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RESEARCH ARTICLE

Barnyardgrass (*Echinochloa crus-galli)* seed production and shattering in response to its emergence time and transplanted rice geometry

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ABSTRACT

A field experiments were conducted to study the seed production and shattering pattern of barnyardgrass (BYG) in response to its emergence and transplanted rice geometry. A split-plot design with four replications was used with transplanted rice geometry (M1- 15×15 cm, M2- 25×25 cm) in main-plots and BYG emergence timings [S1- 0 days after transplanting (DAT), S2- 20 DAT, S3- 40 DAT] as sub-plot treatments. The increase in crop spacing by 10 cm in each row and column (M2) increased the BYG seed production by 20% over M1. The wider crop geometry (M2) also recorded significantly higher density (17.2%), dry matter production (39.6%), leaf length (11.6%) and panicle count (24.7%) than M1. With respect to time of emergence, the maximum number of seeds per BYG plant was produced (31987) by S1 (BYG emergence at 0 DAT) while S3 (BYG emergence from 40 DAT) recorded the lowest (5641) number of seeds. The delay in BYG emergence by 40 days leads to 82% reduction in BYG seed production/plant. With respect to seed shattering, the maximum seed (152/panicle) shattering was recorded in crop geometry M1 (15×15 cm) which is 18% higher over M2 (25×25 cm) at 20 days after installation (DAI) of weed seed trap, while at harvest the difference was non-significant. However, seed shattering was significantly more with M2 (25×25 cm) compared to M1 (15×15 cm) and with S1 (BGY emergence from 1st DAT), which was higher by 46% and 50% at 20 DAI and at harvest, respectively, over S3. The seed shattering percentage of BYG was 22 to 26% while around 75% of the seeds produced by BYG remained intact at the time of harvest making BYG a suitable candidate for harvest weed seed control (HWSC). Management techniques need to be developed to control escaped or late emerged BYG in order to prevent its soil weed seedbank enrichment and to ensure sustainable weed management.

Keywords: Barnyardgrass, Crop geometry, *Echinochloa crus-galli,* Seed production, Seed shattering, Time of emergence, Transplanted rice

INTRODUCTION

Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], belonging to the family Poaceae, is a troublesome monocot weed in Asian rice fields and it mimics rice (Jinger *et al.* 2016; Rao *et al.* 2019; Rao 2021) and found to have wider geo-climatic adaptability. The menace of barnyardgrass (BYG) is more under puddled low-land transplanted rice in comparison to non-puddled upland rice during both the rainy and winter seasons (Chauhan and Johnson 2011). Yield loss due to BYG was higher in the wet season compared to the dry season due to its fast growth (Ni *et al.* 2004). The high seed production potential of BYG increases its seedbank in the soil and makes weed control practices more difficult and expensive particularly when it has evolved resistance to herbicides (Mahajan *et al.* 2020). Seven herbicide resistance mechanisms of action were reported in BYG (Heap 2019). Resistance-management programmes are likely to fail if the seedbank renewal of resistant individuals is not entirely arrested (Bagavathiannan *et al.* 2012). Thorough knowledge about biology of BYG is fundamental for designing effective management programmes (Gressel 2011). Seed production and seed shattering of weeds are important determinants of long-term weed population dynamics (Mahajan *et al.* 2020), and weed management programmes that do not aim beyond a single growing season will probably be ineffective (Vijayakumar *et al.* 2022). Weed seeds should be collected before the weed seed rain as it creates the opportunity to prevent their input into the soil weed seedbank. The recent concept of harvest weed seed control (HWSC) aims to prevent the enrichment of

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soil weed seedbank and the efficacy of HWSC depends upon seed retention and seed shattering pattern of the target weed species at crop maturity (Vijayakumar *et al.* 2022). However, the efficacy of these systems is reliant on a high proportion of weed seeds being retained on the plant and collected during harvest.

The reproductive potential of BYG is affected by the time of emergence relative to cotton and rice (Bagavathiannan *et al.* 2012; Chauhan 2013). The BYG emerged 5 and 7 weeks after crop emergence in rice and cotton respectively reported to produce a significant amount of seeds (Bagavathiannan *et al.* 2012). The BYG emerged under wide rows spacing produce greater biomass and more seeds than under narrow rows (Chauhan and Johnson 2010). A greater understanding of specific weed–crop interaction as a function of the time of weed emergence and crop spacing will aid the formulation of effective weed management strategies (Pooja *et al.* 2021a; Ramesh *et al.* 2021). The level of seed shattering in a species is likely influenced by agro-ecological and environmental factors (Schwartz-Lazaro *et al.* 2021). For example, in rice, BYG seed production ranged from 2800 seeds/plant when it emerged with the crop to 100 seeds/plant when it emerged 45 days after rice emergence (Chauhan and Johnson 2010). Understanding of weed biology is critical for devising effective weed management strategies (Gressel 2011) as earlier researchers have proven that BYG seed production is highly variable across crops and environments, yet no such investigations have been carried out in India, where BYG is a major weed in conventional transplanted rice (Rao *et al.* 2021; Saha *et al.* 2021). Such studies will help in finding the suitability of BYG as a candidate weed species for HWSC. Hence, we conducted a two-season field study to evaluate the effect of time of emergence and transplanted rice spacing on seed production and seed retention of BYG at rice crop maturity.

Methodology

A two-season field study was conducted in the winter season of 2020-21 and 2021-22 in the research farm of ICAR-National Rice Research Institute (Latitude: 20.45°, Longitude: 85.94°), Cuttack, Odisha, India. The study area falls in the tropical monsoon climate, with heavy cyclonic rainfall during the monsoon. The average annual rainfall of the study area is 1500 mm, with 80 percent received between June and September. The maximum temperature, minimum temperature, rainfall, and pan evaporation during the crop season were measured in a meteorological weather station located near the experimental site and are presented in **Figure 1**. The soil texture of the experimental site is silty loam (medium texture) and the average organic carbon is 0.55%, soil reaction is neutral (pH 6.7), available N (120.1 mg/kg), available P (6.5 mg/kg), and available K (50.4 mg/kg).

The experiment was laid out in a split-plot design with four replications. Main plot treatments were crop geometry (M1 - 15 × 15 cm, M2 - 25 × 25 cm) and sub-plot treatments were time of BYG emergence [S1 - 0 days after transplanting (DAT); S2 - 20 DAT; S3 - 40 DAT]. The short duration (120-125 days) rice cultivar 'Naveen' was used. The experimental field was puddled twice and levelled before transplanting. The 25-30 days old rice seedling were transplanted (2-3 seedling/hills) as per the treatment geometry. In S1, the BYG was not controlled since transplanting. While in S2 and S3 the plots are kept barnyardgrass free until 20 and 40 DAT. All other weeds in the experimental field during the crop season were removed by manual weeding at regular intervals. All other agronomic management practices like irrigation, fertilizer application (80-40-40 kg NPK per hectare), disease and insect pest management were carried out as per the standard recommendation. The density of BYG in 1 × 1 m quadrat was counted manually and multiplied with gross plot size (8 m × 7 m) to derive the total number of BYG per plot. The panicle lengths and leaf lengths were measured in each plot in five randomly selected plants using a measuring scale and the average is expressed in cm. In each treatment, the number of panicles per BYG was recorded for five randomly selected plants and the average was computed for statistical analysis. Similarly, five BYG was cut at ground level from each plot after flowering and sun-dried for about one week and the dry weight was measured and the average is

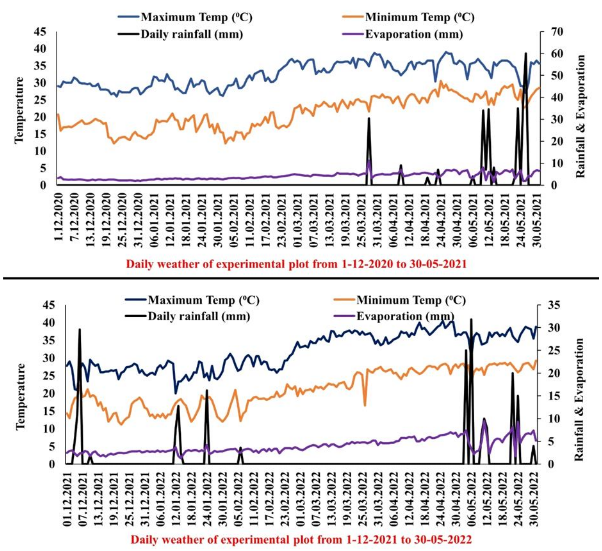

Figure 1. Daily weather of experimental plot during the crop season

expressed in gram (g). Before the installation of the trap, from each plot, the height of five BYG was measured using a 1 m measuring scale and the average is expressed in cm.

In order to study the weed seed production and shattering pattern of BYG, we developed a low-cost weed seed trap using a porous net (galvanized iron wire), plastic nylon tie, polyethylene bag and bamboo stick (**Figure 2**). After the initiation of panicles in BYG, the trap was installed in the field. One trap was installed in each plot. Height of the trap was modified according to the height of BYG by adjusting the length of bamboo stick at the time of installation. The polythene bag was fixed in the bottom of the trap using cello tape and the shattered weed seeds were collected at 20 days after installation (DAI) and at harvest and the shattered seeds were counted manually. Before one day of crop harvest, the BYG panicle inside the trap was harvested to count the un-shattered weed seeds. The total weed seed production per panicle was calculated by summing shattered and un-shattered weed seeds. The shattering percentage of BYG was calculated using the following formula.

$$\text{Shattering percentage} = \frac{\textit{Number of shed seeds collected}}{\textit{Total number of seed produced}} \times 100$$

$$\textit{Total seeds per panicle} = \textit{Shattered seeds @ 20 DAI} + \textit{Shattered seeds @ harvest} + \textit{Unshattered seeds @ harvest}$$

$$\textit{Total seeds per BYG} = \text{Average number of panicle per BYG} \times \text{Average number of seeds per panicle}$$

An exponential function was used to regress the weed count and reproductive traits of BYG (panicle length, panicles/plant, and seeds/plant) relative to the time of emergence (Eqn 1).

$$y = ae^{-bx} \quad ----------(1)$$

Where, y is the predicted variable (weed count, panicle length, panicles/plant and seeds/plant), a represents the reproductive potential of BYG when it emerges with the crop, e is the exponent, b is a fitted constant and x is the time of weed emergence.

The experimental data were analysed in the Strengthening Statistical computing for National Agricultural Research System (SSCNARS) portal. The F-test was used to decide the significant effects of crop spacing and time of emergence of BYG on seed production and shattering of BYG and the least significant difference (LSD) was used to compare means.

Figure 2. Weed seed trap installed in the experimental field

RESULTS AND DISCUSSION

The number of BYG per plot was found influenced by both crop geometry and its time of emergence. Among the crop geometry, the highest BYG density (1698/plot) was recorded at M2 (25 × 25 cm), and the crop geometry M1 (15 × 15 cm) recorded 15% lower BYG density (1448/plot) compared to M2 (**Table 1**). It shows, a significant decrease in the density of BYG in closer crop spacing compared to wider crop spacing. This might be due to the early closure of the ground surface in M1 as the seedling were transplanted in closer spacing compared to M2 which had wider crop spacing. With respect to BYG emergence, the highest weed density (3274/plot) was recorded in S1 (BGY emergence from 1st DAT) while the lowest density (270/plot) was recorded in S3 (BGY emergence from 40 DAT). The weed density in S3 and S2 plots were lower by 92% and 64% respectively over S1 (**Figure 3**). In S3 the ground surface was covered well by crop plants at 40 DAT as the rice crop produced more dry matter. The complete closure of the crop canopy in turn reduces the germination of BYG and ultimately its density. Whereas, in S1 the ground surface was not covered well as the rice seedling were very young. This shows that the emergence of BYG was reduced with increasing days after transplanting and the higher density of BYG in S1 over S3 is clearly visible at the panicle initiation stage of the rice crop. The dark red coloured panicle of BYG made it easier to distinguish with rice crop.

The height of BYG was not affected significantly by crop geometry whereas the time of emergence of BYG after rice transplanting showed statistical significance (**Table 1**). The significantly highest BYG height (123 cm) was recorded in S1 (BGY emergence from 1st DAT) while the lowest height (107.3 cm) was recorded in S3 (BGY from 40 DAT). The height of BYG was taller than the rice crop in S1 while in S3 it was almost equal to the rice crop. This could be due to the early emergence and competitive advantage of BYG over the rice crop in S1. BYG outgrew rice in height and was able to shade it due to its ability to intercept a greater amount of light with its increased height. BYG seedlings that emerge concurrently with rice seedlings were tall enough to avoid crop shading. Therefore, the shade should occur early in the season to suppress the emergence of BYG in comparison to rice. The tall-growing character of BYG enabled late emerged weed to compete with rice and resulting in significant seed production. The dry matter production, leaf length, leaf number, and panicle number per BYG plant were found to reduce significantly with a delay in its emergence (**Table 1**). Between the crop geometry, the higher weed biomass was recorded in M2 (25 × 25 cm) which was 28% higher than M1 (15 × 15 cm). With respect to the time of emergence of BYG, the highest biomass (4.8 g) was recorded in S1 while S3 recorded the lowest BYG biomass (2.9 g). A similar trend was also found in leaf length and the number of leaves per BYG. The highest leaf length was recorded in M2 (25 × 25 cm) and S1 (BYG emergence from 1st DAT) in the crop geometry and time of emergence treatments, respectively. Crop geometry showed a non-significant effect on the number of leaves per BYG while the time of emergence showed a significant effect. The highest number of leaves per BYG was recorded in S1 (14.25) while S3 recorded the lowest (3.5). The maximum number of panicle/BYG was recorded in S1 (BGY emergence from 1st DAT) followed by S2 (BGY emergence from 20 DAT) and S3 (BGY emergence from 40 DAT). The delay in the emergence of BYG by 20 and 40 days resulted in a 41% and 75% reduction in panicle production per BYG respectively (**Figure 3**). Similarly, the narrow crop spacing M1 (15 × 15 cm) reduced the number of panicle production per BYG by 20% over wider crop spacing M2 (25 × 25 cm). BYG would be anticipated to encounter less resource competition while emerging concurrently with the rice crop than cohorts that arose later, allowing for more effective growth and reproduction. In contrast, it was observed that BYG seedlings would face greater competition from the rice when they emerged after the crop that produced a new and robust root system (Bagavathiannan *et al.* 2012).

The lower density, height, biomass, leaf number, leaf length, panicle number and panicle length of BYG in M1 (15 × 15 cm) and S3 (BYG emergence from 40 DAT) might be due to narrow spacing and delayed emergence, respectively. The narrow crop row spacing helped in suppressing the BYG growth by closing the canopy quickly and increasing shade on BYG as weeds compete with crops for moisture, nutrients, light, and space. Under closer spacing (M1) with delayed emergence after 40 DAT (S3), the competition for growth resources (space, nutrients, water, light) increased and favoured the rice crop rather than BYG (Chauhan and Johnson 2011). When compared to BYG grown in full sunlight, the 75 percent continuous shade reduced *E. crus-galli* height by 22% (Chauhan 2013). However, the extent of competition depends on weed density, weed type and weed species. Weed emergence time and growth habit, influenced the extent of weed-crop competition. Competition for above and below-ground resources can affect the growth and development of weeds, as individuals that emerge during the early crop growth stages have the ability to compete well with crops (Gibson et al. 2002). BYG is a C_4 weed and capable of competing well with C_3 crop rice (Bagavathiannan *et al.* 2012).

The reproductive attributes (number of panicles/plant, panicle length and number of seeds/panicle) of BYG were found to decline for each delay in emergence relative to the crop, but some seed

Table 1. The growth, reproduction and shattering of *Echinochloa crus-galli* (BYG) seed as influenced by transplanted rice geometry and time of emergence of *E. crus-galli*

Treatment	No of BYG/plot	BYG height (cm)	No of leaf/BYG	BYG leaf length (cm)	BYG dry weight (g)	No of panicle/ BYG	Panicle length (cm)	Seed count /panicle) (no.)	Total seed/BYG (no.)	Shattered SC (20 DAI)	Shattered SC @ harvest (no.)	Un-shattered SC (no.)	% shattering
Crop geometry													
M1 - 15 × 15 cm	1448.4^{B}	115.0	6.02	19.9^{B}	3.33^{B}	7.75^{B}	15.3	1935	16021^{B}	152^{A}	352	1431^{B}	26.0^{A}
M2 - 25 × 25 cm	1697.5^{A}	117.6	6.26	22.2^{A}	4.65^{A}	9.67^{A}	15.6	1938	20020^{A}	125^{B}	298	1515^{A}	21.5^{B}
LSD (p=0.05)	112.13	NS	NS	1.34	0.46	1.70	NS	NS	3704	9.80	NS	65.06	3.08
Time of emergence of BYG after rice transplanting													
S1 – BYG germination from 1st DAT	3274.1^{A}	123.3^{A}	6.62^{A}	22.4^{A}	4.79^{A}	14.25^{A}	16.8^{A}	184.9^{A}	31988^{A}	395^{A}	1662^{A}	2242^{A}	25.9
S2 - BYG germination from 20 DAT	1175.1^{B}	118.2^{B}	6.09^{B}	20.9^{AB}	4.28^{B}	8.38^{B}	15.5^{B}	133^{B}	16432^{B}	317^{B}	15078^{B}	1958^{B}	22.9
S3 - BYG germination from 40 DAT	269.6^{C}	107.3^{C}	5.71^{C}	19.8^{B}	2.91^{C}	3.5^{C}	14.1^{C}	98.4^{C}	5641^{C}	263^{B}	1248^{C}	1609^{C}	22.3
LSD (p=0.05)	350.4	3.89	0.30	1.82	0.13	1.08	0.49	17.7	2919	69.77	69.65	102.0	NS
Interaction	NS	NS	NS	NS	NS	NS	S	NS	NS	NS	NS	NS	NS

DAI – Days after installation, SC- Seed count, BYG - Barnyardgrass production was still observed when BYG emerged several days after rice (**Figure 3**). Crop geometry showed a non-significant effect on BYG panicle length while the time of emergence showed a significant effect (**Table 1**). The maximum panicle length (16.8 cm) was recorded in S1 (BGY emergence from 1st DAT) while S3 (BGY from 40 DAT) recorded the lowest (14.1 cm). The early emergence of BYG in S1 increased the panicle length by 11% over S3. The total seed production per panicle of BYG was not influenced by crop geometry while the time of emergence of BYG showed statistical significance. The maximum number of seeds per panicle (2242/panicle) was recorded in S1 (BGY emergence from 1st DAT) while S3 (BGY emergence from 40 DAT) recorded the lowest number (1609/panicle) of it. This might be due to the longer growth period of BYG in S1 compared to S3. Whereas, the shorter growth duration of BYG and higher competition for growth resources in S3 led to a lower number of leaves, dry matter production and height. In S1, BYG takes the advantage of early emergence while in S3 rice crop takes the advantage of early emergence. Due to more number of panicles/BYG and seeds/panicle, the total seed production per BYG was higher again in M2 (25 × 25 cm). The increasing crop spacing by 10 cm in each row and column increased the seed production of BYG by 20%. With respect to time of emergence, the maximum seed production per BYG was recorded in S1 (31987) while S3 recorded the lowest (5641) of it. Seed production per BYG was reduced by 82% due to 40 days delay in emergence. BYG seed production was greater when seedlings emerged with the crop, but some seed production was observed even if seedlings emerged several weeks after crop emergence. The current findings confirm earlier findings that the delayed emergence of BYG lowers seed production relative to the crop (Travlos *et al.* 2011). The total seed production per BYG plant was influenced significantly by the time of emergence of BYG while different crop spacing showed a non-significant effect on it. According to Mitich (1990), BYG can produce up to 1 million seeds/plant under ideal growing conditions, but BYG seed production was highly variable across environments (Bagavathiannan *et al.* 2012).

Both crop geometry and the time of emergence of BYG influenced the seed shattering of BYG. At 20 days after installation (DAI), the maximum seed shattering (152 no./panicle) was recorded in crop geometry 15 × 15 cm (M1) which is 18% higher than M2 (25 × 25 cm). However, at harvest, the crop geometry showed a non-significant effect on BYG seed shattering. Among the sub-plot treatments, the maximum BYG seed shattering was recorded in S1 (BGY emergence from 1st DAT), which is higher by 46% and 50% at 20 DAI and at harvest respectively

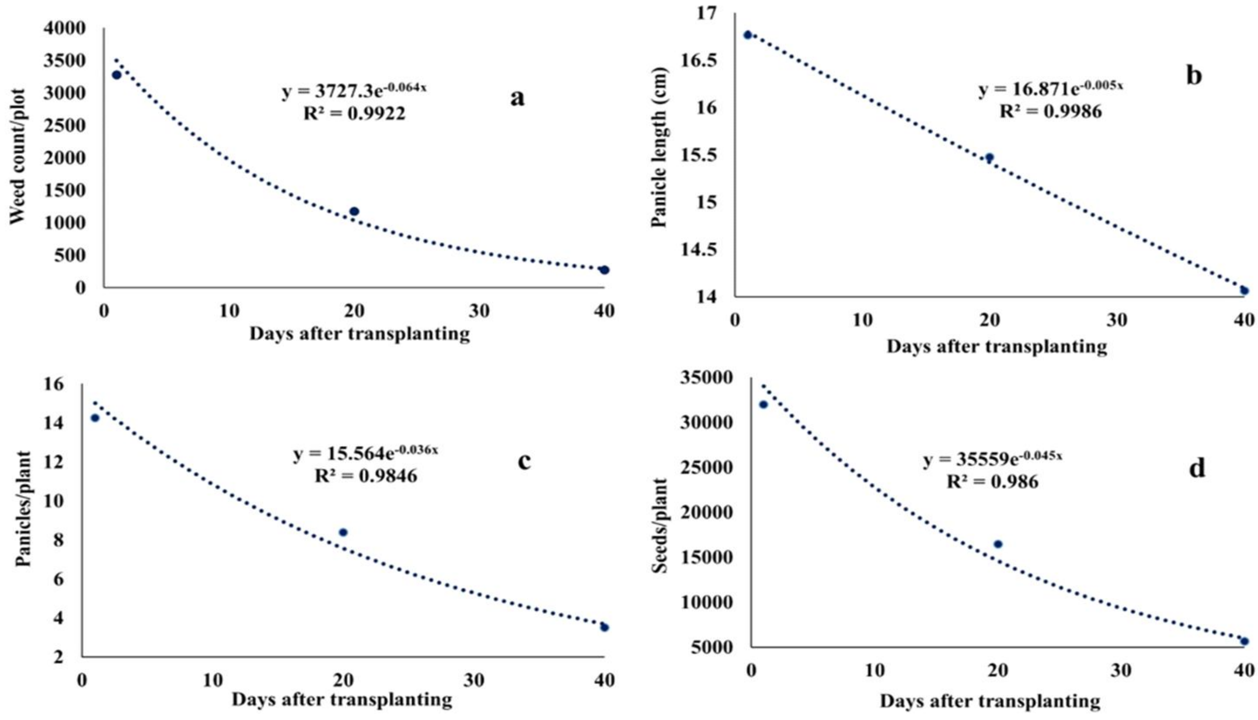

Figure 3. Regression curve for barnyardgrass density (a), panicle length (b), panicles/plant (c) and seeds/plant (d) at different times of emergence in transplanted rice. The data conformed to an exponential relationship ($y=ae^{-bx}$), where a is the initial value that starts the exponential function and b is the fitted constant. The quality of the model fit was expressed using the R^2 value.

over S3. The un-shattered BYG seeds are higher in wider crop geometry i.e. 25 × 25 cm compared to closer crop geometry. The percentage of un-shattered BYG seeds in M2 is 6% higher over M1. The higher BYG seed shattering in M1 might be due to higher competition and early maturity of seeds. With respect to the time of emergence of BYG, the maximum number of un-shattered seeds is recorded in S1 (1662/panicle) while S3 recorded the lowest (1248/panicle). The late emergence and late maturity of BYG in S3, resulted in the lowest number of un-shattered seeds. Although the number of shattered seeds was higher in M1, the percentage of seed shattering was significantly more in M2 (25 × 25 cm) compared to M1 (15 × 15 cm). However, the time of emergence of BYG showed a non-significant effect on shattering percentage though the delayed emergence showed a numerically lower shattering percentage. The seed shattering per BYG was found in the range of 22 to 26%. It reveals that almost 75% of the seed produced by BYG remained intact at the time of harvest. This makes BYG a suitable candidate for HWSC. Removing BYG at the time of harvest by any HWSC method could prevent the enrichment of soil weed seedbank significantly. Shading by the rice canopy is an important mechanism of interference between rice crops and BYG. The growth and reproduction of shaded BYG are significantly hampered by phytochrome-mediated activities as a result of rice crop canopy formation, which normally limits the quantity and quality of light passing through the canopy. Furthermore, it appears that cohorts that emerge earlier than rice seedlings do not experience the effects of shadowing as severely. But for later cohorts of BYG, there would have been fierce competition for both above and below-ground growth resources. The early establishment gives rice crop a competitive advantage over the BYG. *E. crus-galli* seeds are added to the soil seed bank and affect the sustainability of any weed management strategy; thus, practices that reduce weed seed inputs should be viewed as a critical component of a sustainable weed management approach (Chauhan and Johnson 2010). Shade provided by crop interference, on the other hand, should not be viewed as a stand-alone strategy for BYG management in rice. Several best management practices, such as water management, nutrient management, planting time, weed competitive cultivars, and herbicide use, must be combined (Pooja *et al.* 2021b).

Correlation

There was a positive correlation found between BYG biomass and yield attributes [panicle per plant (r = 0.836), panicle length (r = 0.712), seeds per panicle (r = 0.715), total seeds per plant (r = 0.804), revealing that big plants produce more seeds than smaller plants (**Table 2, Figure 3**). Similarly, a positive correlation

Table 2. Pearson correlation coefficients between growth attributes and yield attributes of barnyardgrass

	WD	WH	WDM	WLC	WLL	PP	PL	SPP	TSPP	SWSCH	SWSC20	UWSC	% S
WD	1												
WH	0.769												
	<.0001	1											
WDM	0.710	0.797											
	0.0001	<.0001	1										
WLC	0.767	0.729	0.722										
	<.0001	<.0001	<.0001	1									
WLL	0.527	0.582	0.737	0.395									
	0.0081	0.0029	<.0001	0.0559	1								
PP	0.941	0.858	0.836	0.802	0.642								
	<.0001	<.0001	<.0001	<.0001	0.0007	1							
PL	0.814	0.774	0.712	0.633	0.605	0.869							
	<.0001	<.0001	<.0001	0.0009	0.0017	<.0001	1						
SPP	0.894	0.857	0.715	0.714	0.465	0.925	0.751						
	<.0001	<.0001	<.0001	<.0001	0.0219	<.0001	<.0001	1					
TSPP	0.951	0.852	0.804	0.794	0.617	0.994	0.844	0.944					
	<.0001	<.0001	<.0001	<.0001	0.0013	<.0001	<.0001	<.0001	1				
SWSCH	0.605	0.454	0.268	0.327	0.090	0.569	0.480	0.727	0.601				
	0.0018	0.0259	0.2048	0.1186	0.6772	0.0037	0.0176	<.0001	0.0019	1			
SWSC20	0.826	0.644	0.413	0.636	0.309	0.799	0.713	0.808	0.808	0.624			
	<.0001	0.0007	0.0450	0.0008	0.1420	<.0001	<.0001	<.0001	<.0001	0.0011	1		
UWSC	0.838	0.892	0.818	0.743	0.561	0.905	0.712	0.942	0.916	0.470	0.669		
	<.0001	<.0001	<.0001	<.0001	0.0043	<.0001	<.0001	<.0001	<.0001	0.0204	0.0004	1	
% S	0.344	0.110	-0.100	0.070	-0.136	0.273	0.284	0.403	0.298	0.875	0.560	0.075	
	0.0998	0.6104	0.6404	0.7468	0.5250	0.1962	0.1786	0.0508	0.1575	<.0001	0.0044	0.7281	1

Note: Weed Density, WH - Weed height, WDM - Weed Dry Matter, WLC - Weed Leaf Count, WLL - Weed Leaf Length, PP – Panicles per plant, PL - Panicle Length, SPP - Seeds per panicle, TSPP – Total Seeds per plant, SWSCH – Shattered weed seed count at harvest, SWSC20 - Shattered weed seed count at 20 days after installation, UWSC – Un shattered weed seed count, % S – percentage shattering was also found between weed height and yield attributes [panicle per plant (r = 0.858), panicle length (r = 0.774), seeds per panicle (r = 0.857), total seeds per plant (r = 0.852), revealing that tall plants produce more seeds than short plants. The positive correlation between total seeds per plant and yield attributes [panicles per plant (r = 0.994), panicle length (r = 844), seeds per panicle (0.944)] reveals the total seed production of BYG is highly influenced by yield attributes. However, no correlation was found between BYG leaf length and yield attributes (**Table 2, Figure 3**). Similarly, no correlation was found between shattering percentage and growth (weed density, weed height, weed biomass, weed leaf count, weed leaf length) and yield attributes (panicles per plant, panicle length, seeds per panicle, total seeds per plant) of BYG. The positive correlation between non-shattered weed seed count and growth and yield attributes reveals healthier plants may shatter fewer seeds than weaker plants (**Table 2**). Alternatively, the plant which grows tall, produces more leaves, dry matter, large panicle size and more panicles per plant will retain more of the seeds it produces and shatter only a very less number of seeds.

Conclusion

Characteristics like longer duration of emergence and tall growing nature of BYG enables it competitive with high seed production. BYG seedlings that emerge 40 DAT could produce a significant number of seeds and contribute to the soil seed bank. The majority of the seeds (~75%) produced by BYG are retained in the mother plant at the time of rice crop harvest. This makes BYG a suitable candidate for HWSC. Additionally, the closer crop spacing reduces the density of BYG compared to wider spacing. Thus, crop competitiveness against weeds can be increased by using production strategies like closer row spacing and higher planting density. Cultural approaches that delay the emergence of BYG or approaches that make the associated rice crop more competitive will be useful in integrated management programmes.

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