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Evaluation of Growth Indices, Quality Characteristics, and Source and Sink Relationships in Promising Rice Genotypes

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ABSTRACT

Leaves are the most important photosynthetic sources in rice plant. In order to analyze growth indices and determine the contribution of leaves to grain filling, a study was carried out with nine genotypes and six levels of source limitations at grain filling stage in 2017-2018, at the Rice Research Institute of Iran, Mazandaran. The experiment was carried out as a split plot in the form of a randomized complete block design with three replications and placing the genotypes in the main plot and leaf cutting treatments in the sub- plots. The results showed that genotype 959 had the highest Leaf Area Index (LAI) at the flowering stage. The highest Crop Growth Rate (CGR) with 23.3 g m^{-2} and Net Assimilating Rate (NAR) with 7.5 g m^{-2} belonged to the genotype 952. Genotypes 957 and 959 had the highest number of tillers and genotype 952 had the highest yield. The results of combined analysis of variance revealed that leaf removal treatments had significant effects on 1000-grain weight, percent of filled grains and paddy yield per hill (P< 1%). The comparison of means between two years showed that leaf removal treatment caused significant decrease in panicle length, grain length and number of filled and total number of grains per hill. The highest yield reduction of 47.7 and 46.5% occurred in treatment of complete leaf removal for genotypes 953 and 954, respectively. The most destructive level of leaf removal treatments was the removal of all leaves, two top leaves, all leaves except flag leaf, flag leaf and all leaves except upper two leaves which caused paddy yield losses of, respectively, 37.4, 20.2, 16.5, 14.1, and 9.4%, compared to the control (no removal of leaves) with 6133 kg ha^{-1}. According to the results, about 90% of the carbohydrates needed by rice in the grain filling stage are provided by the upper two leaves in each rice plant.

Keywords: Grain filling, Growth indices, Leaf removal, Physiological indicators, Source-Sink relation.

INTRODUCTION

Selecting the right parents for breeding is an important goal of plant breeders, which can be facilitated by using phenotypic and physiological traits related to yield and quality. Physiological indices such as Crop Growth Rate (CGR), Relative Growth Rate (RGR), Leaf Area Ratio (LAR), Leaf Area Duration (LAD), Net Assimilation Rate (NAR), Specific Leaf Area (SLA), and Leaf Area Index (LAI) have been reported to be correlated with yield in local and improved rice cultivars (Pirdashti, 2000). As there is a close relationship between temperature and crop growth rate, it could be used for calculating growth functions in terms of

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changes in dry matter weight relative to changes in temperature indices instead of a time calendar. The analysis of growth indices based on growing degree days (GDD), compared to the time calendar, is more reliable due to its stability and fact that the physiological stages of plant development are not consistent among different genotypes.

Grain yield in cereals is mainly dependent on three carbohydrate sources, namely, current photosynthesis, transfer of stored assimilates before the flowering stage to grain, which is mostly stored in the stem, and temporary stored assimilates in the stem after flowering stage (Kobata *et al*., 2000). Plant leaves are the main source of photosynthesis. The transfer of photosynthetic products from source (leaves) to sink (number and size of panicles, number of spikelets per panicle and average weight of grains produced per plant) depends on the capacity of photosynthetic contents produced by the source and the amount of consumption in the sink (Mali, 1999; Mahdavi *et al*., 2005). If the balance between source-sink become improper, paddy yield will be diminished, therefore, the maximum paddy yield is not reachable (Mail, 1999). Mali (1999) also reported that leaf removal at early stages of grain development and growth (flowering and milky stages) affected biological yield, 1,000-grain weight, paddy yield and harvest index, so that the amounts of decrease were significant (P< 1%) and equaled to 19, 13.8, 29.2, and 12.8%, respectively. Sadeghi and Mobasser (2010) altered source-sink ratio through the removal of the upper one-third of panicles and flag leaf removal of Fajr rice cultivar in different cultivation systems and observed that the incomplete panicle removal led to the least unfilled grain in the whole plant compared to the control. Therefore, it can be concluded that source limitation exists in Fajr cultivar. Flag leaf removal increased the number of unfilled spikelets per panicle at 7.3% compared to the control. So, the importance of flag leaf is inevitable during grain filling period, which could cause decrease paddy yield by 16.4% compared to the control. Sink removal (removal of one third of the panicle) reduced the number of grains per panicle and resulted in significant differences among the cultivars. The reported results also indicated that genetic differences in the number of grains per panicle in the breed cultivars were from grain production potential, more panicle number and source and sink limitation had a significant effect on the number of unfilled grains per panicle. The highest number of unfilled grains was related to the maximum source limitation treatment, and on the other hand, the sink limitation reduced the number of unfilled grains. The removal of the sink (one-third removal of the panicle treatment) reduced the number of grains per panicle. It also indicated that significant differences among cultivars showed genetic differences in terms of the number of grains per panicle, whereas bred cultivars had more grain production potential in a panicle (Nik-Nezhad, 2003). Occasionally the limitation can be diagnosed by a change in source or sink, if the source is reduced (e.g., removal of leaves) and the grain yield does not change, there is a sink limitation and if the number of breeding places is changed and grain yield remained unchanged, that is a source limitation (Radmehr *et al*., 2004).

Bahrani and Tahmasebi (2007) concluded that more LAI at flowering stage can enhance more carbohydrates reserves for the growing grain in the panicle. It must be considered that number of grains per panicle has a critical threshold as a result more competition will be triggered in panicle and number of unfilled or half-filled grains will increase drastically (Koocheki and Sarmad-Nia, 2013). Reducing size of the sink through spikelet removal will be an additive effect on average grain weight (Bijanzadeh and Emam, 2012). Source limitation through leaf removal, reduced 1,000-grain weight significantly (Madani *et al*., 2010). Flag leaf area is considered the most important source for grain filling and paddy yield in rice crop (Haque *et al*., 2015). Noori *et al*., (2014) showed that removal of all leaves, except flag leaf, in rice drastically reduced grain per panicle, 1000-grain weight and paddy yield per plant and per square meter. On the other hand, it is reported that removing part of panicle, grain number per panicle, paddy yield per plant significantly decreased compared to the control. (Felekari *et al*., 2014).

The purpose of this study was to evaluate the growth indices in different genotypes and also to investigate the source and sink relationships of these genotypes in order to determine the factors limiting quantitative and qualitative rice production.

MATERIALS AND METHODS

This research was carried out in 2017 and 2018 at the Rice Research Institute of Iran, Mazandaran Rice Research Station of Tonekabon, with longitude of 50° 46'´ East and latitude of 36° 51'´ North, which is 20 m lower than the mean sea level. According to climatic and meteorological data, this region is close to the warm Mediterranean subtropical climate and has high humid summers, high temperatures and low rainfall, and temperate winters with high rainfall. The average annual temperature is 15°C. The soil characteristics of the research field are shown in Table 1.

The experiment was set based on split-plot arrangement with three replications. Genotypes were assigned to the main plots at nine levels (Table 2) and leaf removal treatment in sub-plots at six levels consisting of (flag leaf removal, removal of two uppermost leaves, removal of all leaves except flag leaf, removal of all leaves except two-top leaves, removal of completed leaves, and control).

The size of each plot was 20 m^2 with a 25×25 cm plant spacing. Seedlings at 4-5 leaf stage with 3 plants per hill were planted in the plots. At 50 percent flowering stage, each plot was divided into six equal parts, sub-factors were used for each genotype. The amount of fertilizer used in the field was according to the technical recommendation of Rice Research Institute of Iran 115 kg ha^{-1} pure nitrogen (from urea fertilizer) plus 50 kg ha^{-1} P_2O_5 (from ammonium phosphate fertilizer) and 100 kg ha^{-1} K_2O (from potassium sulfate fertilizer). Half of the nitrogen and potash fertilizer and all of phosphate fertilizer were applied at the

Table 1. Physical and chemical characteristics of soil in the study site.

Soil depth (cm)	EC (dS m^{-1})	pH	TNV	OC (%)	N (%)	P (ppm)	K (ppm)	Clay (%)	Silt (%)	Sand (%)	Soil texture
0-30	0.63	6.61	3.21	1.57	0.12	24.3	130	59.8	39.9	5.7	Clay

Table 2. Characteristics of genotypes and varieties used in the study.

Genotypes	♂ Paternal parents	♀ Native parents
951	IRRI (Control)	-
952	[IR-67015.22.6.2 (A37632)] of number 115	Number 3×Amol 3
953	Shiroodi cultivar	Mosa-Tarom cultivar
954	Tarom-Amiri cultivar	Aghaei-Siya cultivar
955	Number 876 (Not-released)	[IR-67015.22.6.2 (A37632)] of number 54×(Number 3×Amol 3)
956	Shiroodi cultivar	[IR-67015.22.6.2 (A37632)] of number 54×(Number 3×Amol 3)
957	Shiroodi cultivar	Number 843 (Not-released)
958	Deylamani-Tarom cultivar×Khazar cultivar (Control)	-
959	Fajr cultivar (Heydari selection)	-

time of the last tillage, and the rest of the urea and potassium fertilizer were applied at panicle initiation stage. Growth indices were determined only for genotypes in the main plots, so, effects of leaf removal treatments are not included.

Leaf Area Index (LAI)

$$LAI=\frac{(LA2 + LA1)}{2} \times \frac{1}{GA}$$

Crop Growth Rate (CGR)

$$CGR=\frac{1}{GA}\times\frac{(W2-W1)}{(T2-T1)}$$

Relative Growth Rate (RGR)

$$RGR=\frac{(LnW2-LnW1)}{(T2-T1)}$$

Net Assimilation Rate (NAR)

$$NAR=\frac{(CGR)}{(LAI)}$$

LAI: The ratio of the leaf area (only one side of the leaf) to the area occupied by the product is unitless.

CGR: The amount of dry matter produced per unit of land surface is per unit of time, and the unit is g m^{-2} day^{-1}.

RGR: Changes in dry matter production compared to the initial weight in the plant, and the unit is g g m^{-2} day^{-1}.

NAR: The amount of dry matter produced per LAI per unit of time decreases with time, and the unit is g m^{-2} day^{-1}.

Before final harvest, panicle length and yield components such as number of filled, unfilled and total grains per panicle and 1,000-grain weight were measured by taking five random panicles from each plot. Filled and unfilled grains per panicle were counted and their total number of grains were determined. To calculate the percentage of panicle fertility, the following relationship was used:

$$\text{Percent of fertility panicle} = \frac{\text{Filled grain per panicle}}{\text{Total grain per panicle}} \times 100.$$

To determine the 1,000-grains weight, 200 well-matured whole seeds were separated from five normal panicle and weighed by a digital scale, then, the weight was multiplied by five. To measure panicle length, five hills were randomly selected from each plot before harvesting at full maturity and panicle length was measured with a ruler. To study the fertile tillers number in each plot, five hills were randomly selected and the fertile tillers number was counted and averaged. To determine grain yield, two square meters of each plot were harvested, discarding border of the plots. After reducing moisture with the thresher, the grains were separated from straw and yield was recorded. The moisture content was measured using a humidity meter (Ricester-L, KIYA SEISAKUSHO Japan) and converted for 14 percent moisture.

To measure the quality traits of the samples at the laboratory, their moisture was measured and the moisture of the samples were reduced to 11 percent with an electric oven. Then, 250 grams of paddy from each rice sample was milled into brown rice and white rice with a dehusking and polishing machine (from Japan). To calculate the milling recovery, the weight of white rice was divided by the weight of the initial paddy given to the machine. Percent of husk was obtained from the ratio of shell weight to primary paddy weight and percent of bran was obtained from the ratio of bran weight to primary paddy weight. The milling degree was obtained by dividing the weight of white rice by brown rice. The head rice recovery and broken rice recovery was obtained by dividing the weight of head and broken rice by the amount of primary paddy, respectively, and its sum was equal to the recovery of milling. The gelatinization temperature was also measured by the diffusion scale in alkali. To determine the chalkiness using a bleach device (model C-100 Japan), 20 grams of the sample was divided into four equal parts, in all four parts the chalkiness grains were separated, weighed and divided by the total weight of the grain, then, chalkiness was calculated. The amylose content was determined by colorimetric method at 620 nm with iodine complex formation.

Data were statistically analyzed following the normality test of data distribution using Shapiro and Wilk method (1965), with SAS statistical software (Ver. 9.4) and graphs were drawn by Microsoft Excel (2019) software.

RESULTS AND DISCUSSION

Physiological Indices

Leaf Area Index (LAI) indicates the ratio of leaf area to the land area occupied by the plant. The results of combined analysis of variance among the genotypes were significant (P< 1%) in the LAI (Table 3). Comparison means showed that Genotypes 951, 955, and 959 had the highest LAI (Table 4). LAI increased first and the trend reached the highest value in all genotypes before the panicle initiation stage and then decreased due to the wilting of the lower leaves. Among the studied genotypes, the highest and lowest leaf area index of 5 and 2.5 were in genotypes 959 and 958 at the flowering stage, respectively (Figure 1). The highest paddy yield was observed in genotype 952 and the lowest in genotype 951. At the flowering stage, the maximum leaf area index was obtained by receiving 1,000 GDD. The optimal LAI for receiving more than 95% of the sun's energy in grains was about 5 (Puppala and Fowler, 1999).

The results of combined analysis of variance among the genotypes in CGR were significant (P< 1%) (Table 3). Comparison of means showed the highest CGR in genotype 952 (Table 4). CGR in all genotypes were low at the beginning of the growing season and increased exponentially with the advancement of the growing season. At the flowering stage, all genotypes reached their maximum, and were minimum at maturity. The final grains had a downward trend and in the final stages of growth due to the loss of plant shoots, its value was negative (Figure 2). According to environmental reports in the Philippines and Japan, the maximum CGR in rice was about 30-36 g m^{-2} (Koocheki and Sarmad-Nia, 2013).

The results of combined analysis of variance for RGR among the genotypes were not significant (Table 3). The trend of RGR changes were similar in all genotypes and decreased due to the increase in the degree of growth days, and reached a minimum over time and became negative due to increasing plant age and leaf fall (Figure 3). It seems that the reason for the decrease in RGR during the growing season is that with increasing plant age, the ratio of structural tissues to metabolically active tissues decreased, and upper leaf shading on lower leaves increased, so, lower leaf aging

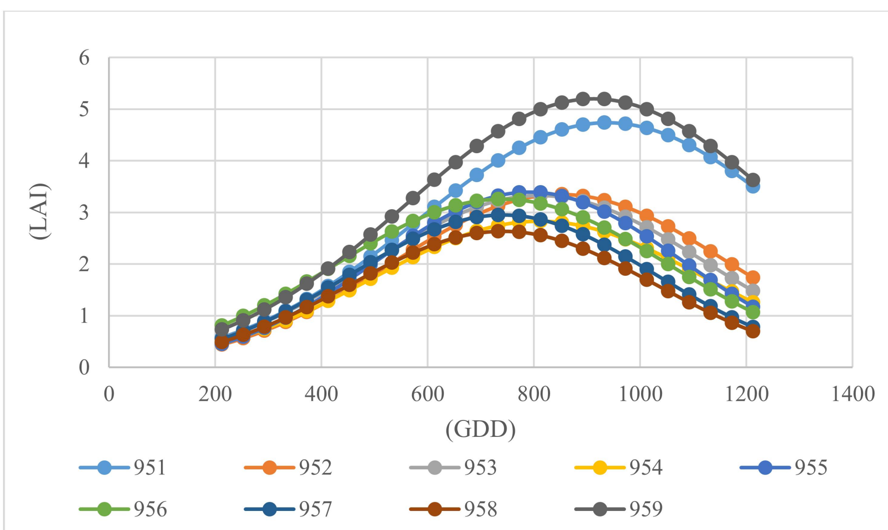

Figure 1. Changes in Leaf Area Index (LAI) in the studied rice genotypes.

limits the ability to use available photosynthetic products or resources.

The results of combined analysis of variance among the genotypes in NAR were significant (P< 1%) (Table 3). Comparison means showed that genotype 952 had the highest NAR (Table 4). NAR in terms of the effect of increasing the degree of growth day in different genotypes shows that the trend of changes in all genotypes is such that, at first, NAR was maximal, then, gradually decreased (Figure 4). At the early stages of seedling growth, all photosynthetic surfaces were exposed to direct sunlight and production of photosynthetic materials were higher. Afterwards, with the gradual growth of the plant and increasing intra-plant and inter-plant competition, the NAR decreased and the reason for the difference in NAR among different genotypes in the final stage of growth were certainly related to the amount of vegetation (active leaf area).

Agronomic Traits and Grain Yield

Plant Height and Tiller Number per Hill

The results of combined analysis of variance of the genotypes in plant height and tillers number per hill were not significant (Table 3). Comparison of means showed that the highest plant heights in the genotypes 953, 955, and 959 were in a statistical group and the highest tillers number per hill was recorded 21 in 957 and 14 in 959 genotypes

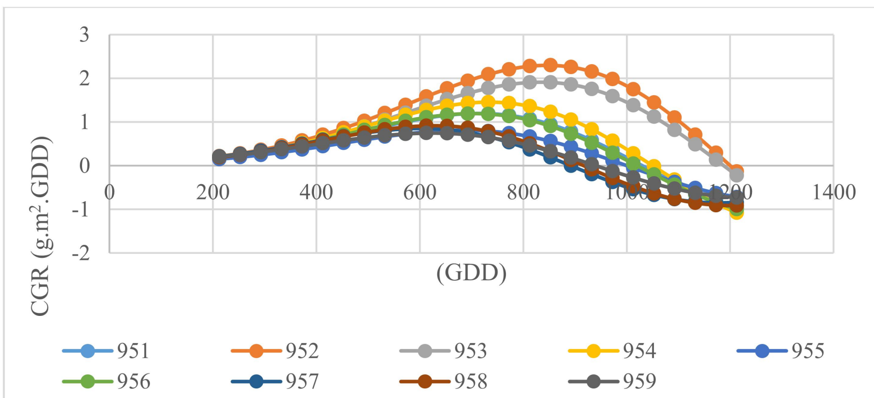

Figure 2. Changes in Crop Growth Rate (CGR) in the studied rice genotypes.

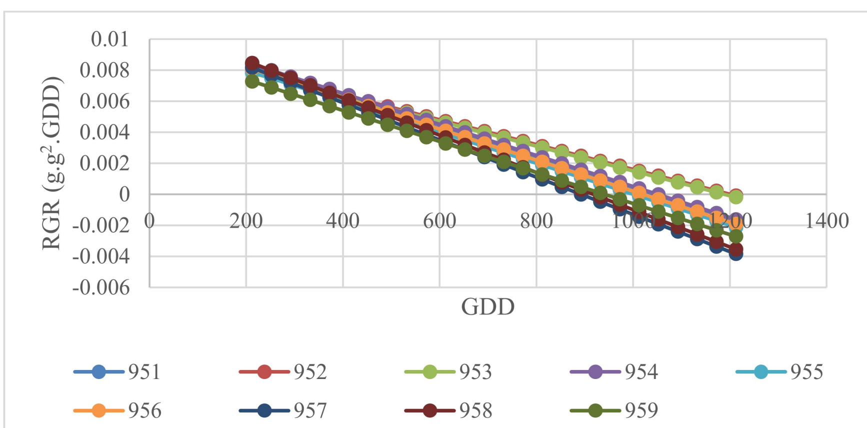

Figure 3. Changes in Relative Growth Rate (RGR) in the studied rice genotypes.

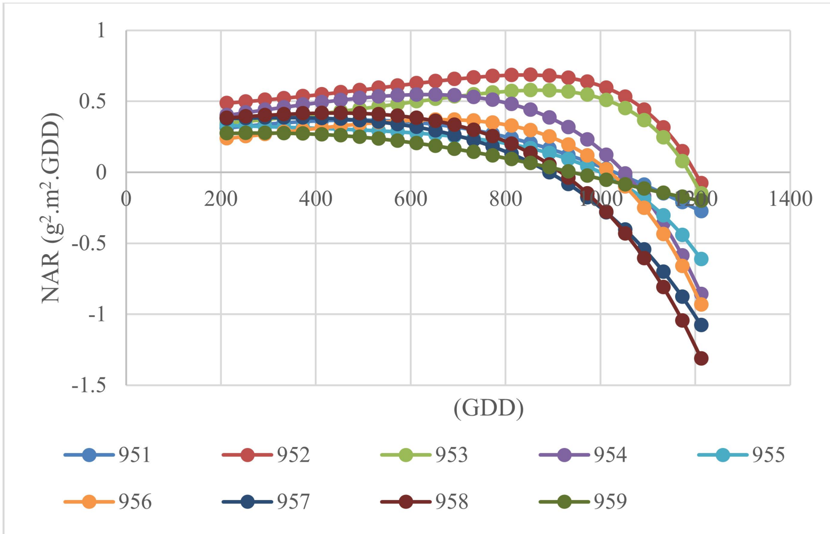

Figure 4. Changes in Net Assimilation Rate (NAR) in the studied rice genotypes.

(Table 4). Changes in plant height growth trend in all genotypes were ascending, with the highest and shortest plant heights belonging to 959 and 956 genotypes, respectively. Increase in the rice plant height continued until the stage of full emergence of the cluster and after that the height remained usually constant. Genotypes 957 and 958 had more tiller number per hill at the tillering stage.

Grain Length and Width

The results of combined analysis of variance revealed significant differences among the genotypes for grain length (α=0.01) but differences for grain width were not significant (Table 3). Comparison of means showed that the highest grain length was in genotype 955 with a value of 1.19 cm followed by genotype 959 with 1.2 cm; grain widths in all genotypes were in one statistical group (Table 4).

Paddy Yield

The results of combined analysis of variance for paddy yield were significantly different (P< 0.01) (Table 3). Comparison of means showed that the highest paddy yield was recorded in genotype 955 with a value of 7,272 kg ha^{-1}, and it was due to the significant LAI, RGR, and plant height. Therefore, it could be said that high paddy yield in some genotypes and lower yield in some other genotypes were relationship to sources and sink (Table 4).

Importance of leaves in production of photosynthetic materials

The results of the combined analysis showed that differences in all studied traits were significant (P< 0.01) and among leaves removal treatments, the number of filled and unfilled grain, 1,000-grain weight, and paddy yield were significant (P< 0.01 or, 0.05) (Table 5). The average simple effect between two years of the genotypes on studied traits indicated that paddy yield of the control cultivars statistically was lower than the other studied lines. The highest grain yield was obtained in line 952 (5,724 kg ha^{-1}), which was higher than the yield of two control cultivars (951 and 958) with 3,780 and 5,405 kg ha^{-1}, respectively.

Table 3. Combined analysis of variance for growth indices of rice genotypes.

Source of variations	df	Means squares									
		LAI	CGR	RGR	NAR	TDW	Plant height	Tiller number of hill	Grain length	Grain width	Paddy yield
Replication	2	0.37^{ns}	22.55^{*}	35×10^{-6ns}	0.27^{ns}	502536054.1^{*}	7.62^{ns}	19.74^{ns}	0.0008^{ns}	0.002^{ns}	14027194.6^{ns}
Genotypes	8	1.37^{**}	30.67^{**}	33×10^{-6ns}	4.81^{**}	52505.06^{**}	103.98^{ns}	20.67^{ns}	0.012^{**}	0.001^{ns}	35078280.7^{**}
Error	16	0.14	5.36	32×10^{-6}	0.92	7180.09	63.38	12.67	0.002	0.001	645205.49
CV (%)	-	11.73	14.77	21.05	19.42	14.3	7.84	19.24	4.01	15.58	13.02

*and **: significant at (p<0.05) and (p<0.01) probability levels, respectively, Ns: non-significant.

Table 4. Comparison of means of growth indices of rice genotypes.

Genotypes	Traits									
	LAI	CGR ($g\ m^{-2}\ day^{-1}$)	RGR ($g\ g\ m^{-2}\ day^{-1}$)	NAR ($g\ m^{-2}\ day^{-1}$)	TDW ($g\ m^{-2}$)	Plant height (cm)	Tiller number of hill	Grain length (cm)	Grain width (cm)	Paddy yield ($kg\ ha^{-1}$)
951	3.89^{a}	16.67^{bc}	0.032^{a}	4.24^{bcd}	527.07^{bcd}	100.16^{ab}	15.1^{b}	1.14^{ab}	0.23^{a}	4007.1^{c}
952	3.16^{bc}	23.33^{a}	0.026^{a}	7.55^{a}	902.55^{a}	98.16^{ab}	21.2^{ab}	1.15^{ab}	0.21^{a}	7196.1^{a}
953	3.75^{ab}	17.21^{b}	0.027^{a}	4.67^{bcd}	634.79^{bc}	109.43^{a}	16.53^{ab}	1.16^{ab}	0.25^{a}	5648.0^{b}
954	2.36^{d}	13.91^{bc}	0.027^{a}	5.88^{b}	514.34^{cd}	99.63^{ab}	18.43^{ab}	1.12^{ab}	0.21^{a}	7160.0^{a}
955	3.87^{a}	14.87^{bc}	0.023^{a}	3.89^{cd}	662.51^{b}	105.63^{a}	17.06^{ab}	1.19^{a}	0.26^{a}	7272.9^{a}
956	2.75^{cd}	14.65^{bc}	0.031^{a}	5.29^{bc}	468.00^{d}	91.63^{b}	21.2^{ab}	1.02^{c}	0.26^{a}	6797.5^{ab}
957	2.66^{cd}	13.78^{bc}	0.028^{a}	5.2^{bc}	515.34^{cd}	101.2^{ab}	21.55^{a}	1.11^{b}	0.25^{a}	6294.8^{ab}
958	2.8^{cd}	13.06^{c}	0.025^{a}	4.65^{bcd}	519.00^{bcd}	98.06^{ab}	19.76^{ab}	1.03^{c}	0.2^{a}	5555.0^{b}
959	4.26^{a}	13.54^{bc}	0.022^{a}	3.14^{d}	588.77^{bcd}	109.96^{a}	15.3^{a}	1.2^{a}	0.24^{a}	5564.3^{b}
LSD	0.66	4.008	0.009	1.66	146.67	13.78	6.16	0.07	0.06	1390.3

[a] (a-d) Means followed by the same letters in each column have not-significant differences at (p<0.05) level using LSD test.

Table 5. Combined analysis of leaves removals treatment in rice genotypes on studied traits.

Source of variations	df	Means squares: Panicle length	Filled grain	Unfilled grain	Total grain	Percent of fertility	Grain length	Grain width	1000-grain weight	Paddy yield
Year	1	35.11 ^{ns}	103.2 ^{ns}	17206.88 **	19352.05 **	5608.23 **	0.0107 ^{ns}	0.1431 **	68.78 **	9620657.8 **
Year × Replication (Error 1)	4	4.71	2.13	202.22	213.76	128.9	0.001	0.0047	21.99	1781539.8
Genotypes	8	98.65 **	1894.26 **	2648.9 **	5619.5 **	892.02 **	0.164 **	0.0128 *	431.53 **	13666627.7 **
Genotypes×Year	8	20.84 ^{ns}	316.67 *	526.49 **	1373.93 **	82.57 ^{ns}	0.0049 ^{ns}	0.0118 ^{ns}	16.62 **	992669.1 ^{ns}
Year×Replication×Genotypes (Error 2)	32	12.65	187.48	308.49	543.25	102.12	0.005	0.0125	8.24	2039556.0
Removal of leaves	5	12.55 ^{ns}	5598.85 **	6097.57 **	146.22 ^{ns}	4400.88 **	0.0106 ^{ns}	0.0038 ^{ns}	32.08 **	33303567.0 **
Removal of leaves×Genotypes	40	10.71 ^{ns}	181.03 *	214.2 ^{ns}	234.33 ^{ns}	95.7 *	0.0045 ^{ns}	0.0057 ^{ns}	7.4 ^{ns}	727853.5 ^{ns}
Removal of leaves×Year	5	9.52 ^{ns}	469.92 **	621.94 **	364.23 ^{ns}	400.72 **	0.0069 ^{ns}	0.0039 ^{ns}	4.96 ^{ns}	839913.9 ^{ns}
Removal of leaves×Genotypes×Year	40	9.94 ^{ns}	164.21 ^{ns}	163.58 ^{ns}	146.45 ^{ns}	95.06 **	0.0059 ^{ns}	0.0057 ^{ns}	6.35 ^{ns}	1082282.0 ^{ns}
Total Error	180	11.02	123.54	147.2	175.6	63.01	0.0048	0.006	5.76	766418.8
CV (%)	-	12.22	16.03	27.58	11.69	12.75	6.2	35.18	8.2	17.18

^{ns}, * and **: Indicate not-significant and significant at (P< 0.05) and (P< 0.01), respectively.

Table 6. Comparison of means of simple effect between rice genotypes on studied traits in two years. [a]

Genotypes	Traits: Panicle length (cm)	Filled grain	Unfilled grain	Total grain	Percent of fertility (%)	Grain length (cm)	Grain width (cm)	1000-grain weight (g)	Paddy yield (kg ha^{-1})
951	26.9 ^{cd}	81.0 ^{a}	47.2 ^{dc}	129.3 ^{ab}	64.4 ^{c}	1.1 ^{bc}	0.1 ^{c}	21.8 ^{f}	3780 ^{e}
952	25.7 ^{d}	66.4 ^{cd}	38.0 ^{d}	104.4 ^{ef}	64.5 ^{bc}	1.1 ^{b}	0.2 ^{bc}	27.9 ^{e}	5724 ^{a}
953	25.5 ^{d}	62.2 ^{ed}	36.0 ^{e}	98.3 ^{gf}	64.1 ^{c}	1.1 ^{b}	0.2 ^{bc}	33.1 ^{a}	5150 ^{c}
954	26.5 ^{cd}	79.0 ^{a}	37.4 ^{e}	116.4 ^{c}	68.6 ^{a}	1.1 ^{bc}	0.2 ^{c}	31.8 ^{bc}	5290 ^{bc}
955	29.1 ^{ab}	68.2 ^{c}	55.1 ^{ab}	123.3 ^{b}	56.1 ^{d}	1.2 ^{a}	0.2 ^{abc}	32.26 ^{ab}	5606 ^{ab}
956	25.5 ^{d}	60.3 ^{e}	49.5 ^{bc}	109.9 ^{de}	55.3 ^{d}	0.9 ^{e}	0.2 ^{ab}	29.9 ^{d}	5042 ^{c}
957	26.7 ^{cd}	63.8 ^{cde}	32.4 ^{e}	96.3 ^{g}	68.1 ^{ab}	1.1 ^{c}	0.3 ^{a}	30.9 ^{cd}	5400 ^{abc}
958	27.6 ^{bc}	68.7 ^{bc}	43.7 ^{d}	112.4 ^{cd}	61.5 ^{c}	1.1 ^{d}	0.2 ^{c}	27.1 ^{e}	5405 ^{abc}
959	30.3 ^{a}	73.8 ^{b}	56.2 ^{a}	130.1 ^{a}	57.3 ^{d}	1.2 ^{a}	0.2 ^{abc}	28.2 ^{e}	4449 ^{d}
LSD	1.5	5.1	5.6	6.1	3.6	0.03	0.03	1.1	407.1

[a] (a-g) Means followed by the same letters in each column are not significantly differences at (P< 0.05) level using LSD test.

Table 7. Comparison of means of simple effect among removals of leaves treatments on studied traits during two study years. [a]

Removal Leaves Treatments	Traits								
	Panicle length (cm)	Filled grain	Unfilled grain	Total grain	Percent of fertility (%)	Grain length (cm)	Grain width (cm)	1000-Grain weight (g)	Paddy yield (kg ha^{-1})
Removal flag leaf	28.1 ^{a}	69.9 ^{c}	40.9 ^{c}	111.2 ^{a}	65.1 ^{bc}	1.1 ^{a}	0.2 ^{a}	29.4 ^{ab}	5228 ^{bc}
Removal of two top leaves	27.1 ^{ab}	62.7 ^{d}	50.0 ^{b}	113.0 ^{a}	56.6 ^{d}	1.1 ^{a}	0.2 ^{a}	29.1 ^{b}	4842 ^{d}
Removal of all leaves except flag leaf	27.1 ^{ab}	70.9 ^{c}	41.8 ^{c}	112.9 ^{a}	63.5 ^{c}	1.1 ^{ab}	0.2 ^{a}	29.4 ^{ab}	5072 ^{cd}
Removal all leaves except two top leaves	27.1 ^{ab}	76.7 ^{b}	38.9 ^{c}	115.7 ^{a}	67.2 ^{b}	1.1 ^{a}	0.2 ^{a}	29.5 ^{ab}	5516 ^{b}
Removal of completed leaves	26.7 ^{b}	53.3 ^{e}	61.5 ^{a}	114.9 ^{a}	47.5 ^{e}	1.1 ^{b}	0.2 ^{a}	27.8 ^{c}	3773 ^{e}
Control	26.8 ^{ab}	82.0 ^{a}	30.5 ^{d}	112.6 ^{a}	73.4 ^{a}	1.1 ^{ab}	0.2 ^{a}	30.1 ^{a}	6133 ^{a}
LSD	1.2	4.2	4.6	5.03	3.01	0.02	0.02	0.9	332.4

[a] (a-c) Means followed by the same letters in each column have no significant differences at ($P< 0.05$) level using LSD test.

Table 8. Percent of paddy yield due to removals of leaves treatments compared to the control for different rice genotypes (two-years average). [a]

Genotypes	Treatments						Decreased percent of grain yield[a]				
	Flag leaf removal	Removal of two top leaves	Removal of all leaves except flag leaf	Removal of all leaves except two top leaves	Removal of completed leaves	Control	C_1	C_2	C_3	C_4	C_5
951	3781	3666	3877	3920	3405	4034	6.3	9.1	3.9	2.8	15.6
952	5865	5197	5674	6179	4227	7206	18.6	27.9	21.3	14.3	41.3
953	5688	4850	5105	5990	3183	6088	6.6	20.3	16.1	1.6	47.7
954	5158	4684	5538	5681	3720	6963	25.9	32.7	20.5	18.4	46.6
955	5528	5487	5211	6250	4638	6527	15.3	15.9	20.2	4.3	28.9
956	5235	4986	4891	5547	3580	6015	13	17.1	18.7	7.8	40.5
957	5758	5442	5613	5546	3993	6048	4.8	10	7.2	8.3	34
958	5644	5142	5275	5521	3911	6940	18.7	25.9	24	20.4	43.6
959	4403	4127	4471	5012	3305	5377	18.1	23.3	16.9	6.8	38.5
Grain yield average (kg ha^{-1})	5228	4842	5072	5516	3773	6133	14.1	20.2	16.5	9.4	37.4

[a] C_1: Removal of flag leaf, C_2: Removal of two top leaves, C_3: Removal of all leaves except flag leaf, C_4: Removal of all leaves except two top leaves, and C_5: Removal of completed leaves.

Table 9. Variation effect due to year on the studied traits. [a]

Year	Panicle length (cm)	Filled grain	Unfilled grain	Total grain	Percent of fertility (%)	Grain length (cm)	Grain width (cm)	1000-Grain weight (g)	Paddy yield (kg ha^{-1})
2017	26.8^{a}	68.7^{a}	36.6^{b}	105.6^{b}	66.4^{a}	1.1^{a}	0.2^{a}	29.7^{a}	5266^{a}
2018	27.4^{a}	69.8^{a}	51.2^{a}	121.1^{a}	58.0^{b}	1.1^{a}	0.1^{b}	28.8^{b}	4922^{b}
LSD	0.72	2.43	2.66	2.90	1.74	0.01	0.01	0.5	194.9

Traits: columns Panicle length through Paddy yield.

[a] (a-b) Means followed by the same letters in each column do not differ significantly at ($P< 0.05$) level using LSD test.

Table 10. Combined analysis of variance for qualitative indices and removals of leaves of rice genotypes.

Source of variations	df	Recovery of milling	Percent of husk	Percent of bran	Milling degree	Head rice recovery	Broken rice recovery	Gelatinization temp	Chalkiness	Amylose content	Harvest index
Replication	2	0.1^{ns}	0.3^{ns}	0.5^{ns}	1.3^{ns}	0.2^{ns}	0.2^{ns}	0.3^{ns}	0.05^{ns}	0.3^{ns}	6.4^{ns}
Genotypes	10	19.95**	3.6**	14.6**	26.7**	570**	436.4**	17.6**	85.9**	73.5**	350.7**
Replication×Genotypes	20	0.62	0.4	0.2	0.8	3.1	2.7	0.08	0.18	0.1	6.4
Removal leaves	2	10.2^{ns}	3.4^{ns}	1.9^{ns}	1.9^{ns}	62.9**	68**	0.7**	5.5**	0.2^{ns}	323.4**
Removal leaves×Genotypes	20	3.4^{ns}	1.5^{ns}	3.03**	6.7**	9^{ns}	12.5**	0.12^{ns}	3**	0.67**	43.1**
Error	44	1.14	0.42	0.56	0.83	2.7	1.2	0.04	0.3	0.14	4.9
Total error	98	-	-	-	-	-	-	-	-	-	-
CV (%)	-	1.6	3	6.36	1.07	3.05	8.6	4.6	8.3	1.8	3.7

** and *= Significant at ($p<0.01$) and ($p<0.05$) probability levels, respectively. ns: Not significant.

Table 11. Comparison of means for qualitative indices and removals of leaves of rice genotypes. [a]

Genotypes	Recovery of milling	Percent of husk	Percent of bran	Milling degree	Head rice recovery	Broken rice recovery	Gelatinization temp	Chalkiness	Amylose content	Harvest index
951	63.9^{f}	22.0^{b}	14.0^{a}	81.8^{h}	42.1^{g}	21.8^{b}	3.1	6.0^{e}	20.5^{f}	55.9^{fe}
952	66.7^{bc}	21.0^{d}	12.4^{bc}	84.3^{ef}	48.5^{f}	18.4^{c}	3.4	6.4^{d}	25.1^{a}	57.3^{e}
953	65.6^{de}	21.4^{bcd}	12.8^{b}	83.5^{fg}	41.1^{g}	24.4^{a}	3.2	7.2^{c}	19.2^{h}	53.8^{f}
954	66.2^{cd}	21.2^{cd}	12.5^{b}	84^{efg}	52.9^{e}	13.8^{e}	3.4	12.7^{a}	24^{b}	58.4^{cde}
955	64.9^{e}	23.1^{a}	11.8^{d}	83.3^{g}	49.5^{f}	15.4^{d}	6.8	4.5^{fg}	22.4^{e}	60.4^{c}
956	68.8^{a}	21.5^{bcd}	9.8^{g}	87.5^{a}	60.8^{b}	8.1^{g}	3.1	11.5^{b}	22.3^{e}	59.9^{cd}
957	67.3^{b}	21.5^{bcd}	11.3^{e}	85.7^{cd}	57.8^{c}	10.0^{f}	6.5	7.1^{c}	23.7^{c}	54.5^{f}
958	68.0^{a}	21.8^{bc}	10.0^{g}	87.1^{ab}	54.8^{d}	13.1^{e}	3.0	4.1^{g}	23.4^{d}	59.9^{cd}
959	65.6^{de}	21.9^{bc}	12.3^{bcd}	84.2^{efg}	60.7^{b}	4.8^{hi}	4.8	4.7^{f}	15.8^{j}	67.9^{b}

[a] (a-i) Similar letters in each column indicate Not significant difference at 0.05 probability level in the LSD test.

Line 952 had the highest paddy yield among the studied lines in both years. The highest percentage of filled grain was in line 951 with 81 percent and line 954 with 79 percent, respectively, and these were in one statistical group (Table 6). These results suggested that the total grain number could be increased by increasing the capacity of the sink. There was a need for more photosynthetic materials production by the source and the most important role was played by the flag leaf, as it was the closest source to the sink. Based on the results of this study, it is suggested that the relationship between the source and the sink is very important in achieving the full production potential. The source and sink relationship is also important during filling stage and dry matter production and temporary storage in stem and transfer to the grain at grain filling stage. Therefore, total remobilization of dry matter and current photosynthesis from the flowering stage to the maturity stage are most important in achieving high cultivar potential for paddy yield, as also noticed by Bijanzadeh and Emam (2012) in wheat cultivars. If the amount of temporary storage is more before the flowering stage, the damage would be less in case of unfavorable environmental conditions during the grain filling stage.

Comparison of mean simple effect of simple leaf cutting treatments showed that the average yield in the control treatment (no leaf cutting), removal of all leaves except the top two leaves, removal of the flag leaf, removal of all leaves except the flag leaf, removal of the two upper leaves and removal of all leaves It was 6133, 5516, 5228, 5072, 4842 and 3773 kg ha-1 per hectare respectively. In the control treatment, the leaves were fully active after the anthesis stage and had current photosynthetic material production remained undisturbed, the paddy yield was the highest with 6,133 kg ha^{-1} and the complete removal of leaves with 3773 kg ha^{-1}, which was the lowest value (Table 7). The results showed that, under the shortage of current photosynthetic assimilates, rice cultivars used the carbohydrates stored in the shoot (remobilization), which, to some extent, compensated for the reduced paddy yield (Table 7). Therefore, it can be stated that the role of the source, especially leaves, in the production of current photosynthesis after the anthesis stage is of great importance.Comparison of means of removal of flag leaf showed that the highest percentage of paddy yield reduction in removal of flag leaf treatment was in line 954 (25.9%) and the lowest paddy yield reduction was in line 957 (4.7%) (Table 8). Based on the results in Table (8), from flowering to maturing stage, flag leaf had a significant effect on the amount of photosynthetic material production and its role was different in the rice grain filling stage. This indicates that flag leaf is more important in genotypes with higher grain yield, a large percentage of rice grains were filled after removing leaves. High percentage filling of rice grain with removal leaves treatments, especially removal all leaves treatment, indicates that the amount of photosynthetic material production before the flowering stage and remobilization to the grain after the anthesis stage plays an important role in grain filling. Genotype 952 showed a significant decrease in paddy yield due to high source bulk and sink limitation with removal of flag leaf (Table 8). Removal of two top leaves had the highest and the lowest paddy yield reduction observed in lines 954 and 951 with 32.7 and 9.1 percent, respectively (Table 8). Removal of all leaves except the two top leaves led to the highest paddy yield decrease in line 957 (20.4%) and the lowest paddy yield in line 953 with 1.62 percent (Table 8). Removal of all leaves had the highest paddy yield loss in line 953 (47.7%) and the least reduction yield was in line 951 with (15.6%) (Table 8).

Mean paddy yield of all genotypes in flag leaf removal, removal of the two top leaves, removal of all leaves except flag leaf, removal of all leaves except the two top leaves, and removal of completed leaves resulted in 5,228, 4,842, 5,072, 5,516, and

3,773 kg ha^{-1}, respectively, i.e. the amount of paddy yield decreased by 14.1, 20.2, 16.5, 9.4, and 37.4 percent, respectively. Comparison of paddy yield means in different genotypes showed that the highest was in line 955 in removal of all leaves except the two top leaves (6,249 kg ha^{-1}) and line 952 in the control treatment (7,206 kg ha^{-1}), and the lowest unfilled grain yield was also observed for line 957 in the control treatment with 14.5 percent (Table 8).

By removing flag leaf, the grain weight of all genotypes decreased in both years compared to the control treatment. This result showed that with decreasing current photosynthesis due to removal of flag leaf, the complete requirement of carbohydrates for grain filling was not filled and, therefore, grain weight decreased (Table 6). Therefore, it can be stated that leaves, especially the two top leaves as the largest source of photosynthetic material producer, play an important role in producing current photosynthesis after anthesis stage and achieving the production potential of each cultivar (Table 8).

Results of year effects for traits studied during the two years showed that panicle length, grain length, and filled grain did not differ significantly. However, 1000-grain weight, unfilled grain, percent of fertility, and total grain weight were significantly different and affected by removal of various leaves in both years. Therefore, the role of source, especially leaves, in the production of current photosynthesis after the anthesis stage is of great importance. According to the meteorological information of the research field, the average annual relative air humidity and temperature were higher in the first year from June to August than in the second year. Therefore, the first year showed a lower number of unfilled grain and a higher percent of fertility rate than the second year, resulting in higher paddy yields. (Table 9).

Combined analysis of variance (Table 10) showed that the effect of genotypes on all studied quality traits were significant ($P< 0.01$). Also, the effect of removal of leaves on some traits was statistically significant ($P< 0.01$) and the interaction effect of leaves removal and the genotype on all qualitative traits was significant ($P< 0.01$). The comparison of means (Table 11) showed that the highest milling efficiency belonged to genotype 956 (68.8%), which was in one statistical group with genotype 958 (68%). Also, the highest percent of husk belonged to genotype 955 (23.1%) and the highest percent of bran (14%) belonged to the 951-control genotype. Production of larger quantities of head rice recovery and increasing its share in the conversion process, regardless of processing conditions, is completely affected by the characteristics of the variety, chalkiness, and environmental conditions at the time of ripening and some agricultural operations. This study found that genotypes 956 and 959 had the highest head rice recovery at 60.8 and 60.7%, respectively. Genotype 959 had the lowest broken rice recovery. Regarding rice cooking quality, the highest amylose content belonged to genotype 952.

CONCLUSIONS

Any damage to the leaves results in reduced photosynthesis and production of rice grain per unit area. The results showed that different genotypes were different in yield and the highest paddy yield was obtained from line 952 with 5,724 kg ha^{-1} and line 955 with 5,606 kg ha^{-1}. Removal of leaves had different effects on yield reduction in the studied rice genotypes. The highest yield reduction occurred in the complete leaf removal in genotypes 953 and 954 with 47.7 and 46.5%, respectively. The most destructive level of leaf removal treatments was the removal of all leaves, two top leaves, all leaves except flag leaf, flag leaf and all leaves except upper two leaves, which caused yield losses of 37.4, 20.2, 16.5, 14.1, and 9.4, compared to the control (no removal of leaves) that had yield of 6,133 kg ha^{-1}, respectively. It can be said that the percentage of paddy yield reduction with removal of leaves was greater in genotype 951, so, the flag leaf in this genotype was more important in producing current photosynthesis from the flowering stage to the maturity stage.

In terms of cooking quality of rice, the highest amylose content was in genotype 952, the highest gelatinization temperature was in genotype 955, and the lowest chalkiness and broken rice recovery were in genotype 959.

Based on the results, it can be stated that by removing the leaves of rice plant, the production of photosynthetic materials and the yield per unit area are greatly reduced. Therefore, to increase the storage of food in the grain, rice plant needs more activity of the leaves in the production of photosynthetic materials, especially from the flowering stage to the physiological maturity, i.e. it is source-limited.

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REFERENCES

1. Allahgholi-pour, M., Zeinali, H. and Rostami, M. A. 1998. Correlation Study of Some Important Agronomic Traits with Grain Yield Using Path Analysis in Rice. *Iranian J. Agric. Sci*., **29(3):** 627-637. (In Persian)
2. Akbari, G. A., Salehi-Zarkhooni, R., Mottaghi, S., Lotfifar, O., Yusefi-Rad, M. and Nasiri, M. 2009. Comparison of Yield, Yield Components and Remobilization of Assimilates in Old and New Rice Genotypes. *Plant Prod. Technol.,* **1(2):** 21-32. (In Persian)
3. Bahrani, A. and Tahmasebi Sarvestani, Z. 2007. Effect of Rate and Times of Nitrogen Application on Accumulation and Remobilization Efficiency of Flag Leaf in Two Wheat Cultivars. *J. Water Soil Sci*., **11(40)**: 147-155. (in Persian)
4. Bijanzadeh, E. and Y. Emam. 2012. Evaluation of Assimilate Remobilization and Yield of Wheat Cultivars under Different Irrigation Regimes in an Arid Climate. *Arch. Agron. Soil Sci.,* **58(11)**: 1243–1259. (In Persian)
5. Felekari, H., Ghobadi, M. E., Ghobadi, M., Jalali Honarmand, S. and Saeidi, M. 2014. The Effect of Post-Anthesis Source and Sink Limitation in Wheat Cultivars under Moderate Conditions. *Int. J. Biosci*., **5(5):** 52-59.
6. Haque, M. M., Pramanik, H. R., Biswas, J. K., Iftekharuddaula, K. M. and Hasanuzzaman, M. 2015. Comparative Performance of Hybrid and Elite Inbred Rice Varieties with Respect to Their Source-Sink Relationship. *Sci. World J.,* Volume 2015, Article ID 326802, 11 PP.
7. Kazemi-Poshtmasari, H. 2005. Study the Effect of Nitrogen Fertilizer Rates and Split Application on Nitrogen and Dry Matter Remobilization in Rice (*Oryza sativa* L.) Cultivars. M.Sc. Thesis, Department of Agronomy, Faculty of Crops Sciences, Sari Agricultural Sciences and Natural Resources University, Sari, Iran, 110 PP. (In Persian)
8. Kobata, T., Sugware, M. and Takata, S. 2000. Shading during the Early Grain-Filling Period Does Not Affect Potential Grain Dry Matter Increase in Rice. *Agron. J*., **92(3):** 411-417.
9. Koocheki, A. R. and Sarmad-Nia, GH. H. 2013. Physiology of Agricultural Plants. 17th Edition. Publications Jahad University of Mashhad. Mashhad, Iran. 400pp.
10. Madani, A., Shirani-Rad, A. H., Pazoki, A., Nourmohammadi, G., Zarghami, R. and Mokhtassi-Bidgoli, A. 2010. The Impact of Source or Sink Limitations on Yield Formation of Winter Wheat (*Triticum aestivum* L.) due to Post-Anthesis Water and Nitrogen Deficiencies. *Plant Soil Environ*., **56(5):** 218-227. (In Persian)

11. Mahdavi, F. 2004. Study of Physiological and Morphological Indices of Growth in New and Old Varieties of Rice. M.Sc. Thesis, Sari Agricultural Sciences and Natural Resources University, Sari, Iran. 132 PP. (In Persian)
12. Mahdavi, F., Esmaeili, M. A., Fallah, A., and Pirdashti, H. 2005. Study of Morphological Characteristics, Physiological Indices, Grain Yield and Tts Components in Rice (*Oryza sativa* L.) Landraces and Improved Cultivars. *Iran. J. Crop Sci*., **7(4):** 280-297. (in Persian)
13. Mali, M. 1999. Effects of Leaf Removal after Flowering on Wheat Grain Yield. M.Sc. thesis, Faculty of Plant Production. Gorgan University of Agricultural Sciences & Natural Resources, Gorgan, Iran, 67 PP. (In Persian)
14. Mazandarani, A. and Nasiri, M. 2018. Purification and Introduction of New Rice Cultivars by Plant Selection Method from Fajr Improved Cultivar Mass. 18th National Rice Conference. Sari University of Agricultural Sciences and Natural Resources. 19-20 November, Sari, Iran. (in Persian)
15. Nik-Nezhad, Y. 2003. Investigation Relationship Sink-Source and Yield in Different Rice Cultivars. M.Sc. Thesis, Department of Agronomy, Faculty of Agriculture, Islamic Azad University, Varamin Branch, Varamin, Iran, 108 PP. (In Persian)
16. Noori, H., Ahmadi, A. and Poustini, K. 2014. Evaluation of Remobilization Potential under Source Limited Condition in Iranian Wheat Cultivars. *Iran. J. Field Crop Sci.,* **45(2):** 317-326. (In Persian)
17. Pirdashti, H., 2000. Investigation Planting Date on Nitrogen Remobilization and Grow Indices, Yield and Yield Component in Different Rice Cultivar. M.Sc. Thesis. Department of Agronomy, Faculty of Agricultural, Tarbiat Modarres University, Tehran, Iran. 158p. (In Persian).
18. Puppala, N. and Fowler, J. L. 1999. Growth Analysis of Lesquerella in Response to Moisture Stress. Perspectives on new crops and new uses. ASHS, Alexandria. 244-246pp.
19. Radmehr, M., Lotf-Ali Aeyneh, G. A. and Naderi, A. 2004. A Study on the Source-Sink Relationship of Wheat Genotypes under Favorable and Terminal Heat Stress Conditions in Khuzestan. *Iran. J. Crop Sci*., **6(2):** 101-114. (in Persian)
20. Sadeghi, S. A., and Mobaser, H. R. 2010. Investigation of Source-Sink Relations in Different Rice Planting Systems. *J. Crop Prod. Res*., **2(4)**: 401-413. (In Persian)
21. Shapiro, S. S., and Wilk, M. B. 1965. An Analysis of Variance Test for Normality (complate samples). *Biometrika*, **52(3/4)**: 591-611.
22. Vali-pour, A. 2013. Study of the Contribution of Dry Matter Remobilization on Growth and Yield of Cultivars and Rice Lines. M.Sc. Thesis. Islamic Azad University, Chalous Branch, Chalous, Iran, 88 PP. (In Persian)

ارزیابی شاخص‌های رشد، ویژگی های کیفی و روابط منبع و مخزن در ژنوتیپ‌های امیدبخش برنج

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چکیده

برگ‌های برنج مهم‌ترین منبع برای تولیدکربوهیدرات‌ها از طریق فرایند فتوسنتز هستند. به‌منظور تعیین شاخص‌های رشد و سهم برگ‌ها در مرحلهٔ پُرشدن دانه، پژوهشی با نه ژنوتیپ و شش تیمار قطع برگ (محدودیت مبدا فیزیولوژیک) در مرحلهٔ پُرشدن دانه در دو سال زراعی ۱۳۹۶ و ۱۳۹۷ در مؤسسه تحقیقات برنج کشور (مازندران) انجام شد. آزمایش به‌صورت اسپلیت پلات در قالب طرح بلوک‌های کامل تصادفی با سه تکرار و با قراردادن ژنوتیپ‌ها درکرت اصلی و تیمارهای قطع برگ در کرت‌های فرعی اجرا گردید. نتایج نشان دادکه ژنوتیپ ۹۵۹ بیش‌ترین شاخص سطح برگ (LAI) را در مرحلهٔ گل‌دهی داشت. بیش‌ترین سرعت رشد محصول (CGR) با ۲۳/۳ گرم در مترمربع و سرعت جذب خالص (NAR) با ۷/۵ گرم برگرم در مترمربع متعلق به ژنوتیپ ۹۵۲ بود. ژنوتیپ‌های ۹۵۷ و ۹۵۹ بیش‌ترین تعداد پنجه درکپه و ژنوتیپ ۹۵۲ بیشترین عملکرد را به خود اختصاص دادند. نتایج تجزیه واریانس مرکب نشان داد که تیمارهای قطع برگ اثر معنی داری بروزن هزار دانه، درصد دانه‌های پر و عملکرد شلتوک در هکتار داشته‌اند. مقایسه میانگین میان تیمارهای قطع برگ در دو سال نشان داد که تیمارهای قطع برگ کاهش معنی‌داری در طول خوشه، طول دانه، تعداد دانه‌های پُر و تعداد کل دانه در کپه داشتند. بیش‌ترین کاهش عملکرد شلتوک، متعلق به تیمار حذف کامل برگ با ۴۷/۷ و ۴۶/۵ درصد به‌ترتیب برای ژنوتیپ ۹۵۳ و ۹۵۴ بود. میزان کاهش عملکرد ناشی از تیمارهای قطع همهٔ برگ‌ها، دو برگ بالایی، همهٔ برگ‌ها به جز برگ پرچم، قطع برگ پرچم و همهٔ برگ‌ها به جز دو برگ بالایی به‌ترتیب ۳۷/۴، ۲۰/۲، ۱۶/۵، ۱۴/۱ و ۹/۴ درصد نسبت به شاهد (بدون قطع برگ) با عملکرد ۶۱۳۳ کیلوگرم در هکتار بودند. با توجه به نتایج حاصل از این آزمایش می‌توان بیان کرد که حدود ۹۰ درصد کربوهیدرات‌های موردنیاز برنج در مرحلهٔ پُرشدن دانه، با دو برگ فوقانی در هر بوته برنج تامین می‌شود.