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Competitiveness of swamp rice against *Echinochloa crus-galli* and *Monochoria vaginalis* weeds

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Abstract

Weed competition, especially with *Echinochloa crus-galli* and *Monochoria vaginalis*, is a major constraint in rice production as they reduce yield by competing with crops for resources such as light, nutrients, and water. Therefore, this study aims to determine rice competitiveness against *Echinochloa crus-galli* and *Monochoria vaginalis* weeds. The experimental design was a split-plot with four replications, with the main plot being weed-free, *E. crus-galli*, and *M. vaginalis* treatments, while the subplot was rice varieties namely Inpara 3, 4, 7, and 8. The result showed that existence of weeds reduced the plant height, tillers, photosynthetic rate, leaf area, biomass, percentage of filled grain, and yield of rice due to competition, with losses up to 15%. Furthermore, the rice varieties differed in their yield performances and weed competitiveness. The grain yield ranged from 7.75 t ha^{-1} to 5.96 t ha^{-1} for Inpara 4 and 8, respectively, under the weed-free condition. A low weed tolerance and suppress ability was found in Inpara 7, both for *E. crus-galli* and *M. vaginalis*. Inpara 8 had a low weed tolerance in *E. crus-galli*, but high in *M. vaginalis*, while Inpara 4 produced the highest yield in a weedy condition, along with high weed tolerance and suppress ability. Traits related to the leaf area and rice dry weight at grain filling stage are associated with rice competitiveness. Based on the results, competitive rice can be an important strategy for reducing hand weeding and herbicide inputs in rice production.

Keywords: Swamp rice, weed tolerance, weed suppressive ability, grain yield.
Abbreviations: DAS_days after sowing; DAT_days after transplanting; WT_weed tolerance; WSA_weed suppress ability; LAI_leaf area index; ANOVA_analysis of variance; STAR_statistical tools for agricultural research.

Introduction

Rice is a food security cereal crop, especially in Asian countries. The global food security is dependent on the rice production in Asia and the contribution of this region is approximately 90.6% (Bandumula, 2017). Meanwhile, several efforts have been made to produce crop varieties with higher yield potential through genetic and cultivation approaches. One of the problems in increasing production is biotic factors, namely weeds, which is a major constraint that decreases the rice yield. Weeds also affect crops through their influence on insect and diseases, given that they are food resources for various insects (Capinera, 2005). The yield loss due to this competition can reach 43-82% among the several rice varieties (Rahman et al., 2017). Additionally, the presence of weeds leads to losses amounting to 50-60% in transplanted rice and 70-80% in the direct seeded (Daas et al., 2017).

Crop competition often leads to limited available resources. Weeds compete with cultivated plants for primary resources such as light, nutrients, and water to survive and reproduce. Competition for light is practically null in the early stages but as the seedling gradually develops, they begin to shade one another (Santín-Montanyá et al., 2015). The light quality is also an important factor affecting crops. Changes in the R:FR (Red/Far red) signal affected the morphological and physiological performances of maize due to the actions of *Amaranthus retroflexus* (Liu et al., 2009). Moreover, the presence of multiple plants can induce nutrient stress in any nearby plants. Numerous nutrients limit plant growth and each has different properties in the soil (Craine and Dybzinski, 2013). For example, the competitiveness of N uptake is an important trait in the competition between rice and weed. This is due to plant N concentration correlated with relative leaf growth and N assimilation. Increased availability of NO_3 in aerobic rice soils is advantageous for the competitiveness of upland weeds (Vu et al., 2021).

Weeds found in swampland include barnyard grass (*Echinochloa crus-galli*) and pickerel weed (*Monochoria vaginalis*). *E. crus-galli* is one of the world's most harmful rice weeds, with a C4 pathway of carbon fixation. It causes approximately 50% decrease in rice production (Aminpanah et al., 2013). The number of barnyard grass plants is affected by the time between the sowing and emergence of rice seedling, with the Japonica variety having a faster emergence and a lower barnyard grass number compared to Indica (Ntanos and Koutroubas, 2000). Furthermore, the shoot competition with the barnyard grass is another important factor that causes differences in the rice genotype and a reduction in the biomass (Suzuki et al., 2002). The decreased shoot growth and root traits during the post-heading stages contribute to the reduction in the rice yield (Zhang et al., 2020). *M. vaginalis* grows in all agroecosystems except dry lands. It has rapid growth, and causes approximately 44% yield loss (Kuk et al., 2003).

Weeds in paddy fields are very diverse, making their control difficult with a negative impact on grain yield and increased costs. Farmers often use chemical herbicides to control weed's growth because they require less labor, quick, and time-saving. However, long-term use can damage the environment and cause crop toxicity (Myers et al., 2016; Schutte et al., 2017; Kniss, 2017). Therefore, sustainable weed management which can reduce the use of synthetic herbicides is needed as an alternative strategy. The use of plants that can compete with weeds is an alternative to overcome this problem. This competition is defined as an interaction between individuals or populations that has a negative impact on both parties. It occurs directly such as allelopathy, or indirectly where plants affect one another by taking limited resources in the surrounding environment. Therefore, it is very difficult to determine the effect of a single competition in the field because it is an interaction that involves several factors (Schreiber et al., 2018).

Crop competitiveness against weed consists of two components, namely weed tolerance (WT) and weed suppressive ability (WSA). WT is the ability to maintain high yield despite weed competition, while WSA is the ability to suppress weed growth (Gibson et al., 2003). The lower the relative yield loss, the higher the weed tolerance and vice versa (Arefin et al., 2018). The high yield potential must also ensure economically acceptable production. Therefore, WT, WSA, and yield potential will mutually affect grain production under weedy conditions. The competitiveness of a variety/species is measured through the ability to obtain limited resources when growing together with other species. Germplasm/varieties have the potential to be competitive against weeds in paddy fields, but the agronomic characters and grain yields are still below commercial standards (Chen et al., 2008). Previous studies showed that the variability among the genotypes is due to their ability to compete with weeds (Aminpanah et al., 2013; Mahajan et al., 2014; Islam et al., 2021). The development of varieties that can compete with weeds is an aspect that needs to be investigated in rice production. However, it is important to note that increasing the ability to compete with weeds can reduce grain yields. Competitiveness is a contribution of various morphological and physiological characteristics of plants which are not only controlled by genetics but also the environment (Olofsdotter et al., 2002). Selecting a competitive crop can be a way to suppress weed growth without sacrificing grain yield. Therefore, this study aims to determine the competitiveness of swamp rice against *Echinochloa crus-galli* and *Monochoria vaginalis* weeds.

Results and Discussion

Growth of rice

The weeds significantly affected plant height and tillers of rice at all observations except for plant height at 21 DAT. The interaction between weeds and rice varieties only had a significant effect on plant height at 42 DAT, tillers at 21 DAT, and harvest (Table 1). Weeds caused a decrease in plant height and tillers namely 3 and 7%, respectively. The decrease was due to *E. crus-galli* being higher than *M. vaginalis*. *E. crus-galli* reduced plant height by 5% and tillers by 9%, while *M. vaginalis* caused a decrease of 2 and 5%, respectively. A previous study showed that plant height reduction by weeds ranged from 1 to 9% and tillers reduction was 38% (Moukoumbi et al., 2011).

The *E. crus-galli* had a high posture. Hence, it can shade and prevent light for photosynthesis in shorter rice. Light is an important factor affecting the growth process of plants. Shading changes the composition received by plants and any alteration in the quality of blue, green, red, and R/FR light affects photosynthesis in leaves (Chen et al., 2019). Additionally, shading reduces the photosynthetic activity of the lower leaf as well as the distribution ratio of the C compounds from leaves in the upper position to organs in the lower parts, thereby minimizing the root activity which might lead to the retardation of plant growth (Osaki et al., 1995). *E. crus-galli* has larger roots than paddy and it has the potential to absorb more nutrients from the soil. The presence of this weed reduced the surface area of absorption by 50%, thereby limiting the ability of paddy roots to absorb nutrients with water for growth and development (Zhang et al., 2020). It also reduced N uptake in leaves and stems of paddy by 0.48 and 0.15 N kg ha^{-1} 43 days after sowing (Ulguim et al., 2020). *E. crus-galli* is a severe competitor of rice growth even at an early stage (Irshad and Cheema, 2002). Meanwhile, *M. vaginalis* had a height of approximately 50 cm, but the development of tillers and leaf were rapid. The leaves covered the entire surface of growing space which prevented short paddy from getting light compared to the weeds. Plants use different parts including leaves/roots to compete for space and light as well as nutrients and water in the soil. Successful acquisition of space provides access to energy and nutrients sources. The taller plant height of rice ensures that *M. vaginalis* grows in low light conditions. However, at early stages, rice tillers are shaded by *M. vaginalis* foliage causing carbon deficit and eventually increasing tiller abortion of rice (Breen et al., 1999).

Inpara 3 had a higher plant height than other varieties at the beginning of growth, but the plant height at harvest was lower than Inpara 8. The lowest plant height was found in Inpara 4 at the early growth until harvest as shown in Table 1. Meanwhile, Inpara 3 plant height at 42 DAT was higher than other varieties in the weed-free and *E. crus-galli* but the plant height was similar with Inpara 8 in *M. vaginalis* (Fig. 1). This indicates that plant height was influenced by the surrounding weeds. Inpara 3 plant height in *E. crus-galli* was not significant with *M. vaginalis*, while Inpara 4 and 7 plant height in *E. crus-galli* was lower than the *M. vaginalis* treatment. *M. vaginalis* did not reduce plant height in Inpara 8, the weed-free treatment showed no significant difference with *M. vaginalis*.

Tall paddy has a great potential to compete with weeds and suppress their growth (Sunyob et al., 2015). Previous studies showed that plant height affects the dry weight of weeds (Zhao et al., 2006; Anwar et al., 2010; Fofana and Rauber, 2000). Rice height less than 1.2 m tends to have low weed dry weight (Garrity et al., 1992). However, Fischer et al. (1997) stated that there is no clear relationship between plant height and its ability to suppress weeds. Meanwhile, extremely tall plants are susceptible to lodging (Kruepl et al., 2006). IRRI (2013) divided the plant height into three categories, (1) semidwarf (<110 cm); (2) intermediate (110-130 cm); and (3) tall (>130 cm). Based on this category, only Inpara 8 was included in the tall, while the three varieties were intermediate.

Inpara 4 had significantly more tillers than the other three varieties, the lowest was found in Inpara 8, followed by Inpara 3 (Table 1). The rice tillers play an important role in suppressing weeds (Mahajan et al., 2020). The tiller is associated to the plant's ability to capture light and canopy allowing it to shade the weeds and suppress their growth (Schreiber et al., 2018). Additionally, the ability of the plant to produce numerous tillers enables effective competition especially for underground resources (Fradgley et al., 2017). Inpara 4 had more tillers under weed-free, *E. crus-galli*, and *M. vaginalis* treatments (Fig. 2). At 21 DAT, tillers of Inpara 3, Inpara 4, and Inpara 7 were significantly higher in the weed-free treatment than weedy. In contrast, Inpara 8 tillers were higher in *M. vaginalis*, followed by weed-free and the lowest was found in *E. crus-galli*. The results obtained at harvest were different as Inpara 4 and 7 had the same tillers in weed-free and *M. vaginalis*, while tillers of Inpara 8 were not significantly different with weed-free, *E. crus-galli*, and *M. vaginalis*.

The photosynthetic rate in the weed-free was higher than weedy conditions at panicle initiation, but was similar at grain filling. Furthermore, the presence of weeds reduced the leaf area and dry weight of rice at panicle initiation and grain filling (Table 2). The reduction of photosynthetic rate, leaf area, and dry weight of rice in weedy was 18, 20, and 8%, respectively. The weeds among the rice varieties caused competition which decreased the photosynthetic rate due to biochemical limitation in the Calvin cycle, namely a reduction in the ratio of red-infrared (R/FR) in phytochromes (McKenzie-Gopsill et al., 2020). In contrast, rice cultivation under a weed-free condition will reduce competition, thereby increasing growth rate and leaf area index (Mubeen et al., 2014).

Inpara 8 had a photosynthetic rate lower than the other three varieties at panicle initiation, but leaf area and dry weight were similar. Meanwhile, Inpara 3 and Inpara 4 had a high photosynthetic rate and leaf area, but the dry weight of Inpara 4 was significantly lower than 3 at grain filling stage. The result was different in Inpara 8 which had a low photosynthetic rate, but high leaf area and dry weight. The dry matter accumulation is influenced by canopy architecture, photosynthetic rate, and leaf area (Qu et al., 2017). In this study, a high photosynthetic rate was not always followed by a high dry weight. According to a previous study, an increased photosynthetic rate followed by a high leaf area will have a significant effect on the production of dry weight (Usuda, 2000). The photosynthetic rate is influenced by the leaf area that determines the light interception capacity (Weraduwage et al., 2015). High leaf area in rice potentially increases light absorption and growing space. Rice genotypes with a large leaf area showed higher ability to compete with weeds (Mahajan et al., 2014). Furthermore, the high leaf area of rice caused shading over weeds; thereby, reducing the light availability and ultimately interfering with growth. However, high leaf area needs to be supported by a balanced canopy architecture to prevent the overlapping of upper and lower leaves.

The dry weight of Inpara 8 in the weed-free treatment was significantly lower than other varieties, but the four varieties had a similar dry weight at panicle initiation stage and under weedy condition (Table 3). Inpara 8 had the same dry weight under weed-free and weedy conditions, while Inpara 3, Inpara 4, and Inpara 7 had a lower dry weight in the weedy compared to the weed-free treatments. These results differ at grain filling stage where the dry weight of Inpara 3 was significantly higher than other varieties under the weed-free condition, but produced a lower dry weight than Inpara 8 when planted with *E. crus-galli*. Furthermore, the dry weight of Inpara 3 and Inpara 4 was lower in *E. crus-galli* than *M. vaginalis*, while Inpara 8 had a higher dry weight in the presence of *M. vaginalis* than weed-free, namely 7%. Plants with a high dry weight can significantly reduce weed dry weight and the general population (Mwenda et al., 2020).

Yield component and grain yield

The sample weeds significantly affected the percentage of filled grain and yield as shown in Table 4. The percentage of filled grain under the weed-free condition was not significantly different from *M. vaginalis*, which was more than 80%. The decrease in the filled grain caused by *E. crus-galli* was 5%, while yield due to *E. crus-galli* and *M. vaginalis* decreased by 15 and 9%, respectively. This indicates that *E. crus-galli* has a greater influence in weed competition with rice. These results are in line with Take-tsaba et al. (2018) which showed that there was no significant difference in panicle number, spikelet per panicle, and 1000 grain weight under weed-free and weedy conditions, but grain yield decreased by 11.6% in soil dominated by *Cleome rutidosperma* and *Cyperus iria*. However, a different result was found in rice dominated by *Echinochloa colona* weed which reduced panicle and spikelet number, 1000 grain weight, as well as the relative yield by 18.2% (Sunyob et al., 2015).

Inpara 4 had the highest panicles, spikelet number, and percentage of filled grain, but the size was relatively small, as the 1,000 grain weight was only 20 g. This was in contrast to Inpara 8 which had low panicles, spikelet number, and filled grain, but had a high 1,000 grain weight. Furthermore, Inpara 4 produced the highest grain yield, followed by Inpara 3 but the grain yield of Inpara 3 was similar to Inpara 7, and the lowest occurred in Inpara 8.

Relative yield loss and weed biomass

A decrease in the grain yield of a variety can be used as an indicator to determine the weed tolerance (WT), while the weed suppressive ability (WSA) can be observed from the weed biomass in rice. The grain yield of the four varieties under a weed-free condition was higher than the weedy (Table 5). The highest yield was found in Inpara 4 under *E. crus-galli* and *M. vaginalis* compared to the three varieties planted

Table 1. Effect of weeds and varieties on plant height and tillers of rice.

Treatments	Plant height (cm)				Tillers per hill			
	21 DAT	42 DAT	63 DAT	Harvest	21 DAT	42 DAT	63 DAT	Harvest
Weed								
Weed-free	40 a	73 a	94 a	122 a	9.4 a	24.2 a	19.0 a	16.7 a
E. crus-galli	39 a	68 c	90 c	119 c	8.8 b	22.7 b	16.7 c	14.9 c
M.vaginalis	39 a	71 b	92 b	120 b	9.2 ab	23.2 b	17.3 b	16.1 b
Varieties								
Inpara 3	44 a	82 a	103 a	125 b	8.2 c	20.6 c	15.8 c	14.2 c
Inpara 4	32 d	55 d	75 c	111 d	10.8 a	28.7 a	23.3 a	19.0 a
Inpara 7	38 c	68 c	85 b	113 c	9.0 b	23.3 b	17.2 b	16.5 b
Inpara 8	43 b	80 b	104 a	132 a	8.5 c	20.8 c	14.3 d	14.0 c
Mean	39	71	92	120	9.1	23.4	17.6	15.9
Weed	ns	**	**	**	*	*	**	**
Varieties	**	**	**	**	**	**	**	**
Interaction	ns	*	ns	ns	**	ns	ns	**

Data in a column followed by the same letter are not significantly different at the 0.05 levels by Duncan Multiple Range Test. **: p<0.01; *: p<0.05; ns: not significant.

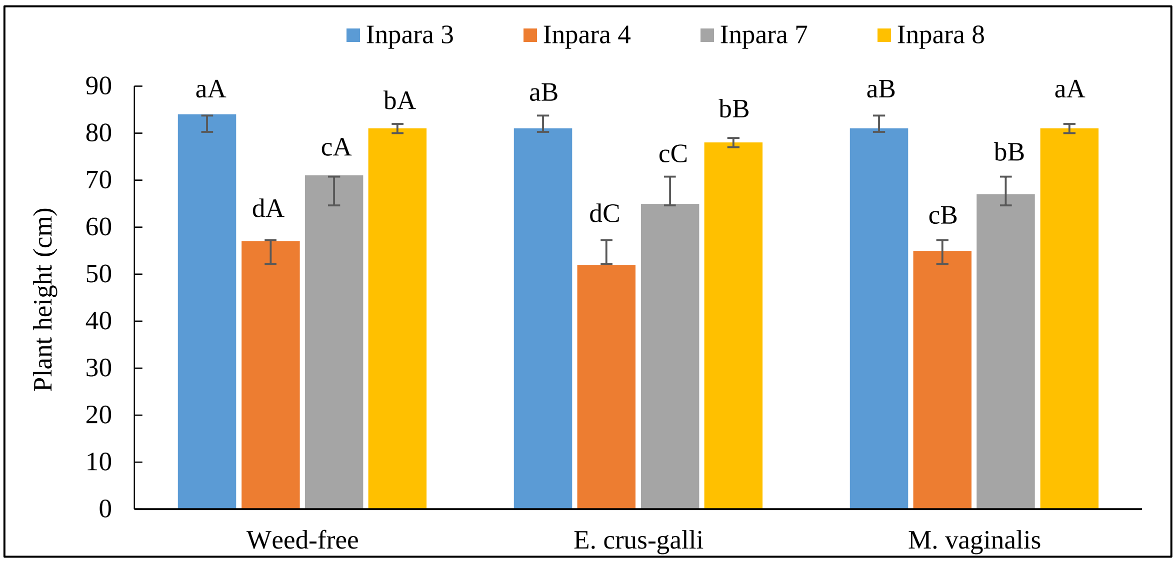

Fig 1. Plant height of rice at 42 DAT in weed-free, *E. crus-galli*, and *M. vaginalis*. Means with the same letter are not significantly different at P <0.05 using Duncan's test. Lowercase letters showed the comparison among varieties in each weed condition, while uppercase letters showed the comparison of varieties among weed conditions. The bars indicate SEm (standard error of the mean).

Table 2. Effect of weeds and rice varieties on photosynthetic rate, leaf area, and dry weight.

Treatments	Photosynthetic rate (CO_2 µmol m^{-2} s^{-1})		Leaf area per hill (cm^2)		Dry weight per hill (g)	
	PI	GF	PI	GF	PI	GF
Weed						
Weed-free	14.820 a	12.978 a	3054 a	4198 a	39.38 a	70.85 a
E. crus-galli	10.680 b	11.473 a	2298 b	3373 b	35.90 b	62.53 c
M. vaginalis	12.340 b	10.869 a	2591 b	3358 b	36.85 b	67.96 b
Varieties						
Inpara 3	14.040 a	11.910 ab	2744 a	3971 a	37.69 a	70.46 a
Inpara 4	14.360 a	15.600 a	2543 a	3636 ab	37.86 a	67.15 b
Inpara 7	12.100 ab	11.090 b	2692 a	3366 b	37.25 a	61.65 c
Inpara 8	9.960 b	8.500 b	2610 a	3907 a	36.71 a	69.17 a
Mean	12.615	11.775	2647	3720	37.38	67.11
Weed	**	ns	**	*	*	**
Varieties	*	*	ns	*	ns	**
Interaction	ns	ns	ns	ns	**	**

Data in a column followed by the same letter are not significantly different at the 0.05 levels by Duncan Multiple Range Test. **: p<0.01; *: p<0.05; ns: not significant. PI: panicle initiation GF:grain filling.

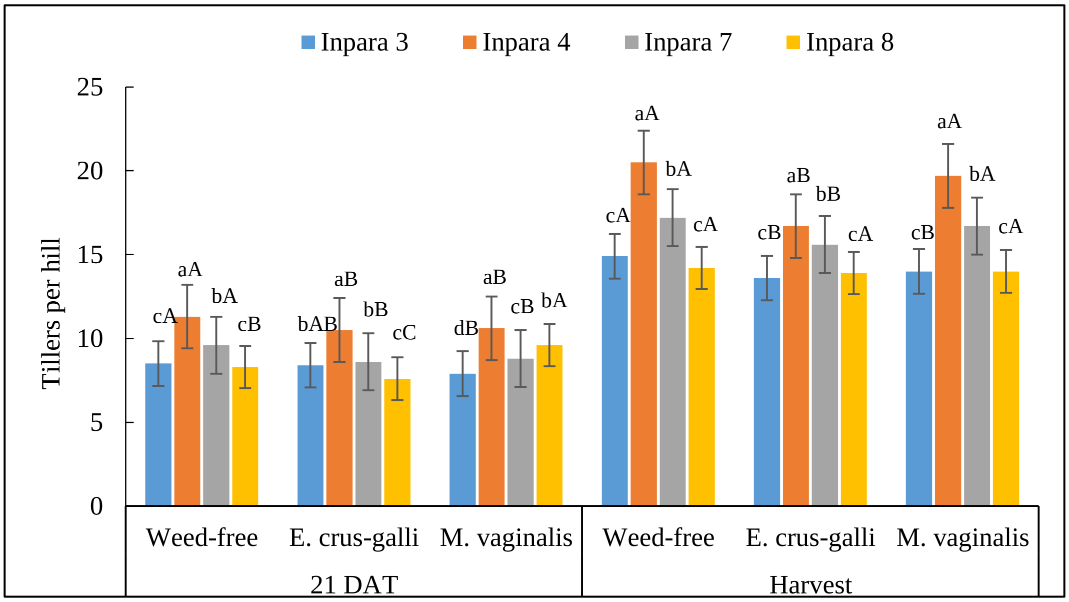

Fig 2. Tillers of rice at 21 DAT and harvest in weed-free, *E. crus-galli*, and *M. vaginalis*. Means with the same letter are not significantly different at P <0.05 using Duncan's test. Lowercase letter showed the comparison among varieties in each weed condition, while uppercase letter showed the comparison of each variety among weed conditions. The bars indicate SEm (standard error of the mean).

Table 3. Interaction weed and varieties on dry weight.

Varieties	Dry weight per hills (g)					
	Panicle initiation			Grain filling		
	Weed-free	*E. crus-galli*	*M. vaginalis*	Weed-free	*E. crus-galli*	*M. vaginalis*
Inpara 3	40.75 aA	35.83 aB	36.50 aB	79.68 aA	60.33 cC	71.37 aB
Inpara 4	41.14 aA	35.02 aB	37.43 aB	70.61 bA	63.98 bC	66.89 bB
Inpara 7	41.26 aA	35.11 aB	35.37 aB	65.07 dA	59.11 cB	60.78 cB
Inpara 8	34.38 bA	37.63 aA	38.11 aA	68.04 cB	66.69 aB	72.80 aA

Data in a column followed by the same lowercase letter are not significantly different at the 0.05 levels by Duncan Multiple Range Test. Data in a cell followed by the same uppercase letter are not significantly different at the 0.05 levels by Duncan Multiple Range Test.

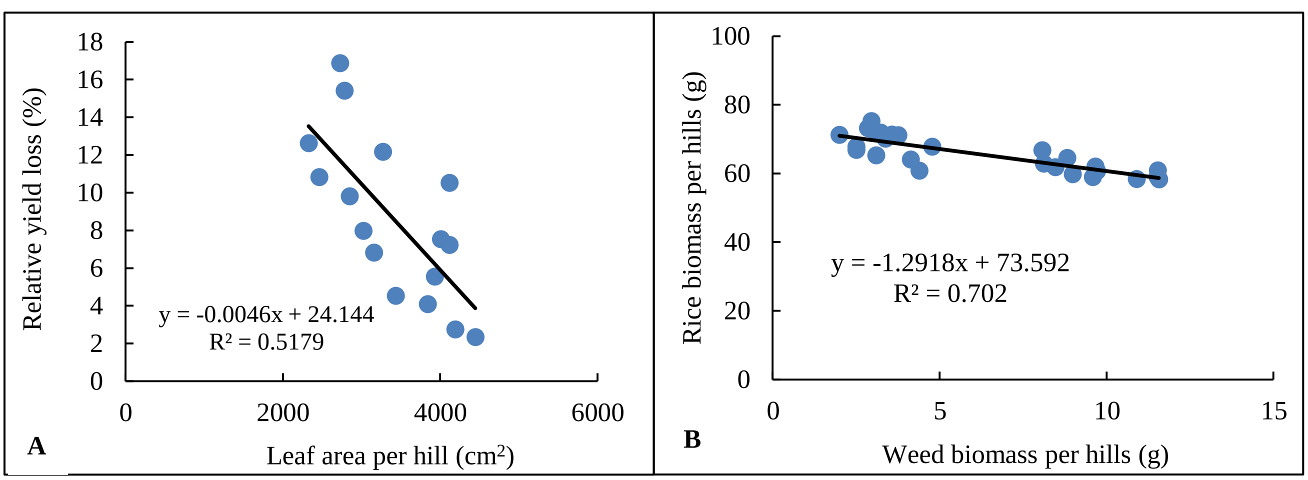

Fig 3. Correlation between relative yield loss and leaf area (A), as well as rice biomass and weed biomass (B).

Table 4. Effect of weeds and varieties on yield component and grain yield of rice.

Treatments	Panicles number	Spikelet number	Percentage of filled grain	1000 grain weight (g)	Grain yield (t ha^{-1})
Weed					
Weed-free	14.3 a	131.5 a	82.0 a	26.5 a	6.70 a
E. crus-galli	13.3 a	127.2 a	77.8 b	26.3 a	5.66 b
M. vaginalis	13.7 a	131.4 a	81.5 a	26.4 a	6.13 b
Variety					
Inpara 3	12.3 c	134.1 b	79.2 c	26.9 b	6.08 b
Inpara 4	16.5 a	166.2 a	86.0 a	20.1 c	7.26 a
Inpara 7	14.4 b	96.4 d	81.1 b	29.6 a	5.78 bc
Inpara 8	11.9 c	123.5 c	74.4 d	29.1 a	5.53 c
Average	13.8	130.0	80.4	26.4	6.16
Weed	ns	ns	*	ns	**
Variety	**	**	**	**	**
Interaction	ns	ns	ns	ns	ns

Data in a column followed by the same letter are not significantly different at the 0.05 levels by Duncan Multiple Range Test. **: p<0.01; *: p<0.05; ns: not significant.

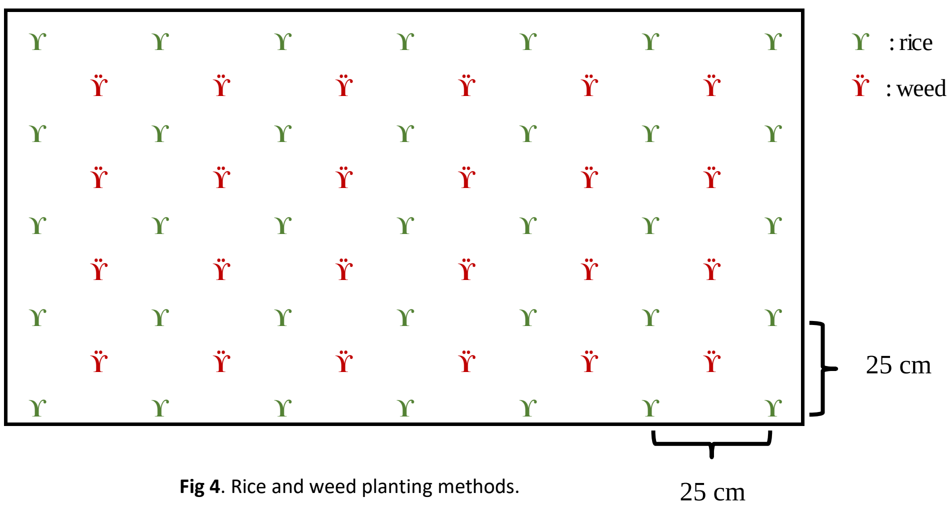

Fig 4. Rice and weed planting methods.

Table 5. Grain yield of rice and weed dry weight.

Variety	Grain yield (t ha^{-1})			Weed biomass per plant (g)	
	Weed-free	*E. crus-galli*	*M. vaginalis*	*E. crus-galli*	*M. vaginalis*
Inpara 3	6.47	5.72	6.06	9.48 b	3.14 b
Inpara 4	7.75	7.01	7.02	8.37 c	3.22 b
Inpara 7	6.62	4.87	5.84	11.38 a	4.41 a
Inpara 8	5.96	5.04	5.61	10.08 b	3.04 b

Data in a column followed by the same letter are not significantly different at the 0.05 levels by Duncan Multiple Range Test.

under weed-free conditions. Furthermore, the average yield loss due to weed competition varied, ranging between 6-27% among the different varieties. The highest relative loss due to *E. crus-galli* and *M. vaginalis* weeds was noted in Inpara 7 with an average of 19%. Meanwhile, a 14% decrease in Inpara 8 yield was caused by *E. crus-galli,* while that of *M. vaginalis* was quite low at 6%. This indicates that Inpara 8 has a high tolerance for *M. vaginalis*, and a low tolerance for *E. crus-galli*. Also, Inpara 3 and Inpara 4 had the lowest relative loss, which was 9%, indicating that both varieties have a higher weed tolerance than Inpara 7 and Inpara 8. The relative yield loss was negatively correlated with leaf area at grain filling stage (Fig. 3A) suggesting that leaf area is an important trait for weed tolerance. The larger leaf area of a variety leads to less yield loss and higher weed tolerance. Mahajan et al. (2014) reported that rapid growth, high leaf area index (LAI) at the early stage, as well as high root biomass and volume are the important traits for weed competitiveness.

The ability of Inpara 7 to suppress the growth of *E. crus-galli* and *M. vaginalis* was lower than other varieties, as demonstrated in their higher weed biomass. The low biomass of *E. crus-galli* was found in Inpara 4, while *M. vaginalis* biomass in Inpara 3, Inpara 4, and Inpara 8 was similar. The lower weed biomass indicates that the variety has a high weed suppressive ability. Furthermore, the weed biomass in Inpara 4 decreased by 27% compared to Inpara 7. It was negatively correlated with dry weight of rice in grain filling (Fig. 3B). This indicates that the weed suppressive ability is influenced by the degree of high rice dry weight produced at the grain filling. Ahmed et al. (2021) reported that weed biomass was negatively correlated with rice biomass, suggesting their ability to suppress tiller production. Furthermore, the production of high weed biomass led to a greater grain yield reduction due to interspecific competition. This is demonstrated by Inpara 7 which had high weed biomass caused by a high decrease of grain yield. The decrease in grain yield of Inpara 7 caused by *E. crus-galli* and *M. vaginalis* was 27 and 14%, respectively.

High grain yield under weedy conditions indicates that the variety has strong competitiveness (Dimaano et al., 2017). Based on the results, the relative yield loss in Inpara 3 and Inpara 4 was similar. However, Inpara 4 produced the highest yield when planted with *E. crus-galli* and *M. vaginalis*, namely 7 t ha^{-1}. Subsequently, Inpara 4 proved to have a better *E. crus-galli* and *M. vaginalis* competitor than other varieties. The large grain yield in this variety was due to the high yield potential, weed tolerance, and the weed suppressive ability. A previous study stated that competitiveness against weeds is related to the ability of a plant genotype to maintain high yield under weeds infestation and its ability to suppress their biomass (Mahajan et al., 2014). The strong competitiveness in certain varieties against weeds was due to having a faster initial ability to close the canopy, producing tillers, higher biomass (Islam et al., 2021), reduced ability of weeds to compete against limited resources, and production of compounds through root exudates, thereby inhibiting weed growth (Andrew et al., 2015). Furthermore, the yield potential of Inpara 7 was higher than Inpara 3, but the weed tolerance and suppressive ability were lower. Although Inpara 8 had a higher weed tolerance and weed suppressive ability than Inpara 7, it produced a lower grain yield, which is attributed to the low yield potential of Inpara 8. This is consistent with Islam et al. (2021), which reported that the varieties BU dhan 1 and Binadhan-11 have good weed competitive ability but lower yield potential. Furthermore, high weed suppress ability did not always ensure high yield (Rahman et al., 2017). Therefore, the three components namely yield potential, weed tolerance, and weed suppressive ability greatly determine grain yield in weedy conditions.

Materials and Methods

Field experiment

The experiment was carried out in the rainy season from November 2020 to April 2021 in Patokbeusi District, Subang Regency, West Java Province, Indonesia. The design used a split-plot with 4 replications, with the main plot being the type of weeds, including weed-free, *E. crus-galli*, and *M. vaginalis,* while the subplots were 4 swamp rice varieties comprising of Inpara 3, 4, 7, and 8. The weeds and rice were planted using the transplanting method at 21 days after sowing (DAS) for rice and *E. crus-galli,* while 30 DAS for *M. vaginalis.* Each treatment was planted on a 5 m x 6 m, and the planting placement referred to Ahn et al. (2005) with slight modifications (Fig. 4).

The fertilizer dosage given was based on the paddy soil test kit, with low N of 115 N kg ha^{-1}, high P containing 18 P_2O_5 kg ha^{-1} and moderate K of 60 K_2O kg ha^{-1}. Furthermore, integrated management was used to control pests, disease attacks, and other weeds growth except for *E. crus-galli* and *M. vaginalis* which were controlled manually without herbicides. The measured variables include plant height, tillers, photosynthetic rate using Li6800 Portable Photosynthesis System, leaf area using Li300C, rice dry weight, panicle number, number of spikelets, percentage of filled grain, 1,000 grain weight, yield, and weed biomass.

Data analysis

The data were analyzed using analysis of variance (ANOVA) with a Statistical Tool for Agricultural Research (STAR). Significant differences among mean were adjudged using Duncan Multiple Range Test at $p \leq 0.05$, while Pearson's correlation was used to draw interferences on the relationship between relative yield loss and leaf area, as well as rice and weed biomass.

Conclusion

Weed competition caused a significant reduction in the growth and grain yield of rice. The decreased yield caused by *E. crus-galli* and *M. vaginalis* reached 15 and 9%, respectively. The yield loss of rice due to the presence of weeds can be minimized by selecting a variety with strong weed tolerance and suppressive ability supported with a high yield potential. Inpara 4 produced grain in weed-infested condition with a lower relative decline and high weed suppressive ability. The high rice competitiveness to weeds was supported by leaf area and dry weight of rice at grain filling stage. Based on the results, the strongly competitive varieties can be used as a part of weed management to reduce dependence on synthetic herbicides. However, the identification of morpho-physiological traits in Inpara 4 is necessary to develop strong weed competitiveness, especially against *E. crus-galli* and *M. vaginalis* weeds.

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