not thrive with competition from the wheat crop. The results clearly indicate the superior competitiveness of *R. rugosum* as a winter weed; however, some weed-suppressive effect of the wheat crop on *A. mexicana* was observed. Weed-suppressive benefits of crops on weeds can be explored by integrating crops in rotation programs and suppressing dominant weeds with poor competitiveness to the chosen crop (Lamego et al. 2013; Olsen et al. 2005; Reiss et al. 2018). Our field visits for weed seed collection during 2015 to 2017 in the northern region of Australia, as well as communications with growers and agronomists, indicated that *A. mexicana* was a major problem in chick pea fields and winter fallows. This weed was rarely observed in wheat. When present in wheat, it was in the crop boundaries or within poor crop stands. Not many reports are available on the competitiveness of *A. mexicana* in crops. A related species, California poppies (*Eschscholzia californica* Cham.), established well under a moist environment; however, it was suppressed by perennial ryegrass (*Lolium perenne* L.) at high densities due to depletion of resources (Kirkpatrick 1998).

There was 100% seed retention for *R. rugosum*, as no seed was observed in the seed-catching trays or on the soil surface. Weed density and seed production followed a hyperbolic relationship (Figure 5). The maximum seed counts in 2016 and 2017 were 32,042 and 29,761 seeds m^{-2}, respectively. High seed production offers an adaptive potential to Brassicaceae weeds. *Raphanus raphanistrum*, a major weed from this family, can produce a substantial number of seeds (Eslami et al. 2006). Although *R. rugosum* exhibited superior competitiveness and seed production, the high level of seed retention is a favorable factor that will help in managing this weed through seed capture and destruction (Walsh et al. 2018; Walsh and Powles 2014). Similar to *R. rugosum*, *R. raphanistrum* and *L. rigidum* exhibit high seed retention at crop harvest, and employing harvest weed seed control for such weeds can offer a possible opportunity to reduce seedbank enrichment (Walsh and Powles 2014). Lack of seed production of *A. mexicana* in both years of the study offers the potential of integrating wheat into crop rotations to manage heavy infestations.

This study reports the interference of *R. rugosum* and *A. mexicana* in wheat. *Rapistrum rugosum* caused a yield reduction of 72% to 78% at high density, and around 18 to 24 plants m^{-2} caused a yield reduction of 50%. The yield reduction in wheat was primarily due to a lower number of panicles per unit area and the number of grains per panicle as a result of weed competition. The high level of seed production further enhances the adaptive potential of *R. rugosum* to become a dominant weed. However, high seed retention and weed maturity coinciding with crop harvest provide an opportunity for controlling *R. rugosum* through harvest weed seed control tactics.

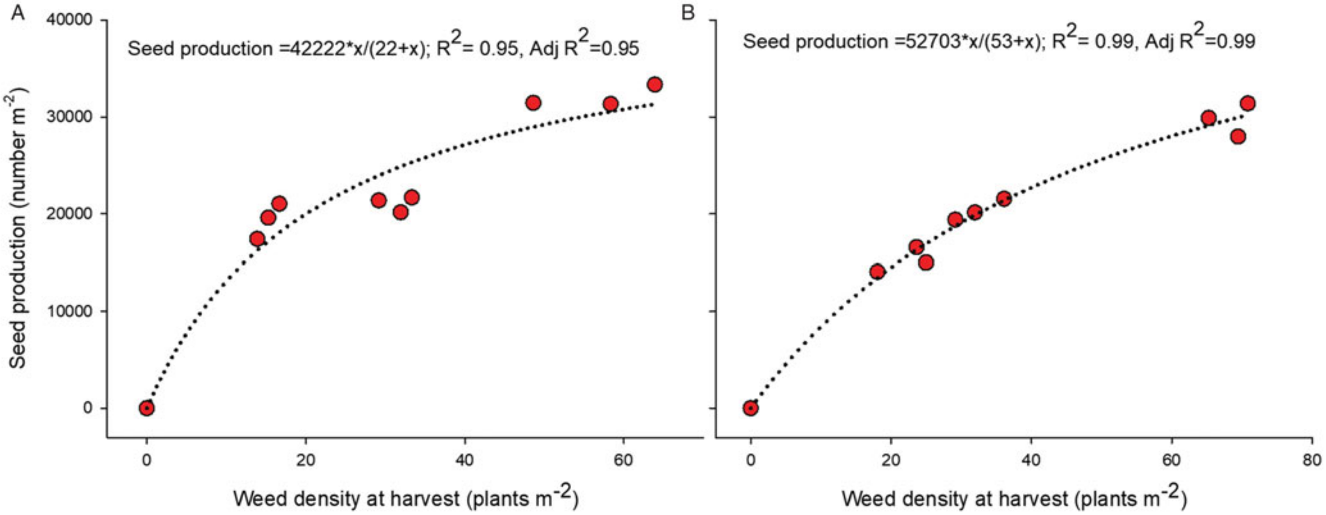

Figure 5. Seed production of *Rapistrum rugosum* in 2016 (A) and 2017 (B). The lines represent a hyperbolic model fit to the data.

Argemone mexicana failed to establish and set seeds in wheat, although there was a yield reduction due to this weed. This study indicates the opportunity to manage this weed by integrating wheat into crop rotation programs.

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