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Interference of junglerice (*Echinochloa colona*) in mung bean

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Abstract

Junglerice [*Echinochloa colona* (L.) Link] is increasing its prevalence in eastern Australia by adapting to Australia's changing climatic conditions and conservation agricultural systems and by evolving resistance to glyphosate. Information is limited on the growth and seed production dynamics of *E. colona* when it interferes with mung bean [*Vigna radiata* (L.) R. Wilczek], a major potential export crop for eastern Australia. This field study examined the interference of *E. colona* in mung bean for two summer seasons (2020 and 2021) at Gatton, QLD. Different infestation levels (0, 2, 4, 8, 16, and 32 plants m^{-2}) of *E. colona* were assessed for their potential to cause yield reductions in mung bean. Seed yield of mung bean was highest in the weed-free plots (2,767 kg ha^{-1}) and declined by 20%, 27%, 34%, and 43% at weed infestation levels of 4, 8, 16, and 32 plants m^{-2}, respectively. *Echinochloa colona* biomass in mung bean varied from 11 to 137 g m^{-2} as weed density increased from 2 to 32 plants m^{-2}. Based on a three-parameter hyperbolic rectangular decay model, crop yield loss was 52% and 57%, respectively, when weed density and weed biomass approached maximum. *Echinochloa colona* at the highest density (32 plants m^{-2}) produced a maximum of 15,140 seeds m^{-2}, and this seed production was reduced by 50% at a weed density of 10 plants m^{-2}. *Echinochloa colona* plants retained 63% to 68% seeds at mung bean maturity, indicating a great opportunity for harvest weed seed control. This study suggests that a high infestation of *E. colona* in mung bean fields could cause a substantial yield loss and increase the weed seedbank.

Introduction

Mung bean [*Vigna radiata* (L.) R. Wilczek] is a high potential export pulse crop of Australia. This crop occupies an area of about ~100,000 ha in Australia and produces 130 trillion kg of beans (GRDC 2017; Rachaputi et al. 2019). Almost 90% of mung bean produced in Australia is exported to Asia, Europe, the Middle East, and North America, resulting in revenue gains of AU$180 million (GRDC 2017). Mung bean in Australia is grown with wider row spacings (50 to 100 cm), which leads to heavy weed infestation and increases weed seedbank replenishment (GRDC 2017). Weeds in mung bean cause a huge seed yield loss, which can result in an 87% reduction (Chauhan et al. 2017; Yadav et al. 1983). Information on yield loss of mung bean with the interference of junglerice [*Echinochloa colona* (L.) Link] is very limited.

Echinochloa colona is one of the most common grass weeds that infest mung bean in eastern Australia (GRDC 2017). Its prolific seed production, dispersal by water and wind, and evolved glyphosate-resistant biotypes could be the reasons for the prevalence of *E. colona* throughout the cropping region of eastern Australia (Mahajan et al. 2019b, 2020). *Echinochloa colona* has multiple cohorts in spring and summer in eastern Australia (McGillion and Storrie 2006). Early spring emergence of *E. colona* is a common problem in mung bean fields; therefore, preplant control with glyphosate is a common practice for the management of early-season *E. colona* infestation.

Adoption of a no-till system and overreliance on glyphosate as preplant weed control have led to the problem of glyphosate-resistant *E. colona* in Australia. The first incidence of glyphosate resistance in an Australian biotype of *E. colona* was reported in New South Wales in 2007 (Preston 2010). Later, several glyphosate-resistant biotypes of *E. colona* were reported in eastern Australia (Heap and Duke 2018; Mahajan et al. 2020). With the advent of glyphosate-resistant biotypes, it is important to assess yield losses at different levels of *E. colona* competition.

Echinochloa colona populations in Australia are highly adapted to water-stress conditions, and they can germinate under a wide range of environmental conditions (Mahajan et al. 2019a;

Mutti et al. 2019a). In sorghum [*Sorghum bicolor* (L.) Moench], *E. colona* has been ranked fifth when assessed in terms of management costs incurred due to herbicide-resistant weeds in Australia. Australia loses about 800 million kg of grains (cereal, pulses, and oilseeds) every year due to *E. colona* infestation, resulting in a revenue loss of AU$14.7 million yr^{-1} (Llewellyn et al. 2016).

The concept of threshold in weed science is assessed in terms of economic, damage, time period, and action threshold levels (Coble and Mortensen 1992). Knowledge of the economic threshold level (ETL) of *E. colona* is important to implement cost-effective and timely weed management in mung bean production. The ETL of weeds indicates the density of weeds at which their control is required for economic gain (Hamouz et al. 2013). It is an important metric for making decisions for the most economic weed control. However, the ETL is underestimated if we do not account for the seed production of weeds that are allowed to grow when they are below the ETL. The high seed production ability of weeds that are below the ETL may increase the cost of weed control in the next season by producing seeds and reinfesting fields through seed rains. This suggests that restricting seed production of weed plants, even when they are below the ETL, is important for sustainable weed control.

Knowledge of the competitiveness of weeds in crops such as mung bean could aid in developing integrated weed management (IWM) strategies (Amini et al. 2014; Eslami et al. 2006; Manalil et al. 2020). Various authors have reported that crops differ in their potential when competing with different weeds (Eslami et al. 2006; Lemerle et al. 2014; Reiss et al. 2018; Sardana et al. 2017). For example, barley (*Hordeum vulgare* L.) is more competitive with weeds than wheat (*Triticum aestivum* L.) or faba bean (*Vicia faba* L.). Therefore, competitive crops that smother weed flora are preferred in crop rotations when formulating IWM strategies (Dhima et al. 2018; Tautges et al. 2017). This information could help in framing IWM measures.

The time of seed maturity and seed retention ability of *E. colona* in relation to mung bean maturity is important, particularly when exploring the possibility of harvest weed seed control (HWSC) for implementing IWM measures (Mahajan et al. 2019b; Walsh et al. 2018a, 2018b). The phenology, seed production, and seed dispersal ability of weeds change with crops of various developmental phases (Goplen et al. 2016). There is a lack of information on the growth, seed production, and seed retention ability of *E. colona* relative to mung bean developmental phases. At crop maturity, weed seeds that fall during seed rains or are captured by the harvester are generally returned to the fields and may cause further reinfestation (Walsh et al. 2013). Weed control measures, such as HWSC, could restrict weed seed return by capturing seeds on the plants at crop harvest and then destroying them with practices such as burning the chaff in narrow windrows, chaff lining, or through the Harrington Seed Destructor system (Walsh and Newman 2007; Walsh et al. 2018a). Weed seed retention at crop harvest provides estimates of the proportion of weed seeds that can be reduced with HWSC practices (Mahajan et al. 2019b; Soni et al. 2020). *Echinochloa colona* is a short-duration weed that can complete its life cycle in 56 d (Mutti et al. 2019b), which may allow the capture of weed seeds of *E. colona* in a short-duration crop such as mung bean. Knowledge gaps exist regarding the competitiveness of *E. colona* in mung bean in Australia. Therefore, the objective of this study was to evaluate the competitiveness and seed production dynamics of *E. colona* in mung bean crops at different infestation levels.

Materials and Methods

Experimental Details

Field experiments were conducted during the summer seasons of 2020 and 2021 (from January to March) at the research field of the University of Queensland, Gatton, QLD (27.5514°S, 152.3428°E). The soil type in the experimental field was clay loam with an organic matter content of 1.1% and pH 7.1. Before mung bean planting, the field was tilled twice with a cultivator (Ergon N120-205, Celli, Forli, Italy) to ensure a fine seedbed at planting time. The field study was conducted with six infestation levels (0, 2, 4, 18, 16, and 32 plants m^{-2}) of *E. colona* in mung bean. All treatments were arranged in a randomized complete block design, with three replicates.

The mung bean cultivar 'Jade-Au' was planted at 35-cm row spacing with a density of 30 plants m^{-2} (i.e., 300,000 plants ha^{-1}). Previous workers suggested that an optimum stand of about 300,000 plants ha^{-1} is an essential requirement to obtain high yields in mung bean under Australian conditions (Rachaputi et al. 2019). The crop was sown on January 24 and January 19 in 2020 and 2021, respectively. Sowing was done manually, and seeds were sown at a depth of 5 cm. The dimension of an individual plot was 1.5 m by 1.0 m. The plots were irrigated after sowing using a drip-irrigated system until crop and weed establishment (up to 4 wk after planting), and thereafter, the crop was rainfed to simulate growers' conditions. No fertilizer was applied to the crop.

Seeds of *E. colona* utilized in this study were originally collected from Dalby, QLD (27.6197°S, 151.4511°E), with the permission of the property owner in October 2017. Weed seed multiplication was done at the Research Farm of the University of Queensland, Gatton, in the summer season of 2019. Seeds were collected from 50 to 60 mature plants and stored at room temperature until used.

Echinochloa colona seeds were planted initially in plastic trays (January 21 and January 16 in 2020 and 2021, respectively) filled with a potting mix (Centenary Landscape, Darra, QLD, Australia) and kept in a screenhouse. Weed seeds were planted 3 d before mung bean sowing to match the weed emergence time with crop emergence. Desired densities of *E. colona* plants were then transplanted at the 2-leaf stage (January 30 and January 25 in 2020 and 2021, respectively) into the respective plots (as per the planting pattern shown in Supplementary Figure 1) at the emergence time of mung bean. The plots were regularly hand weeded to maintain *E. colona* density in each plot.

Seed production and biomass of *E. colona* were assessed at mung bean harvest. For estimation of seed production of *E. colona*, seedheads from 1 m^2 (using a 1 m by 1 m quadrat at the center of the plot) were counted. Seed production per head was determined using two intact seed heads that were chosen randomly from each plot. To estimate the total number of seeds, each rachilla segment (pedicel base) was counted and then averaged to calculate seeds per head (Mahajan et al. 2019b). The seeds that were still attached to the rachilla segment at harvest were counted separately to assess seed loss due to shattering.

For weed biomass analysis, samples were collected by cutting all *E. colona* plants at the ground level in each plot (1 m by 1m) and drying them in an oven at 70 C for 72 h. At crop harvest, two *E. colona* plants were selected randomly from each plot for height measurements, and their heights were averaged. Height was measured from the base of the plant to the top of the tallest inflorescence. Mung bean pods were harvested manually, and seed yield after threshing was determined from the same 1 m^2 in each plot from which the weed biomass was sampled. Seed yield was converted to kilograms per hectare (kg ha^{-1}) at 12% moisture content. Emergence, flowering, and maturity of mung bean and *E. colona* were related to growing degree-day base 10 (GDD_{10}) as:

$$GDD_{10} = [(\text{maximum daily temperature} + \text{minimum daily temperature})/2) - 10] \quad [1]$$

Weather data for the Gatton location were obtained from the Bureau of Meteorology, Australia (http://www.bom.gov.au/climate) situated within 500 m of the experimental field.

Statistical Analyses

The data for both years were subjected to an ANOVA using the software CPCS1, verified with GENSTAT (19th ed., VSN International, Hemel Hempstead, UK). Year by treatment interactions were nonsignificant for each parameter; therefore, data were pooled over the years (a total of six replications) for further analysis. Treatment means were compared at the 5% level of significance using Fisher's protected least significant difference (LSD). Data were also validated to meet the assumptions of normality and variance before analysis.

The relationship between mung bean yield and weed biomass, and mung bean yield and weed density were fit using a three-parameter hyperbolic decay model in SigmaPlot 14.5 (Systat Software, San Jose, CA, USA):

$$G = G_0 + (a * x/b + x) \quad [2]$$

where G is the mung bean yield as a percentage of weed-free control at weed density or weed biomass x, G_0 is mung bean yield (%) under weed-free conditions, a is the crop yield loss as weed density or weed biomass approaches maximum, and b is the slope (SigmaPlot 14.5, Systat Software).

The relationship between weed density and weed seed production was estimated with a three-parameter logistic model using:

$$S = a/[1 + (x/d_{50})^b] \quad [3]$$

In this model, S is weed seed production in relation to weed density x, a is the maximum seed production, d_{50} is the weed density (plants m^{-2}) required for a 50% reduction in seed production, and b is the slope. The fit of the selected models was determined using R^2 values.

Results and Discussion

Weather Data and Crop Growth

Mung bean emerged at 5 d (91 GDD) and 7 d (99 GDD) after seeding 2020 and 2021, respectively. *Echinochloa colona* flowered at 35 d (596 GDD) and 42 d (688 GDD) after seeding in 2020 and 2021, respectively. The crop was matured at 65 d (997 GDD) and 71 d (1053 GDD) after seeding in 2020 and 2021, respectively. The maximum temperature during February 2021 was relatively higher than in February 2020 (Figure 1). However, the minimum temperature during February 2021 was also lower than in February 2020. The crop received 122 and 39 mm of rainfall in February 2020 and 2021, respectively. However, in March, the crop received 41 and 134 mm of rainfall in 2020, and 2021, respectively (Figure 1).

In 2020, there were 27 rainy days during the cropping season, 20 of which occurred during the vegetative stage; whereas in 2021, there were 20 rainy days during the season with only 6 rainy days during the vegetative stage. These rainfall quantities and timing differences may explain the differences in observed absolute yields.

Echinochloa colona Interference in Mung Bean

Echinochloa colona seed production in mung bean plots increased from 589 to 15,300 seeds m^{-2} with an increase in weed density level from 2 to 32 plants m^{-2} (Table 1). A similar trend was noticed for the biomass of *E. colona* (Table 1). At a weed density of 2 plants m^{-2}, *E. colona* in mung bean plots accrued biomass of 11 g m^{-2}, which increased to 137 g m^{-2} at the weed density of 32 plants m^{-2}. *Echinochloa colona* biomass and seed production in mung bean plots remained similar at weed densities of 2 and 4 plants m^{-2} but was lower than at weed densities of 16 and 32 plants m^{-2}. The seed retention component of *E. colona* remained similar at different infestation levels, and values ranged from 63% to 68% (Table 1).

The mung bean seed yield in weed-free plots was 2,767 kg ha^{-1} (Table 1). The mung bean seed yield at weed infestation levels of 4, 8, 16, and 32 plants m^{-2} was reduced by 20%, 27%, 34%, and 43%, respectively, compared with weed-free plots. Based on the hyperbolic decay model (Equation 2), crop yield loss was 52% and 57%, respectively, at the highest weed density and weed biomass (Figures 2 and 3). The yield reduction in mung bean due to interference of weeds was primarily due to a lower number of pods per plot, because the 100-seed weight of mung bean did not vary with weed interference levels (data not shown).

A three-parameter logistic model (Equation 3) was fit to explain the effect of weed density on seed production of *E. colona* (Figure 4). Based on the logistic model, the highest density (32 plants m^{-2}) of *E. colona* in mung bean produced a maximum of 15,140 seeds m^{-2}, and weed seed production was reduced by 50% at a weed density of 10 plants m^{-2}. The high level of seed production of *E. colona* at weed densities ranging from 8 and 32 plants m^{-2} can enhance the adaptive potential of *E. colona* to become a dominant weed. Weeds compete for growth resources with crop plants; therefore, seed yield reduction in mung bean due to interference of *E. colona* was expected. In a crop–weed interaction, the density of both the crop and the weed plays a crucial role in competition. In this study, crop density was fixed, and the yield of mung bean was assessed in relation to varying *E. colona* density. At the lowest weed density (2 plants m^{-2}), the seed yield of mung bean was not affected. It is quite possible that at this density, individual weeds might not have had to share the same resources, reducing the chances of interference in that case. Various studies predicted little crop yield loss when the weed density was low (Bhan 1983; Chauhan et al. 2017; Smith 1968; Zimdahl 1980).

With increasing weed density, the proximity between neighboring crop plants and weeds is likely to increase, which may result in increased intra- and interspecific competition. Thereafter, crop and weed plants react to the presence of neighboring plants at high density and compete for space and growth resources. This was quite evident in the present study, as mung bean seed yield decreased due to greater competition when the density of *E. colona* increased from 4 to 32 plants m^{-2}. Plants share their space in proportion to their size. At high densities, the area occupied by individual plants overlaps, and resources for plants become limited. It is a well-established fact that density-dependent processes play a crucial role in establishing natural plant populations, and at an "ecologically effective distance," increased weed density did not further reduce yield (Antonovics and Levin 1980).

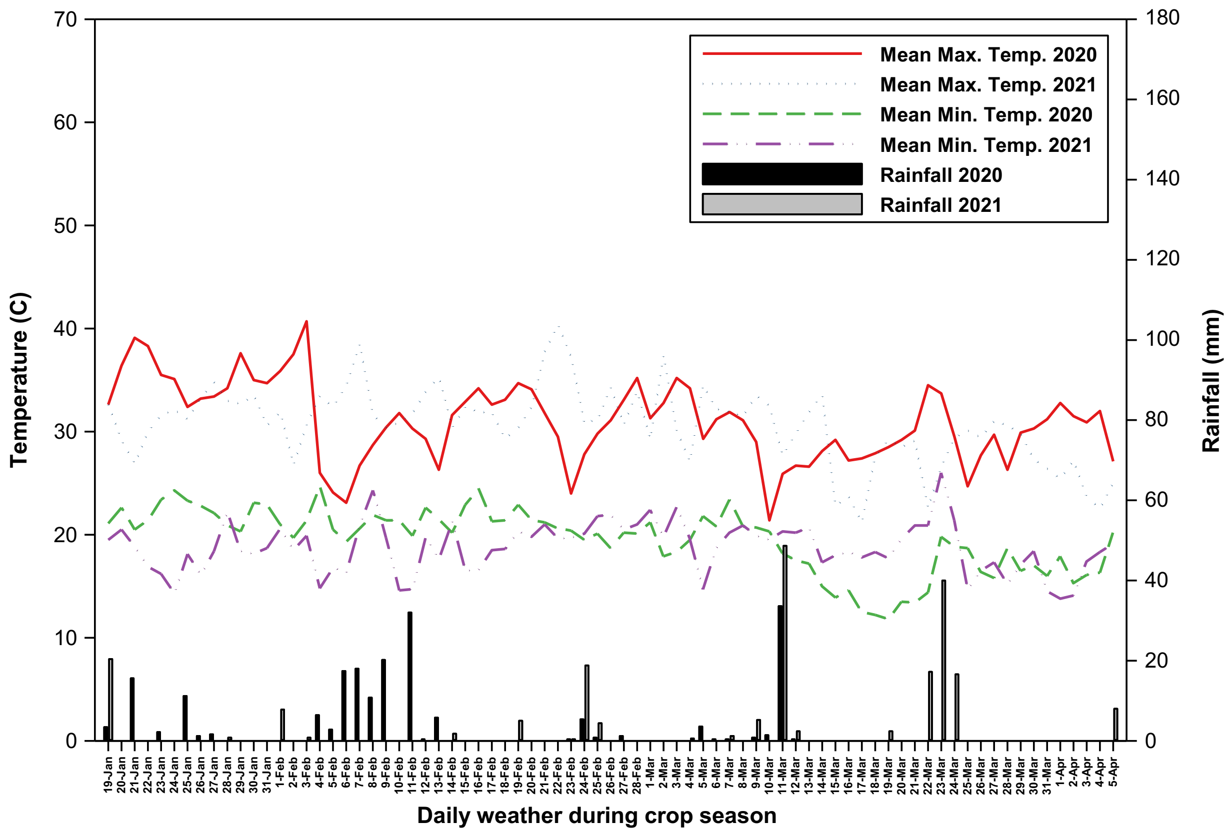

Figure 1. Weather conditions in Gatton, QLD, Australia, during crop seasons of mung bean.

Overall, our results are in line with previous studies that reported grain/seed yield losses in crops such as mung bean and rice (*Oryza sativa* L.) due to infestation of *E. colona* (Gwon et al. 2006; Kumar and Kairon 1990; Mercado and Talatala 1977; Punia et al. 2004; Singh et al. 2003). Data on specific crop yield losses due to infestation of *E. colona* in Australia are limited. A competition study on Japanese millet [*Echinochloa esculenta* (A. Braun) H. Scholz], a close mimic of barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], reported that 80 plants m^{-2} of *E. esculenta* could reduce sorghum yield by up to 1,600 kg ha^{-1} (Wu et al. 2010).

Our recent studies suggested that the biological traits of *E. colona* enabled this weed to complete its life cycle under a wide range of environments, competition, and water-stress conditions (Mahajan et al. 2019a, 2019b; Mutti et al. 2019a, 2019b). Therefore, this weed could invade the agroecological system if allowed to grow, including in mung bean fields. *Echinochloa colona* tends to emerge in spring or early summer (>20 C mean temperature) if suitable soil moisture is available (Walker et al. 2010). Under lab conditions, it was observed that *E. colona* could germinate over a wide range of alternating day/night temperatures (20/10 to 35/25 C) (Chauhan and Johnson 2009; Mutti et al. 2019a). These results suggest that *E. colona* could interfere with mung bean crops under a range of planting times and environmental conditions and produce seeds.

A recent pot study in Australia also suggested that one plant of *E. colona* tends to produce enough seeds (~4,000 seeds per pant) when grown in competition with four mung bean plants per pot (Mutti et al. 2019b). Previous studies in Australia also revealed that *E. colona* could produce multiple cohorts under a wide range of environmental conditions (Walker et al. 2010). These observations suggest that *E. colona* can infest mung bean crops at different planting times and reduce mung bean yield, if not managed in a timely way.

In Australia, mung bean is grown under rainfed conditions, which can result in multiple cohorts of *E. colona*, and the planting time of mung bean varies with the occurrence of rainfall. Consequently, preemergence and postemergence herbicides may not provide adequate control of this weed in mung bean. Therefore, IWM strategies, including preplant control and cultural techniques that increase crop competition through early canopy closure, judicious use of herbicides, and HWSC practices could provide sustainable control of *E. colona*.

The present study supports the possibility of HWSC of *E. colona* in mung bean, as the seed retention of *E. colona* at mung bean maturity ranged from 63% to 68%. A previous study on sorghum suggested that seed retention of *E. colona* ranged from 42% to 56% at sorghum maturity (Mahajan et al. 2019b). The high seed retention ability of *E. colona* in mung bean suggests that sustainable control of *E. colona* in the no-till production systems of Australia can be achieved by using measures such as HWSC. Because HWSC programs help to break the cycle of seed replenishment in the soil, these methods could reduce weed infestation by reducing the soil seedbank. Weed seeds that remain on the soil surface in a no-till system may decay quickly, as the persistence of *E. colona* seeds on the soil surface is short (<2 yr) (Walker et al. 2010). No-till systems tend to foster a greater occurrence of weed seed predators than conventional tillage.

In fields where *E. colona* is dominant, an attempt should be made for early control with suitable herbicide measures to restrict mung bean yield loss. Agronomic practices such as

Table 1. Effect of *Echinochloa colona* density on weed parameters and seed yield in mung bean.

Weed density	Weed biomass	Weed seed production	Weed seed retention	Mung bean yield
plants m^{-2}	g m^{-2}	no. m^{-2}	%	kg ha^{-1}
0	—	—	—	2,767
2	10.8	589	68	2,489
4	23.4	1,594	68	2,213
8	44.6	5,607	63	2,011
16	70.3	8,972	66	1,813
32	136.7	15,349	68	1,584
LSD (0.05)	35.9	3,973	NS	459

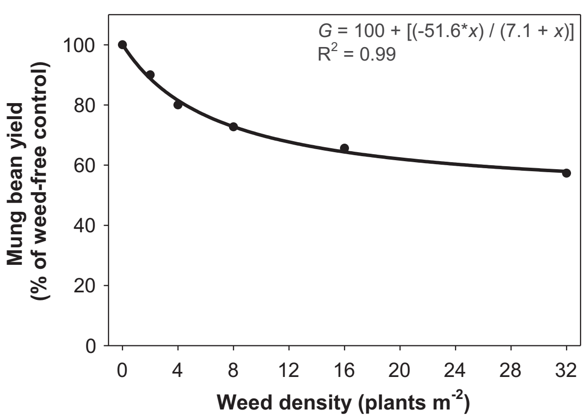

Figure 2. Effect of *Echinochloa colona* density on mung bean seed yield as a percent of weed-free control. Symbols indicate means from a total of six replications in 2020 and 2021, and the response was fit using a three-parameter hyperbolic decay model (Equation 2).

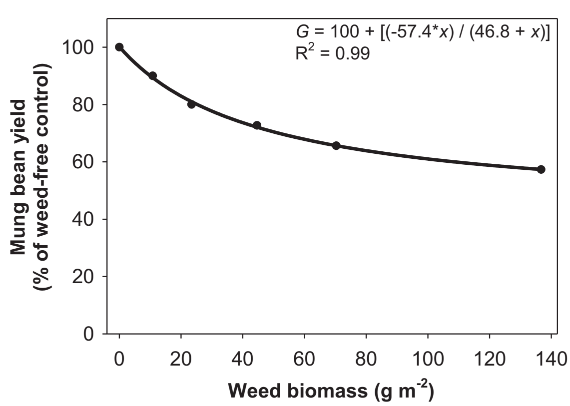

Figure 3. Effect of *Echinochloa colona* biomass on mung bean seed yield as a percent of weed-free control. Symbols indicate means from a total of six replications in 2020 and 2021, and the response was fit using a three-parameter hyperbolic decay model (Equation 2).

delayed planting, strategic tillage, exploring weed-competitive cultivars, and closer row spacing, all of which help in early canopy closure, may prove to be useful tools that can be integrated with suitable herbicides for the early control of weeds and thus may be effective tools for an IWM approach to managing *E. colona* in mung beans.

Various studies reported that biomass of *E. colona* could be reduced by >90% by following integrated control measures

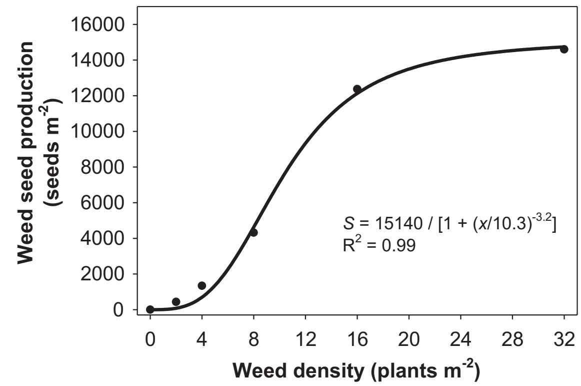

Figure 4. Effect of *Echinochloa colona* density on weed seed production. Symbols indicate means from a total of six replications in 2020 and 2021, and the response was fit using a three-parameter logistic model (Equation 3).

(Kaur et al. 2017; Kumar et al. 2020). Our results illustrate that even low densities (2 plants m^{-2}) of *E. colona* in mung bean could lead to considerable seed production (590 seeds m^{-2}) for reinfestation without timely control. Therefore, the approach must be oriented toward complete control of *E. colona* in the field.

Further, there is a need to generate more data on how different populations of *E. colona* behave and to assess the competitive interaction with mung bean under various environmental conditions. This study was conducted with one population of *E. colona* and with one planting date of mung bean for each of the two planting seasons. The competitive ability of weeds may vary with crop cultivars, seasons, moisture regimes, and weed populations (Carlson and Hill 1985). The relative time of emergence of *E. colona* and mung bean may also influence the competitive ability of the weed. Therefore, there is a need to explore the potential of cultural weed management practices such as sowing time, seeding rate, exploring competitive cultivars, and row spacing under a wide range of environmental conditions and variables.

As mentioned earlier, the outcome of competition depends not only on the density and proportion of weed species but also on the crop attributes. Therefore, different varieties of mung bean may show different responses to weed interference and weed seed retention levels. It would be interesting to study the interference of different *E. colona* populations with some promising mung bean varieties under various tillage regimes. A recent pot study showed that increased mung bean density in pots reduced seed production and biomass of *E. colona* (Mutti et al. 2019b). Therefore, future research on crop–weed competition in mung bean could be oriented toward identifying more inherently competitive cultivars and the manipulation of crop population to improve the competitive ability of currently grown cultivars of mung bean against weeds such as *E. colona*.

In conclusion, this study revealed that based on the three-parameter hyperbolic decay model (Equation 2), *E. colona* density ranging from 2 to 32 plants m^{-2} caused a substantial reduction in mung bean yield. Based on the logistic model relationship between weed density and weed seed production, *E. colona* at the highest density (32 plants m^{-2}) in mung bean produced a maximum of 15,140 seeds m^{-2}, and seed production declined by 50% at a weed density of 10 plants m^{-2}. The seed retention component of *E. colona* in mung bean is high. The current study emphasized that efforts need to be made toward control of low densities of *E. colona* with the aim of minimizing crop–weed interference at an early stage to reduce yield loss. It implied that HWSC may be a useful tool for reducing weed seed replenishment for the integrated management of *E. colona* in mung bean production in Australia.

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Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/wsc.2022.24

References

Amini R, Alizadeh H, Yousefi A (2014) Interference between red kidneybean (*Phaseolus vulgaris* L.) cultivars and redroot pigweed (*Amaranthus retroflexus* L.). Eur J Agron 60:13–21

Antonovics J, Levin DA (1980) The ecological and genetic consequences of density-dependent regulation in plants. Annu Rev Ecol Syst 111:411–452

Bhan VM (1983) Effects of hydrology, soil moisture regime and fertility management on weed populations and their control in rice. Pages 47–56 *in* Proceedings of the Conference on Weed Control in Rice. Los Baños, Philippines: International Rice Research Institute

Carlson HL, Hill JE (1985) Wild oats competition with spring wheat: plant density effects. Weed Sci 33:176–181

Chauhan BS, Florentine SK, Ferguson JC, Chechetto RG (2017) Implications of narrow crop row spacing in managing weeds in mungbean (*Vigna radiata*). Crop Prot 95:116–119

Chauhan BS, Johnson DE (2009) Seed germination ecology of junglerice (*Echinochloa colona*): a major weed of rice. Weed Sci 57:235–240

Coble HD, Mortensen DA (1992) The threshold concept and its application to weed science. Weed Technol 6:191–195

Dhima K, Vasilakoglou I, Gatsis T, Gougoulias N (2018) Faba bean–barley intercrops for high productivity and corn poppy suppression. Exp Agric 54: 163–180

Eslami SV, Gill GS, Bellotti B, McDonald G (2006) Wild radish (*Raphanus raphanistrum*) interference in wheat. Weed Sci 54:749–756

Goplen JJ, Sheaffer CC, Becker RL, Coulter JA, Breitenbach FR, Behnken LM, Johnson GA, Gunsolus JL (2016) Giant ragweed (*Ambrosia trifida*) seed production and retention in soybean and field margins. Weed Technol 30:246–253

[GRDC] Grains Research and Development Corporation (2017) GrowNotes: Mungbeans. Northern 2017. Canberra, ACT, Australia: Grains Research and Development Corporation. https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy/grownotesmungbeansnorthern/GRDC-GrowNotes-Mungbeans-Northern.pdf. Accessed: April 12, 2021

Gwon OD, Kim HY, Mun BC, Guk YL, Kim JG (2006) Effect of densities of *Echinochloa crus-galli* and *Monochoria vaginalis* in wet seeding and transplanting rice cultivation on rice yield and rice quality, and economic threshold levels of the weeds. Korean J Weed Sci 26:155–167

Hamouz P, Hamouzová K, Holec J, Tyšer L (2013) Impact of site-specific weed management on herbicide savings and winter wheat yield. Plant Soil Environ 59:101–107

Heap I, Duke SO (2018) Overview of glyphosate-resistant weeds worldwide. Pest Manag Sci 74:1040–1049

Kaur S, Mahajan G, Chauhan BS (2017) Integrated weed management techniques in rice. Pages 377–399 *in* Sasaki T, ed. Achieving Sustainable Cultivation of Rice. Volume 2. Cultivation, Pest and Disease Management. 1st ed. Cambridge, UK: Burleigh Dodds Science Publishing. 10.4324/9781351114196

Kumar S, Kairon MS (1990) Studies on crop-weed competition in summer mungbean. Legume Res 13:110–112

Kumar V, Mahajan G, Sahil, Chauhan BS (2020) Challenges and opportunities for weed management in no-till farming systems. Pages 107–125 *in* Dang Y, Dalal R, Menzies NW, eds. No-Till Farming Systems for Sustainable Agriculture: Challenges and Opportunities. Cham, Switzerland: Springer International Publishing. 10.1007/978-3-030-46409-7

Lemerle D, Luckett DJ, Lockley P, Koetz E, Wu H (2014) Competitive ability of Australian canola (*Brassica napus*) genotypes for weed management. Crop Pasture Sci 65:1300–1310

Llewellyn R, Ronning D, Clarke M, Mayfield A, Walker S, Ouzman J (2016) Impact of Weeds in Australian Grain Production: The Cost of Weeds to Australian Grain Growers and the Adoption of Weed Management and Tillage Practices. Report for GRDC. Canberra, ACT, Australia: Common wealth Scientific and Industrial Research Organisation. 112 p

Mahajan G, Kaur V, Thompson M, Chauhan BS (2020) Growth behavior and glyphosate resistance level in 10 populations of *Echinochloa colona* in Australia. PLoS ONE 15:e0221382

Mahajan G, Mutti NK, Walsh M, Chauhan BS (2019a) Effect of varied soil moisture regimes on the growth and reproduction of two Australian biotypes of junglerice (*Echinochloa colona*). Weed Sci 67:552–559

Mahajan G, Walsh M, Chauhan BS (2019b) Junglerice (*Echinochloa colona*) and feather fingergrass (*Chloris virgata*) seed production and retention at sorghum maturity. Weed Technol 43:272–276

Manalil S, Ali HH, Chauhan BS (2020) Interference of annual sowthistle (*Sonchus oleraceus*) in wheat. Weed Sci 68:98–103

McGillion T, Storrie A, eds (2006) Integrated Weed Management in Australian Cropping Systems: A Training Resource for Farm Advisors. Adelaide, SA, Australia: Cooperative Research Centre for Australian Weed Management. 248 p

Mercado B, Talatala R (1977) Competitive ability of *Echinochloa colonum* L. against direct-seeded lowland rice. Pages 161–165 *in* Proceedings of the 6th Asian-Pacific Weed Science Society Conference. Volume 1. Jakarta, Indonesia. Asian-Pacific Weed Science Society

Mutti NK, Mahajan G, Chauhan BS (2019a) Seed germination ecology of glyphosate-resistant and glyphosate-susceptible biotypes of *Echinochloa colona* L. (Link) in Australia. Crop Pasture Sci 70:367–372

Mutti NK, Mahajan G, Prashant J, Chauhan BS (2019b) The response of glyphosate-resistant and glyphosate-susceptible biotypes of junglerice (*Echinochloa colona*) to mungbean interference. Weed Sci 67:419–425

Preston C (2010) Managing glyphosate-resistant weeds in Australia. Pages 250–253 *in* Proceedings of the 17th Australasian Weeds Conference. Christchurch, New Zealand: New Zealand Plant Protection Society

Punia SS, Malik RS, Yadav A, Rinwa RS (2004) Effect of varying density of *Cyperus rotundus*, *Echinochloa colona* and *Trianthema portulacastrum* on mungbean. Indian J Weed Sci 36:280–281

Rachaputi RCN, Sands D, McKenzie K, Agius P, Lehane J, Seyoum S (2019) Eco-physiological drivers influencing mungbean *Vigna radiata* (L.) Wilczek productivity in subtropical Australia. Field Crops Res 238:74–81

Reiss A, Fomsgaard IS, Mathiassen SK, Stuart RM, Kudsk P (2018) Weed suppression by winter cereals: relative contribution of competition for resources and allelopathy. Chemoecology 28:109–121

Sardana V, Mahajan G, Jabran K, Chauhan BS (2017) Role of competition in managing weeds: an introduction to the special issue. Crop Prot 95:1–7

Singh S, Yadav A, Malik RK, Singh, M (2003) Rhizotron study on soil moisture and plant population effect on root competition of cotton and mungbean with *Trianthema portulacastrum* and *Echinochloa crus-galli*. Pages 1059–1064 *in* The BCPC International Congress: Crop Science and Technology. Volumes 1 and 2. Proceedings of an International Congress Held at the SECC, Glasgow, Scotland, UK, 10–12 November 2003. Alton, UK: British Crop Protection Council

Smith RJ Jr (1968) Weed competition in rice. Weed Sci 16:252–255

Soni N, Nissen SJ, Westra P, Norsworthy JK, Walsh MJ, Gaines TA (2020) Seed retention of winter annual grass weeds at winter wheat harvest maturity shows potential for harvest weed seed control. Weed Technol 34:266–271

Tautges NE, Burke IC, Borrelli K, Fuerst EP (2017) Competitive ability of rotational crops with weeds in dryland organic wheat production systems. Renew Agric Food Syst 32:57–68

Walker S, Wu H, Bell K (2010) Emergence and seed persistence of *Echinochloa colona*, *Urochloa panicoides* and *Hibiscus trionum* in the sub-tropical environment of north-eastern Australia. Plant Prot Q 25:127–132

Walsh M, Newman P (2007) Burning narrow windrows for weed seed destruction. Field Crops Res 104:24–30

Walsh M, Newman P, Powles S (2013) Targeting weed seeds in-crop: a new weed control paradigm for global agriculture. Weed Technol 27:431–436

Walsh MJ, Broster JC, Powles SB (2018a) iHSD mill efficacy on the seeds of Australian cropping system weeds. Weed Technol 32:103–108
Walsh MJ, Broster JC, Schwartz-Lazaro LM, Norsworthy JK, Davis AS, Tidemann BD, Beckie HJ, Lyon DJ, Soni N, Neve P, Bagavathiannan MV (2018b) Opportunities and challenges for harvest weed seed control in global cropping systems. Pest Manag Sci 74:2235–2245
Wu H, Walker SR, Osten VA, Taylor IN, Robinson G (2010) Competition of sorghum cultivars and densities with Japanese millet (*Echinochloa esculenta*). Weed Biol Manag 10:185–193
Yadav SK, Bhan VM, Singh SP (1983) Crop weed competition studies in mung beans (*Vigna radiata*). Exp Agric 19:337–340
Zimdahl RL (1980) Weed Competition: A Review. Corvallis, OR: International Plant Protection Center, Oregon State University. 198 p