

WEED-COMPETITIVE ABILITY OF A HYBRID AND AN INBRED RICE CULTIVAR IN MANAGING *Ischaemum rugosum* IN DRY-SEEDED RICE

Tahir Hussain Awan^{1,2,3*}, Charlemagne Alexander A. Lim^{1,2}, Sharif Ahmed¹, Muhammad Ehsan Safdar⁴ and Bhagirath Singh Chauhan⁵

¹Weed Science, Crop and Environmental Sciences Division, International Rice Research Institute (IRRI), Los Baños, Philippines; ²Crop Science Cluster, College of Agriculture, University of the Philippines Los Baños, Philippines; ³Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan; ⁴Department of Agronomy, College of Agriculture, University of Sargodha, Punjab, Pakistan; ⁵The Centre for Plant Science, The Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Toowoomba, Queensland 4350, Australia

*Corresponding author's e-mail: tahirawanrri@gmail.com

Ischaemum rugosum Salisb. commonly known as ribbed murainagrass is a problematic herbicide-resistant weed in direct-seeded rice systems. To evaluate the competitive ability of rice cultivars against *I. rugosum*, a study was established with two rice cultivars (Mestiso 21, a hybrid and IR 64, an inbred). These cultivars were sown at density of 4 plants per pot with four different densities of *I. rugosum* (0, 2, 4, and 8 plants pot⁻¹). Across weed density levels, IR 64 had 14% lower while Mestiso 21 had 20% higher plant height than *I. rugosum*. In competition with eight *I. rugosum* plants per pot, Mestiso 21 had 17% higher plant height (85 cm) than of IR 64 (73 cm). Without competition, IR 64 had higher tiller number, leaf number, leaf area, and root biomass than Mestiso 21 while in competition with eight weed plants per pot, Mestiso 21 had higher leaf biomass (29%), stem biomass (13%), specific stem length (38%), panicle biomass (29%), florets number (41%), and florets biomass (36%) than IR 64. In comparison with control (no weed competition), weed densities of 2, 4, and 8 plants pot⁻¹ reduced the total rice biomasses and grain yields by 32, 42, and 50%; and 26, 46, and 56% for IR 64 and by 23, 37, and 45%; and 20, 28, and 42% for Mestiso 21, respectively. The Mestiso 21 reduced the *I. rugosum* plant height, number of tillers, leaf biomass, inflorescence biomass, root biomass, and total aboveground biomass by 16.3, 0.3, 22.1, 31.3, 21.8, and 22.7%, respectively, compared with IR 64. The results of this study suggest that the hybrid rice Mestiso 21 has a better competitive ability to suppress *I. rugosum* than IR 64 therefore can be used in an integrated weed management of problematic weeds in direct-seeded rice systems.

Keywords: Biomass production, canopy closure, competitiveness, early-vigor, interference, inflorescence.

INTRODUCTION

Ischaemum rugosum is a problematic weed in many crops including rice (Holm *et al.*, 1977; Itoh, 1991). It can cause around 50-60% yield losses in direct-seeded rice (DSR) as it favors shallow flooding conditions (Jabran and Chauhan, 2015; Jabran *et al.*, 2012a,b). Morphologically, it is an erect or ascending annual or perennial type of plant which can grow up to 150 cm tall. This weed can be established through seeds or rooted culms, and seedlings emerge even when buried at a 10-cm depth because of their long coleoptile length (Holm *et al.*, 1977). *Ischaemum rugosum* has a high level of seed dormancy which delays its seed germination after shedding, enabling it to escape from herbicides. It matures at the same time as do the rice plants, thereby contaminating the rice seeds around harvest period (Marenco and Santos, 1999).

Factors such as farm labor shortage, scarcity of irrigation water, and the adverse effects of conventional puddled flooded rice have pushed many rice growing countries in Asia to shift from transplanted to DSR production system

(Mahajan and Chauhan, 2013a; Ahmed and Chauhan, 2014; Jabran *et al.*, 2015). Direct-seeded rice goes by many forms - wet seeding, dry seeding, and water seeding. Among these, dry seeding is gaining more popularity in Asia because it saves water and is conducive to mechanization (Awan *et al.*, 2015a). In addition, alternate wetting and drying events occur in the whole life cycle of the crop in DSR systems, which triggers weed emergence and growth (Singh *et al.*, 2006). In DSR, rice and weeds emerge simultaneously. Many previous studies reported that weeds are major constraints to the success of DSR and herbicides are considered the best weed management tool (Mahajan and Chauhan, 2013b; Awan *et al.*, 2015a; Chauhan *et al.*, 2015). It has also been reported that if weeds are managed properly, the yield obtained from DSR could be similar to the yield obtained from transplanted rice (Singh *et al.*, 2005; Chauhan *et al.*, 2015).

Several previous studies reported that the best weed control option in DSR systems is the application of a pre-emergence (PRE) herbicide followed by (fb) a post-emergence (POST) herbicide, mixture of POST fb one hand weeding (Mahajan

and Timsina, 2011; Chauhan and Opena, 2012) or sequential application of a PRE fb two POST herbicides (Rahman *et al.*, 2012; Anwar *et al.*, 2013). Weed control in DSR, therefore, warrants the intensive use of herbicides (Mahajan and Timsina, 2011).

In some countries, intensive herbicide use has resulted in the evolution of the weeds' resistance to some herbicides. Although herbicides are considered the most effective and reliable tool for weed control in DSR, the excessive use of herbicides can cause environmental contamination and can lead to the evolution of herbicide-resistant weeds (Buhler *et al.*, 2002; Heap, 2015). Many weed species including *I. rugosum* have already evolved herbicide resistance due to its continuous use (Valverde, 2007). This makes it difficult to control *I. rugosum* in DSR systems and needs an integrated approach.

Effective weed management in DSR involves the integration of many practices such as altering plant geometry, the use of high seeding rates, the use of narrow row spacing, and the use of weed-competitive cultivars which could reduce farmers' reliance on intensive applications of herbicides (Zhao *et al.*, 2006a; Chauhan and Opena, 2013; Ahmed *et al.*, 2014; Awan *et al.*, 2014a). In addition, herbicide performance can be improved with the use of cultivars that have superior competitiveness as reported by many previous studies (Lemerle *et al.*, 1996; Gibson and Fischer, 2004). A competitive cultivar might help in curtailing the dose of herbicides in DSR by suppressing weed emergence and growth, resulting in reduced yield losses (Gibson *et al.*, 2003; Mahajan *et al.*, 2014).

Weed-competitive cultivars have the ability to maintain high yields despite weed competition and weed-suppressive cultivars have the ability to reduce weed growth through competition (Jannink *et al.*, 2000). It has been observed that rice cultivars that compete well against weeds are often thought to be tall and have early vigor, droopy leaves, high specific leaf area, and high specific stem length (Garrity *et al.*, 1992; Ni *et al.*, 2000; Zhao *et al.*, 2006b). Similarly, hybrid rice may potentially have this competitiveness due to its improved vigor (Zhao *et al.*, 2006b).

After the green revolution, high-yielding semi-dwarf type rice cultivars have gained popularity among farmers in Asian countries and have been grown in large scales. The cultivar IR 64 is a semi-dwarf type derived from extensive intercrossing of improved lines of IR 8 and released by the International Rice Research Institute (IRRI) (Narciso and Hossain, 2002). It is a popular cultivar which is widely grown in irrigated and rainfed areas of many Asian countries because of its good yield potential, satisfactory grain type, and resistance to several biotic stresses (Khush, 1995). Because of its wide adaptability and semi-dwarf habit, IR 64 has been used as a parent for a range of cultivars in the tropics (Khush, 1995). In Asian countries, transplanted systems are still the dominant rice cultivation method and farmers mostly grow

high-yielding semi-dwarf types of rice cultivars. Previous studies reported that rice performed well in transplanted conditions. Some other studies found that rice did not perform well in DSR conditions due to high weed pressure in DSR (Zhao *et al.*, 2006a; Mahajan *et al.*, 2014). Hybrids showed better performance than inbreds in DSR systems due to their high competitiveness (Chauhan *et al.*, 2011; Mahajan *et al.*, 2014).

We hypothesized that the weed-competitive ability of Mestiso 21 is better than that of IR 64 which will be helpful in suppressing problematic weeds of rice like *I. rugosum*. To test this hypothesis a study was conducted to determine the competitive ability of an inbred (IR 64) and a hybrid (Mestiso 21) rice cultivars against varying *I. rugosum* plant densities, based on growth parameters of weed and rice, and yield-contributing characteristics and grain yield of rice.

MATERIALS AND METHODS

Time and place of study: The study was conducted at the laboratory and screen house (a large framed chamber covered with 2-mm steel mesh having environmental conditions similar to the field) facilities of the International Rice Research Institute (IRRI), Los Banos, Laguna, Philippines from November 2012 to June 2013.

Collection of seeds and germination test: Mature seeds of *I. rugosum* were collected from the IRRI rice fields. Immature and contaminant seeds were removed from the seed lot. To prevent bacterial and fungal contamination, the *I. rugosum* seeds were soaked in 5.25% sodium hypochlorite for 5 minutes and rinsed with running tap water for 3-5 min before the germination test.

Pot preparation, sowing, experimental design and management: Experiment was conducted for two rice cultivars (hybrid Mestiso 21 and inbred IR 64) with four *I. rugosum* density levels (0, 2, 4, and 8 plants pot⁻¹). The experiment was conducted by growing *I. rugosum* at four density levels (0, 2, 4, and 8 plants pot⁻¹) with four rice plants in 25 cm diameter and 25 cm height plastic pots filled with sterilized soil collected from IRRI rice fields. The soil used in the experiments had a pH of 6.7, organic carbon of 2.5%, and sand, silt, and clay contents of 26, 48, and 26%, respectively. Phosphorus and potassium were hand-incorporated before sowing at the rate of 40 kg ha⁻¹ each. Nitrogen at 150 kg ha⁻¹ was applied in three splits: at 14 DAS (30%), at 35 DAS (30%), and at 55 DAS (panicle initiation) (40%). These application rates correspond to what is commonly followed by farmers in DSR systems in the Philippines. Both weed and rice seeds were sown in the pots at an 8 cm x 8 cm square dimension. Two to three seeds of each species were placed at the allocated place in the pots, covered with a thin layer of soil and subsequently thinned to the desirable density after 3 days of emergence. To avoid water stress, the pots were irrigated daily with a hose fitted with a sprinkler nozzle. The

experiment was repeated in two independent trials, with the second trial started one month after the start of the first trial. Pots were arranged in a completely randomized design with four replications. The pots were placed at a spacing of 50 cm from one another.

Observation: Both crop and weed data were recorded at 30, 55, 80, and 110 DAS. Plant height was measured from the surface of the soil to the tip of the longest leaf, and the numbers of leaves and tillers per plant were counted while the plants were still intact in the pots. Plants were cut at the soil surface, and then removed and separated into leaves, stems and inflorescences. The leaf area was measured by using a leaf area meter (model #LI-3100, LICOR). The remaining roots were removed from the pots with the soil still intact and gently washed to remove soil particles while leaving the roots intact. The rice and weed roots were separated. At final harvest (110 DAS), rice florets were counted and grain yield was estimated at the 14% moisture content. The plant and weed components were placed in separate paper bags and oven dried at 70°C for constant biomass determination. Specific stem length (SSL) was calculated by dividing the stem length by the stem biomass.

Statistical analyses: The analysis of variance (ANOVA) was performed for all weed- and crop-related parameters using the statistical software CropStat 7.2 (IRRI, Philippines). A combined analysis of data indicated no significant interactions between treatments and experimental trials; therefore, the data were pooled over the two trials for further analysis. After ANOVA, the means were separated using least significant difference (LSD) at the 5% level of significance. Regression analyses were done using SigmaPlot 11.0 (Systat Software, Inc., Point Richmond, CA). Parameter estimates for each model were compared using their standard errors. Plant height, leaf biomass, and total biomass were analyzed using a three-parameter sigmoid model:

$$y = a / \{1 + \exp [-(x - d_{50}) / b]\}$$

where y is the estimated plant height (cm), leaf biomass (g pot⁻¹), or total biomass (g pot⁻¹) at time x (DAS); a is the maximum of the parameter; d_{50} is the time to reach 50% of the final plant height, leaf biomass, or total biomass per plant; and b is the slope.

A polynomial quadratic model was fitted to tiller number, leaf number, leaf area, stem biomass, and root biomass:

$$y = a + bx + cx^2$$

Where y is the estimated tillers (number m⁻²), leaves (number pot⁻¹), leaf area (cm² pot⁻¹), stem biomass (g pot⁻¹), and root biomass (g pot⁻¹) at time x (DAS), a is the intercept, and b and c describe the slope of the regression curve.

A two-parameter exponential decay curve was fitted to specific stem length (SSL):

$$y = a \cdot e^{-bx}$$

where y represents the SSL; x is the time; a is the maximum of the parameter; and b is the slope. R^2 values were used to determine the fitness of the selected model.

RESULTS

Plant height: The plant height of both rice cultivars was affected by *I. rugosum* interference (Fig. 1), and Mestiso 21 was taller than IR 64. When rice cultivars were grown alone (without weed competition), Mestiso 21 reached a maximum height of 103 cm and IR 64 reached 82 cm at 110 DAS. At 30 DAS, the plant height of IR 64 and *I. rugosum* across its planting densities was similar but the weed became taller than the rice after 30 DAS. In contrast, Mestiso 21 was always taller than *I. rugosum*. The rice and weed plant height decreased as the density of *I. rugosum* increased from 2 to 8 plants pot⁻¹. Height of *I. rugosum* was higher (88 cm) when grown with the rice cultivar IR 64 than in Mestiso 21 (73 cm) at maturity, showing that Mestiso 21 reduced the weed height by 16.3% more than IR 64 (Fig. 1).

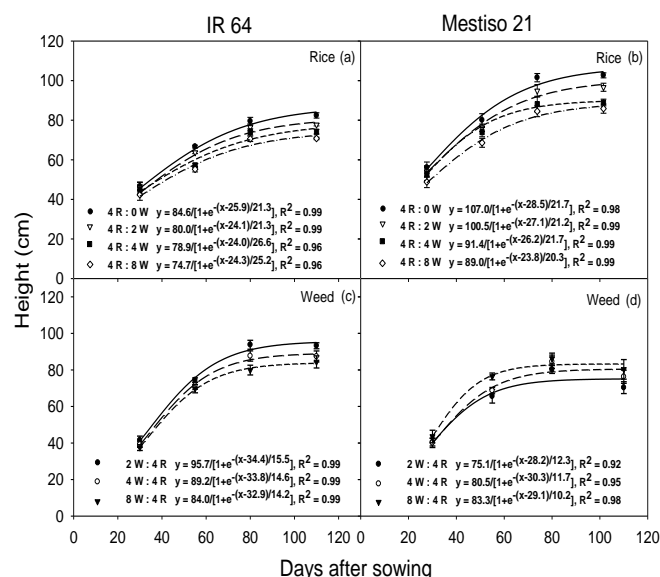


Figure 1. Plant height of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot⁻¹). 4R, density of rice plant pot⁻¹; 2W, 4W, and 8W, densities of *I. rugosum* plant pot⁻¹. The lines represent a three-parameter sigmoid model ($y = a / [1 + e^{-(X - d_{50}) / b}]$) fitted to the data. Vertical bars indicate standard error of means.

Tiller density: Tiller densities were significantly influenced by the interference of *I. rugosum* (Fig. 2). As the density of weed increased, rice tillers decreased but the tiller number of the weed increased. Out of the cultivars, IR 64 produced more tillers than Mestiso 21. At 30 DAS, IR 64 grown alone produced 21 tillers per pot while Mestiso 21 produced only 15 tillers per pot. *Ischaemum rugosum* density of 2, 4, and 8

plants per pot reduced tiller numbers by 26, 35, and 38% for IR 64 and by 22, 31, and 35 % for Mestiso 21 at 110 DAS.

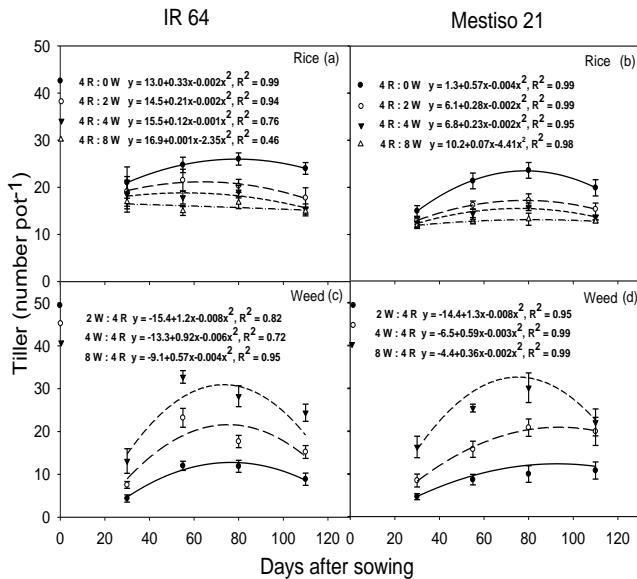


Figure 2. Tiller (number pot⁻¹) of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot⁻¹). 4R, density of rice plant pot⁻¹; 2W, 4W, and 8W, densities of *I. rugosum* plant pot⁻¹. The lines represent polynomial quadratic models [($y = a + bx + cx^2$)] fitted to the data. Vertical bars indicate standard error of means.

Leaf number, biomass, and area: The leaf number of rice plants decreased with the increase in *I. rugosum* density (Fig. 3). IR 64 produced more leaves than Mestiso 21. IR 64 grown alone produced the maximum leaf number of 133 per pot at last harvest while in competition with *I. rugosum* at densities of 2, 4, and 8 plants pot⁻¹ resulted in 5, 26, and 35% less leaves, respectively, compared with rice grown without competition. Similarly, Mestiso 21 produced the maximum leaf number of 102 per pot at last harvest when grown alone while in competition with 2, 4, and 8 *I. rugosum* plants resulted in leaf number reduction by 13, 42, and 46%, respectively. The leaf number of *I. rugosum* was always higher at the highest density of 8 plants pot⁻¹. In competition with Mestiso 21 rice cultivar, the leaf number of *I. rugosum* remained lower than in competition with rice cultivar IR 64. Similar to the results for leaf number, leaf area and leaf biomass data also followed the same trend. Compared with IR 64 when was grown alone, competition with *I. rugosum* reduced leaf area at final harvest by 26, 38, and 46% at densities of 2, 4, and 8 plants (Fig. 4).

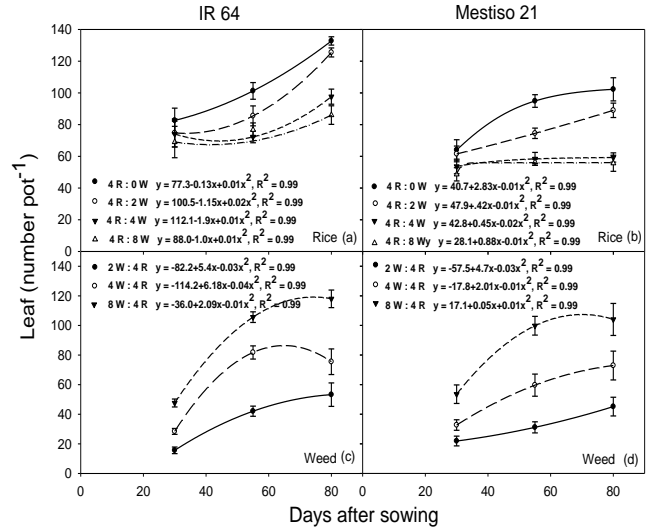


Figure 3. Leaf (number pot⁻¹) production of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot⁻¹). 4R, density of rice plant pot⁻¹; 2W, 4W, and 8W, densities of *I. rugosum* plant pot⁻¹. The lines represent polynomial quadratic models [($y = a + bx + cx^2$)] fitted to the data. Vertical bars indicate standard error of means.

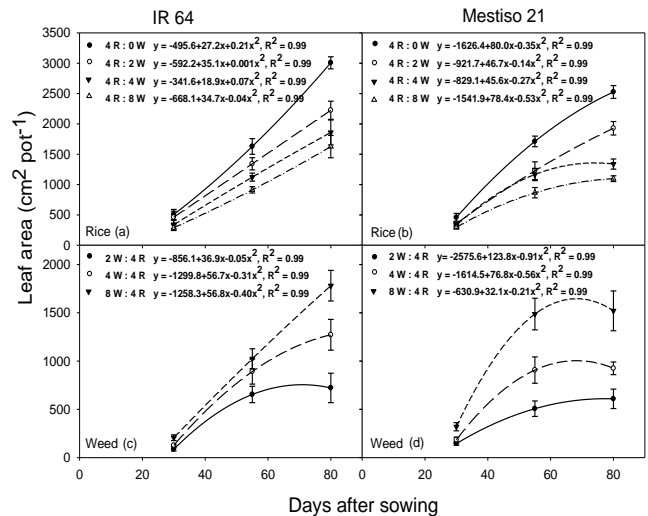


Figure 4. Leaf area (cm² pot⁻¹) of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot⁻¹). 4R, density of rice plant pot⁻¹; 2W, 4W, and 8W, densities of *I. rugosum* plant pot⁻¹. The lines represent polynomial quadratic models [($y = a + bx + cx^2$)] fitted to the data. Vertical bars indicate standard error of means.

For Mestiso 21, these values were 24, 47, and 47%. The leaf area of *I. rugosum* increased as its planting density increased. Between the two cultivars, IR 64 had higher leaf area than Mestiso 21 when they were grown alone. *I. rugosum* interference with the rice plants reduced IR 64 leaf biomass by 29, 32, and 46% and Mestiso 21 biomass by 16, 24, and 27% at final harvest at *I. rugosum* densities of 2, 4, and 8 plants, respectively, compared with no weed competition (Fig. 5). Across all *I. rugosum* plant densities (2, 4, and 8 plants pot⁻¹) at maturity, leaf biomass per plant of *I. rugosum* was higher (1.17 g) when grown with IR 64 than with Mestiso 21 (0.91 g) at maturity. Mestiso 21 reduced the leaf biomass per plant of *I. rugosum* by 22.1% more than IR 64.

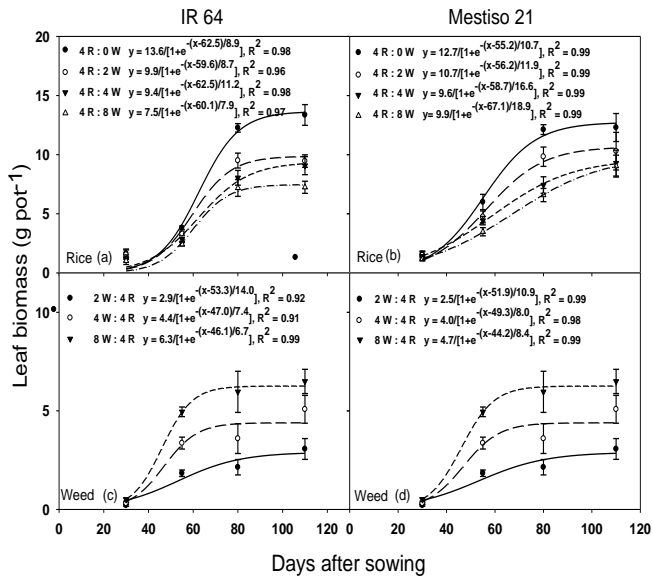


Figure 5. Leaf biomass (g pot⁻¹) of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot⁻¹). 4R, density of rice plant pot⁻¹; 2W, 4W, and 8W, densities of *I. rugosum* plant pot⁻¹. The lines represent a three-parameter sigmoid model ($y = a / [1 + e^{-(X-d50)/b}]$) fitted to the data. Vertical bars indicate standard error of means.

Stem biomass: Mestiso 21 always had a higher stem biomass than IR 64 (Fig. 6). At 110 DAS, rice grown alone had significantly higher stem biomass than that grown with *I. rugosum*. At maturity (110 DAS), *I. rugosum* competition reduced rice stem biomass by 29, 35, and 57% for IR 64 and by 10, 37, and 41% for Mestiso 21 at densities of 2, 4, and 8 weed plants pot⁻¹, respectively, compared with no weed competition. Also, across these three densities, the stem biomass per plant of *I. rugosum* was higher (3.9 g) in IR 64

than in Mestiso 21 (3.0 g), with Mestiso 21 reducing the stem biomass of *I. rugosum* by 21.2% more than IR 64 (Fig. 6).

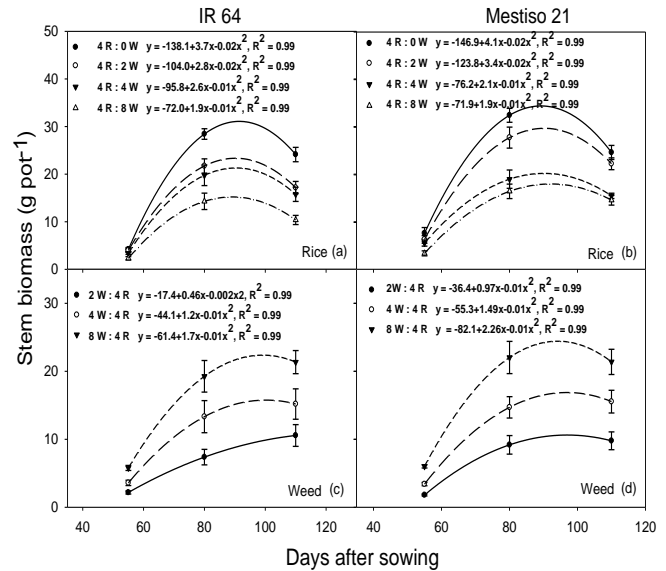


Figure 6. Stem biomass (g pot⁻¹) of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot⁻¹). 4R, density of rice plant pot⁻¹; 2W, 4W, and 8W, densities of *I. rugosum* plant pot⁻¹. The lines represent polynomial quadratic models [$y = a + bx + cx^2$] fitted to the data. Vertical bars indicate standard error of means.

Root biomass: Between the two rice cultivars, IR 64 had greater root biomass than Mestiso 21. However, the interference of *I. rugosum* significantly reduced the root biomass of both cultivars except at 35 DAS. At final harvest (110 DAS), the root biomass of rice decreased by 16, 31, and 42% for IR 64 and by 20, 26, and 30% for Mestiso 21 when they competed with 2, 4, and 8 *I. rugosum* plants pot⁻¹, respectively (Fig. 7). Root biomass of *I. rugosum* also influenced by the cultivar and density. Irrespective of the weed densities, the root biomass of *I. rugosum* was higher when grown in competition with IR 64 than with Mestiso 21. Similar to stem biomass at maturity, the root biomass per plant of *I. rugosum* was higher (0.68 g) in IR 64 than in Mestiso 21 (0.53 g) across all *I. rugosum* plant populations. Mestiso 21 reduced root biomass per plant of *I. rugosum* by 21.8% compared to IR 64 (Fig. 7).

Total biomass: The total biomass of both rice and weed plants was influenced by the planting densities of *I. rugosum* (Fig. 8).

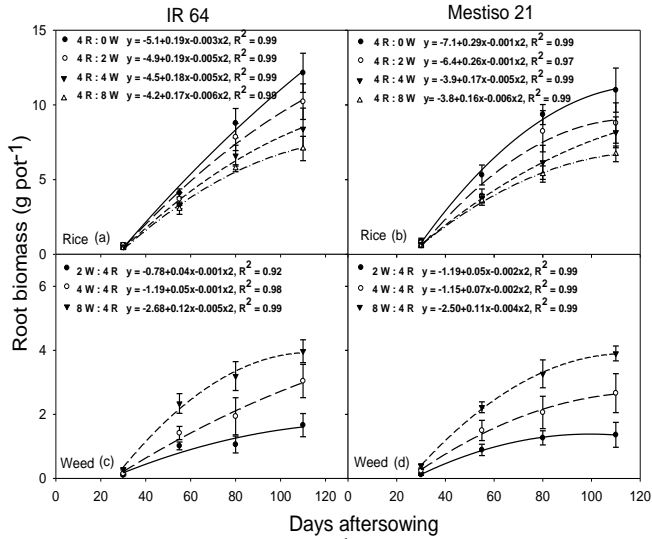


Figure 7. Root biomass (g pot^{-1}) of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot^{-1}). 4R, density of rice plant pot^{-1} ; 2W, 4W, and 8W, densities of *I. rugosum* plant pot^{-1} . The lines represent polynomial quadratic models [$y = a + bx + cx^2$] fitted to the data. Vertical bars indicate standard error of means.

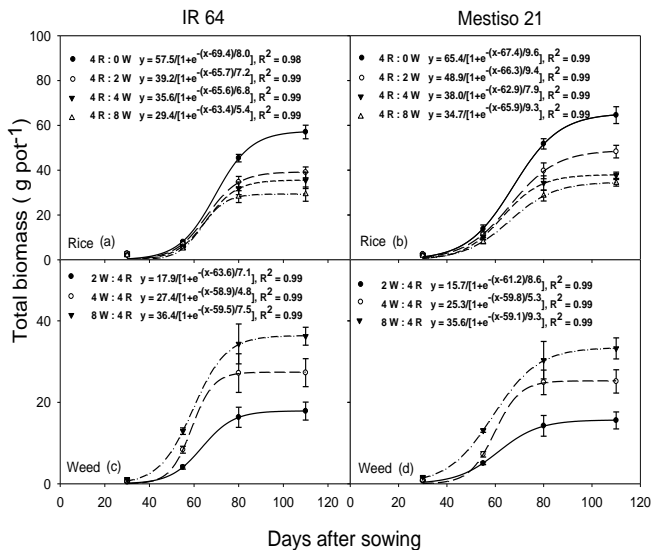


Figure 8. Total biomass (g pot^{-1}) of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot^{-1}). 4R, density of rice plant pot^{-1} ; 2W, 4W, and 8W, densities of *I. rugosum* plant pot^{-1} . The lines represent a three-parameter sigmoid model [$y = a / [1 + e^{-(x-ds0)/b}]$] fitted to the data. Vertical bars indicate standard error of means.

Mestiso 21 produced higher biomass than IR 64. At final harvest, for example, Mestiso 21 grown alone produced a total biomass of 65 g pot^{-1} whereas IR 64 produced only 57 g pot^{-1} . Competition with *I. rugosum* at densities of 2, 4, and 8 plants pot^{-1} reduced total biomass by 32, 38, and 49% for IR 64 and by 25, 42, and 47% for Mestiso 21, respectively. At maturity (110 DAS) and across the three *I. rugosum* planting densities (2, 4, and 8 plants pot^{-1}), the total aboveground biomass of *I. rugosum* was higher (6.0 g) when grown in IR 64 than in Mestiso 21 (4.6 g). Mestiso 21 reduced the total biomass per plant of *I. rugosum* by 22.7% more relative to IR 64 (Fig. 8). **Specific stem length:** The specific stem length (SSL) of both rice cultivars increased as the plant population of *I. rugosum* increased (Fig. 9). The SSLs of IR 64 were 75.7, 83.6, and 91.4 at the weed densities of 2, 4, and 8 plants pot^{-1} , respectively. The corresponding values for Mestiso 21 were 112.5, 113.4, and 125.7. Mestiso 21 had 49, 36, 38% higher SSL than IR 64 when in competition with 2, 4, and 8 plants of *I. rugosum* pot^{-1} , respectively. *I. rugosum* had 13-24% lower SSL when competing with Mestiso 21 than with IR 64.

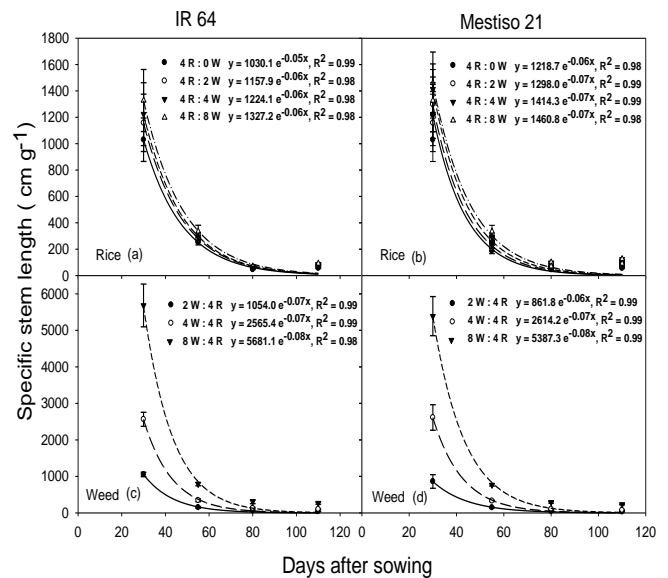


Figure 9. Specific stem length (cm g^{-1}) of the rice cultivars IR 64 (a) and Mestiso 21 (b) and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot^{-1}). 4R, density of rice plant pot^{-1} ; 2W, 4W, and 8W, densities of *I. rugosum* plant pot^{-1} . The lines represent an exponential model ($y = a \cdot e^{-bx}$) fitted to the data. Vertical bars indicate standard error of means.

Inflorescence biomass of *I. rugosum*: Inflorescence biomass per plant of *I. rugosum* decreased as its population increased from 2 to 8 plants pot^{-1} (Fig. 10c). When *I. rugosum* was

grown with IR 64 at densities of 2, 4, and 8 plants pot^{-1} , inflorescence biomass was 2.86, 3.85, and 4.98 g, respectively. Lower values for the inflorescence biomass of *I. rugosum* were noted when it was grown with Mestiso 21 with 2.0, 2.53, and 3.50 g, respectively. Results showed that Mestiso 21 has more capacity than IR 64 to reduce the inflorescence biomass production of *I. rugosum*, reducing it by 31.3% across all the weed plant populations.

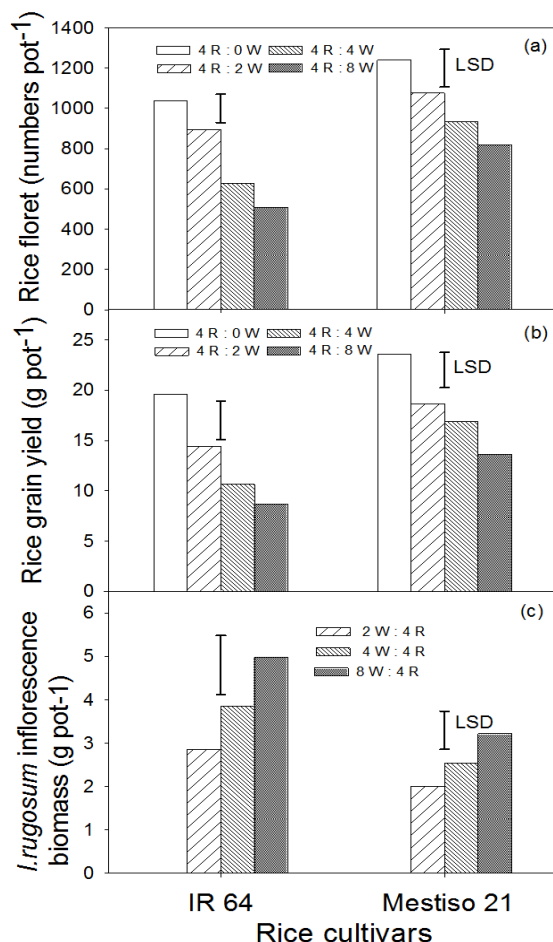


Figure 10. Rice florets (number m^{-2}) (a) and grain yield (g pot^{-1}) (b) of the rice cultivars IR 64 and Mestiso 21 and of the weed *Ischaemum rugosum* (c and d) when grown alone and in competition with different interference levels of *I. rugosum* (0, 2, 4, and 8 plants pot^{-1}). 4R, density of rice plant pot^{-1} ; 2W, 4W, and 8W, densities of *I. rugosum* plant pot^{-1} . Vertical bars indicate LSD at 5% level.

Rice florets number and grain yield: Rice florets were significantly influenced by *I. rugosum* interference, Mestiso 21 having higher florets number than IR 64 (Fig. 10a). Highest florets numbers were recorded in the rice plants

grown without weed competition. Both rice cultivars grown with 2 *I. rugosum* plants pot^{-1} had similar florets numbers as that of rice grown alone; however, rice grown in competition with 4 or more *I. rugosum* plants pot^{-1} had significantly lower florets. Compared with rice grown alone, *I. rugosum* interference reduced rice florets by 14, 40, and 50% in IR 64 and by 13, 25, and 34% in hybrid Mestiso 21 at densities of 2, 4, and 8 *I. rugosum* plants pot^{-1} , respectively. Similarly, grain yield was also influenced by *I. rugosum* interference (Fig. 10b). Grain yield of IR 64 was reduced by 23, 46, and 56% when competing with *I. rugosum* densities of 2, 4, and 8 plants pot^{-1} , respectively. The corresponding values for Mestiso 21 were 21, 28, and 42%, respectively.

DISCUSSION

The hybrid Mestiso 21 had higher grain yield than IR 64 in competition with different *I. rugosum* densities. In DSR systems, rice and weed plants emerge simultaneously and if early crop growth is slower than the weed growth, the weeds can easily suppress the crops, resulting in reduced crop growth. Therefore, higher crop vigor, crop growth rate, tiller production, and biomass accumulation at the early crop growth stage, coupled with rapid ground cover by crop canopy under weedy conditions, will help to improve weed suppressive ability as well as crop yield. These traits are positively correlated with crop yield under competition and negatively with weed biomass (Zhao *et al.*, 2006a). The results of the current study depicted that Mestiso 21 had higher plant height than IR 64 at the early growth stage (30 DAS) as well as at final harvest (110 DAS). The attainment of higher plant height at earlier growth stages by Mestiso 21 rice cultivar caused the suppression of *I. rugosum* weed resulting in its lower plant height. In contrast, *I. rugosum* in competition with IR 64 always had higher plant height than IR 64. When *I. rugosum* density increased from 2 to 8 plants pot^{-1} , the height of both rice and weed decreased due to intra- and inter-plant competition.

Previous studies reported that *Ludwigia hyssopifolia* and *Rottboellia cochinchinensis* plants grown alone were always taller than those grown with rice interference and that rice reduced weed plant height (Chauhan and Johnson, 2010a; Awan *et al.*, 2015b). In our study, IR 64 in competition with *I. rugosum* had always lower plant height than the weed. This result is supported by the findings of Awan *et al.* (2014b) in which they reported that *I. rugosum* was taller than the rice plants when grown in competition with the rice cultivar IR154. These findings suggest that *I. rugosum* will suppress semi-dwarf type rice cultivars in DSR systems.

Many previous studies suggested that shoot length has a positive correlation with the fresh and dry weight of seedlings and that the shoot length of the crop plays an important role in suppressing weeds (Verma and Singh, 1989; Chauhan and Johnson, 2010a). The findings of Chauhan and Johnson

(2010b) suggested that shoot competition for light may be the primary mechanism determining competitive outcomes between DSR and *Echinochloa colona* (L) Link.

Rice tiller is one of the most important characters which determine the number of panicles per unit area (Zou *et al.*, 1991). The results revealed that at the early growth stage as well as at final harvest, IR 64 produced more tillers than Mestiso 21. This is consistent with the findings of Yuan (1998) who reported that hybrid varieties have a moderate tillering capacity. Excessive tillering at an early stage could result in reduced leaf biomass and photosynthesis at a later stage, which is eventually becoming one of the major reasons for low yields (Song *et al.*, 2009). Another possible reason might be that high tillering cultivars produce more tertiary and less productive tillers relative to low tillering cultivars (Awan *et al.*, 2007).

Leaf number and leaf area in rice grown alone and with various levels of interference of *I. rugosum* were higher for IR 64 than Mestiso 21. Similarly, *I. rugosum* produced higher leaf number and leaf area when in competition with IR 64 than with Mestiso 21. Despite its higher leaf production, IR 64 could not suppress the leaf production of *I. rugosum* which might be due to its lower plant height.

Although Mestiso 21 produced lower number of leaf and leaf area than IR 64, it still decreased and suppressed the leaf production of *I. rugosum* when they were grown together which might be caused by Mestiso 21 having higher plant height than the weed. This result was more pronounced for leaf biomass, with IR 64 having a higher leaf biomass than Mestiso 21 when grown without weed competition; however, under competition with different levels of *I. rugosum* densities, IR 64 had a lower leaf biomass than Mestiso 21. This suggests that leaf biomass of IR 64 was more affected (reduced) by *I. rugosum* competition than with Mestiso 21.

Having a thick stem is an important characteristic of hybrid rice, which acts as a photosynthates storage organ and affects yield by accumulating biomass (Katsura *et al.*, 2007). The results of the present study show Mestiso 21 had higher stem biomass relative to IR 64 both when grown alone and with weed interference. On the other hand, IR 64 had slightly higher root biomass than Mestiso 21, similar to the root biomass of *I. rugosum* when in competition with both cultivars had similar root biomass. This result indicates that both cultivars had a similar effect on the root biomass of *I. rugosum*. In this study, although leaf and root biomass of IR 64 was higher than Mestiso 21, the total plant biomass of Mestiso 21 was higher than IR 64 due to the hybrid's higher stem biomass and florets biomass. This shows that Mestiso 21 had lower root-to-shoot weight ratio than IR 64 when in competition with weeds. This plasticity in growth to allocate more biomass to shoot than root increases the competitive ability of the plant. *I. rugosum* interference at different levels reduced total rice biomass for both cultivars; however, reduction was lower for Mestiso 21 than for IR 64.

Mahajan *et al.* (2014) reported that the tall and higher dry matter of the rice cultivar IET-21214 at its initial stages contributed to its greater weed suppression ability compared to the cultivar PR-115, which is of semi-dwarf type and had lower biomass. A higher SSL and lower root-to-shoot weight ratio under crop-weed interference may be a strategy to enable plants to compete more effectively for solar radiation under competition situations (Chauhan and Johnson, 2010b; Awan *et al.*, 2015b). The results of this study show that under competitive conditions, both rice cultivars had higher SSL than when they are grown alone, with Mestiso 21 having higher SSL than IR 64. Owing to this phenotypic plasticity, Mestiso 21 was less suppressed by *I. rugosum* at a double planting density. In addition, Mestiso 21 was always taller than *I. rugosum*, putting its leaves on the top of the canopy to intercept maximum solar radiation (Awan *et al.*, 2014b). The findings of Chauhan and Johnson (2010a) suggested that shoot competition for light may be the primary mechanism determining competitive outcomes between rice and weeds.

In this study, the competitive ability of the hybrid cultivar Mestiso 21 was higher than IR 64 owing to its higher plant height and total plant biomass, higher SSL, higher florets number, and higher grain yield under competition with *I. rugosum*. Similar results were reported by previous researchers that a weed-competitive cultivar has the ability to suppress the growth of the weeds and had higher plant height, growth rate, biomass, leaf area index, specific leaf area, SSL, canopy ground cover, and early vigor (Lotz *et al.*, 1995; Jannink *et al.*, 2000; Ni *et al.*, 2000; Caton *et al.*, 2003; Zhao *et al.*, 2006a).

The survival of a weed species fundamentally depends on the production of sufficient numbers of viable seeds. Weeds that mature in the field contribute to an increase in the seed bank of existent weed populations. If the weed seed production can be stopped or reduced by management practices, ultimately it will help to reduce the weed seed bank and eventually weed infestation. Results of the present study depict that inflorescence biomass production by *I. rugosum* was reduced by Mestiso 21 more effectively than IR 64. This means that *I. rugosum* can produce more seeds that will eventually increase the soil seed bank when grown with IR 64 relative to Mestiso 21.

The present study provides useful information on the biomass and reproduction of weeds grown with interference of two rice cultivars. The results of the present study support previous findings that showed that delay in weed emergence relative to crop growth (Gibson *et al.*, 2002; Chauhan and Johnson, 2010a) and the use of high seed rate (Chauhan *et al.*, 2011), narrow row spacing (Chauhan and Johnson, 2011b) and weed-competitive rice cultivars should be basic tools in devising integrated weed management strategies. Nevertheless, in the context of herbicide-resistant weed management, the use of weed-competitive cultivars like Mestiso 21 can prevent and reduce the production and return

of weed seeds to the soil seed bank for its renewal by the resistant biotypes, is the key to manage the resistant biotypes. The results also suggest that sustainable weed control can be obtained by delaying weed emergence relative to the crop and/or by making the crop more competitive. Therefore, farmers need to grow weed-competitive rice cultivars and adopt weed management practices that can suppress and inhibit the renewal of the seed bank without sacrificing the rice grain yield.

Management practices such as early flooding after rice seed emergence, changing planting date, deep tillage, row spacing, planting geometry, planting density, mulching, crop sowing through zero tillage, high planting density, nutrient management, early canopy closure, and weed-competitive cultivars can be utilized to improve crop competitiveness over weeds. To reduce reliance on herbicides, the use of weed-competitive cultivars is a cultural management tool and a valuable component of integrated weed management (IWM). This is further supported by the results of this study which suggest that the use of rice cultivars having high weed-competitive ability would provide an effective, season-long, and sustainable weed control in DSR systems.

Conclusion: The reductions in biomass and grain yield in Mestiso 21 were less than in IR 64 at all the levels of *I. rugosum* competition. Mestiso 21 has the potential to suppress the height, growth and reproduction of *I. rugosum* weed at its all levels of competition. Owing to its higher SSL, Mestiso 21 plants were always taller and were not overshadowed by the weed plants. This cultivar can decrease the weed biomass considerably and make *I. rugosum* weak and vulnerable to be easily controlled later through other weed control measures. It also has the potential to reduce the weed's inflorescence biomass production by 30-35% more than IR 64, hence, it can help in reducing the size of the weed seed bank. These results suggest that weed-competitive cultivars have the potential to become part of IWM approaches to suppress the growth of weeds and reduce the use of herbicides to control the most problematic weeds of rice like *I. rugosum*. The findings of present study would play an important role in combating the environmental pollution by reducing the herbicide use for weed control in DSR systems.

Acknowledgements: Authors would like to thank Anny for providing comments on the manuscript.

REFERENCES

- Ahmed, S. and B.S. Chauhan. 2014. Performance of different herbicides in dry-seeded rice in Bangladesh. *Sci. World J.* 2014:1-14.
- Ahmed, S., M. Salim and B.S. Chauhan. 2014. Effect of weed management and seed rate on crop growth under direct dry seeded rice systems in Bangladesh. *PLoS ONE* 9:e101919.
- Anwar, M.P., A.S. Juraimi, M.T.M. Mohamed, M.K. Uddin, B. Samedani, A. Puteh and A. Man. 2013. Integration of agronomic practices with herbicides for sustainable weed management in aerobic rice. *Sci. World J.* 2013:1-12.
- Awan, T.H., M. Ahmad, R.I. Ali, M. Anwar and Z. Manzoor. 2007. Contribution of different tillers with in a plant of super basmati to grain yield of rice. *J. Agric. Res.* 45:237-245.
- Awan, T.H., P.C. Sta. Cruz and B.S. Chauhan. 2015a. Agronomic indices, growth, yield-contributing traits, and yield of dry-seeded rice under varying herbicides. *Field Crops Res.* 177:15-25.
- Awan, T.H., P.C. Sta. Cruz and B.S. Chauhan. 2015b. Ecological significance of rice (*Oryza sativa* L.) planting density and nitrogen rates in managing the growth and competitive ability of itchgrass (*Rottboellia cochinchinensis*) in direct-seeded rice systems. *J. Pest Sci.* 88:427-438.
- Awan, T.H., P.C. Sta. Cruz and B.S. Chauhan. 2014a. Growth plasticity of junglerice (*Echinochloa colona*) for resource use when grown with different rice (*Oryza sativa* L.) planting densities and nitrogen rates in dry-seeded conditions. *Weed Sci.* 62:571-587.
- Awan, T.H., B.S. Chauhan and P.C. Sta. Cruz. 2014b. Physiological and morphological responses of *Ischaemum rugosum* Salisb. (wrinkled grass) to different nitrogen rates and rice seeding rates. *PLoS One* 9:e98255.
- Buhler, D.D. 2002. Challenges and opportunities for integrated weed management. *Weed Sci.* 50:273-280.
- Caton, B.P., A.E., Cope and M. Mortimer. 2003. Growth traits of diverse rice cultivars under severe competition: Implications for screening for competitiveness. *Field Crops Res.* 83:157-172.
- Chauhan, B.S., T.H. Awan, S.B. Abugho, G. Evengelista and Sudhir-Yadav. 2015. Effect of crop establishment methods and weed control treatments on weed management, and rice yield. *Field Crops Res.* 172:72-84.
- Chauhan, B.S. and D.E. Johnson. 2010a. Relative importance of shoot and root competition in dry seeded rice growing with junglerice (*Echinochloa colona*) and ludwigia (*Ludwigia hyssopifolia*). *Weed Sci.* 58:295-299.
- Chauhan, B.S. and D.E. Johnson. 2010b. Responses of rice flatsedge (*Cyperus iria*) and barnyardgrass (*Echinochloa crus-galli*) to rice interference. *Weed Sci.* 58:204-208.
- Chauhan, B.S., V.P. Singh, A. Kumar and D.E. Johnson. 2011. Relations of rice seeding rates to crop and weed growth in aerobic rice. *Field Crops Res.* 121:105-115.
- Chauhan, B.S. and J. Opeña. 2013. Implications of plant geometry and weed control options in designing a low-seeding seed-drill for dry-seeded rice systems. *Field Crops Res.* 144:225-231.
- Garrity, D.P., M. Movillon and K. Moody. 1992. Differential weed suppression ability in upland rice cultivars. *Agron. J.* 84:586-591.

- Gibson, K.D., A.J. Fischer, T.C. Foin and J.E. Hill. 2003. Crop traits related to weed suppression in water-seeded rice (*Oryza sativa* L.). *Weed Sci.* 51:87-93.
- Gibson, K.D. and A.J. Fischer. 2004. Competitiveness of rice cultivars as a tool for crop based weed management. In: Inderjit (ed.), *Weed Biology and Management*. Kluwer Academic Publishers, Netherlands; pp.517-537.
- Heap, I. 2015. International Survey of Herbicide Resistant Weeds. Weed science society of America. Available online at <http://www.weedscience.org/>
- Holm, L.G., D.L. Plucknett, J.V. Pancho and J.P. Herberger. 1977. *The World's Worst Weeds: Distribution and biology*. University of Hawaii Press, Honolulu, Hawaii, USA.
- Itoh, K. 1991. *Life Cycles of Rice Field Weeds and Their Management in Malaysia*. Tropical Agriculture Research Center, Peang, Malaysia.
- Jannink, J.L., J.H., Orf, N.R. Jordan and R.G. Shaw. 2000. Index selection for weed-suppressive ability in soybean. *Crop Sci.* 40:1087-1094.
- Jabran, K. and B.S. Chauhan. 2015. Weed management in aerobic rice systems. *Crop Prot.* 78:151-163.
- Jabran, K., M. Farooq, M. Hussain, M.B. Khan, M. Shahid, and L. Dong-Jin. 2012a. Efficient weeds control with penoxsulam application ensures higher productivity and economic returns of direct seeded rice. *Int. J. Agric. Biol.* 14:901-907.
- Jabran, K., M. Hussain, M. Farooq, M. Babar, M.N. Doğan and Dong-Jin Lee. 2012b. Application of bispyribac-sodium provides effective weed control in direct-planted rice on a sandy loam soil. *Weed Biol. Manage.* 12:136-145.
- Jabran, K., B.S. Chauhan. 2015. Weed management in aerobic rice systems. *Crop Prot.* 78:151-163.
- Jabran, K., Ehsanullah, M. Farooq, M. Hussain, N. Haider and B.S. Chauhan. 2015. Water saving, water productivity and yield outputs of fine-grain rice cultivars under conventional and water-saving rice production systems. *Exp. Agric.* 51:567-581.
- Katsura, K., S., Maeda, T., Horie and T. Shiraiwa. 2007. Analysis of yield attributes and crop physiological traits of Liangyoupeijiu, a hybrid rice recently bred in China. *Field Crops Res.* 103:170-177.
- Khush, G. 1995. Modern varieties: Their real contribution to food supply and equity. *Geo. J.* 35:275-284.
- Lemerle, D., B. Verbeek, R.D. Cousens and N.E. Coombes. 1996. The potential for selecting wheat varieties strongly competitive against weeds. *Weed Res.* 36:505-513.
- Lotz, L.A.P., J. Wallinga and M.J. Kropff. 1995. Crop-weed interactions: Quantification and prediction. In: D.M. Glen, M.P. Greaves and H.M. Anderson (eds.), *Ecology and Integrated Farming Systems*. John Wiley & Sons Ltd; pp.31-37.
- Mahajan, G. and B.S. Chauhan. 2013a. Herbicide options for weed control in dry-seeded aromatic rice in India. *Weed Technol.* 27:682-689.
- Mahajan, G., and B.S. Chauhan. 2013b. The role of cultivars in managing weeds in dry-seeded rice production systems. *Crop Prot.* 49:52-57.
- Mahajan, G. and J. Timsina. 2011. Effect of nitrogen rates and weed control methods on weeds abundance and yield of direct-seeded rice. *Arch. Agron. Soil Sci.* 57:239-250.
- Mahajan, G. V. Poonia and B.S. Chauhan. 2014. Integrated weed management using planting pattern, cultivar, and herbicide in dry-seeded rice in Northwest India. *Weed Sci.* 62:350-359.
- Marenco, R.A. and R.V.C.D. Santos. 1999. *Ischaemum rugosum* and rice intra and interspecific competition. *Revista Brasileira De Fisiologia Vegetal.* 11:107-111.
- Narciso, J. and M. Hossain. 2002. World Rice Statistics. Available online at <http://www.irri.org/science/ricestat>
- Ni, H., K. Moody, R.P. Robles, E.C. Paller and J.S. Lales. 2000. *Oryza sativa* plant traits conferring competitive ability against weeds. *Weed Sci.* 48:200-204.
- Rahman, M., A.S. Juraimi, J. Suria, B.M. Azmi and P. Anawar. 2012. Response of weed flora to different herbicides in aerobic rice system. *Sci. Res. Essays* 7:12-23.
- Singh, S., L., Bhushan, J.K. Ladha, R.K. Gupta, A.N. Rao and B. Sivaprasad. 2006. Weed management in dry-seeded rice (*Oryza sativa* L.) cultivated in the furrow-irrigated raised-bed planting system. *Crop Prot.* 25:487-495.
- Singh, S., G., Singh, V.P. Singh and A.P. Singh. 2005. Effect of establishment methods and weed management practices on weeds and rice in rice-wheat cropping system. *Ind. J. Weed Sci.* 37:51-57.
- Song, C., C. Sheng-guan, C. Xin, Z. Guo-Ping. 2009. Genotypic differences in growth and physiological responses to transplanting and direct seeding cultivation in rice. *Rice Sci.* 16:143-150.
- Valverde, B.E. 2007. Status and management of grass-weed herbicide resistance in Latin America. *Weed Technol.* 21:310-323.
- Verma, O.P. and P.V. Singh. 1989. Path analysis for seedling characters in rice. *Narendra Deva J. Agric. Res.* 4:12-14.
- Yuan, L. 1998. Hybrid rice breeding for super high yield. In: G.L. Denning and T.W. Mew (eds.), *China and IRRI: Improving China's Rice Productivity in the 21st Century*. IRRI, International Rice Research Institute, Manila, Philippines; pp.10-12.
- Zhao, D.L., G.N. Atlin, L. Bastiaans and J.H.J. Spiertz. 2006a. Developing selection protocols for weed competitiveness in aerobic rice. *Field Crops Res.* 97:272-285.
- Zhao, D.L., G.N. Atlin, L. Bastiaans and J.H.J. Spiertz. 2006b. Comparing rice germplasm groups for growth, grain yield and weed-suppressive ability under aerobic soil conditions. *Weed Res.* 46:444-452.
- Zou, Y., Q. Tang, C. Hu, S. Liu and D. Xiao. 1991. Dynamic simulation for rice growth and yield. The comparison and application of rice tillering statistical models. *Crop Res.* 5:18-22.