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Optimizing Rice (*Oryza sativa* L.) Irrigation to Introduce the Optimum Genotype for Grain Yield and Quality Promotion

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ABSTRACT

Utilizing new irrigation techniques to introduce cultivars into paddy fields experiencing water scarcity is one way to combat water shortage and increase water productivity. To this end, this experiment was conducted as a strip plot in a randomized complete block design with three independent replications over two years (2016 and 2017) at the Rice Research Institute of Iran, Amol, Iran. Ten rice genotypes (V1 to V10) were subjected to three types of irrigation systems, including conventional Flood Irrigation (FI) and Alternate Wetting and Drying (AWD) at 10 (AWD10) and 20 (AWD20) cm below the soil surface. These results demonstrate that AWD10 and AWD20 methods reduced water consumption by 20 and 17%, respectively, compared to the conventional methods. This decreased water usage resulted in 1.4 and 0.2% yield losses compared to the conventional flood irrigation system. Moreover, milling recovery in flood irrigation (68.7%) was lower than AWD10 and AWD20 methods (69.6 and 69.8%, respectively). In conclusion, Neda, Shiroodi, and 8611 rice genotypes showed a better response to AWD irrigation, and may be considered as suitable genotypes for increasing water productivity in paddy fields.

Keywords: Irrigation management, Photosynthetic characteristics, Rice grain yield.

INTRODUCTION

Rice (*Oryza sativa* L.) occupies more than 9% of arable land and is the staple food for more than half of the world's population (Phan *et al*., 2022). Rice has the largest cultivated area and the lowest irrigation recovery of all cereals compared to other irrigated crops. One kilogram of rice requires approximately three times the amount of water as one kilogram of wheat. In fact, rice plants receive two to three times more water than other crops (Bouman *et al*., 2007). Therefore, drought is the most significant factor limiting global production, necessitating optimal use of water resources to determine rice's actual water needs (Ram *et al*., 2003).

Generally, 75% of Iran's rice crop is irrigated by flooding. Due to Iran's location in arid and semi-arid regions, water stress is one of the most significant agricultural production challenges (Nouri *et al*., 2020). Wetting and drying paddy fields with intermittent irrigation has been considered one of the most effective water management techniques in agriculture, as it meets the needs of plants in arid environments (Shanmugasundaram, 2015). This irrigation method induces an air exchange between the soil and the atmosphere (Tuong *et al*., 2005). When watering a plant every few days, the root system receives sufficient oxygen, accelerating the mineralization of organic chemicals and stabilizing nitrogen in the soil. These factors result in improved plant nutrient uptake and increased growth rates (Tan *et al*., 2013; Dong *et al*., 2012). Water

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savings is the most important advantage of intermittent rice irrigation with multiple-day irrigation cycles (Uphoff *et al*., 2013).

Jia-guo *et al*. (2003) demonstrated that water stress significantly decreased rice yield within 25 days of 80% maturity. After twenty-five days, this effect becomes very weak, and soil water is able to sustain the physiological viability of rice plants for ten days. Razavipour (1994) proposed that rice can thrive in wet conditions without flooding. If soil moisture exceeds 80% saturation, soil performance should remain unaffected: Not only is there no decrease in yield under these conditions, but the rice grows well, and the grains and stems are healthy and undamaged.

It is possible to develop new rice cultivars through short- or long-term breeding programs due to the existence of significant genetic diversity in response to stresses and coping mechanisms (Limouchi *et al*., 2018). Despite the need for high-yielding cultivars, it is also important to consider the stress tolerance of local cultivars (Wu *et al*., 2011; Habibi *et al*., 2022). Drought-tolerant programs aim to identify and introduce cultivars that are more tolerant to stress than other genotypes and experience less yield loss under identical environmental conditions (Srivastava *et al*., 1987). Fernandez (1992) categorized wheat genotypes into the following four groups based on their responses to stressful and non-stressful environmental conditions:

1. Dominant genotype in non-stress and stressed conditions and yielding more grain (Group A).
2. Dominant genotypes are exclusively in the desired environment and partially low-yielding in the stressful environment (Group B).
3. Genotypes with relatively high yield in stressful environments, whose yield will decrease in non-stress environments (Group C), and
4. Genotypes with low yield in both non-stress and stressed environments (Group D).

This study evaluated the agronomic and yield characteristics of selected rice genotypes in Amol, Mazandaran Province, using an alternate wetting and drying irrigation system.

MATERIALS AND METHODS

Location and Experimental Design

The experiment was conducted at experimental field of the Rice Research Institute of Iran, Amol, Mazandaran, Iran (52° 23' N, 36° 28' E, 29.8 m asl). Analysis of the region's climate reveals that summers are mild and winters are relatively cold and dry. In addition, the research was conducted over two consecutive growing seasons. Table 1 shows the growing season's weather conditions.

Treatments

This survey used a Randomized Complete Block Design (RCBD) with a strip-plot layout. Before planting, the soil characteristics are shown in Table 2. Ten experimental rice cultivars (V1 to V10) were selected from 56 genotypes based on greenhouse evaluation of drought tolerance traits and mechanisms, such as physiological traits. These genotypes tolerate drought during the dry period (Nasiri *et al*., 2020). These traits included the dry weight of the roots and shoots, the plant's height, the relative water content of the leaves, and the relative membrane permeability. Chlorophyll a, b, and carotenoids are components of chlorophyll photosynthesis and fluorescence (Nasiri *et al*., 2020). The names and origins of the rice genotypes are listed in Table 3.

Before the field operations, the mentioned cultivars' seeds were germinated. Then,

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Table 1. Amol annual growing season temperature and precipitation for 2016-2017.

Season	Temperature (ºC)		Humidity (%)		Total precipitation (mm)	Total sunny hours
2016	Min	Max	Min	Max		
March	10.3	16.6	63	94	44.5	140.2
April	16	24.2	61	93	52.2	149
May	20.4	28	63	93	3.5	228
June	21.8	31.5	61	94	6	232.4
July	23.2	34	56	93	12	269
August	22.5	32.7	63	90	38.5	262.6
Sum	114.2	169.2	367	557	156.3	1281
Average	19	28.2	61	93	26	213.5
2017						
March	12	18	63	93	41.4	129
April	15.7	25	56	91	6.4	177.2
May	20	28	61	93	13.4	155
June	23.3	34	61	91	7	238
July	24	32.7	59	94	27	131
August	21.4	30.5	59	94	4.5	171.4
Sum	116.5	168	359	556	99.5	1001.3
Average	19.4	28	60	92.6	16.5	167

Table 2. The experimental site's soil physical and chemical traits during the 2016 and 2017 seasons

Soil component texture				Soil elements (mg kg^{-1})						
Texture	Clay (%)	Silt (%)	Sand (%)	K	P	N	$CaCO_3$ (%)	EC (dS.m^{-1})	O.C (%)	pH
Clay-Loam	34	40	26	224	8.2	0.1	29	0.99	2.5	6.65

Table 3. Name and origin of rice cultivars and genotypes.

Genotype code	Genotype name or code	Origin	Growth duration (Transplant to harvest) (Days)
V1	IR74428-153-2-3 (53 or 8605)	International Rice Research Institute (IRRI)	88
V2	IR75482-149-1-1 (55 or 8611)		92
V3	IR70416-53-2-2 (56 or 8616)		87
V4	IR79907-B-493-3-3-1 (AR8)		100
V5	G28	Rice Research Institute of Iran Fars (RRII)	95
V6	Firozan	Rice Research Institute of Iran Esfahan (RRII)	92
V7	Vandana	International Rice Research Institute (Philippines) IRRI	86
V8	Shiroodi	Rice Research Institute of Iran.Mazandaran (RRII)	102
V9	Keshvari		85
V10	Neda		105

based on the project implementation plan, they were sown in the seed box, and when the seedlings had three to four leaves, two seedlings were planted in each heap at a distance of 25×25 cm on the research farm (Habibi *et al*., 2022). Other farm management practices were consistently applied to all treatments per technical production directives (Mehdiniya *et al*., 2019). All treatments utilized the same amount of urea fertilizer, triple superphosphate, and potassium sulfate: 250, 100, and 100 kg per hectare, respectively.

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All triple super phosphate fertilizers were applied in conjunction with 50% urea and potassium sulfate as the base, 25% urea fertilizer 20 days after transplanting, and another 25% along with 50% potassium sulfate fertilizer 40 days after transplanting (Habibi *et al*., 2022). Two applications of Diazinon granule insecticide were used to combat the rice stem worm.

Three treatments, including flooded irrigation (up to 5 cm above the soil surface) and alternate wetting and drying at 10 cm (AWD10) and 20 cm (AWD20) below the soil surface, were conducted to determine the effect of irrigation on rice traits. In order to implement the irrigation method, three 15-centimeter-diameter, 40-centimeter-long UPVC pipes (cylinders) were placed in the middle of each 60-square-meter main plot (6×10 meters). The pipes were positioned 30 cm within and 10 cm above the soil's surface. To apply alternate wetting and drying treatments, when the water depth decreased to 10 and 20 cm below the soil surface, irrigation was conducted up to a height of 5 cm above the soil surface. Throughout the entire growth period, the water was flooded up to 5 cm above the soil level for flood irrigation treatment. In each irrigation, water was measured based on the flow rate of the incoming water (L S^{-1}), and irrigation duration was recorded (Habibi *et al*., 2022).

The above rice genotypes were selected among the 56 genotypes in the greenhouse evaluation based on 20 drought stress tolerance traits and mechanisms such as morpho-physiological traits and traits related to photosynthesis pigments and chlorophyll fluorescence components, and other traits related to drought tolerance based on research of Nasiri *et al*. (2020). In general, two cultivars, Keshvarii and Shiroodi, were more sensitive to drought than others.

Measurements

In this investigation, morphological traits such as Plant Height (PH), Number of Tillers per plant (TN), Panicle Length (PL), Biological Yield (BY), Grain Yield (GY), Thousand-Grain Weight (TGW), Harvest Index (HI), and percentage of unfilled and filled grains were evaluated.

The percentages of chlorophyll a, chlorophyll b, and carotenoids were determined based on their wavelength. In this method, 0.1 g of leaf tissue was gradually dissolved with 80% acetone to allow chlorophyll to enter the acetone solution. Finally, the volume of the solution was increased to 2.5 mL with 80% acetone. The resultant solution was centrifuged at 400 rpm for 10 minutes, and its optical absorption at 470, 646.8, and 663.2 nm was measured using a spectrophotometer (Bausch and Lomb, UK). After collecting initial data, each sample's chlorophyll and carotenoid content was calculated (Lichtenthaler and Welburn, 1994).

The Amylose Content (AC) was measured in two steps according to the International Rice Research Institute's (IRRI) standard method (Tomar, 1987). In the initial step, samples and standards for measuring amylose were prepared, and in the subsequent step, amylose was measured using standard samples. The Gelatinization Temperature (GT) of rice was determined per the method described by Little *et al.* (1958). This was accomplished by employing a 7.1% potassium hydroxide solution on rice samples. Consequently, the treatments under study were ranked as follows:

1: The potassium hydroxide solution is inert, and the grains are healthy; Rank

2: The grains are healthy and swollen; Rank

3: The grains are swollen, and the outer layer is loose and thin; Rank

4: The grains are swollen with transverse cracks and a dark, cloudy background;

5: The grains are curved and have longitudinal and transverse cracks, and the outer layer is completely dispersed in the solution;

6: The outer layer is completely dispersed in the solution, and Rank

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7: The grains have been completely dissolved and have left no trace (colorless). According to this classification, the lower the rating, the higher the sample's gelatinization temperature and cooking time. The method developed by Juliano and Perez (1984) was used to measure grain elongation after cooking.

Furthermore, the Milling Recovery (MR) (Total weight of white rice/Weight of paddy×100), Milling Degree (MD) (Total white rice weight/Brown rice weight×100), and Percentage of Broken (BRG) and Head Grain (HRG) (Total rice weight/Paddy weight×100), Rice Length Before Cook (RLBC), Rice Length After Cook (RLAC), and Elongation Ratio (ER), were calculated.

Data Analysis

An Analysis Of Variance (ANOVA) was conducted at the end of each year. The collected data were subjected to a variance analysis using SAS v. 9.3 (SAS Institute, 1997) to determine the statistical significance of the treatment effect. When the F-value was significant, the means were compared using the LSD test. Moreover, a multivariate Pearson correlation analysis based on Principal Components Analyses Ranking (PCA Ranking) was performed to examine the relationship between variables (McCune and Mefford, 1999).

RESULTS

The data analysis revealed that the year and genotype treatment effect was significant at the 1 and 5% probability levels for chlorophyll a and b and carotenoids. Nonetheless, irrigation was insignificant at the 1% probability level for chlorophyll a (Table 4). According to (Table 5), the effect of the treatment interaction was insignificant. The mean comparisons showed that the second year of irrigation systems had the highest chlorophyll a and b and carotenoid content. In addition, the highest chlorophyll concentration was found in V4-6, while the lowest was in V2. In addition, the mean comparison (Table 6) indicated that V7 and 8 had the highest chlorophyll b content, while other cultivars had the lowest. In addition, V7 and V8 exhibited the highest levels of carotenoids in the first year, whereas the carotenoid content of the whole cultivars was not significant in the second year.

The results generally indicated that all morphological parameters were significantly affected by genotype treatments; however, the effect of year was significant for most parameters except TN, HI, and PL. However, irrigation was statistically significant at the 1% probability level for PH and TN (Table 7). The highest plant height and percentage of unfilled grains belonged to variety V5, while the lowest belonged to V10. In addition, V8 had the most significant number of tiller and panicle lengths. Furthermore, the highest percentage of whole grains was found in V1 and V9. Moreover, V10 had the highest grain yield and harvest index, whereas V4 had the lowest. In addition, the mean comparison revealed that V4 had the highest biological yield, while some treatments had the lowest (Table 8).

The mean comparison of the effect of year and different irrigation treatments on morphological traits (Table 9) revealed that none of the parameters were statistically significant in the two study years. Observations indicated that the AWD20 treatment resulted in an average of 17.2 TN in the first year. The PH was observed to be 130.8 cm on average within the FI. Moreover, the highest value of PL (29.4 mm) in 2017 was associated with FI. Over the two years, the values of UG were not significantly different from other treatments.

As depicted in Figure 1, Biological Yield (BY) was significantly greater in V1 under three different irrigation systems, while V6 had the lowest yield in the second year.

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Table 4. Analysis of variance in chlorophyll and carotenoid content of 10 rice genotypes cultivated in 2016 and 2017 under different irrigation systems.[a]

SOV	df	Carotenoids	Chl b	Chl a
Year (A)	1	355.6 **	264.7 **	183.8 **
Rep (Year)	4	6.4	1	0.6
Irrigation(B)	2	1.2 ns	3.7 *	2*
A B	2	0.1ns	0.1 ns	0. 5 ns
Error 1	8	6.7	1.4	0.6
Genotype (C)	9	18.6 **	4 **	2 **
B × C	18	15.6 **	4.6 **	1 ns
A × C	9	0.4ns	0.1ns	0.7 ns
A × B × C	18	1ns	0.1ns	0.4 ns
Error 2	108	3.2	1.3	0.4

[a] *and**: Significant at 5% and 1% probability level, respectively; ns= Non-significant difference, df: Degrees of freedom, Chl a: Chlorophyll a, Chl b: Chlorophyll b, and Car: Carotenoids.

Table 5. The comparison of means of chlorophyll and carotenoid content affected by different irrigation systems during 2016 and 2017.[a]

		2016			2017	
	FI	AWD10	AWD20	FI	AWD10	AWD20
Chl a (mg g^{-1} FW)	7b	6.8b	7b	9.8 a	9.5 a	9.9 a
Chl b (mg g^{-1} FW)	4.5c	4d	4.5 c	6.9 a	6.5b	6.8 a
Carotenoids (mg g^{-1} FW)	1.8c	2.3 b	1.9 c	3.9 a	4a	4a

[a] (a-c): Means with a similar letter are not significantly different (P< 0.01). Chl a: Chlorophyll a, Chl b: Chlorophyll b, and Car: Carotenoids, Flooded Irrigation (FI), AWD10: Alternate Wetting and Drying at 10 cm, AWD20: Alternate Wetting and Drying at 20 cm.

Table 6. The comparison of the means of chlorophyll and carotenoid content of 10 genotypes in each rice column in 2016 and 2017.[a]

	2016			2017		
	Chl.a (mg g^{-1} FW)	Chl b (mg g^{-1} FW)	Car (m g^{-1} FW)	Chl a (mg g^{-1} FW)	Chl b (mg.g^{-1} FW)	Carotenoids (mg g^{-1} FW)
V1	6.9ab	3.9 b	2 ab	9.4 ab	6.4 b	3.9 a
V2	4.7 c	3.7 b	2.2 ab	7.2 b	6.2 b	4.4 a
V3	7.6 a	4.4 ab	1.4 b	10 ab	6.6 b	3.7 a
V4	8 a	4 ab	1.7 ab	11a	6.7 b	3.7 a
V5	7.4 a	4 ab	2 ab	10.3 a	6.7 b	4.2 a
V6	7.8 a	4 ab	1.5 b	11 a	6.4 b	3.8 a
V7	7.4 a	5.2 a	2.4 a	9.9 ab	7.7 a	4.6 a
V8	7 ab	4.9 a	2.6 a	9.8 ab	7.4 a	3.6 a
V9	6.3 b	4.3 ab	1.8 b	9.3 ab	6.5 b	3.9 a
V10	6.3 b	4.8 d	2.6 a	9.6 ab	6.9 ab	4.4 a

[a] (a-b): Means with a similar letter are not significantly different (P< 0.01). V1-V10: Ten genotypes of rice ranged from V1 to V10; Chl a: Chlorophyll a, Chl b: Chlorophyll b, and Car: Carotenoids.

No significant differences were observed in Grain Yield (GY) over the two years.

Based on the composite variance analysis (Table 10) of the data obtained from the experiment, the simple effect of the year on all qualitative parameters, excluding HRG and AC, was significant. In addition, the simple effect of various irrigation regimes

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Table7. Analysis of variance of morphological traits of 10 rice genotypes cultivated in 2016 and 2017 under different irrigation systems.[a]

S.O.V	df	GY	BY	HI	PH	TN	PL	UG (%)	FG	TGW
Year (A)	1	**23177045	**52800554	9.6ns	**4442	0.02ns	39.8ns	43.8**	**	96.3**
Rep (Year)	4	975965.7	27041970	24.8	4295.8	16.5	23	42.7	472.7	38.3
Irrigation(B)	2	815535.8ns	65.5ns	0.0005 ns	**346	**29.6	4.5 ns	6.3 ns	0.04 ns	17.5 ns
A ×B	2	977191 ns	631.8 ns	0.0001 ns	76.4 ns	2.3 ns	2 ns	5.8 ns	0.2 ns	10.9 ns
Error 1	8	392167.3	9967632	26.9	276.3	11.4	15	23.7	0.4	9.5
Genotype (C)	9	26547144.8**	**286367.2	**1899.3	**6206.7	**98.9	*89.9	*748.5	**739.2	**136.2
B ×C	18	923271.4 ns	142.7 ns	0.002 ns	**222.8	**11	6.2 ns	26.3 ns	0.1 ns	9.6 ns
A × C	9	953565.4 ns	32087564.6**	119.5**	108.5 ns	1 ns	15.4 ns	**92.7	ns 1	10.8 ns
A × B ×C	18	703126 ns	107.1 ns	0.001 ns	11 ns	1 ns	12.8ns	**49.8	0.1 ns	13.3 ns
Error 2	108	163597	1350	0.0002	80.4	41	9.4	13	01	2.2

[a] * and **: Significant at 5 and 1% probability level, respectively. ns= Non-significant difference, df: Degrees of freedom, Grain Yield: GY, Biological Yield: BY, Harvest Index: HI, 1000-Grain Weight: TGW, Unfilled Grain percent: UG, Full Grain percent: FG, Tiller Number: TN, Plant Height: PH, Number of Tillers/Plant: TN, and Panicle Length: PL.

Table 8. The comparison of means of morphological traits of 10 rice genotypes.[a]

Genotype	PH (cm)	TN	PL (cm)	UG (%)	FG (%)
V_1	117.7c	17.7c	28.3bc	8.8h	92.5a
V_2	112cd	16.8c	27.7c	23.9b	76c
V_3	107d	18bc	28.7bc	19d	81.8bc
V_4	139.2b	14.9d	30.5ab	12e	88.4b
V_5	151a	15d	28.4bc	25.9a	75.3c
V_6	146.7a	12.3e	27.5c	21.5c	79.5bc
V_7	137.3b	14.7d	23d	10.9f	89.5b
V_8	109d	19.6a	31.4a	12e	88.5b
V_9	116c	14.7d	29.3abc	10g	90.5ab
V_{10}	97.5e	19.2ab	29abc	11f	88b

[a] (a-g): Means with a similar letter are not significantly different (P< 0.01). V1-V10: Ten genotypes of rice ranged from V1 to V10; Unfilled Grain percent: UG, Full Grain percent: FG, Tiller Number: TN, Plant Height: PH, Number of Tillers/Plant: TN, and Panicle Length: PL.

Table 9. The comparison of means of morphological traits affected by different irrigation systems during 2016 and 2017.

	2016			2017		
	FI	AWD10	AWD20	FI	AWD10	AWD20
PH (cm)	130.8a	124.6b	129.6a	118.4c	116.6c	120c
TN	15.8ab	15.8ab	17.2a	15.6ab	16.3ab	16.9ab
PL (cm)	28a	27.7a	28a	29.4a	28.6a	28.6a
FG (%)	15b	15b	15b	16.1a	1a	15.9a
UG (%)	83.4a	83.6a	83.8a	84.4a	85.5a	85.5a

[a] (a-c): Means with a similar letter are not significantly different (P< 0.01). Unfilled Grain percent: UG, Full Grain percent: FG, Tiller Number: TN, Plant Height: PH, Number of Tillers/Plant: TN, and Panicle Length: PL, Flooded Irrigation: FI, Alternate Wetting and Drying at 10 cm: AWD10, Alternate Wetting and Drying at 20 cm: AWD20.

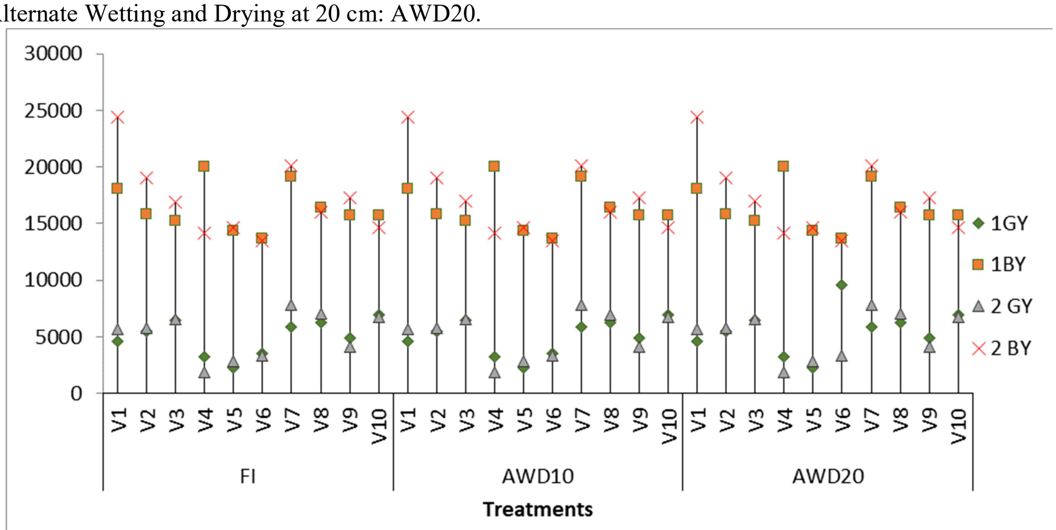

Figure 1. The comparison of means of Grain Yield (GY, kg ha^{-1}) and Biological Yield (BY, kg ha^{-1}) of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1: 2016 and 2: 2017. Flooded Irrigation: FI; Alternate Wetting and Drying at 10 cm: AWD10, Alternate Wetting and Drying at 20 cm: AWD20.

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was significant for all parameters, except RSP, RLBC, RLAC, and ER at 1 and 5%. However, the simple effect of the studied genotypes on all quality traits of grains was significant (Table 10).

Figure 2 displays the results of comparing means of HI and MR. For the two years, no significant differences were observed in these parameters. The results indicated that V10 had the highest HI, and V4 had the lowest HI compared to other varieties under three different irrigation treatments.

Comparing the means of TGW and MD in the two years revealed no statistically significant differences, except for V5 in AWD20 (Figure 3). Furthermore, water treatment did not affect these parameters.

The amount of Broken Rice Grain (BRG) of the studied genotypes in the second year compared to the first year increased significantly in V8, decreased significantly in V7, and did not differ significantly between the two years for the remaining genotypes (Figure 4). In addition, V4, V7, and V8 had the highest BRG value, whereas V4 and V7 had the lowest HRG value.

Compared to the first year, the amount of Rice Length Before Cooking (RLBC) and RLAC of the genotypes studied decreased significantly in the second year (Figure 5). V1 possessed the greatest RLAC. In addition, V4 possessed the most significant number of RLBCs.

As shown in Figure 6, no significant differences in Gelatinization Temperature (GT) were observed between cultivars over two years. The highest Elongation Ratio (ER) was associated with the V10 and V7 in AWD20, while all other cultivars exhibited the same level of this parameter. In addition, the comparison of means revealed that V710 had the highest number of Amylose Content (AC) across all three irrigation systems.

Principal Component Analysis (PCA) was used to examine the relationships between the morphological and qualitative characteristics of 10 genotypes of rice and irrigation treatments (Figure 7). The figure indicates that the first and second components accounted for approximately 26.5 and 24.1%, respectively. Approximately every association between traits was affected by rice genotypes and irrigation treatments. In addition, V7 to V10 exhibited significant variations in all parameters, whereas V6 exhibited no variation.

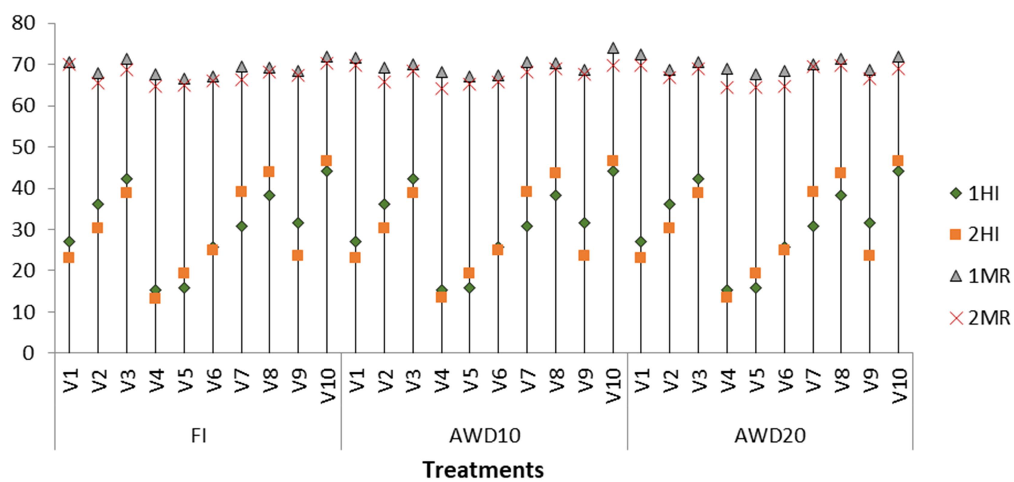

Figure 2. The comparison of means of Harvest Index (HI, %) and Milling Recovery (MR, %) of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1: 2016 and 2: 2017. Symbols FI, AWD10, and AWD20 are defined under Figure 1.

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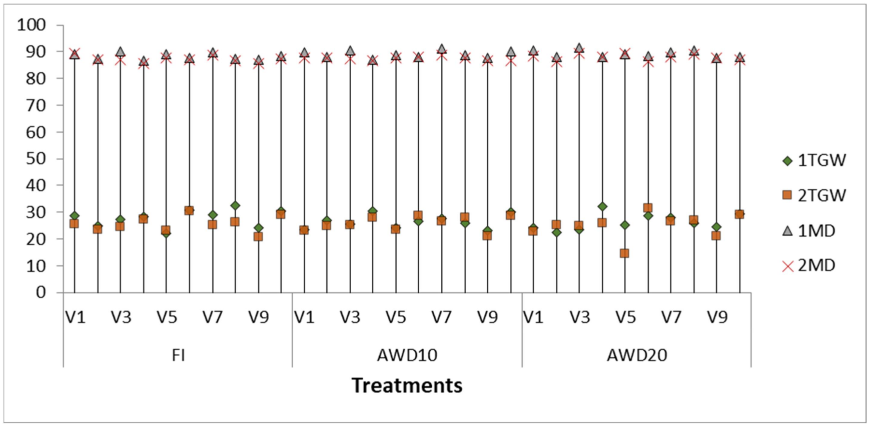

Figure 3. The comparison of means of 1000-Grain Weight (TGW, g) and Milling Degree (MD, ˚) of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1: 2016 and 2: 2017. Symbols FI, AWD10, and AWD20 are defined under Figure 1.

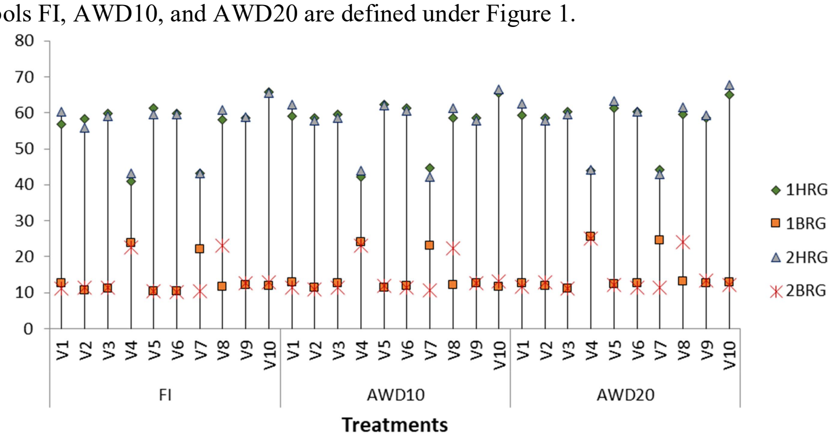

Figure 4. The comparison of means of Head Rice Grain (HRG, %) and Broken Rice Grain (BRG %) of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1: 2016 and 2: 2017. Symbols FI, AWD10, and AWD20 are defined under Figure 1.

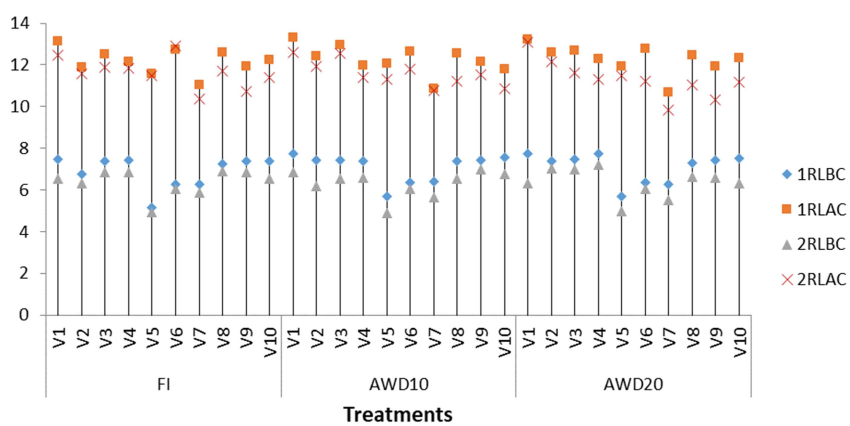

Figure 5. The comparison of means of Rice Length Before Cooking (RLBC, mm) and Rice Length After Cooking (RLAC, mm) of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1: 2016 and 2: 2017. Symbols FI, AWD10, and AWD20 are defined under Figure 1.

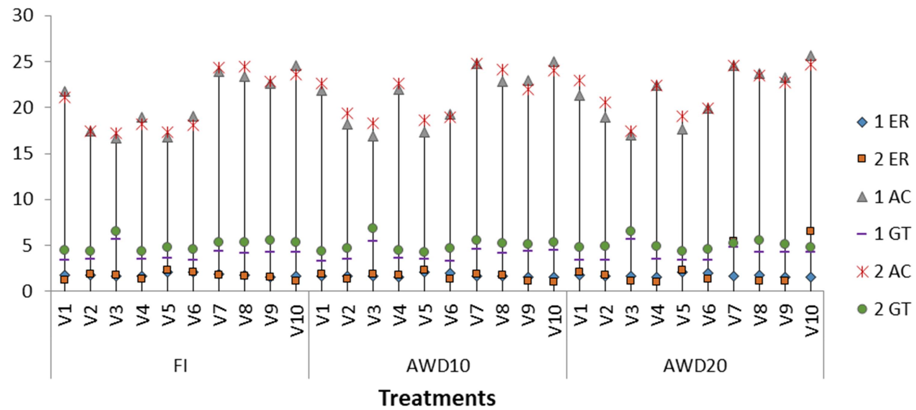

Figure 6. The comparison of means of Elongation Ratio (ER), Amylose Content (AC, %), and Gelatinization Temperature (GT, ˚C) of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1: 2016 and 2: 2017. Symbols FI, AWD10, and AWD20 are defined under Figure 1.

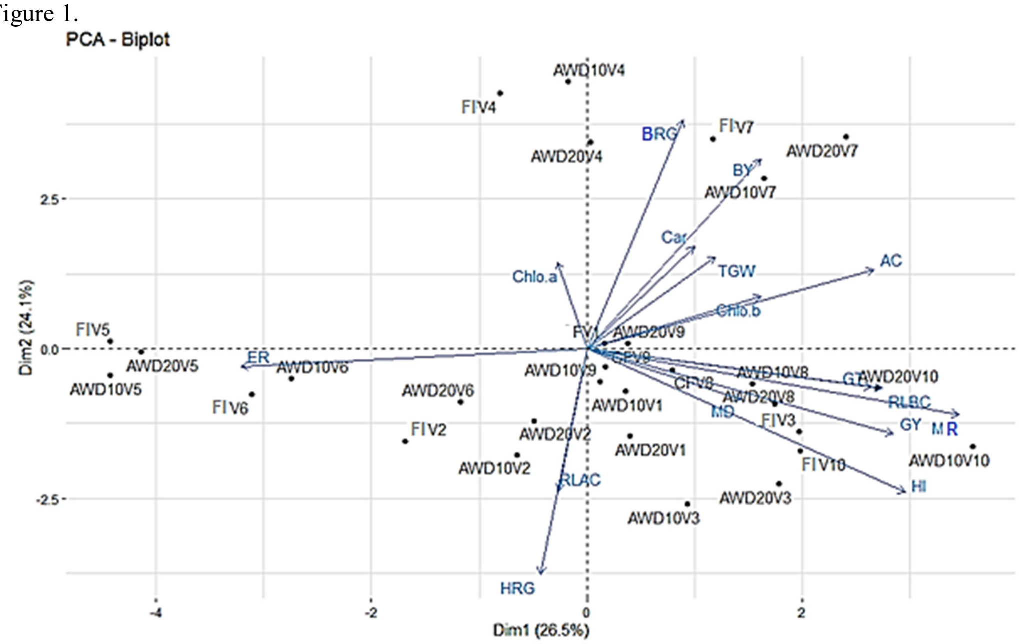

Figure 7. Principal component analysis showing association among measured traits of 10 genotypes of rice ranging from V1 to V10 subjected to Flooded Irrigation (FI), Alternate Wetting and Drying at 10 cm (AWD10) and 20 cm (AWD20), Milling Recovery (MR), Rice Shell Percentage (RSP), Rice Bran Percentage (RBP), Milling Degree (MD), Head Rice Grain (HRG), Broken Rice Grain (BRG), Rice Length Before Cooking (RLBC), Rice Length After Cooking (RLAC), Elongation Ratio (ER), Amylose Content (AC), Gelatinization Temperature (GT), Chlorophyll a (Chl a), Chlorophyll b (Chl b), Carotenoids (Car), Grain Yield (GY), Biological Yield (BY), Harvest Index (HI), and 1000-Grain Weight (TGW).

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Table 10. Analysis of variance of qualitative traits of 10 rice genotypes during 2016 and 2017 under different irrigation treatments.[a]

SOV	df	MR (%)	RSP	RBP	MD	HRG	BRG	RLBC	RLAC	ER	AC	GT
Year (A)	1	224.2**	34.6**	31.9**	76.4**	10.9ns	4.7*	**20.2	**23.9	**0.34	2.2ns	**50
Irrigation(B)	2	4.9*	1.3 ns	**10	**10.6	**19.4	**18.3	0.01 ns	0.2ns	0.04ns	**20.8	0.004ns
A×B	2	1.7ns	**3.3	**10.2	0.59ns	1 ns	1.2ns	*0.3	0.68*	0.03ns	0.9ns	0.006ns
Error 1	8	1.4	2.3	1.02	6	5.9	1.4	0.4	0.89	0.04	2.4	0.07
Genotype (C)	9	**63.2	**29.4	**8.2	**15.5	**1043.8	**314.5	7.8 **	**7.3	**0.061	137.4**	**8.5
B×C	18	1.6ns	**1.6	0.06 ns	*2.4	1.4 ns	1.4 ns	*0.16	**0.49	0.01 ns	2.9**	0.09 ns
A×C	9	2.3 ns	**1.9	*1.2	1.9ns	11.2**	135.3**	0.19*	*0.38	0.04**	**2	0.1 ns
A×B×C	18	1.3 ns	*1.1	0.07 ns	1.2 ns	4.1 ns	0.06 ns	0.08 ns	0.2ns	0.01 ns	0.06 ns	0.09 ns
Error 2	108	1.2	0.6	0.6	1.3	3.3	1.1	0.08	0.17	0.01	0.7	0.06

[a] * and **: Significant at 5 and 1% probability level, respectively. ns= Non-significant difference, Milling Recovery: MR, Rice Shell Percentage: RSP, Rice Bran Percentage: RBP, Milling Degree: MD, Head Rice Grain: HRG, Broken Rice Grain: BRG, Rice Length Before Cooking: RLBC, Rice Length After Cooking: RLAC, Elongation Ratio: ER, Amylose Content: AC, Gelatinization Temperature: GT.

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DISCUSSION

This study demonstrated that the Neda genotype was one of the rice genotypes with the highest percentage of whole grains. According to Xu *et al*. (2020), the percentage of filled grains has a positive and significant relationship with grain yield. The AWD20, with an average height of 120 cm, had the highest plant height in the second year of the experiment, whereas the control and AWD10 had the lowest in both years.

According to the research of Limouchi *et al*. (2018), by wetting and drying the soil surface with intermittent irrigation, a process of air exchange between the soil and the atmosphere is established, allowing the roots of the plant to receive sufficient oxygen within a few days of watering. These circumstances accelerate the soil's organic chemical mineralization and nitrogen fixation. These factors contribute to increased plant nutrients and, consequently, its growth (Limouchi *et al*., 2018). In addition, two less-applied irrigation treatments in the study had the highest number of tillers in the second year, with an average of 16.3 and 16.9 tillers for AWD10 and AWD20, respectively.

More frequent water management and drying will improve the environment of the root system. This is because the root system will have sufficient water and oxygen during tiller development (Mboyerwa *et al*., 2021). In other studies, AWD increases the proportion of productive tillers, increases the transfer of carbohydrates to the grain, and decreases spike sterility (Ishfaq *et al*., 2020). In addition, AWD increased the grain filling rate by boosting the activity of enzymes involved in the filling process, increasing grain yield (Mboyerwa *et al*., 2021).

In addition, the results revealed that the two-year peak harvest index, which averaged 46%, was unaffected in the Neda genotype. The harvest index for the AR8 genotype was the lowest over the two years, averaging 15.4 and 13.3% in the first and second years, respectively. According to Jearakongman *et al*. (1995), high-yielding varieties typically have short heights and a high harvest index. They demonstrated that the high yield potential of drought-tolerant genotypes results from a high harvest index under favorable conditions, an optimal flowering time to avoid water stress, and the capacity to maintain growth during drought.

In the genotypes Firozan, Shiroudi, and Neda, the total number of grains and the 1,000-grain weight differed from those of other varieties and were the highest. These genotypes, therefore, can be introduced as drought-resistant genotypes. Among all genotypes, the AR8 has the highest number of empty grains and, consequently, the lowest number of whole grains. Gent (1994) suggested that photosynthetic material stored in the stem is considered a source of grain-filling capacity replenishment under water stress conditions. Thus, the weight of the grain remains unchanged.

The cluster length of the genotypes under stress conditions also contributes to the increase in 1000-grain mass. In other words, a longer tip length indicates a greater capacity, and rice cultivars with a greater capacity have more potential to attract photosynthetic materials to themselves (Zhai *et al*., 2020). In this study, the genotype AR8 has one of the longest cluster lengths. Cooler conditions in 2016 decreased the husk and bran percentages of the genotypes in the present study. In line with these results, it was reported that cooler conditions during grain ripening decreased the amount of rice husk (Limouchi *et al*., 2018). During the blanching of brown rice, the rice bran, which accounts for 8 to 10% of the rice's weight and contains the majority of the embryo, pericarp layer, and aleuronic layer, is removed (Karam *et al*., 2021). According to Gilani *et al*. (2012), humidity also positively regulates temperature and reduces rice bran.

The degree of conversion is one of the quality parameters related to the physical and appearance characteristics of rice grains, and it is essential in marketing and pricing (Gilani *et al*., 2012). Because the bran percentage of rice genotypes was higher in the second year than in the first, it was consistent with the study's reduction of processing level in the second year. Limouchi *et al*. (2018) demonstrated that better humidity conditions in the first year did not affect genotype amylose content compared to the second year, which had much less rainfall. Due to lower ambient humidity, the gelatinization temperature decreased by 25% in 2016 compared to 2015.

Gelatinization temperature and amylose content are rice quality characteristics that are especially significant for evaluating cooking quality (Rayee *et al*., 2021). The study revealed that water stress during spawning, particularly during the grain-filling phase until ripening, decreased gelation temperature, reducing cooking time (Desamero *et al*., 2020; Vidal *et al*., 2007). Furthermore, a study reported that the amount of amylose varies depending on the genotype of the rice plant (Kitara *et al*., 2019). Most rice consumers and traders desire medium amylose content (Suman *et al*., 2020). Thus, the Neda, Vandana, Shiroudi, Kishori, IR74428-153-2-3, and IR75482-149-1-1 genotypes are among those with moderate amyloidosis and excellent cooking qualities, whereas the Firozan, G28, and IR70416-53 -2-2 genotypes are among those with low amylose content.

CONCLUSIONS

According to the evaluations conducted in this study, the results of plant traits indicated that the Neda and Shiroudi rice genotypes, as well as the IR70416-53-2-2 and IR75482-149-1-1, have likely a suitable response to alternate wetting and drying irrigation conditions in Mazandaran Province and similar climates. Therefore, this irrigation method is suitable for increasing the water productivity of the mentioned genotypes and lines. Also, one of the two pure lines i.e. IR70416-53-2-2 and IR75482-149-1-1, which have superior physical and chemical qualities compared to the Neda and Shiroudi cultivars, can be considered as drought-tolerant rice genotypes.

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بهینه سازی آبیاری برنج (*Oryza sativa* L.) برای معرفی ژنوتیپ بهینه برای عملکرد دانه و ارتقای کیفیت

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چکیده

استفاده از روش های نوین آبیاری برای معرفی ارقام به شالیزارهایی که با کمبود آب مواجه هستند، یکی از راه های مبارزه با کم‌آبی و افزایش بهره وری آب است. بدین منظور، این آزمایش به صورت کرت های نواری در قالب طرح بلوک های کامل تصادفی با سه تکرار مستقل طی دو سال (۱۳۹۵ و ۱۳۹۶) در پژوهشکده برنج ایران، آمل، ایران انجام شد. ده ژنوتیپ برنج (V1 تا V10) تحت سه نوع سیستم آبیاری، شامل آبیاری غرقابی معمولی (FI) و مرطوب و خشک کردن متناوب (AWD) به ترتیب در ۱۰ (AWD10) و ۲۰ (AWD20) سانتی متر زیر سطح خاک قرار گرفتند. این نتایج نشان می‌دهد که روش‌های AWD10 و AWD20 مصرف آب را به ترتیب ۲۰ و ۱۷ درصد در مقایسه با روش‌های معمول کاهش می‌دهند. این کاهش مصرف آب در مقایسه با سیستم آبیاری غرقابی معمولی منجر به کاهش ۱.۴% و ۰.۲% عملکرد شد. همچنین، بازیافت آسیاب در آبیاری غرقابی (۶۸/۷ درصد) کمتر از سایر روش‌های تر و خشک کردن ۱۰ و ۲۰ (به ترتیب ۶۹/۶ و ۶۹/۸ درصد) بود. در نتیجه، ژنوتیپ‌های ندا، شیرودی و ۸۶۱۱ برنج که پاسخ بهتری به آبیاری AWD نشان داده‌اند، می‌توانند به‌عنوان ژنوتیپ‌های مناسب برای افزایش بهره‌وری آب در شالیزارها در نظر گرفته شوند.

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