



The interaction between yield and yield components in cultivated rice and weedy rice in the Nile Delta of Egypt

Wesam MH. Abdallah, Mamdouh S. Serag, Reham M. Nada, Gaber M. Abogadallah, Sami H. Rabei

Department of Botany and Microbiology, Faculty of Science, Damietta University, New Damietta 34517, Egypt

Rice has economic importance all over the world. However, rice production faces many challenges. Weedy rice is among the most dangerous weeds that attack Egyptian rice in paddy fields and harm rice production. In the present study, five sites in the Nile Delta of Egypt, planted with cultivated rice and infested with weedy rice, were selected to determine the variation in yield traits between cultivated and weedy rice and evaluate the association between yield and other yield traits in cultivated and weedy rice. Red rice had greater flag leaf length, grain length-to-width ratio, number of grains per panicle, panicle weight, and plant height than the cultivated rice. The dry weight (DW) of ten grains increased in the cultivated rice more than in the weedy rice, suggesting that the grain filling was more efficient in the cultivated rice than that in the weedy rice. The number of grains per panicle, grain dry weight, panicle length, panicle weight, and plant height could positively affect high grain yield in cultivated rice. Meanwhile, the length of the flag leaf is positively correlated to grain yield in the weedy rice; however, a high seed shattering rate could negatively affect the net grain yield in these weedy rice plants. The highest weedy rice density over cultivated rice made weedy rice more competitive with cultivated rice by increasing the percentage of grain yield and biomass for the weedy rice against cultivated varieties, and negatively affecting cultivated rice yield.

Keywords: Competitive ability, Grain yield, Red rice, Seed shattering, Weedy rice, Yield traits

INTRODUCTION

Rice (*Oryza sativa*) is a crucial field crop in Egypt and a major staple food worldwide. The highest rice producer in Africa is Egypt, which produces about 6 million tons per year (El-Shahway et al., 2016). Egyptian rice is considered an important export crop that generates foreign exchange for the country (Eliw et al., 2022). Several limitations challenge self-sufficiency in rice yield in many countries (FAO, 2003). This includes weedy rice, which affects rice yield (Mispan et al., 2019). Egyptian weedy rice infests paddy fields and exhibits morphological characteristics like the cultivated one, especially before producing panicles, causing difficulties in red rice control. Most weedy rice may be distinguished by high germination rate, seedling vigor, vigorous

vegetative growth, tillering ability, strong root structure, awned grains, elevated shattering of seeds, seed dormancy, early seed maturity, and longevity (Esqueda, 2000; Karim et al., 2006). Moreover, most weedy rice height increased than the cultivated rice; so, they compete with cultivated rice for light, space, water, and elements (Hidayatul, 2014). These characteristics affect the development of cultivated rice and its yield. Red rice has more nitrogen use efficiency that is incomparable with rice cultivars (Burgos et al., 2006). Moreover, weedy rice had a bad effect on the grain quality of rice and impacted rice yield (Ottis et al., 2005).

Yield is a key complex trait of rice cultivars. The factors that control yields include environmental and genetic factors (Wang et al., 2012; Zeng et

ARTICLE HISTORY

Submitted: February 25, 2025

Accepted: July 3, 2025

CORRESPONDANCE TO:

Wesam MH. Abdallah

Department of Botany and Microbiology,
Faculty of Science, Damietta University, New
Damietta 34517, Egypt

Email: wesamhamdy@du.edu.eg

DOI: 10.21608/ejbo.2025.359338.3186

EDITED BY: Fawzy Mahmoud Salama

al., 2017; Zhang et al., 2017). Moreover, rice yield depends on plant height, panicle number per plant, tillering ability, thousand-grain weight, filled grains per panicle, growth period, panicle length, seed length, and grains per panicle (Sakamoto & Matsuoka, 2008; Huang et al., 2013). Harvest index (HI) is a key factor that participates in improving crops (Reddy et al., 2003) and it is measured by dividing the total biomass by the grain yield (Donald & Hamblin, 1976; Hay, 1995; Sinclair, 1998). It represents the plant's capacity to turn the total dry matter to produce an economic yield (Sharifi et al., 2009). Various authors have referred to the yield improvement linked with increasing harvest index (Sharma-Natu & Ghildiyal, 2005).

To the best of detailed evaluation of the relationship between yield and yield components in Egyptian cultivated and weedy rice is absent. This study was conducted using data of cultivated and weedy rice traits from field surveys in different paddy fields in the Nile Delta of Egypt and aims to investigate the variations in grain yield, straw yield, and harvest index in the cultivated and weedy rice; assessing the distinction in the relation of yield and yield components in cultivated and weedy rice; and studying the influence of infestation of weedy rice on cultivated rice yield in Egypt as a step in finding a programmed control of these weeds.

MATERIALS AND METHODS

Field survey

After conducting numerous field surveys of weedy rice infestation in all rice-planting areas of the Nile delta in Egypt, five sites were selected (Table 1). Samples of cultivated rice and red rice were gathered from paddy fields of these five sites to determine the yield components of cultivars under the competitiveness of weedy rice. Sampling was carried out using 0.5×0.5m quadrats. The distribution maps showing these sites were drawn using ArcGIS 10.2 (Figure 1). Different stands were selected from each site. Five stands were picked from site 1; the collected cultivated rice was Sakha 104 labeled as S104, while five weedy rice samples were collected from each stand called S1s1WR, S1s2WR, S1s3WR, S1s4WR, and S1s5WR. Four stands were selected from site 2; the collected cultivated rice was Giza 178 labeled as G 178, while four weedy rice samples were collected from each stand named S2s1WR, S2s2WR, S2s3WR and S2s4WR. Three stands were picked from site

3; the collected cultivated rice was Sakha 104 while three weedy rice samples were gathered from each stand, called S3s1WR, S3s2WR, and S3s3WR. One stand was picked from site 4, where no other weedy rice was found; the collected rice cultivar was Sakha Super 300 labeled as SUP300, while the collected weedy rice was S4s1WR. Two stands were selected from site 5; the collected cultivated rice was Sakha 101 labeled as S 101, while two weedy rice samples were gathered from each stand, called S5s1WR and S5s2WR. The collected weedy weedy rice and cultivated rice were clarified in (Table 2). Studied cultivated rice, and their pedigree and types were shown in (Table 3). The measured morphological and yield traits were the number of leaves per culm, leaf length (cm), leaf width (cm), length of flag leaf (cm), plant height, palea and lemma length (cm), panicle length (cm), grain length-to-width ratio, awn length (cm), awn color, awn number, pericarp (kernel) color, hull color, hull number, panicle weight, grains number per panicle, grains dry weight, shoots dry weight, percentage of grains yield, percentage of biomass yield, and harvest index. Each parameter was measured at each stand in each site. Plant height was determined from the ground to the apex of the panicle. Leaf length was determined from the base to the apex. Flag leaf length was specified from the base to the apex. The length of the panicle was established from the neck to the apex. Grain length, width, and length-to-width ratio were determined from randomly selected grains. The number of grains was computed. The weight of ten grains was determined after drying as a function of the whole weight.

Table 1. Geographical locations of the collected cultivated and weedy rice

Sites	Location
1	31°25'30.6"N, 31°38'05.9"E
2	31°24'10.0"N, 31°36'59.8"E
3	31°24'07.4"N, 31°39'35.1"E
4	31°24'03.5"N 31°39'39.7"E
5	31°25'24.4"N 31°38'16.5"E

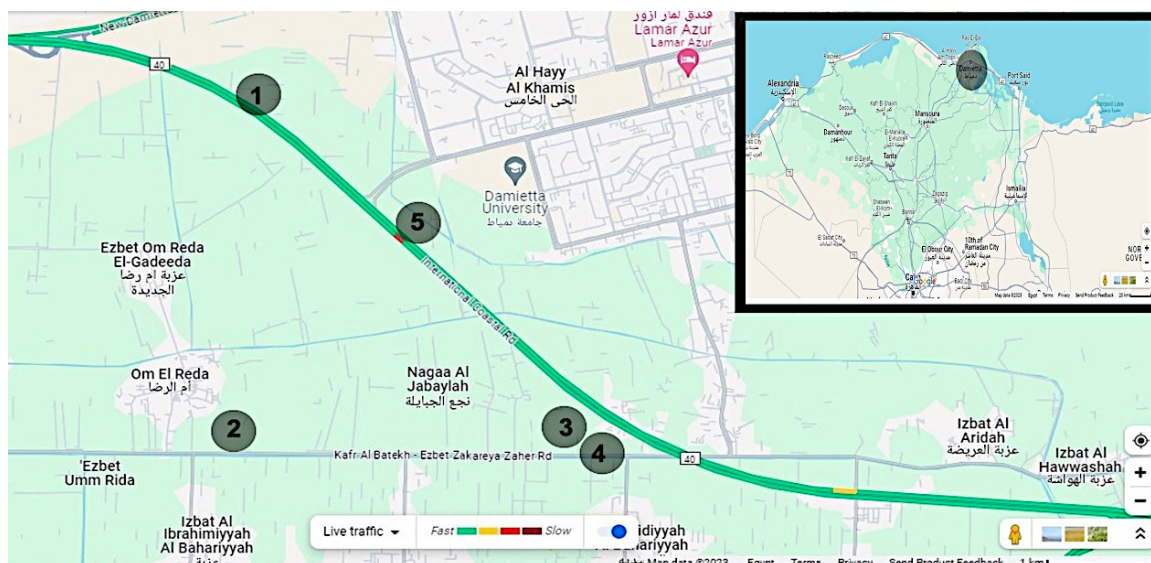


Fig. 1. The surveyed sites of the collected cultivated and weedy rice [1= site1, 2= site 2, 3= site 3, 4= site 4 and 5= site 5]

Table 2. Collected cultivated and weedy rice and their numbers per stand in the five sites. S: site, s: stand.

Site and stand No.	Cultivated rice	Plant numbers/ stand	Weedy rice	Plant numbers/ stand
S1s1	<i>Sakha 104</i> (S 104)	36	S1s1WR	44
S1s2	<i>Sakha 104</i> (S 104)	77	S1s2WR	4
S1s3	<i>Sakha 104</i> (S 104)	8	S1s3WR	164
S1s4	<i>Sakha 104</i> (S 104)	37	S1s4WR	57
S1s5	<i>Sakha 104</i> (S 104)	55	S1s5WR	70
S2s1	<i>Giza 178</i> (G 178)	40	S2s1WR	31
S2s2	<i>Giza 178</i> (G 178)	33	S2s2WR	5
S2s3	<i>Giza 178</i> (G 178)	46	S2s3WR	23
S2s4	<i>Giza 178</i> (G 178)	69	S2s4WR	2
S3s1	<i>Sakha 104</i> (S 104)	74	S3s1WR	15
S3s2	<i>Sakha 104</i> (S 104)	16	S3s2WR	28
S3s3	<i>Sakha 104</i> (S 104)	72	S3s3WR	10
S4s1	<i>Sakha Super 300</i> (SUP300)	52	S4s1WR	4
S5s1	<i>Sakha 101</i> (S 101)	0	S5s1WR	79
S5s2	<i>Sakha 101</i> (S 101)	10	S5s2WR	67

Table 3. The studied Egyptian rice genotypes and their pedigree and type (Ghidan et al., 2016)

Genotypes	Pedigree	Type
<i>Giza 178</i>	Giza 175 / Milyang 49	<i>Indica/japonica</i>
<i>Sakha 101</i>	Giza 176 / Milyang 79	<i>Japonica</i>
<i>Sakha 104</i>	GZ 4096-8-1 / GZ 4100-9-1	<i>Japonica</i>
<i>Sakha Super 300</i>	PTGMS38/China2	<i>Indica/Japonica</i>

Cladistics analysis according to morphological characters

Morphological characters were recorded for cultivated rice and red rice, and the data were analyzed using Past Software V 3.23 (folk.uio.no/ohammer/past).

Measurement of grain yield and shoot biomass

The panicles from the cultivated varieties and weedy rice were collected separately, placed in a seed bag made of paper, dried in air, and then the dry weights were recorded.

Shoot fresh weight was detected, and then the samples were dried for 3 days at 60°C till reaching a constant weight to record the dry weight. Five replicates were used for the cultivated and weedy rice in all stands from each site.

Measurement of harvest index

The harvest index was calculated according to the equation (Bennie et al., 1994):

$$HI = Y/AGDM,$$

Where: AGDM = above ground dry matter accumulation (kg/ha); Y = grain yield (kg/ha); HI= Harvest index”.

Evaluation of the percentage of seed shattering

Seed shattering was determined manually by cutting and collecting the panicles inside the bag to avoid any dispersal of the seed away from the bag. Shattered seeds and non-shattered seeds were counted. The ratio of shattered seed number to the whole seed number is used to express the seed shattering percentage (Gu et al., 2005). Five replicates were used for the cultivated and weedy rice in each stand from each site.

Evaluation of the hierarchical relationship between cultivated rice varieties and weedy rice according to yield traits

Heatmaps were accomplished through the Orange software (Demšar et al., 2013). Each score is the mean of 5 replicates in the heatmap visualization. Hierarchical clustering analysis was used to detect groups of identically valued rows, since these are shown as regions with comparable colors.

Statistical analysis

All measurements were replicated as described in each section. The significance of differences in yield traits between cultivated and weedy rice was assessed using one-way analysis of

variance (ANOVA) using Sigma Plot V11.0. The standardized major axis regression was used to determine whether the regression coefficients in the percentage of grain yield and other yield components varied significantly in cultivated and weedy rice at a significant level of $P \leq 0.05$ (Michaletz et al., 2014). The normality of residuals was verified by XLSTAT 2011 software. The data were displayed as untransformed and log-transformed to normalize their distribution and eliminate any heteroscedasticity.

RESULTS

Morphological traits of cultivated and weedy rice

Weedy rice morphological characters were comparable to cultivated rice morphological characters except for hull color, hull number, pericarp color, the presence of awn, and awn color, in addition to several growth traits, including plant height, length and width of leaf, flag leaf length, grains number in each panicle, and panicle length (Table 4, Figure 2).

Evolutionary relationship between the cultivated and weedy rice based on the morphological traits

According to the morphological data, the rice samples were separated into three groups (GI–GIII) (Figure 3). Group I (GI) comprised three clades. The first clade consisted of S1s4WR and S5s2WR, sub-claded with S1s5WR, S5s1WR, and S3s1WR, respectively. The second clade consisted of S2s1WR, subcladed with S3s3WR and SUP300. The third clade consisted of S1s1WR. The second group (GII) contained two major clades; the first one included a minor clade of S1s2WR and S2s2WR sub-claded S4s1WR; the second major clade contained two clades; the first one of them consisted of S2s4WR and G 178, and the other one consisted of S 101 and S 104. Group III (GIII) included a single clade, where S1s3WR and S2s3WR were sub-claded with S3s2WR.

General differences in yield trait values among cultivated and weedy rice

The red rice had greater plant height, grain number per panicle, length of the flag leaf, grain length-to-width ratio, and panicle weight than the studied cultivated rice (Figure 4). However, DW of ten grains, the percentage of biomass yield, and the percentage of grain yield were less in weedy rice compared to cultivated one (Figure 4).

Table 4. Morphological characters of the studied cultivated and weedy rice [Character number is preceded by # and states of the same character are assigned serial numbers]

Plants characters	Plant species																		
	S 101	S 104	G 178	SUP300	S1s1WR	S1s2WR	S1s3WR	S1s4WR	S1s5WR	S2s1WR	S2s2WR	S2s3WR	S2s4WR	S3s1WR	S3s2WR	S3s3WR	S4s1WR	S5s1WR	S5s2WR
#1. < Plant height (cm)>/	48-53	55-64	62-65	91-96	117-121	72-74	82-83	80-80.5	72-76	80-82	54-55	84-86	63-63.5	91-93	76-78	84-86	83-86	84-85	74-77
#2.< No of leaves /culm >/1.three/2. four>/	1	2	1	1	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1
#3.< leaf length (cm)>/	28-30	37-40	25-26	41-43	53-55	34-35	43-45	41-43	29-33	26-28	27-28	44-46	26-28	50-54	32-33	41-42.6	47-49	36-39	39-39.6
#4.< leaf width (cm)>/	0.7-0.8	0.8-0.9	0.7-0.8	1-1.1	1.1-1.2	0.8-0.9	1.4-1.5	1.1-1.2	1.1-1.2	0.7-0.8	0.6-0.7	0.6-0.7	0.6-0.7	1-1.1	0.9-1	0.8-0.9	0.8-0.9	1.1-1.2	0.8-0.9
#5.< length of panicle(cm)>/	13-15.6	14.5-18	17-21.5	15-18.3	19-20.3	17-21	24-28	20-22.4	16-18.4	20.8-22	14-18.5	25-29	17-18	24-27.5	22-24	22-22.5	16-22.5	16-19	18.5-20.2
#6.< no of grains/panicle>/	48-53	53-66	70-75	105-106	94-115	24-25	143-149	70-75	77-83	99-105	32-38	142-158	81-82	73-75	165-170	103-109	46-48	85-88	71-74
#7.< Flag leaf length (cm)>/	17-18	11-15	18-21	28-29	33-37	24-26	31-33	32-35	29-34	19-21	21-25	36-37	14-16	32-34	26-27	32-34	22-23	30-35	26-27
#8.< palea/lemma length(cm)>/	0.6	0.60.7	0.60.7	0.6	0.7-0.8	0.8-0.9	0.7-0.8	0.7-0.8	0.7	0.7	0.8-0.9	0.7-0.8	0.6-0.7	0.6-0.7	0.8-0.9	0.7	0.8	0.7	0.7
#9.< Awn length(cm)>/1.short/2. long/3.awnless	3	3	3	3	1	2	1	2	2	1	2	1	1	2	3	1	2	2	2
#10.< Awn color>/1.straw/2. red /3. abscent	3	3	3	3	1	1	1	1	1	1	1	1	2	1	3	1	1	1	1
#11.< Awn number>/1.one/2.two/3.abscent	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	1	1	1	2
#12.< pericarp color>/1.white/ 2. Light red brown/3.red brown	1	1	1	1	2	3	2	1	3	2	2	2	2	2	1	2	2	2	2
#13.< hull color>/1.straw/2.brown	1	1	1	1	2	2	2	1	2	1	2	1	1	1	1	1	1	2	1
#14.< hull number>/ 1.one/2.two	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
#15.< Grain width (cm)>/	0.3	0.3	0.4	0.4	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.3	0.4	0.4
#16.< Grain length (cm)>/	0.7	0.8	0.8	0.7	0.8	1	0.9	0.9	0.8	0.8	1	0.9	0.8	0.8	0.9	0.8	0.9	0.9	0.8



Figure 2. Weedy rice infestation in Egyptian rice paddy field

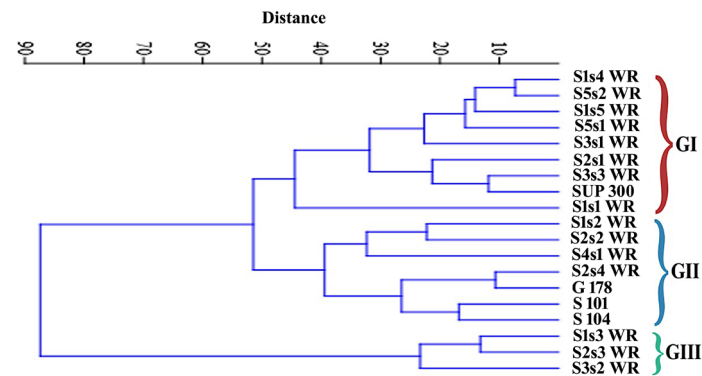


Figure 3. Cladistics shows the relationship among cultivated and weedy rice based on the morphological traits

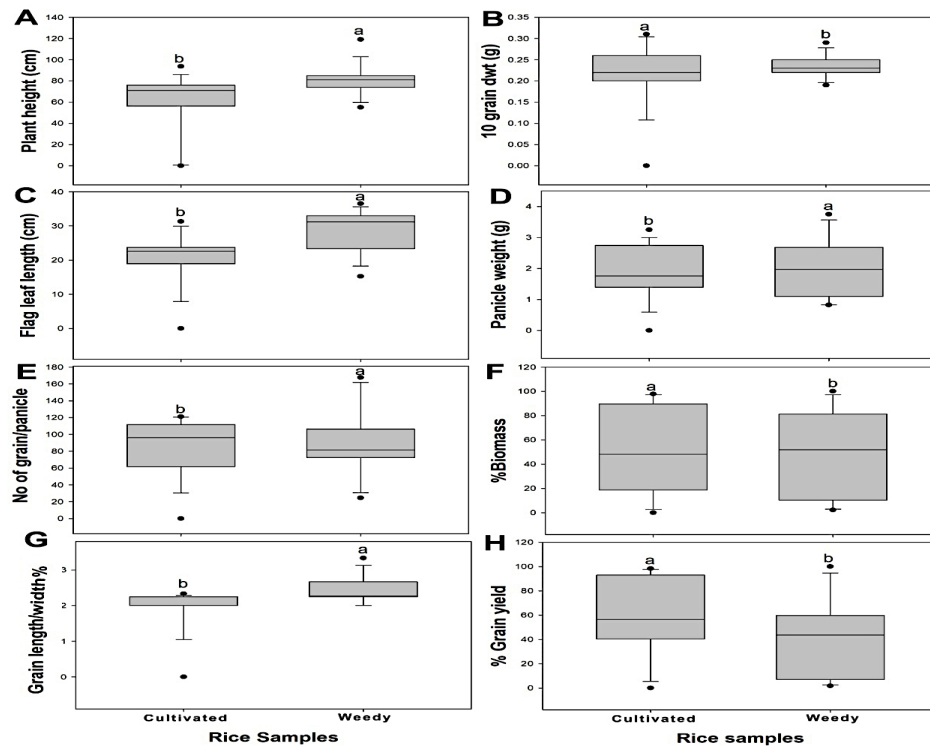


Figure 4. Differences in yield traits value among cultivated and weedy rice [Different letters above a column indicate a significant difference ($P < 0.05$)]

Correlation analysis between the percentage of grain yield and yield traits in cultivated and weedy rice

A strong correlation was observed between the percentage of grain yield and HI in the cultivated rice ($r^2=0.551$, $P=0.455$) and weedy rice ($r^2=0.551$, $P=0.455$), this correlation was equal in the cultivated rice and weedy rice (Figure 5A). The percentage of biomass and HI were positively correlated in the cultivated rice ($r^2=0.557$, $P=1.000$) and weedy rice ($r^2=0.557$, $P=1.000$), this correlation was equal in the cultivated rice and weedy rice (Figure 5B).

A positive correlation was also found between the percentage of grain yield and panicle weight in both cultivated rice ($r^2=0.239$, $P=0.787$), ($r^2=0.092$, $P<0.005$), respectively. However, this correlation was less in weedy rice than in the rice cultivars (Figure 5C). The percentage of grain yield and flag leaf length showed a positive correlation in both cultivated rice and weedy rice ($r^2=0.18$, $P=0.004$), ($r^2=0.241$, $P=0.300$), respectively. However, this correlation was higher in the weedy rice than in the cultivated rice (Figure 5D). A positive correlation was between the percentage of grain yield and number of grains per panicle in cultivated rice ($r^2=0.545$, $P=0.024$) and weedy rice ($r^2=0.205$, $P<0.002$). However, this correlation was stronger in the cultivated rice than in the weedy rice (Figure 5E). A positive correlation was recorded between the percentage of grain yield and panicle length in the cultivated rice ($r^2=0.365$, $P<0.004$). However, this correlation was weaker in the weedy rice ($r^2=0.028$, $P=0.199$) (Figure 5F). The correlation between the percentage of grain yield and panicle weight was positive in all cultivated rice ($r^2=0.544$, $P<0.001$) and weedy rice ($r^2=0.195$, $P<0.001$). However, this correlation was stronger in rice cultivars than in the red rice (Figure 5G). Weak correlation was detected between the percentage of grain yield and the DW of ten grains in the cultivated rice ($r^2=0.144$, $P<0.001$) and weedy rice ($r^2=0.007$, $P<0.001$) (Figure 5H).

Seed Shattering rate in cultivated and weedy rice

The studied red rice had a significantly greater seed shattering rate than cultivated rice (Figures 6, 7 and 8).

Hierarchical clustering analysis of yield

traits between rice cultivars and weedy rice

In the heat map, the default color gradient sets the highest value to white-yellow, mid-range values to green, and the lowest value to dark blue with a shift between these extremes (Figure 9). S5s1WR, S2s4G178, S1s2S104, and S4s1SUP300 recorded the highest percentage of grain yield per stand and percentage of biomass per stand. S3s2S104 and S4s1SUP300 displayed the highest ten-grain DW. S2s3WR and S1s1WR have the highest flag leaf length. S1s1WR is the highest plant height. S3s2WR showed the highest number of grains per panicle per stand. S2s3WR and S1s3WR exhibited the highest length of panicle and panicle DW. S4s1SUP300 is the highest panicle DW among cultivated rice. There was high convergence between each of the following: S5S1 WR and S5S2 WR, S1S2 S104 and S3S1 S104, S2S4 G178 and S3S3 S104, S2S1 G178 and S4S1 SUP 300, S1S4 S104 and S2S3 G178, S2S1 WR and S3S2 S104, S2S3 WR and S3S2 WR, S1S3 S104 and S5S2 S101, S2S2 WR and S4S1 WR.

The data showed that there is more similarity in values between a grain DW and ten grains DW and between the flag leaf and panicle length. A moderate similarity exists between the percentage of grain yield per stand and the percentage of biomass per stand and, between grain DW per stand and the number of samples. A low similarity exists in the number of grains in the panicle and the height of rice samples.

DISCUSSION

Egyptian weedy rice morphological traits were like those of cultivated rice except hull color, pericarp color, awn presence, and high shattering percentage. Moreover, several variations were recorded in growth traits between the cultivated varieties and weedy rice such as plant height, panicle length, leaf length, leaf width, flag leaf length, and grain length. From the result of cladogram analysis (Figure 3), a number of weedy rice clustered in the same group with rice cultivars; on the other hand, the others were clustered in a separate group. S2s1WR and S3s3WR are closely linked with SUP300. S2s4WR is associated with G178. S1s2WR, S2s2WR, and S4s1WR are related to S101 and S104. However, S1s3WR, S2s3WR, and S3s2WR are categorized into a separate group far from cultivated rice, clarifying that they may have different growth traits from the studied cultivated rice.

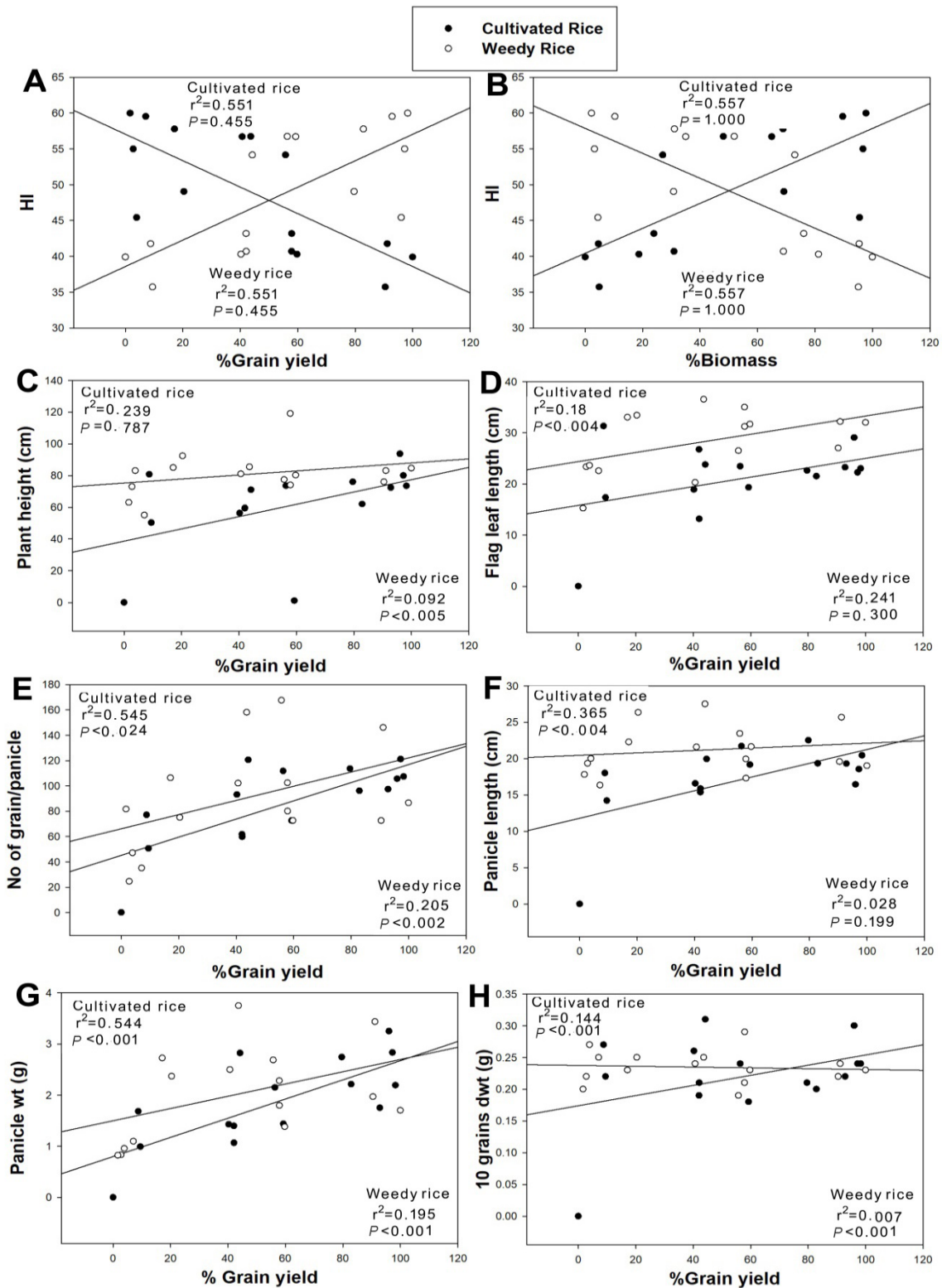


Figure 5. Correlation coefficient between (A) HI and the percentage of grain yield, (B) HI and the percentage of biomass, (C) plant height and the percentage of grain yield, (D) flag leaf length and the percentage of grain yield, (E) number of grains per panicle and the percentage of grain yield, (F) panicle length and the percentage of grain yield, (G) panicle weight and the percentage of grain yield, finally (H) ten grains DW and the percentage of grain yield

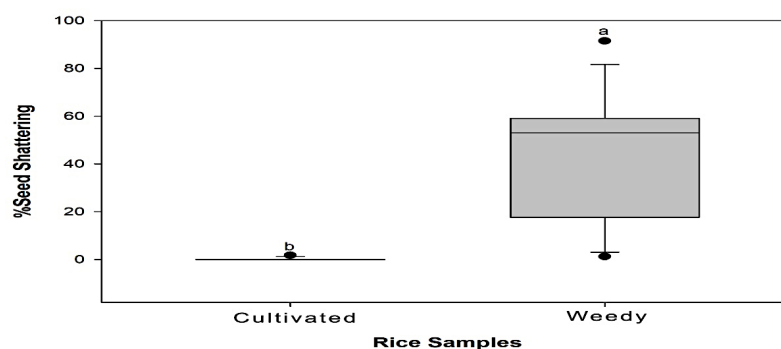


Figure 6. Differences in seed shattering rate among cultivated and weedy rice [Different letters above a column indicate a significant difference ($P < 0.05$)]

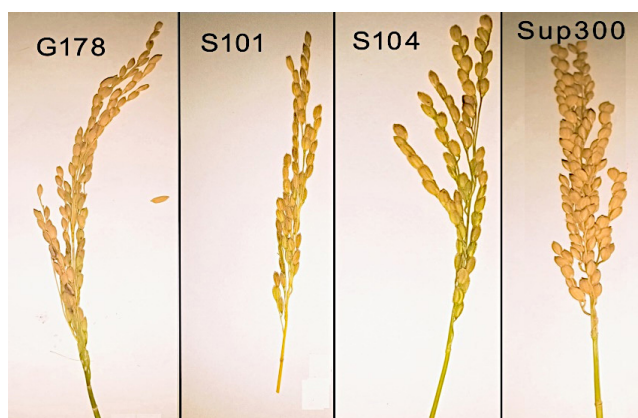


Figure 7. Seed shattering evaluation in cultivated rice



Figure 8. Seed shattering evaluation in weedy rice

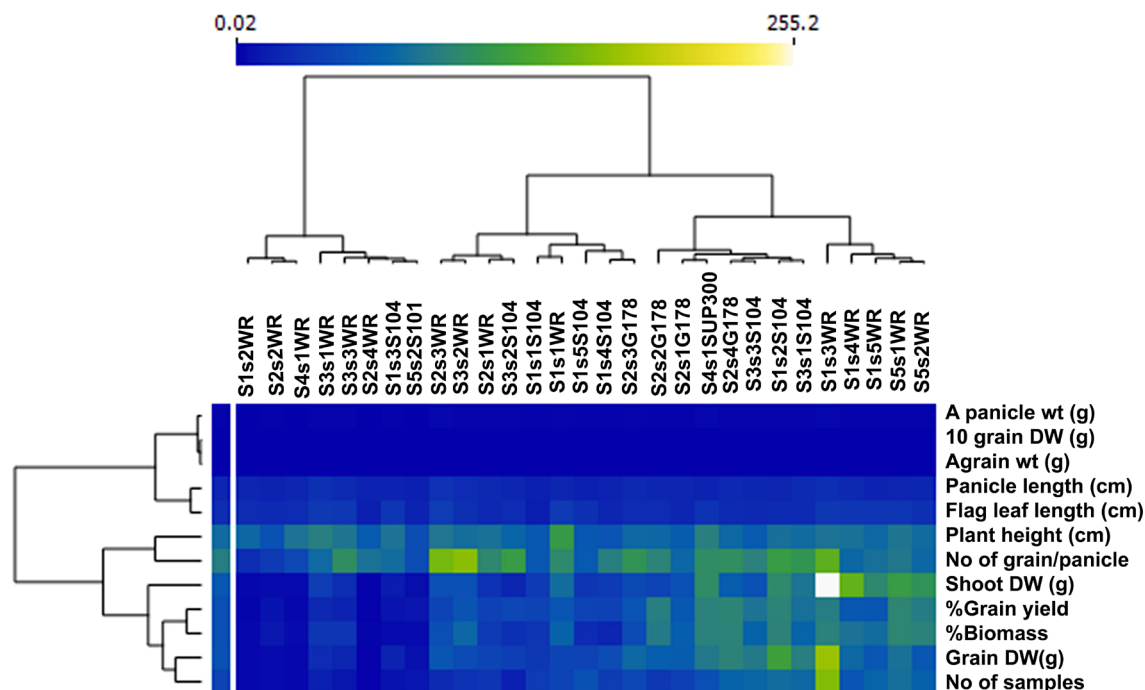


Figure 9. Heat map of yield traits in the cultivated and weedy rice

By comparing yield traits of the studied rice cultivars and weedy rice, it was observed that red rice had an increased flag leaf length and plant height compared to that of rice cultivars. Furthermore, most of the Egyptian weedy rice height is more than cultivated rice. Therefore, Egyptian cultivated rice faces some competition from red rice for nutrients and light, leading to faster growth of weedy rice compared to rice cultivars. Estorninos et al. (2005) indicated that weedy rice shoot length from the southern United States grows higher than cultivated rice varieties, leading to better light capture and also competing with weedy rice for natural resources and space; therefore, weedy rice produces more tillers and biomass (Diarra et al., 1985; Caton et al., 2003; Moukoubi et al., 2011).

The important yield components that affect rice production include grain weight and panicle number (Xing & Zhang, 2010). The studied weedy rice had increased panicle grain numbers and weights than other cultivated rice, although the DW of ten grains increased in cultivated rice than in red rice (Figure 4). This means that the grain filling was more efficient in the cultivated rice than that in the red rice, but the weedy rice overpasses rice cultivars in the number of grains per panicle, so weedy rice overpasses cultivated rice in the weight of the panicle. Therefore, it is necessary to detect factors responsible for a high number of grains in weedy rice to raise the grain

net yield of the cultivated rice. Wu et al. (2021) indicated that grain number is an important trait in improving rice production.

Moreover, grain yield and biomass yield percentage increased in cultivated rice more than in the red rice, which also ensures that the grain filling in cultivated rice is more efficient than that in the weedy rice (Figures 4F and 4H). The weedy rice grain length and width ratio is more than cultivated rice (Figure 4G).

Seed shattering percentage was higher in all studied weedy rice than in cultivated rice (Figure 6). The shattered seeds of this weedy rice could remain dormant inside the soil and grow during the growing season, causing detrimental impacts on rice growth and influencing rice yield (from the author unpublished data). Nunes et al. (2014) showed that South Asian weeds have a greater seed shattering compared to cultivated rice. Moreover, weedy rice infestation lowers grain features and thus harvested rice value due to red rice contamination (Singh et al., 2017).

From the results of the hierarchical clustering analysis (Figure 9), it was detected that the cultivated rice density in S1s2, S2s1, S2s2, S2s3, S2s4, S3s1, S3s3, and S4s1 was higher than that of the weedy rice, leading to a higher grain DW per stand, shoot DW, percentage of grain yield, and percentage of biomass in the cultivated rice than in the red rice. This means that the smaller

the number of red rice compared to the number of cultivated rice, the higher the yield of the cultivated rice. On the other side, the density of weedy rice in S1s3, S1s4, S1s5, S3s2, S5s1, and S5s2 was higher than that of the cultivated rice, resulting in high grain DW per stand, shoot DW, percentage of grain yield, and percentage of biomass in the weedy rice rather than in the cultivated rice. This means that an increased number of weedy rice plants, more than the cultivated rice, could increase the competitiveness of weedy rice by increasing grain DW per stand, shoot DW, the percentage of grain yield, and the percentage of biomass, and have detrimental impacts on cultivated rice production. The highest weedy rice density in the studied stands was recorded in S1s3; so the weedy rice competes aggressively with the cultivated rice in this stand, explaining the lowest grain yield of the rice cultivars and biomass yield in this stand.

The highest value of the percentage of grain yield per stand and the percentage of biomass per stand of the weedy rice in S5s1 - containing only weedy rice- suggests that the weedy rice could surpass the cultivated rice in grain and biomass yield if grown in the absence of the cultivated rice, and the high shattering rate could magnify the trouble of invading weedy rice in other rice fields. However, it could be valuable to benefit from the behavior and traits of weedy rice breeding programs of cultivated rice.

The current investigation's findings showed significant variations in the association between grain yield and studied yield components in the weedy rice and cultivated rice, excluding HI (Figure 5). Strong positive correlation between HI and percentage of grain yield, also between HI and percentage of biomass yield present in both cultivated and weedy rice (Figures 5A and 5B). The highest grain yields were linked with high HI, which is considered beneficial techniques in plant breeding (Pilbeam, 1996). The percentage of grain yield was highly correlated with the number of grains per panicle, ten grains DW, plant height, panicle length, and panicle weight in the cultivated rice than in the weedy rice. The percentage of grain yield was more correlated with the flag leaf length of red rice than the cultivated rice (Figure 5D). The photosynthetic capacity of the flag leaf allowed greater access to light than that of the lower canopy leaf (Adachi et al., 2017). The high cultivated rice yields were highly correlated with the flag leaf length, which accounts for 50% of assimilates utilized in filling of grains (Li et al., 1998). The weedy rice height

is more than cultivated rice, permitting much more capturing of the sunlight and hence increasing the photosynthesis efficiency of the flag leaf. Therefore, the weedy rice flag leaf length was positively correlated with the grain yield than cultivated rice.

It was recommended that the improvement of the cultivated rice yield should depend on increasing plant height, number of grains per panicle, ten grain DW, and panicle weight and length.

From the present results, it was recorded that Sakha Super 300 was the most suitable Egyptian cultivated rice, which competes against weedy rice, where there were only a few weedy rice plants detected on the edges of the rice field, and all fields planted with this rice cultivar were free from the weedy rice.

The weedy rice competes with the cultivated rice for all natural resources, and its growth could overpass the cultivated rice, and it competes with the cultivated rice in grain yield but without advantages because of the high shattering and less grain quality. Thus, it is highly suggested to make efforts to eliminate these harmful weeds and prevent them from expanding in rice paddy fields to maintain national food security.

CONCLUSION

The widespread presence of weedy rice in rice fields detrimentally impacts the yield of cultivated rice due to its high competitiveness for natural resources and its high seed shattering rate. The amelioration of cultivated rice yield could depend on increasing plant height, ten-grain DW, number of grains, and panicle length and weight. While weedy rice traits may be used in improving rice breeding programs, many efforts are needed to eliminate these harmful weeds and prevent them from rapid expansion across rice fields to maintain national food security.

Conflict of interest: Authors declare no conflict of interest.

Authors' contributions: R. Nada, S. Rabei, M. Serag, G. Abogadallah: designed the research and did the field surveys. S. Rabei, R. Nada and W. Abdallah: contributed to data collection from field, data analyses and interpretation. R. Nada: supervised lab work, analyzed the result, used some software to make phylogeny and heatmap and revised the manuscript. W. Abdallah: analyzed the output data, did the statistical analysis and wrote the manuscript.

Ethical approval: Not applicable.

REFERENCE

- Adachi, S., Yoshikawa, K., Yamanouchi, U., Tanabata, T., Sun, J., Ookawa, T., et al. (2017). Fine mapping of Carbon Assimilation Rate 8, a quantitative trait locus for flag leaf nitrogen content, stomatal conductance and photosynthesis in rice. *Frontiers in Plant Science*, 8: 1-11.
- Bennie, A.T.P., Hoffman, J.E., Coetzee, M.J., Very, H.S. (1994). Storage and utilization of rainwater in soils for stabilizing crop production in semi-arid areas. *Water Research Commission (WRC); Pretoria, South Africa*, pp. 31–110. Report 227/1/94.
- Burgos, N.R., Norman, R.J., Gealy, D.R., Black, H. (2006). Competitive N uptake between rice and weedy rice. *Field Crops Research*, 99: 96-105.
- Caton, B.P., Cope, A.E., Mortimer, M. (2003). Growth traits of diverse rice cultivars under severe competition: Implications for screening for competitiveness. *Field Crops Research*, 83: 157–172.
- Demšar, J., Curk, T., Erjavec, A., Gorup, C., Hočevár, T., Milutinovič, M., et al. (2013) Orange: Data mining toolbox in Python. *Journal of Machine Learning Research*, 14: 2349–2353.
- Diarra, A., Smith, R.J., Talbert, R.E. (1985). Growth and morphological characteristics of red rice (*Oryza sativa*) biotypes. *Weed Science*, 33: 310–314.
- Donald, C.M., Hamblin, J. (1976). The biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Advances in Agronomy*, 28: 361–405.
- Eliw, M., Alim, S.S. and Soliman, S.A. (2022) Impact Of Agricultural Policy On Egyptian Rice. *Journal of Animal and Plant Sciences*, 32(2): 496-506.
- El-Shahway, A.S., Mahmoud, M.M.A., Udeigwe, T.K. (2016). Alterations in soil chemical properties induced by continuous rice cultivation: a study on the arid Nile delta soils of Egypt. *Land Degradation and Development*, 27: 231–238.
- Esqueda, V.A. (2000). Control químico del arroz rojo (*Oryza sativa* L.) en arroz, con herbicidas no selectivos protectants a la semilla. *Agronomía Mesoamericana*, 11: 57-61.
- Estorninos, L.E., Gealy, D.R., Gbur, E.E., Talbert, R.E., McClell, M.R. (2005). Rice and red rice interference. II. Rice response to population densities of three red rice (*Oryza sativa*) ecotypes. *Weed Science*, 53: 683–689.
- FAO (2003). Rice irrigation in the near East: Current situation and prospects for improvement. FAO Regional Office for the Near East, Cairo, Egypt.
- Ghidan, W.F., Elmoghazy, A.M., Yacout, M.M., Moussa, M., Draz, A.E. (2016). Genetic variability among Egyptian rice genotypes (*Oryza sativa* L.) for their tolerance to cadmium. *Journal of Applied Life Sciences International*, 4: 1-9.
- Gu, X.Y., Kianian, S.F., Foley, M.E. (2005). Seed dormancy imposed by covering tissues interrelates to shattering and seed morphological characters in Weedy rice. *Crop Science*, 45: 948-955.
- Hay, R.K. (1995). Harvest index: A review of its use in plant breeding and crop physiology. *Annals of Applied Biology*, 126: 197–216.
- Hidayatul, S.A., Mazlan, N., Engku Ahmad, K.E.A., Juraimi, A.S., Yusop, M.R. (2014). A comparative study of vegetative and reproductive growth of local weedy and Clearfield rice varieties in Malaysia. *Journal of the International Society for Southeast Asian Agricultural Sciences*, 20: 41-51.
- Huang, R., Jiang, L., Zheng, J., Wang, T., Wang, H., et al. (2013). Genetic bases of rice grain shape: so many genes, so little known. *Trends in Plant Science*, 18: 218–226.
- Karim, R.S.M., Ismail, B.S., Azmi, M. (2006). A short review of the impact and management of weedy rice. *Plant Protection*, 21: 13-19.
- Li, Z., Pinson, S.R.M., Stansel, J.W., Paterson, A.H. (1998). Genetic dissection of the source–sink relationship affecting fecundity and yield in rice (*Oryza sativa* L.). *Molecular Breeding*, 4: 419–426.
- Michaletz, S.T., Cheng, D., Kerkhoff, A.J., Enquist, B.J. (2014). Convergence of terrestrial plant production across global climate gradients. *Nature*, 512: 39–43.
- Mispan, M.S., Bzoor, M., Mahmod, I.F., MD-Akhir, A.H., Zulrushdi, A. (2019). Managing Weedy rice (*Oryza sativa* L.) in Malaysia: Challenges and ways forward. *Journal of Research in Weed Science*, 2: 149–167.
- Moukoubi, Y.D., Sie, M., Vodouhe, R., N'dri, B., Toulou, B., et al. (2011). Assessing phenotypic diversity of interspecific rice varieties using agromorphological characterization. *Journal of Plant Breeding and Crop Science*, 3: 74–86.
- Nunes, A.L., Markus, C., Delatorre, C.A., Merotto, J.R. (2014). A Nucleotide variability and gene expression reveal new putative genes related to

- seed shattering in Weedy rice. *Annals of Applied Biology*, 166: 39-52.
- Ottis, B.V., Smith, K.L., Scott, R.C., Talbert, R.E. (2005). Rice yield and quality as affected by cultivar and red rice (*Oryza sativa*) density. *Weed Science*, 53: 499-504.
- Pilbeam, C.J. (1996). Variation in harvest index of maize (*Zea mays*) and common bean (*Phaseolus vulgaris*) grown in a marginal rainfall area of Kenya. *Journal of Agricultural Science Cambridge*, 126: 1-6.
- Reddy, Y.N., Shaanker, R.U., Prasad, T.G., Kumar, M.U. (2003). Physiological approaches to improving harvest index and productivity in sunflower. *Helia*, 26: 81-90.
- Sakamoto, T., Matsuoka, M. (2008). Identifying and exploiting grain yield genes in rice. *Plant Biology*, 11: 209-214.
- Sharifi, R.S., Sedghi, M., Gholipouri, A. (2009). Effect of population density on yield and yield attributes of maize hybrids. *Research Journal of Biological Sciences*, 4: 375-379.
- Sharma-Natu, P., Ghildiyal, M.C. (2005). Potential targets for improving photosynthesis and crop yield. *Current Science*, 88: 1918-1928.
- Sinclair, T.R. (1998). Historical changes in harvest index and crop nitrogen accumulation. *Crop Science*, 38: 638-643.
- Singh, V., Burgos, N.R., Singh, S., Gealy, D.R., Gbur, E.E., et al. (2017) Impact of volunteer rice infestation on yield and grain quality of rice. *Pest Management Science*, 73: 604-615.
- Wang, S., Wu, K., Yuan, Q., Liu, X., Liu, Z., Lin, X., et al. (2012). Control of grain size, shape and quality by OsSPL16 in rice. *Nature Genetics*, 44: 950-954.
- Wu, X., Liang, Y., Gao, H., Wang, J., Zhao, Y., Hua, L., et al. (2021). Enhancing rice grain production by manipulating the naturally evolved cis-regulatory element containing inverted repeat sequence of OsREM20. *Molecular Plant*, 14: 997-1011.
- Xing, Y., Zhang, Q. (2010). Genetic and molecular bases of rice yield. *Annual Review of Plant Biology*, 61: 421-442.
- Zeng, D., Tian, Z., Rao, Y., Dong, G., Yang, Y., Huang, L., et al. (2017). Rational design of high-yield and superior-quality rice. *Nature Plants*, 3: 283-294.
- Zhang, L., Yu, H., Ma, B., Liu, G., Wang, J., Wang, J., et al. (2017). A natural tandem array alleviates epigenetic repression of IPA1 and leads to superior yielding rice. *Nature Communications*, 8: 14789.