Indian Journal of Weed Science (2023) **55**(3): 231–237
http://dx.doi.org/10.5958/0974-8164.2023.00043.6

RESEARCH ARTICLE

Deciphering the influence of barnyardgrass (*Echinochloa crus-galli*) density on growth and yield components of dry-seeded rice

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Received: 21 November 2022 | Revised: 18 July 2023 | Accepted: 21 July 2023

ABSTRACT

Echinochloa crus-galli (L.) P. Beauv. is a dominant and competitive weed in the dry-seeded rice system. It imparts negative competition for various resources and may cause a complete yield loss. Therefore, population-dependent *E. crus-galli* (0–175/m^2) with a fixed level of rice density was evaluated to elucidate the influence on the growth and yield of rice plants and *E. crus-galli* as well. It was revealed that rice plants without *E. crus-galli* produced 60% more tillers and generated 57% more leaves with increased dimensions. This resulted in accumulating 36% more rice plant biomass than density at 175/m^2. Likewise, panicles were 4% longer, contained 40% more grains/panicle, and 37% heavier with fewer un-filled grains/panicle than *E. crus-galli* of 175/m^2. Generally, an increase in the density of *E. crus-galli* from 25–175/m^2 gradually decreased the yield attributes. Among the *E. crus-galli* densities at 25/m^2, *E. crus-galli* plants were shorter by 22%, produced 103% more tillers, 36% more leaves, 72% longer, 53% wider and accumulated 56% more plant biomass, with 52% longer inflorescence, 86% more caryopsis/inflorescence, 62% heavier inflorescence over density of 175/m^2. However, from the density at 100/m^2 onwards, caryopsis/m^2 started declining and inflorescence became lighter.

Keywords: *Echinochloa crus-galli*, Density, Growth parameters, Rice, Yield attributes

INTRODUCTION

The world's more than 50% of the population depends on rice for food and consumes more than 50 kg/capita/year. Globally, ∼782 million tonnes (MT) of rice have been produced from ∼167 million hectares (MH) area and over 90% was used directly for human consumption (USDA-ERS 2022). Rice is the principal staple food crop of the Asian population; more than 90% of the world's rice is grown and consumed in Asia. The rice is being cultivated under different establishment methods depending upon the resource availabilities. However, manual transplanting of rice seedlings in puddle soil is the most common method in Asian countries (Chauhan *et al.* 2012, Choudhary 2017). However, in recent times, to save water and to manage the non-availability of manpower, the majority of rice growers have shifted from transplanted rice to dry-seeded rice. However, weeds are the major biological constraint in successful rice production. The yield loss in rice due to weeds has been reported at 57% in transplanted rice and 82% in dry-seeded rice (Mahajan *et al.* 2009; Rao *et al.* 2015) with US$ 4.20 billion monetary loss annually (Gharde *et al.* 2018). The rice grain yield reduction by weeds is largely dependent on the level of weed infestation, species richness, their density, dry matter accumulation, and duration of association (Nkoa *et al.* 2015, Travlos *et al.* 2018). The competition period in transplanted rice is shorter due to 'head start' advantage and a thin water layer over germinating weed seeds, whereas in dry-seeded rice this widens and is further extended in aerobic rice (Choudhary *et al.* 2021a).

The rice fields are generally infested with grasses, broad-leaf weeds (BLWs) and sedges. Among the grasses, jungle rice [*Echinochloa colona* (L.) Link], barnyard grass [*Echinochloa crus-galli* (L.) P. Beauv.] and cockspur grass (*Echinochloa glabrescens* Kossenko) are major weeds, apart from this hairy crabgrass [*Digitaria sanguinalis* (L.) Scop.], viper grass [*Dinebra retroflexa* (Vahl) Panz.], bermuda grass [*Cynodon dactylon* (L.) Pers.] and crowfoot grass [*Dactyloctenium aegyptium* (L.) Willd.] is considered to be a threat to rice production and causes considerable yield loss in several countries (Rao *et al.* 2007). In general, the relative density of grasses varies from maximum to minimum *E. colona*> *E. crus-galli*>*E. glabrescens* (Awan *et al.* 2021). These species are highly competitive for various available resources at the site i.e. soil

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nutrients, water, space, light, *etc*. and also morpho-physiological similarities with rice; which make it more difficult to control (Choudhary *et al.* 2021b). Among the weeds, *E. crus-galli* is the most problematic weed infesting rice field in India (Choudhary and Dixit 2021). It is an annual grass weed that mimics rice, especially at tillering stage. This makes it difficult to differentiate the weed from rice plants and by the time gets recognized it already had caused damage. In the last decade, it has been noticed that rice fields are severely infested with *E. crus-galli*. The infestation of *E. crus-galli* further intensifies with alternate wetting and drying, and the absence of a water layer in rice (Choudhary 2017). Further, the adoption of a rice-rice cropping system increased the severity of *E. crus-galli*. It has been reported that season-long interference of one plant/m^2 of *E. crus-galli* can minimize the rice yield by 257 kg/ha (Stauber *et al.* 1991). This weed has the plasticity to shorten the life period under adverse conditions and can produce substantial seeds (Derakhshan and Gherekhloo 2013). Nevertheless of its negative impact, there is limited information available on the competitive ability of *E. crus-galli* upon rice in dry-seeded rice agro-ecosystem. It is also less known to what extent rice plants can compete with *E. crus-galli* without any yield penalty. Therefore, the present study was conducted to optimize the possible yield penalty under different densities of *E. crus-galli* in the dry-seeded rice system. This study is also focused on the varying densities of weeds and tries to decipher the influence of weeds on the growth and yield attributes of rice.

MATERIALS AND METHODS

A pot study was conducted for two consecutive years (2015 and 2016) at the experimental farm of Indian Council of Agricultural Research (ICAR)–National Institute of Biotic Stress Management, Raipur (extends 21°22’50.4" N 81° 49’31.9" E, 289 m above MSL), India. The climate of the study area was sub–tropical, and humid. Fifty years average annual precipitation was 1250 mm. About 80% of total rain is received from July to September months of the year from the South-West monsoon. It records the minimum monthly mean temperature of 12 °C in December and a maximum monthly mean temperature of 45 °C in May. The soil used in the pots was clay–loam in texture with 25% sand, 42% silt and 33% clay, 0.38% organic carbon with a pH of 6.9. Available nitrogen, phosphorus and potassium content in the soil were 225.2, 16.3 and 355 kg/ha, respectively.

The seeds of *E. crus-galli* were collected at a farmers’ field that adopted a rice-rice cropping system. The experiment was conducted in a completely randomized design (CRD) with three replications and six pots per replication. In each pot, the density of *E. crus-galli* was maintained at 0, 1, 2, 3, 4, 5, 6 and 7 plants which were about 0, 25, 50, 75, 100, 125, 150, and 175/m^2. A pot with a dimension of 20 × 20 cm was used for the study which was filled with 12 kg of homogenous soil. The rice seeds were dibbled at 2 cm depth, whereas *E. crus-galli* seeds were placed at 0.5 cm depth from the surface of the pots on June 15, 2015 and June 19, 2016 for the two consecutive seasons. Rice seedlings were thinned to two seedlings/pot at 15 days after sowing (DAS), whereas densities of *E. crus-galli* were maintained as per the treatments. The weeds that emerged other than *E. crus-galli* were periodically removed. The rice plants were fertilized with the proportion of 100: 60: 40 kg N, P, and K/ha, through urea (46% N), single super phosphate (16% P) and muriate of potash (60% K). Entire P and K were applied at the time of seeding, whereas nitrogen was applied at 10, 30, 45 and 65 days after seeding (DAS) in both years and irrigated the plots as and when required. Rice plants were harvested on 1st and ^{3rd} November of 2015 and 2016, respectively.

Total leaves/tiller, leaf length and width (cm) of rice were measured at 60 DAS. Plant height was measured from soil surface to tip of the uppermost leaf, tillers/hill, panicle length, grains/panicle, chaffy grains/panicle, and biomass (g/plant) was recorded at maturity. Rice plants were harvested when about 85% of the seed head matured. Irrigation was stopped at maturity and the pots were dried in the sun. After drying, plants were cut from the base. Plants were initially air-dried and later kept in a brown paper bag and then oven-dried at 65±2°C for 48 hours. After getting constant weight, the biomass of rice was measured.

In *E. crus-galli,* total leaves/tiller, leaf length and width (cm) were measured at 60 DAS. Plant height was measured from soil surface to tip of the uppermost leaf, tillers/hill, inflorescence length, caryopsis/inflorescence, chaffy caryopsis/inflorescence, inflorescence weight (g/plant) and biomass (g/plant) was recorded at maturity. For estimating caryopsis production/inflorescence in *E. crus-galli*, two intact seed heads were chosen randomly from each plant. Caryopsis was counted from rachilla segment and later multiplied with the total rachilla for the final caryopsis count per plant.

For statistical analysis, the F-test was used to check the difference between year effects with a significant level of $p<0.05$. Therefore, the data were analyzed with a two-factor CRD, where the year was considered as the first factor and *E. crus-galli* density as the second factor. Both year's data were analyzed using OPSTAT. Treatment effects were compared with Tukey HSD test.

RESULTS AND DISCUSSION

Growth parameters of rice

The effect of years and *E. crus-galli* densities significantly ($p<0.05$) affected the growth parameters of rice (**Table 1**). Between the years, the growth parameters were higher in 2016 than in 2015. In 2016, rice plants were taller by 3%, produced 9% more tillers/hill, more leaves by 7%, longer and broader leaves by 4% and accumulated 20% higher biomass/plant than in 2015.

Rice plants were shorter in the pots without *E. crus-galli* whereas plant height gradually increased with an increase in densities and they were taller by 2–8% with *E. crus-galli* densities from 25–175/m^2. This might be due to intra- and inter-specific competition for light. Plants became taller to overcome the shading effect (Choudhary *et al.* 2021b). Ironically, rice plants produced 4–60% lower tillers, lesser leaves by 3–57%, shorter leaves by 1–21%, narrow leaves by 4–37%, and accumulated lesser plant biomass by 10–36% with the progressive weed density from 25–175/m^2 than without *E. crus-galli* (5.7/hill, 4.1 leaves/plant, 23.0 and 0.81 cm and 3.1 g/plant, respectively). Tiller production was greatly and negatively influenced by the presence of *E. crus-galli*. Lesser, shorter and narrower leaves were produced with higher densities. Overall, lower growth parameters with higher densities of *E. crus-galli* were due to resource competition between rice plants and *E. crus-galli* populations. Consequently, less competitive rice plants availed fewer resources than of robust *E. crus-galli*. The interaction between years and *E. crus-galli* densities was found non-significant in the growth parameters of rice.

Yield attributes of rice

Rice yield attributes were affected significantly ($p<0.05$) by the year of the study and densities of *E. crus-galli* (**Table 2**). Higher yield attributes were obtained during 2016 than in 2015. In 2016, rice panicles were longer by 2%, produced 8% more seeds/panicle and heavier panicles by 7% than in 2015. Whereas unfilled grains were 15% less in 2016 than in 2015. Yield loss due to *E. crus-galli* was higher in 2016 than in 2015. Yield attributes of rice were better without *E. crus-galli* pots. Panicles were 1–4% longer, produced 5–40% more seeds/panicle, heavier panicles by 2–37% in without *E. crus-galli* pots and noticed 16–171% fewer unfilled grains than the density of 25–175/m^2. It was observed that yield attributes decreased with an increase in density of *E. crus-galli* and lowest with 175/m^2 (panicles of 16.5 cm, 86.2 seeds/panicle, 1.7 g/panicle with 25.3 unfilled grains/panicle). Contrarily, an increase in the density of *E. crus-galli* (> 50/m^2) had significantly more unfilled rice grains. The highest yield loss of 27–30% was observed with 175/m^2 whereas the lowest yield loss was obtained with 25/m^2 (by 4–5%). Similar results were also reported earlier by Zhang *et al.* (2021) in the rice ecosystem in China. The interaction between years and *E. crus-galli* densities was found non-significant in yield attributes of rice. It was noted that in rice, tillers/plant and chaffy grains/panicles followed a negative linear relationship with r=0.83 (**Figure 1a**). This suggests that with an

Table 1. Effect of *Echinochloa crus-galli* density on growth parameters of rice

Treatment	Plant height (cm)	Tillers / plant	Leaves / plant	Leaf length (cm)	Leaf width (cm)	Plant biomass (g/plant)
Year (Y)						
2015	86.8	4.6	3.3	21.2	0.68	2.5
2016	89.7	5.0	3.6	22.0	0.71	3.0
LSD (p=0.05)	0.59	0.17	0.16	0.27	0.01	0.1
E. crus-galli density/m^2 (E)						
0	84.9	5.7	4.1	23.0	0.81	3.1
25	86.6	5.4	4.0	22.7	0.78	2.9
50	86.4	5.2	3.7	22.6	0.72	2.9
75	87.6	5.1	3.5	22.5	0.72	2.8
100	88.7	4.9	3.4	21.4	0.67	2.7
125	89.9	4.4	3.2	20.9	0.67	2.6
150	90.8	3.9	3.1	20.3	0.61	2.5
175	91.4	3.5	2.6	19.1	0.59	2.3
LSD (p=0.05)	1.18	0.34	0.31	0.54	0.03	0.2
Y x E	NS	NS	NS	NS	NS	NS

Table 2. Effect of *Echinochloa crus-galli* density on yield attributes of rice

Treatment	Panicle length (cm)	Seeds / panicle	Chaffy grains / panicle	Panicle weight (g/panicle)
Year (Y)				
2015	17.9	101.3	17.9	2.0
2016	18.4	109.4	15.6	2.1
LSD (p=0.05)	0.25	1.82	1.16	0.04
E. crus-galli density/m^2 (E)				
0	19.9	120.7	9.3	2.4
25	19.4	115.2	10.8	2.3
50	18.7	111.3	15.5	2.2
75	18.4	108.2	16.0	2.1
100	17.9	104.8	17.5	2.0
125	17.4	100.7	18.5	1.9
150	17.2	96.0	21.0	1.8
175	16.5	86.2	25.3	1.7
LSD (p=0.05)	0.50	3.63	2.32	0.09
Y x E	NS	NS	NS	NS

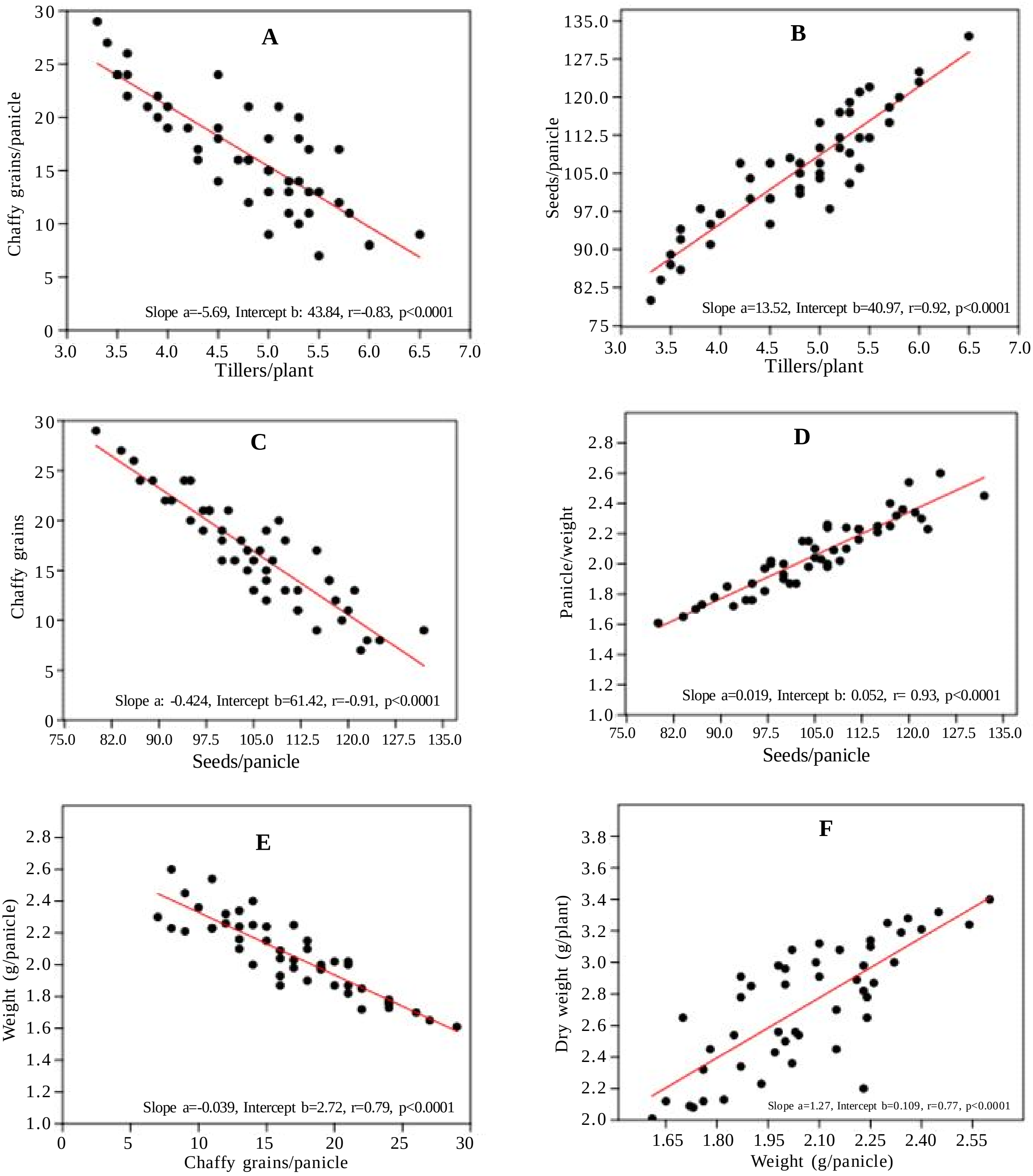

Figure 1. Relationship between a) tillers/plant and chaffy grains/panicle, b) tillers/plant and seeds/panicle, c) seeds/ panicle and chaffy grains/panicle, d) seeds/panicle and panicle/weight, e) chaffy grains/panicle and weight/ panicle, and f) weight/panicle and dry weight/panicle irrespective of *E. crus-galli* densities

increase in tillers/plant there was a reduction in chaffy grains. Fewer tillers were produced in rice due to competition offered by higher densities of *E. crus-galli*, which lead to the production of more numbers of spikelet, but all the spikelet did not fill resulting in higher chaffy grains. Rice tillers/plant and grains/ panicle were linearly but positively associated with r=0.92 (**Figure 1b**). Likewise, chaffy grains and grains/panicle are associated linearly but negatively with r=0.91 (**Figure 1c**). It depicts that with an increase in grains/panicle, the number of chaffy grains declined mainly due to the lower density of *E. crus-galli* which offered less competition. Therefore, panicle weight and grains/panicle also exhibit a positive linear relationship with r= 0.93 (**Figure 1d**). **Figure 1e** illustrated that an increase in the panicle weight of rice reduced the total chaffy grains/panicle linearly with r=0.79. On contrarily, an increase in plant biomass also contributed positively to the panicle weight linearly with r=0.77 (**Figure 1f**).

Growth parameters of *Echinochloa crus-galli*

Growth parameters, *viz*. height, tillers/hill, leaves/plant, leaf length and width, and biomass of *E. crus-galli* were affected significantly by its densities on rice (**Table 3**). Between the years, the plants of *E. crus-galli* were 8% taller, produced 8% more tillers, 4% more leaves, 5% longer and 4% wider leaves and accumulated 21% more biomass in 2016 than in 2015 (106.5 cm height, 6.2 tillers/hill, 7.2 cm leaves, 29.7 cm long and 0.90 cm width and 1.9 g/plant). All the growth parameters in 2016 were significant ($p<0.05$) except leaf width. Densities of *E. crus-galli* influenced different characteristics with fixed rice density. Increase in the density of *E. crus-galli* from 25 to 175/m^2, plants became taller by 4–22% over without *E. crus-galli* (99.2 cm). Contrarily, produced 4–103% fewer tillers, 5–36% lesser leaves, 11–72% shorter, 11–53% narrower leaves and 5–56% lower plant biomass over *E. crus-galli* density at 25/m^2 (7.4/hill, 8.3 leaves/plant, 37.9 cm length and 1.14 cm width). Total tillers per unit area gradually increased with an increase in its density up to 150/m^2 (by 2.45 folds) and a further increase in density (175/m^2) had lesser tillers (by 65%) than 150/m^2. But it largely depended on the total number of tillers which contributed significantly towards more leaf surface area for photosynthesis and thus accumulated higher plant biomass. This resulted in *E. crus-galli* at 150/m^2 densities could accumulate higher plant biomass by 3.5 folds over 25/m^2. This confirmed that excessive density offers competition for resource sharing within the species and thus could accumulate less plant biomass. The rest of the densities were also significant but were less than 150/m^2. The pots with higher densities of *E. crus-galli* had a considerably higher reduction of growth parameters than lower densities. The interaction between years and *E. crus-galli* densities was found non-significant on the growth parameters of *E. crus-galli.*

Table 3. Effect of *Echinochloa crus-galli* density on growth parameters of *E. crus-galli*

Treatment	Plant height (cm)	Tillers / hill	Total leaves / plant	Leaf length (cm)	Leaf width (cm)	Biomass (g/plant)
Year (Y)						
2015	106.5	5.8	7.2	29.7	0.90	1.9
2016	115.1	6.2	7.5	31.2	0.93	2.3
LSD (p=0.05)	1.6	0.07	0.19	1.02	ns	0.10
E. crus-galli density/m^2 (E)						
25	99.2	7.4	8.3	37.9	1.14	2.5
50	103.2	7.1	7.9	34.1	1.03	2.4
75	107.5	6.8	7.7	33.1	0.97	2.3
100	112.5	6.4	7.6	31.2	0.89	2.1
125	114.3	5.6	7.1	28.2	0.84	2.0
150	118.3	5.0	6.6	26.4	0.78	1.9
175	120.8	3.6	6.1	22.1	0.75	1.6
LSD (p=0.05)	3.00	0.38	0.35	1.90	0.10	0.19
Y x E	NS	NS	NS	NS	NS	NS

Per unit more leaf surface area at 175/m^2 densities allows to intercept more sunlight for photosynthesis and assimilated higher biomass. Contrarily, at a lower density of *E. crus-galli*, per plant leaf number, length and width of the leaves are higher than at higher densities. At lower densities, *E. crus-galli* is more competitive and competitiveness increases with an increase in densities up to 100/m^2. However, it can produce more energy to support the taller plant stature and also support more seeds/ plants. Higher densities covered the canopy and gave shade which is detrimental to rice plants. Thus, self-shading rather than leaf angle per se is important for light interception and biomass gain (Falster and Westoby 2003). Contrarily, densities at >150/m^2, and self-shading makes plants weaker, resulting in comparatively less accumulation of plant biomass, thereby producing lesser tillers at this density onwards. Similarly, per unit caryopsis production and rachilla weight can be started reducing at densities >100/m^2, this might be due to intra-specific competition (**Table 4**).

Yield attributes of *Echinochloa crus-galli*

Yield attributes of *E. crus-galli* were affected significantly by the year of the study and its densities (**Table 4**). Yield attributes were obtained better during 2016 than in 2015. In 2016, inflorescence was longer by 11% and produced 8% more caryopsis/ inflorescence than in 2015. Moreover, inflorescence was 3% heavier in 2016 than in 2015 but was statistically ($p<0.05$) comparable.

Among the *E. crus-galli* densities, yield attributes of *E. crus-galli* were density-dependent and obtained better on densities at 25/m^2. Inflorescence was 7–52% longer, produced 12–86% more caryopsis/inflorescence and heavier inflorescence by 7–62% at 25/m^2. In general, per plant yield attributes were in decreasing trend with an increase in density of *E. crus-galli* and lowest with 175/m^2 (inflorescence of 8.6 cm length, 316.8 caryopsis/inflorescence and 0.8 g/inflorescence). However, for a better understanding, some of the parameters were computed per m^2 basis, in 2016, tillers/m^2 was higher by 6%, 13% more caryopsis/m^2, 10% heavier inflorescence and accumulated 24% higher plant biomass than in 2015.

Table 4. Effect of *Echinochloa crus-galli* density on yield parameters of *E. crus-galli*

Treatment	Inflorescence length (cm)	Caryopsis/ inflorescence	Weight (g/inflorescence)	Biomass (g/plant)	Tillers/m^2	Caryopsis/m^2	Inflorescence weight (g/m^2)	Biomass (g/m^2)
Years								
2015	10.3	423.8	1.1	1.9	523.2	208961	519.7	174.9
2016	11.4	459.8	1.1	2.3	555.2	236565	572.0	216.7
LSD (p=0.05)	0.69	9.8	0.02	0.1	25.35	7971.06	24.34	4.27
E. crus-galli density/m^2 (E)								
25	13.1	588.0	1.3	2.5	184.2	108860	242.2	62.5
50	12.2	525.0	1.2	2.4	355.0	186838	437.0	119.5
75	12.0	483.7	1.2	2.3	506.3	245344	586.8	169.5
100	10.6	435.7	1.1	2.1	638.3	278247	705.7	211.9
125	10.1	393.3	1.0	2.0	700.0	275269	688.2	247.3
150	9.8	350.0	0.9	1.9	755.0	263410	644.8	280.5
175	8.6	316.8	0.8	1.6	635.8	201373	516.2	279.4
LSD (p=0.05)	1.28	18.33	0.04	0.19	47.42	14912.5	45.53	8.00
Y x E	NS	25.92	NS	NS	NS	NS	NS	11.31

Densities of *E. crus-galli* from 50 to 175/m^2 increased the caryopsis/m^2 by 72–156%, heavier inflorescence by 80–191% and plant biomass by 91% to 350% higher over *E. crus-galli* at 25/m^2. It produced 278247 caryopsis/m^2 at the density of 100/m^2 and was higher by 156% over the density of 25/m^2. Besides an increase in density from 125 to 175/m^2 gradually decreased the caryopsis/m^2 by 3–71% more than that of 100/m^2. Higher caryopsis/m^2 in density at 100/m^2 could measure heavier inflorescence by 191% and it steadily decreased up to 175/m^2 (by 78%) over 25/m^2. Likewise, caryopsis/m^2 and inflorescence weight/m^2 gradually increased from 25 to 100/m^2 and later gradually decreased up to 175/m^2. Whereas plant biomass increased from 25 to 150/m^2 and it became lower at 175/m^2 over other densities of *E. crus-galli*. The fewer caryopsis, lighter inflorescence and plant biomass at a higher density of *E. crus-galli* were mainly due to intra-species competition which leads to a reduction of per plant capacity to produce caryopsis. Bagavathiannan *et al.* (2012) also reported that caryopsis production of *E. crus-galli* varies with crops, the timing of emergence, cropping system and climate. Likewise, due to fewer caryopsis, inflorescence became lighter and ultimately biomass accumulation was less. The interaction between years and *E. crus-galli* densities was found non-significant on yield attributes of *E. crus-galli* except caryopsis/inflorescence and biomass.

Among the *E. crus-galli* parameters, plant biomass per unit area of *E. crus-galli* and grain yield loss have followed a quadratic relationship with r=0.70 (**Figure 2a**). This elucidates that an increase in biomass of *E. crus-galli* offers more competition to rice plants for the resources resulting in plants becoming weaker and ultimately producing lesser grain yields. Likewise, an increase in the tiller density of *E. crus-galli* has produced more caryopsis/m2 and they followed a quadratic relationship with r=0.80 (**Figure 2b**). It was also noticed that with an increase in plant dry weight and inflorescence weight also gradually increased but linearly with r=0.76 (**Figure 2c**).

The experimental findings proved that there are significant (p<0.05) differences in the growth and yield parameters of rice with variable *E. crus-galli* densities at a fixed level of the rice. The data

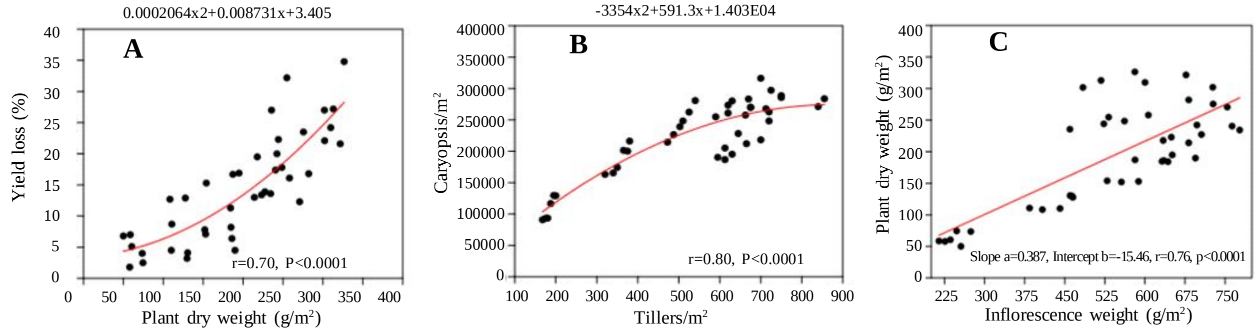

Figure 2. Relationship between a) plant dry weight and yield loss, b) tillers and caryopsis/m^2, c) inflorescence weight and plant dry weight irrespective of *E. crus-galli* densities

presented also support that the growth, development and yield parameters of rice were recorded as the highest without *E. crus-galli* and with an increase in the densities from 25 to 175/m^2 it gradually decreased. Contrarily, the inflorescence length of *E. crus-galli* was higher at 25/m^2, and it gradually decreased, while tiller production and biomass/plant increased up to 150/m^2, and the highest caryopsis production and inflorescence weight observed up to 100/m^2. An increase in the density of *E. crus-galli* from 25–175/m^2 reduced the grain yield up to 63.9%.

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