

1 **Optimizing Rice (*Oryza sativa* L.) Irrigation to Introduce the Optimum** 2 **Genotype for Grain Yield and Quality Promotion**

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3 **Abstract**

4 Utilizing new irrigation techniques to introduce cultivars into paddy fields experiencing water
5 scarcity is one way to combat and increase water productivity. This experiment was conducted
6 as a strip plot in a randomized complete block design with three independent replications over
7 two years (2016 and 2017) at the Rice Research Institute of Iran, Amol, Iran. Ten rice genotypes
8 (V1 to V10) were subjected to three types of irrigation systems, including conventional flooded
9 irrigation (FI) and alternate wetting and drying (AWD) at 10 (AWD10) and 20 (AWD20) cm
10 below the soil surface, respectively. These results demonstrate that AWD10 and AWD20
11 methods reduced water consumption by 20% and 17%, respectively, compared to conventional
12 methods. This decreased water usage resulted in 1.4% and 0.2% yield losses compared to the
13 conventional flood irrigation system. Moreover, milling recovery in flood irrigation (68.7
14 percent) was lower than other wetting and drying methods 10 and 20 (69.6% and 69.8%,
15 respectively). **In conclusion, Neda, Shiroodi, and 8611 rice genotypes which have shown a
16 better response to AWD irrigation may be considered as suitable genotypes for increasing
17 water productivity in paddy fields.**

18 **Keywords:** Growth, grain yield, irrigation management, photosynthetic characteristics, rice

19 **Introduction**

20 Rice (*Oryza sativa* L.) occupies more than 9% of arable land and is the staple food for more
21 than half of the world's population (Phan et al., 2022). Rice has the largest cultivated area and
22
23

24 the lowest irrigation recovery of all cereals compared to other irrigated crops. One kilogram of
25 rice requires approximately three times the amount of water as one kilogram of wheat. In fact,
26 rice plants receive two to three times more water than other crops (Bouman et al., 2007).
27 Therefore, drought is the most significant factor limiting global production, necessitating
28 optimal use of water resources to determine rice's actual water needs (MacLean et al., 2002).
29 Generally, 75% of Iran's rice crop is irrigated by flooding. Due to Iran's location in arid and
30 semi-arid regions, water stress is one of the most significant agricultural production challenges
31 (Nouri et al., 2020). Wetting and drying paddy fields with intermittent irrigation has been
32 considered one of the most effective water management techniques in agriculture, as it meets
33 the needs of plants in arid environments (Shanmugasundaram, 2015). This irrigation method
34 induces an air exchange between the soil and the atmosphere (Tuong et al., 2005). When
35 watering a plant every few days, the root system receives sufficient oxygen, accelerating the
36 mineralization of organic chemicals and stabilizing nitrogen in the soil. These factors result in
37 improved plant nutrient uptake and increased growth rates (Tan et al., 2013; Dong et al., 2012).
38 Water savings is the most important advantage of intermittent rice irrigation with multiple-day
39 irrigation cycles (Uphoff et al., 2013).

40 Guo et al. (2003) demonstrated that water stress significantly decreased rice yield within 25
41 days of 80% **maturity**. After twenty-five days, this effect becomes very weak, and soil water is
42 able to sustain the physiological viability of rice plants for ten days. Razavipour (1994)
43 proposed that rice can thrive in wet conditions without flooding. If soil moisture exceeds
44 80% saturation, soil performance should remain unaffected. Not only is there no decrease in
45 yield under these conditions, but the rice grows well, and the grains and stems are healthy and
46 undamaged.

47 It is possible to develop new rice cultivars through short- or long-term breeding programs due
48 to the existence of significant genetic diversity in response to stresses and coping mechanisms
49 (Limouchi et al., 2018). Despite the need for high-yielding cultivars, it is also important to
50 consider the stress tolerance of local cultivars (Wu et al., 2011; Habibi et al., 2021). Drought-
51 tolerant cultivars aim to identify and introduce cultivars that are more tolerant to stress than
52 other genotypes and experience less yield loss under identical environmental conditions
53 (Srivastava et al., 1987). Fernandez (1992) categorized wheat genotypes into four groups based
54 on their responses to stressful and non-stressful environmental conditions. 1. dominant
55 genotype in both media and yielding more grain (group A). 2-dominant genotypes are
56 exclusively in the desired environment and partially low-yielding in the stressful environment
57 (group B). 3- genotypes with relatively high yield in stressful environments, whose yield will

58 decrease in non-stress environments (group C), and 4-genotypes with low yield in both non-
59 stress and stressed environments (group D).

60 This study evaluated the agronomic and yield characteristics of selected rice genotypes in the
61 Mazandaran (Amol) region using an alternate wetting and drying irrigation system.

62
63 **Materials and methods**

64 **Location and experimental design**

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

70
71

72 **Table 1.** Annual growing season temperature and precipitation for 2016-2017.

2016	Temperature (°C)		Humidity (%)		Total precipitation (mm)	Total sunny hours
	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

73
74 **Treatments**

75 This survey used a randomized complete block design (RCBD) with a strip-plot layout. Before
76 planting, the soil had the following characteristics (Table 2): Ten experimental rice cultivars
77 (V1 to V10) were selected from 56 genotypes based on greenhouse evaluation of drought
78 tolerance traits and mechanisms, such as physiological traits. These genotypes tolerate drought
79 during the dry period (Nasiri et al., 2020). These traits included the dry weight of the roots and
80 shoots, the plant's height, the relative water content of the leaves, and the relative membrane

81 permeability. Chlorophyll a, b, and carotenoids are components of chlorophyll photosynthesis
 82 and fluorescence (Nasiri et al., 2020). The names and origins of the rice genotypes are listed in
 83 Table 3.

84 Before the field operations, the mentioned cultivars' seeds were germinated. Then, based on the
 85 project implementation plan, they were sown in the seed box, and when the seedlings had three
 86 to four leaves, two seedlings were planted in each heap at a distance of 25×25 cm on the research
 87 farm (Habibi et al., 2021). Other farm management was consistently applied to all treatments
 88 per technical production directives (Mehdiniya et al., 2019). All treatments utilized the same
 89 amount of urea fertilizer, triple superphosphate, and potassium sulfate: 250, 100, and 100 kg
 90 per hectare, respectively. All triple super phosphate fertilizers were applied in conjunction with
 91 50% urea and potassium sulfate as the base, 25% urea fertilizer 20 days after transplanting, and
 92 another 25% along with 50% potassium sulfate fertilizer 40 days after transplanting (Habibi et
 93 al., 2021). Two applications of Diazinon granule insecticide were used to combat the rice stem
 94 worm.

95 Three treatments, including flooded irrigation (up to 5 cm above the soil surface) and alternate
 96 wetting and drying at 10 cm (AWD10) and 20 cm (AWD20) below the soil surface, were
 97 conducted to determine the effect of irrigation on rice traits. In order to implement the irrigation
 98 method, three 15-centimeter-diameter, 40-centimeter-long UPVC pipes (cylinders) were placed
 99 in the middle of each 60-square-meter main plot (6 x 10 meters). The pipes were positioned 30
 100 cm within and 10 cm above the soil's surface. To alternate wetting and drying treatments,
 101 irrigation was conducted up to a height of 5 cm above the soil surface when the water depth
 102 decreased to 10 and 20 cm below the soil surface. Throughout the entire growth period, the
 103 water was flooded up to 5 cm above the soil level for flood irrigation treatment. In each
 104 irrigation, water was measured based on the flow rate of the incoming water (L.S⁻¹), and
 105 irrigation duration was recorded (Habibi et al., 2021).

106
 107 **Table 2.** The experimental site's soil physical and chemical traits during the 2016 and 2017
 108 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

109
 110 **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)		88

V2	IR75482-149-1-1 (55 or 8611)	International Rice Research Institute (IRRI)	92
V3	IR70416-53-2-2 (56 or 8616)		87
V4	IR79907-B-493-3-3-1 (AR8)	Rice Research Institute of Iran Fars (RRII)	100
V5	G28		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

111

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

117 **Measurements**

118 In this investigation, morphological traits such as plant height (PH), number of tillers per plant
 119 (TN), panicle length (PL), biological yield (BY), grain yield (GY), thousand-grain weight
 120 (TGW), harvest index (HI), and percentage of unfilled and filled grains were evaluated.

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

128 The amylose content (AC) was measured in two steps according to the International Rice
 129 Research Institute's (IRRI) standard method (Tomar, 1987). In the initial step, samples and
 130 standards for measuring amylose were prepared, and in the subsequent step, amylose was
 131 measured using standard samples. The gelatinization temperature (GT) of rice was determined
 132 per the method described by Little et al. (1958). This was accomplished by employing a
 133 7.1% potassium hydroxide solution on rice samples. Consequently, the treatments under study
 134 were ranked as follows:

135 Rank 1: The potassium hydroxide solution is inert, and the grains are healthy; Rank 2: The
 136 grains are healthy and swollen; Rank 3: The grains are swollen, and the outer layer is loose and
 137 thin; Rank 4: The grains are swollen with transverse cracks and a dark, cloudy background;

138 Rank 5: The grains are curved and have longitudinal and transverse cracks, and the outer layer
139 is completely dispersed in the solution; Rank 6: The outer layer is completely dispersed in the
140 solution, and Rank 7: The grains have been completely dissolved and have left no trace
141 (colorless). According to this classification, the lower the rating, the higher the sample's
142 gelatinization temperature and cooking time. The method developed by Juliano and Perez
143 (1984) was used to measure grain elongation after cooking.

144 Furthermore, the milling recovery (MR) (total weight of white rice/weight of paddy \times 100),
145 milling degree (MD) (total white rice weight / brown rice weight \times 100), and percentage of
146 broken (BRG) and head grain (HRG) (total rice weight/paddy weight \times 100), rice length before
147 cook (RLBC), Rice length after cook (RLAC), and elongation ratio (ER), were calculated.

149 **Data analysis**

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

157 **Results**

158 The data analysis revealed that the year and genotype treatment effect was significant at the 1%
159 and 5% probability levels for chlorophyll a and b and carotenoids. Nonetheless, the irrigation
160 was insignificant at the 1% probability level for chlorophyll a (
161 Table 3). According to Table 4, the effect of the treatment interaction was insignificant. The
162 mean comparisons showed that the second year of irrigation systems had the highest
163 chlorophyll a & b and carotenoid content. In addition, the highest chlorophyll concentration
164 was found in V4-6, while the lowest was in V2. In addition, the mean comparison (**Error!**
165 **Reference source not found.**6) indicated that V7 and 8 had the highest chlorophyll b content,
166 while other cultivars had the lowest. In addition, V7 and 8 exhibited the highest levels of
167 carotenoids in the first year, whereas the carotenoid content of whole cultivars was not
168 significant in the second year.

170 **Table 3.** Analysis of variance in chlorophyll and carotenoid content of 10 rice genotypes
171 cultivated in 2016 and 2017 under different irrigation systems.

S.O.V	df	Carotenoids	Chl.b	Chl.a
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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

172 *ns = non-significant difference*and**: significant at 5% and 1% probability level, respectively; df: degrees of
173 freedom, chl a: chlorophyll a, chl b: chlorophyll b, and car: carotenoids.

174

175 **Table 4.** The comparison of means of chlorophyll and carotenoid content affected by different
176 irrigation systems during 2016 and 2017.

	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	6.9a	6.5b	6.8 a
Carotenoids (m.g ⁻¹ FW)	1.8c	2.3 b	1.9 c	3.9 a	4a	4a

177 *Means with a similar letter are not significantly different (P<0.01); chl a: chlorophyll a, chl b: chlorophyll b, and
178 car: carotenoids, flooded irrigation (FI), alternate wetting and drying at 10 cm: AWD10, alternate wetting and
179 drying at 20 cm: AWD20.

180

181 **Table 6.** The comparison of the means of chlorophyll and carotenoid content of 10 genotypes
182 in each rice column in 2016 and 2017.

	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	11 a	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	11a	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	6/3b	4.3 ab	1.8 b	9.3 ab	6.5 b	3.9 a
V10	6/3b	4.8 d	2.6 a	9.6 ab	6.9 ab	4.4 a

183 *Means with a similar letter are not significantly different (P<0.01); ten genotypes of rice ranged from V1 to V10;
184 chl a: chlorophyll a, chl b: chlorophyll b, and car: carotenoids.

185

186 The results generally indicated that all morphological parameters were significantly affected by
187 genotype treatments; however, the effect of year was significant for most parameters except
188 TN, HI, and PL. However, irrigation was statistically significant at the 1% probability level for
189 PH and TN (Table 5). The highest plant height and percentage of unfilled grains belonged to
190 variety V5, while the lowest belonged to V10. In addition, V8 had the most significant number
191 of tiller and panicle lengths. Furthermore, the highest percentage of whole grains was found in
192 V1 and V9. Moreover, V10 had the highest grain yield and harvest index, whereas V4 had the
193 lowest rate. In addition, the mean comparison revealed that V4 had the highest biological yield,
194 while some treatments had the lowest (Table 8).

195 **Table 5.** Analysis of variance of morphological traits of 10 rice genotypes cultivated in 2016
196 and 2017 under different irrigation systems

S.O.V	df	GY	BY	HI	PH	TN	PL	UG (%)	FG	TGW
Year (A)	1	23177045**	52800584**	9.6ns	4442**	0.02ns	39.8ns	43.8**	472.7**	96.3**
Rep (Year)	4	975965.7	27041970	24.8	4295.8	16.5	23	42/7	1	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	15.4ns	92.7**	ns1	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	4.1	9.4	13	0.1	2.2

197 *ns = non-significant difference*and**: Significant at 5% and 1% probability level, respectively; df: degrees of
198 freedom, grain yield: GY, biological yield: BY, harvest index: HI, 1000-grain weight: TGW, unfilled grain percent:
199 UG, full grain percent: FG, tiller number: TN, plant height: PH, number of tillers/plant: TN, and panicle length:
200 PL.

201

202 **Table 8.** The comparison of means of morphological traits of 10 rice genotypes.

	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

203 *Means with a similar letter are not significantly different (P< 0.01); ten genotypes of rice ranged from V1 to V10;
204 unfilled grain percent: UG, full grain percent: FG, tiller number: TN, plant height: PH, number of tillers/plant: TN,
205 and panicle length: PL.

206

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

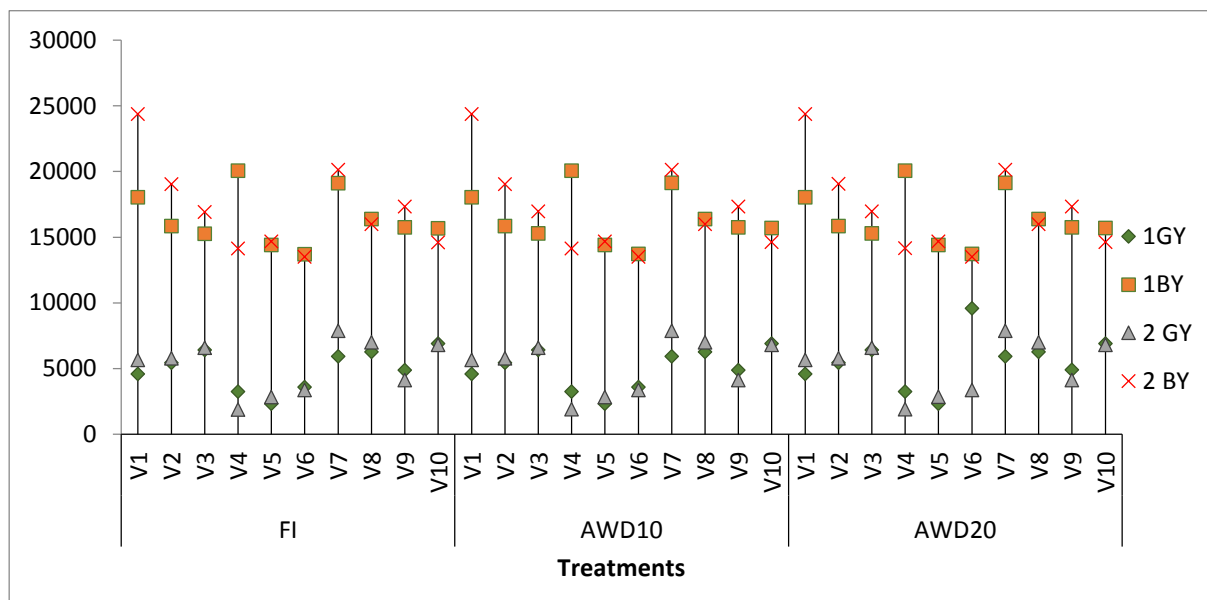
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214 **Table 6.** The comparison of means of morphological traits affected by different irrigation
215 systems during 2016 and 2017.

	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	16a	15.9a
UG (%)	83.4a	83.6a	83.8a	84.4a	85.5a	85.5a

216 *Means with a similar letter are not significantly different ($P < 0.01$); unfilled grain percent: UG, full grain percent:
 217 FG, tiller number: TN, plant height: PH, number of tillers/plant: TN, and panicle length: PL, flooded irrigation:
 218 FI, alternate wetting and drying at 10 cm: AWD10, alternate wetting and drying at 20 cm: AWD20.

219
 220 As depicted in Figure 1, BY was significantly greater in V1 under three different irrigation
 221 systems, while V6 had the lowest yield in the second year. No significant differences were
 222 observed in GY over the two years.



223
 224 **Figure 1.** The comparison of means of grain yield (kg ha^{-1}): GY, Biological yield (kg ha^{-1}): BY
 225 of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1:
 226 2016 and 2: 2017; flooded irrigation: FI, alternate wetting and drying at 10 cm: AWD10,
 227 alternate wetting and drying at 20 cm: AWD20.

228
 229 Based on the composite variance analysis (Table 10) of the data obtained from the experiment,
 230 the simple effect of the year on all qualitative parameters, excluding HRG and AC, was
 231 significant. In addition, the simple effect of various irrigation regimes was significant for all
 232 parameters except RSP, RLBC, RLAC, and ER at 1 and 5%. However, the simple effect of
 233 studied genotypes on all quality traits of grains was significant (Table 10).

234

Table 7. Analysis of variance of qualitative traits of 10 rice genotypes during 2016 and 2017 under different irrigation systems.

S.O.V	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*	1.3ns	10**	10.6**	19.4**	18.3**	0.1 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**	0.61**	137.4**	8.5**
B × C	18	1.6ns	1.6**	0.06ns	2.4*	1.4 ns	1.4 ns	0.16*	0.49**	0.01ns	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	1.3ns	1.1*	0.7 ns	1.2 ns	4.1 ns	0.6 ns	0.08ns	0.2ns	0.01 ns	0.6 ns	0.09ns
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

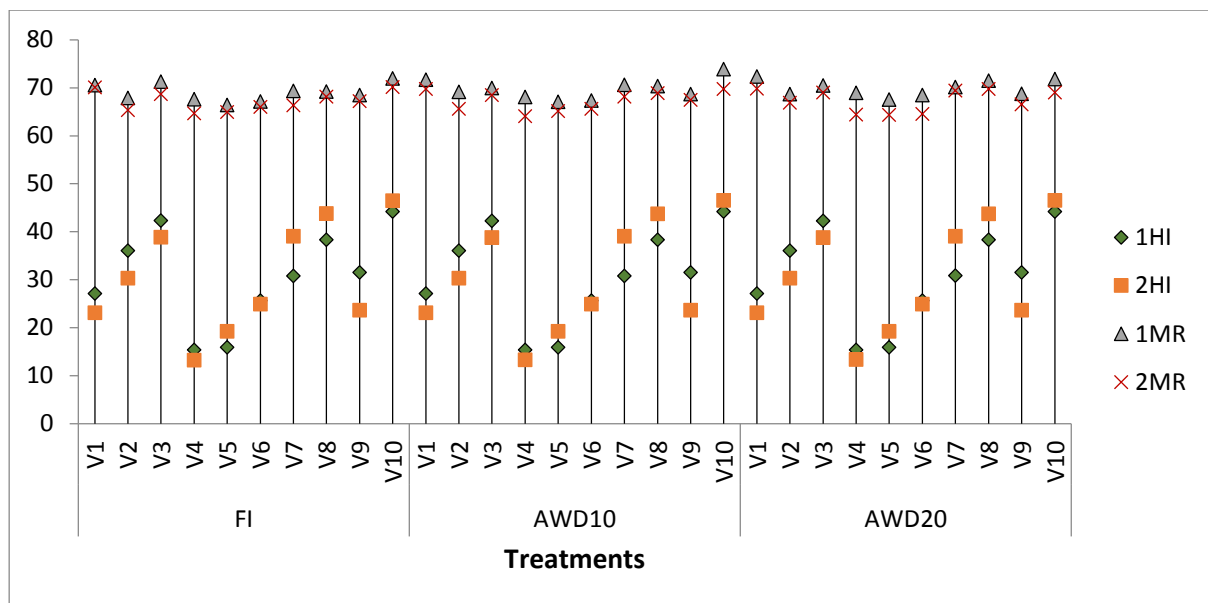
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*ns = non-significant difference*and**: Significant at 5% and 1% probability level, respectively; milling recovery: MR, rice shell percentage: RSP, rice bran percentage: RBP, milling degree: MD, head rice grain: HRG, broken rice grain: BRG, rice length before cooking: RLBC, rice length after cooking: RLAC, elongation ratio: ER, amylose content: AC, gelatinization temperature: GT

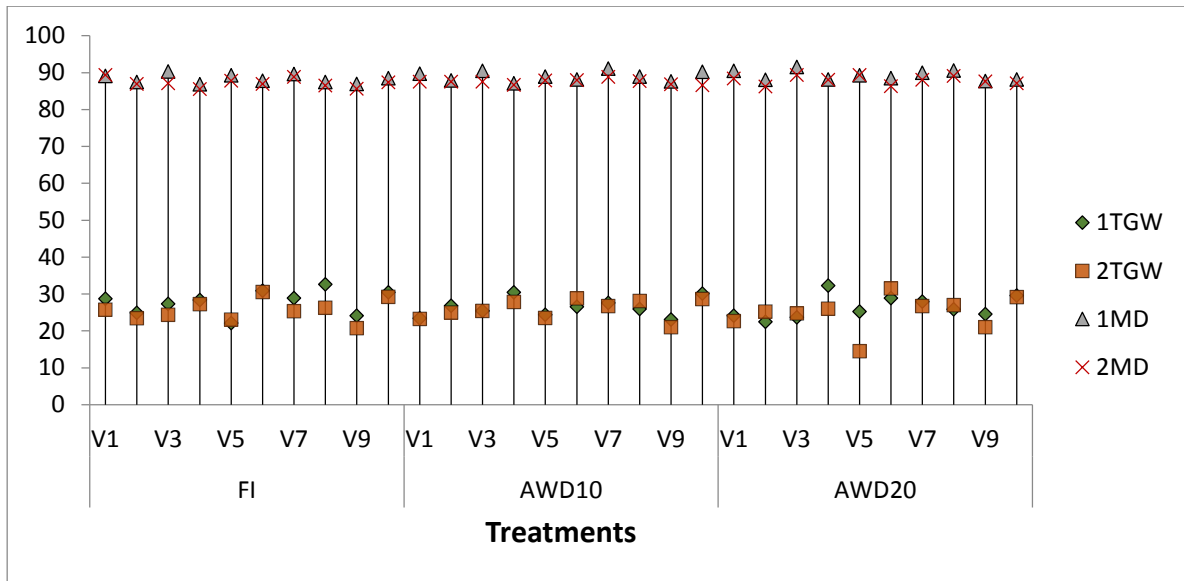
238 Figure 2 displays the results of comparing means of HI and MR. For two years, no significant
 239 differences were observed in these parameters. The results indicated that V10 had the highest
 240 HI, and V4 had the lowest HI compared to other varieties under three different irrigation
 241 systems.
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243
 244 **Figure 2.** The comparison of means of harvest index (%): HI and milling recovery (%): MR of
 245 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1:
 246 2016 and 2: 2017; flooded irrigation: FI, alternate wetting and drying at 10 cm: AWD10,
 247 alternate wetting and drying at 20 cm: AWD20.

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

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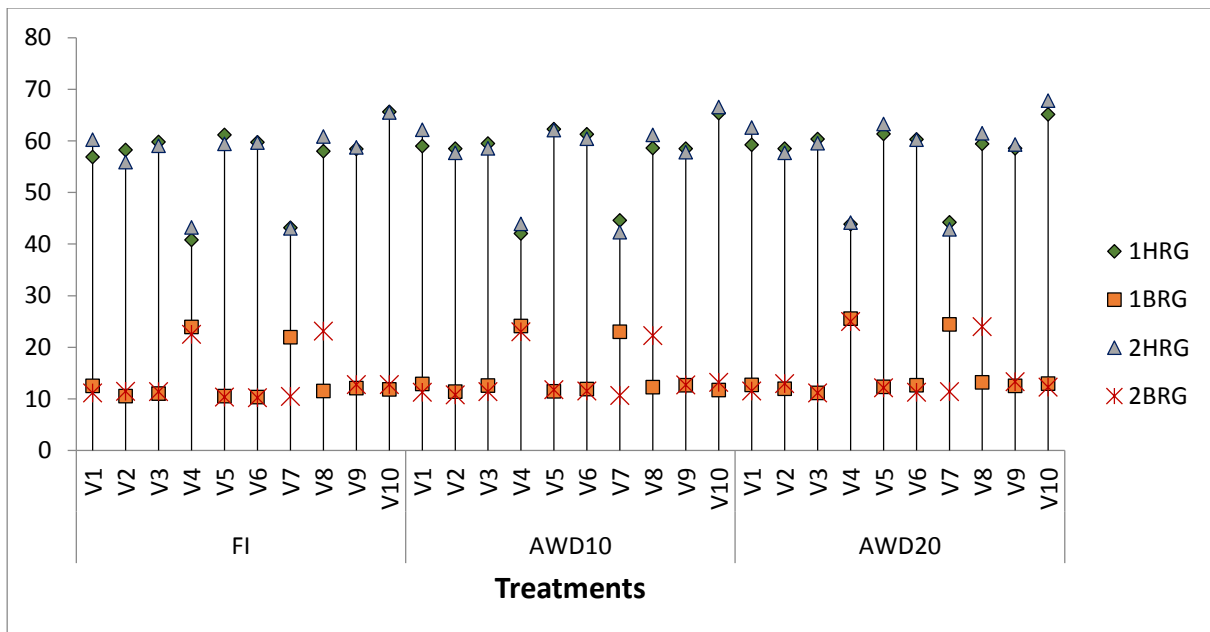


254

255 **Figure 3.** The comparison of means of 1000-grain weight: TGW (gr) and milling degree (°):
 256 MD of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1:
 257 1: 2016 and 2: 2017; flooded irrigation: FI, alternate wetting and drying at 10 cm: AWD10,
 258 alternate wetting and drying at 20 cm: AWD20.

259

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

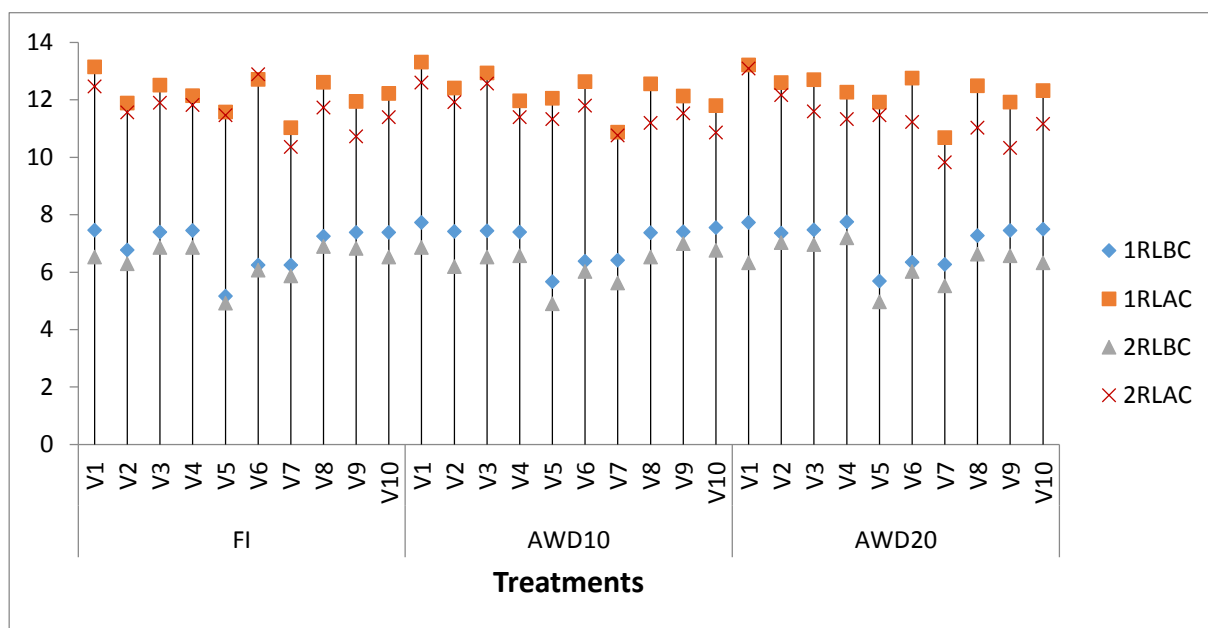


264

265 **Figure 4.** The comparison of means of head rice grain (%): HRG, broken rice grain (%): BRG
 266 of 10 rice genotypes ranged from V1 to V10 affected by different irrigation systems during 1:
 267 2016 and 2: 2017; flooded irrigation: FI, alternate wetting and drying at 10 cm: AWD10,
 268 alternate wetting and drying at 20 cm: AWD20.

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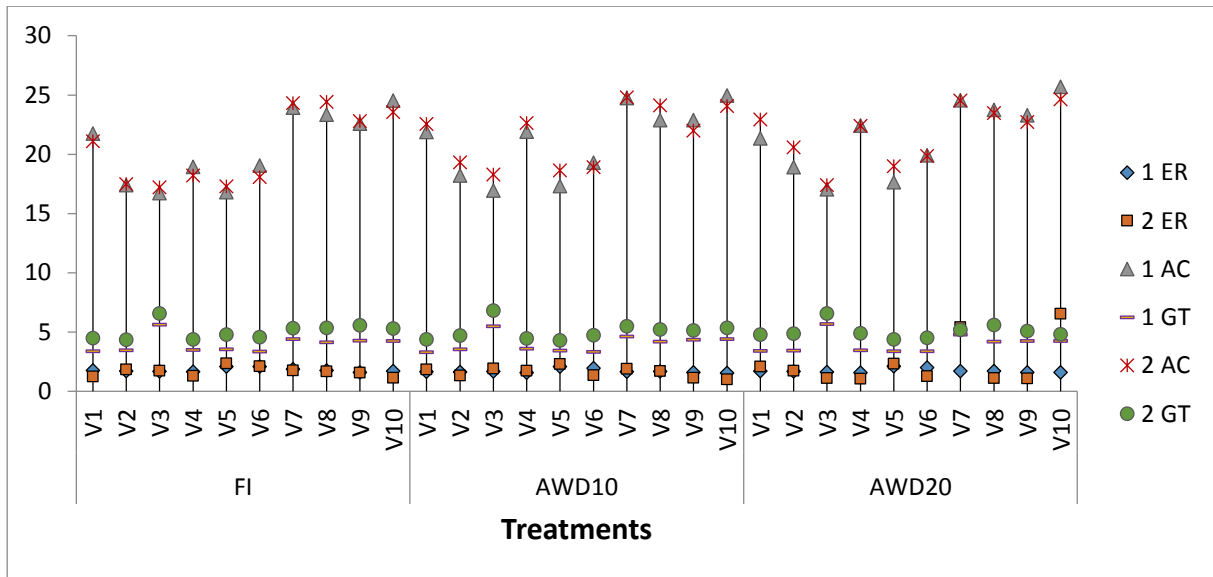
270 Compared to the first year, the amount of RLBC and RLAC of the genotypes studied decreased
 271 significantly in the second year (Figure 5). V1 possessed the greatest RLAC. In addition, V4
 272 possessed the most significant number of RLBCs.



273
 274 **Figure 5.** The comparison of means of rice length before cooking (mm): RLBC, rice length
 275 after cooking (mm): RLAC of 10 rice genotypes ranged from V1 to V10 affected by different
 276 irrigation systems during 1: 2016 and 2: 2017; flooded irrigation: FI, alternate wetting and
 277 drying at 10 cm: AWD10, alternate wetting and drying at 20 cm: AWD20.

278
 279 As shown in Figure 6, no significant differences in GT were observed between cultivars over
 280 two years. The highest ER was associated with the V10 and V7 in AWD20, while all other
 281 cultivars exhibited the same level of this parameter. In addition, the comparison of
 282 means revealed that V710 had the highest number of AC across all three irrigation systems.

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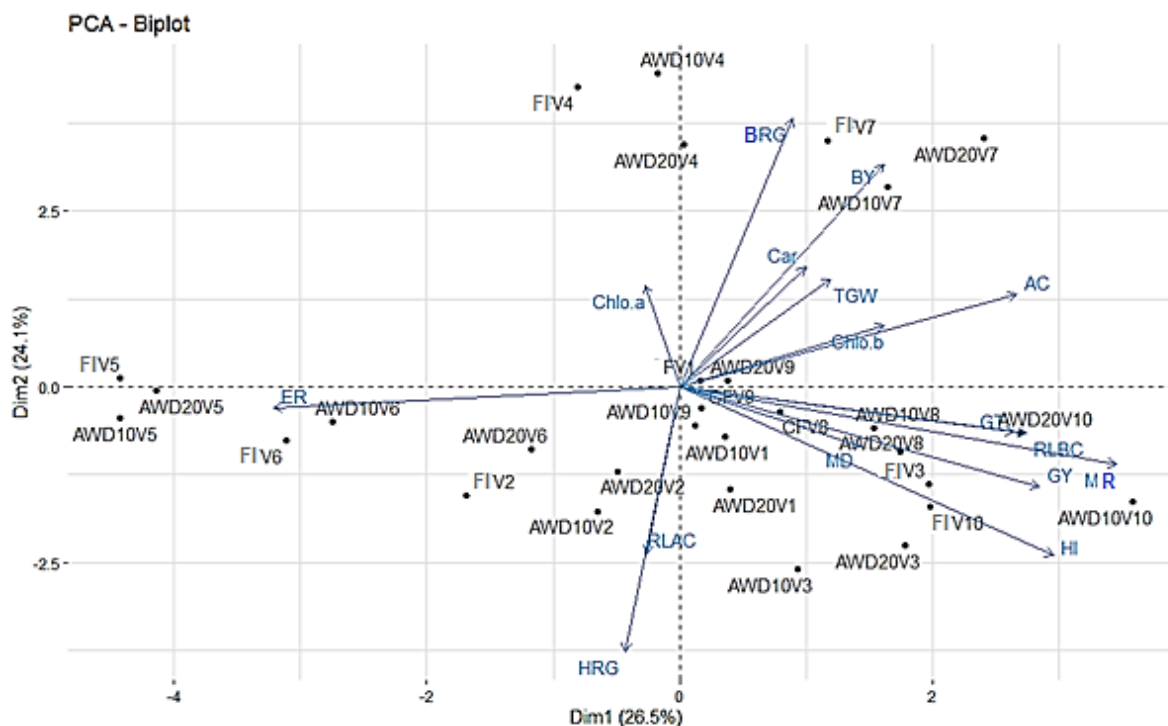
285

286 **Figure 6.** The comparison of means of elongation ratio: ER, amylose content (%): AC,
 287 gelatinization temperature (°C): GT of 10 rice genotypes ranged from V1 to V10 affected by
 288 different irrigation systems during 1: 2016 and 2: 2017; flooded irrigation: FI, alternate wetting
 289 and drying at 10 cm: AWD10, alternate wetting and drying at 20 cm: AWD20.

290

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

297



298
 299 **Figure 7.** PCA showing association among measured traits of 10 genotypes of rice ranging
 300 from V1 to V10 subjected to flooded irrigation (FI), alternate wetting and drying at 10 cm:
 301 AWD10, alternate wetting and drying at 20 cm: AWD20, milling recovery: MR, rice shell
 302 percentage: RSP, rice bran percentage: RBP, milling degree: MD, head rice grain: HRG, broken
 303 rice grain: BRG, rice length before cooking: RLBC, rice length after cooking: RLAC,
 304 elongation ratio: ER, amylose content: AC, gelatinization temperature: GT, chlorophyll a: Chl
 305 a, chlorophyll b: Chl b, carotenoids: Car, grain yield: GY, biological yield: BY, harvest index:
 306 HI, 1000-grain weight: TGW.

307
 308 **Discussion**

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

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

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More frequent soil 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 by 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 1000-grain weight differed from those of other varieties and were the highest. These genotypes can therefore be introduced as drought-resistant genotypes. Among all genotypes, the AR8 genotype 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 to attract photosynthetic materials, and rice cultivars with a greater capacity to attract photosynthetic materials have a greater capacity 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).

356 Because the bran percentage of rice genotypes was higher in the second year than in the first, it
357 was consistent with the study's reduction of processing level in the second year. Limouchi et al.
358 (2018) demonstrated that better humidity conditions in the first year did not affect genotype
359 amylose content compared to the second year, which had much less rainfall. Due to lower
360 ambient humidity, the gelatinization temperature decreased by 25% in 2016 compared to 2015.
361 Gelatinization temperature and amylose content are rice quality characteristics that are
362 especially significant for evaluating cooking quality (Rayee et al., 2021). The study revealed
363 that water stress during spawning, particularly during the grain-filling phase until ripening,
364 decreased gelation temperature, reducing cooking time (Desamero et al., 2020; Vidal et al.,
365 2007). Furthermore, a study reported that the amount of amylose varies depending on the
366 genotype of the rice plant (Kitara et al., 2019). Most rice consumers and traders desire medium
367 amylose content (Suman et al., 2020). Thus, the Neda, Vandana, Shiroudi, Kishori, IR74428-
368 153-2-3, and IR75482-149-1-1 genotypes are among those with moderate amyloidosis and
369 excellent cooking qualities, whereas the Firozan, G28, and IR70416-53 -2-2 genotypes are
370 among those with low amylose content.

371

372 **Conclusion**

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

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492 **بهینه سازی آبیاری برنج (*Oryza sativa* L.) برای معرفی ژنوتیپ بهینه برای عملکرد دانه**
493 **و ارتقای کیفیت**
494 استفاده از روش های نوین آبیاری برای معرفی ارقام به شالیزارهایی که با کمبود آب مواجه هستند، یکی از راه های
495 مبارزه و افزایش بهره وری آب است. این آزمایش به صورت کرت های نواری در قالب طرح بلوک های کامل
496 تصادفی با سه تکرار مستقل طی دو سال (1395 و 1396) در پژوهشکده برنج ایران، آمل، ایران انجام شد. ده
497 ژنوتیپ برنج (V1) تا (V10) تحت سه نوع سیستم آبیاری، شامل آبیاری غرقابی معمولی (FI) و مرطوب و خشک
498 کردن متناوب (AWD) به ترتیب در 10 (AWD10) و 20 (AWD20) سانتی متر زیر سطح خاک قرار گرفتند.
499 این نتایج نشان می دهد که روش های AWD10 و AWD20 مصرف آب را به ترتیب 20 و 17 درصد در مقایسه
500 با روش های معمول کاهش می دهند. این کاهش مصرف آب در مقایسه با سیستم آبیاری غرقابی معمولی منجر به
501 کاهش 1.4% و 0.2% عملکرد شد. همچنین، بازیافت آسیاب در آبیاری غرقابی (68/7 درصد) کمتر از سایر
502 روش های تر و خشک کردن 10 و 20 (به ترتیب 69/6 و 69/8 درصد) بود. در نتیجه، ژنوتیپ های ندا، شیرودی
503 و 8611 برنج که پاسخ بهتری به آبیاری AWD نشان داده اند، می توانند به عنوان ژنوتیپ های مناسب برای افزایش
504 بهره وری آب در شالیزارها در نظر گرفته شوند.
505