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Genotyping of rice (*Oryza sativa* L.) plants according to their root distribution pattern and their tolerance to drought

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Abstract

Drought condition is one of the major problems in producing rice in Indonesia. In plant breeding, selection is the main step to create superior varieties. An indicator of drought stress-tolerant rice varieties is the root distribution pattern because it describes the behavior of the roots in searching for water for photosynthesis and metabolism processes. One of the morphological traits related to drought tolerance in rice is root growth and development. This study aimed to determine the morphological and anatomical characteristics of drought-tolerant rice roots and identify drought-tolerant genotypes. The experiments were arranged in a factorial randomized block design with four replications. The first factor was genotype, consisting of ten genotypes. The second factor was drought stress, consisting of two environments without drought and with drought stress. Drought was given only in the vegetative phase, i.e., 1–14 days after planting. WINDEX analysis was performed to determine rice drought tolerance and identify drought-tolerant genotypes. The results showed that three out of the ten tested genotypes had higher WINDEX values, namely BP30411f (7.62), B13983-KA-6-3 (7.99), and BP29790d-PWK-2-SKI-1-3 (9.25). Based on the root distribution pattern, plants with longer primary root lengths, more seminal roots, longer seminal root lengths, and high root angles were predicted to be drought tolerant characteristics. Selection of these characters could be used in future rice breeding programs to obtain plants with superior genotypes.

INTRODUCTION

The number of rice fields has decreased, especially on Java Island. Utilizing suboptimal land such as lowland swamps and rainfed rice lands becomes an alternative to increase rice production. Climate change affects water availability on suboptimal land, causing drought. Drought is an abiotic factor associated with low groundwater availability, stunted plant growth, and ecological restoration in arid and semi-arid regions. Drought is a long-term shortage of water supply within an area caused by low or no rainfall for an extended period of time. A long dry season, for example, can lead to drought, as the groundwater reserves run out due to evaporation, transpiration, or other human uses. According to Sujinah and Jamil (2016), the level of drought intensity in the plant is divided into four categories: (1) mild, if damage level <25%; (2) moderate, if damage level ≥ 25–50%, (3) heavy, if damage level ≥ 50–85%, and (4) puso, if the damage level ≥ 85%. Drought begins with a decrease in rainfall amounts below normal in one season. This incident is the first

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indication of a drought called a meteorological drought. The decreasing supply of surface and groundwater is called a hydrological drought. Hydrological drought causes the soil water content to decrease to the point where it is unable to meet the water needs of the plants. This condition is called an agricultural drought.

In plants, many genes generally control drought tolerance mechanisms, and the expression of each gene is very complex. Therefore, breeding programs to obtain drought-tolerant plants are directed at obtaining crops that have some properties associated with drought tolerance. Mechanisms of crop tolerance to drought can be grouped into three categories: escape, avoidance, and tolerance. Escape is the plant's ability to complete its life cycle before experiencing extreme drought through flowering and bearing early fruits (Abdullah et al., 2010). Avoidance is the plant's ability to maintain higher potential cell water, aligned with the increasing drought, so that the turgidity cell remains higher by reducing water loss or increasing water absorption (Tubur et al., 2012), while tolerance is the ability of a species or a variety to stay alive and keep performing its function despite the stress (Man et al., 2011).

Roots play a crucial role in detecting changes in soil conditions, particularly in response to water stress. The characteristics of roots, both morphological and physiological, play a crucial role in determining overall plant growth and production (Ghosh and Xu, 2014). When plants face drought stress, they respond by undergoing physiological, biochemical, and morphological changes. The response of rice plants to drought stress is a physiological response followed by morphological changes. Physiological characteristics may include decreased turgor pressure, membrane and protein defects, increased ABA hormone, altered assimilate partition, CO_2 diffusion, and inhibited photosynthesis. Plants having deep roots before drought are more favorable than those with shallow roots, while long and thick roots will be helpful if drought occurs in the early life cycle. The roots of rice plants tolerant to drought stress are expected to have a broad root distribution and extend into the soil so as to facilitate the absorption of water and nutrients.

Silitonga (2004) mentioned that Salumpikit was a variety that can be used as a donor for drought-tolerant varieties, and it showed no symptoms of leaf roll up to the level of drought stress with a soil moisture level of 0.5–1 MPa. One of the drought stress-sensitive varieties is IR20. The IR20 is used as an international drought-sensitive check. Uga et al. (2013) mentioned that Dro1 was a major QTL associated with rooting properties in upland rice. The IR64Dro1 genotype, IR64, contains QTL Dro1. The Dro1 gene provides signals to regulate the hormone auxin and control the elongation of the rice roots. The study by Sanoh et al. (2014) explained that total root length under drought stress conditions showed no significant difference between Dro1-NIL and IR64, although Dro1-NIL has deeper roots than IR64. In drought stress, the maximum depth of the Dro1-NIL root is more than 40 cm, while the IR64 root only reaches a depth of 20 cm. Dro1-NIL has a higher yield than IR64 under drought stress but a lower yield than IR64 under no stress. Therefore, through genetic engineering, the Dro1 gene can be inserted into IR64 to improve root characteristics. There is a positive correlation between drought stress and roots; plants with longer roots can search for water in deeper soil layers. The role of roots in drought conditions is so important that it requires information about the pattern of root distribution in drought conditions to breed drought-tolerant varieties. WINDEX analysis is an analysis used to determine lines that are tolerant to drought stress. WINDEX analysis is a weighted analysis. In this research, the root distribution patterns of potential lines and varieties tolerant and sensitive to drought stress were compared. The main objective was to study the morphology and anatomy of rice plant roots under drought stress and their interactions.

MATERIALS AND METHODS

The experiment was conducted at the Indonesian Center of Rice Research (ICRR) in Subang, West Java, from February to April of 2018. In this study, six lines of rice seeds were utilized, namely BP30411f (G1), B14039E-KA-15 (G2), BP29790d-PWK-2-SKI-1-3 (G3), BP29790d-PWK-SKI-1-5 (G4), B13983E-KA-6-3 (G5), B1398E-KA-7-3 (G6), and four varieties, namely INPARI 38 (G7), Salumpikit (G8), IR20 (G9), and IR64Dro1 (G10). Salumpikit was used as drought-tolerant check, while IR20 was used as drought-sensitive check, and IR64Dro1 was used as root pattern check. The tools used were 60 transparent pots.

The experiment was conducted using a factorial randomized block design, with four replications, under both optimal and drought conditions. There were 20 combinations in each replication. First, rice was germinated for five days in the germinator to determine the viability of the seeds. The sand medium was watered with 120 ml of water and liquid organic fertilizer four days before planting. Four days later, the germinated seeds were transplanted; each pot was planted with three rice seeds. Furthermore, the medium was watered every four days until the plant aged 14 DAT (days after transplanting). The plant received 30 ml of water per pot on day 4, 7, and 10. Treatment of drought stress began four days before planting. Sand medium was watered with 120 ml of water and liquid organic fertilizer. Each pot was planted with three seeds of rice plants but not watered from the beginning of planting up to 14 DAT. Before removing the plant at 14 DAT, soil moisture measurements were taken using the oven method.

Observational variables included plant morphology, root morphology and anatomy, and weight characteristics, such as: (1) Plant morphological characteristics include plant height (cm), leaf dimensions, leaf count, and leaf roll score were recorded at 12 DAT (days after transplanting). The variables were observed at 12 DAT (days after transplanting); (2) Morphological and anatomical characteristics of the root include root angle (°), length of primary root (cm), length of seminal root (cm), number of seminal roots, number of meta-xylem, meta-xylem diameter (µm), and number of proto-xylem. The anatomical root was observed under a microscope with 400× magnification on a 50 µm scale. Meta-xylem diameter measurements were performed using the ImageJ application; (3) The characteristics of plant weight includes the root fresh weight (g), root dry weight (g), shoot fresh weight (g), and shoot dry weight (g). Observations were made at 14 DAT.

Data analysis

Quantitative data were analyzed using analysis of variance (F test) at the 5% level. If the result showed a significant difference, it was further tested using LSD (Least Significant Difference) at 5% significance level. Furthermore, major component analysis was conducted for the selection of variables determining genotypic tolerance to drought, the Stress Tolerance Index (STI) to determine the relative value of each genotype, correlation analysis to determine the level of closeness of relation between variables, and WINDEX analysis to determine the drought-tolerant genotype. The WINDEX analysis is used to compare the lines being tested for tolerance with the tolerant-checks. Based on the ranking of the WINDEX values for each genotype using weighted selection, the genotypes with higher WINDEX values compared to tolerant-checks

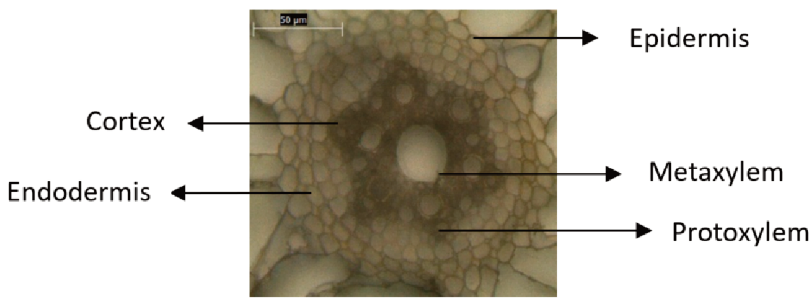


Figure 1. Anatomy of rice roots under 400×

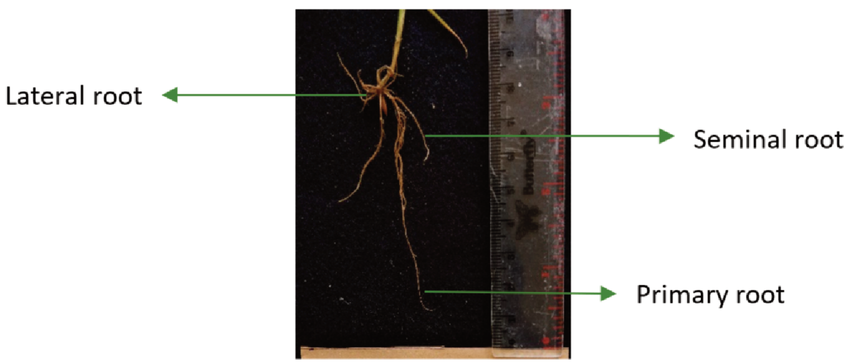


Figure 2. Morphology of rice roots

are predicted to have tolerance to drought. In simpler terms, the WINDEX analysis helps determine which genotypes are more tolerant to drought by comparing them to known tolerant-checks.

RESULTS AND DISCUSSION

Plant morphological characteristics

Drought influences the plant's height characteristics. There was an interaction effect of the test genotypes and the stress (Table 1). There was no interaction effect of genotype and drought stress on the number of leaves, leaf width, and leaf length, but there was only a single factor effect from both factors (Table 2). Plant height is closely related to rooting. Since nutrients are necessary to help plants grow taller, disturbances to the roots of the plant might limit their absorption, which can have an impact on the plant's height. The affected plants will make an effort to obtain various nutrients necessary for their growth. Photosynthesis requires water, CO_2, minerals, and energy. Water and minerals are taken from the ground through roots and used in all chemical reactions, transporting nutrients, retaining turgor, and finally leaving the leaves as vapor or water. In the study of Stock flower (*Matthiola incana*), the relative water content significantly changed with increased drought stress at plant height. (Jafari et al., 2019). The genotype B13983E-KA-6-3 showed the highest plant height under drought stress conditions, whereas IR20 varieties, as comparative checks for drought stress tolerance, had the lowest plant height.

Drought at moderate levels decreases the widening of leaves and photosynthesis, resulting in lower yields, indicated from number of leaves, leaf width, and leaf length. The stress influences the number of leaves in each genotype. The number of leaves under drought-stress conditions is lower than that without drought-stress.

In terms of leaf width and leaf length, different genotypes gave different responses. Genotypes of BP29790d-PWK-2-SKI-1-3 and B13983E-KA-6-3 showed higher values of leaf width and length than IR20 varieties. It shows that the vegetative phase is still susceptible to drought stress. Rice plants respond to

Table 1. Interaction effects of genotypes and stress on the plant height and scoring of leaf roll at 12 DAT

Genotype	Stress		Scoring of leaves roll	
	C0 (Drought)	C1 (Non-drought)	C0 (Drought)	C1 (Non-drought)
G1	23.32 c A	23.61 bcd A	5	3
G2	23.10 bc A	21.28 bc A	3	3
G3	22.92 bc A	28.07 e B	3	3
G4	23.27 c A	24.36 cd A	3	3
G5	24.94 c A	22.73 bc A	3	3
G6	23.14 bc A	22.69 bc A	3	3
G7	15.21 a A	20.90 b B	3	3
G8	23.57 c A	26.31 de A	3	3
G9	15.07 a A	16.10 a A	5	5
G10	19.74 b A	22.27 bc A	5	3
CV (%)	11.01			
LSD 5%	3.45			

Remarks: Means followed by the same uppercase letters in the same row and the same lowercase letter in the same column are not significantly different based on LSD test at 5%. The uppercase letters represent a comparison of stress conditions, while the lowercase letters represent a comparison of genotypes. G1: BP30411f, G2: B14039E-KA-15, G3: BP29790d-PWK-2-SKI-1-3, G4: BP29790d-PWK-SKI-1-5, G5: B13983E-KA-6-3, G6: B1398E-KA-7-3, G7: INPARI 38, G8: Salumpikit, G9: IR20, G10: IR64Dro1.

Table 2. Effects of genotype and stress factor on the number of leaves, leaf width, and leaf length at 12 DAT

Treatment	Number of leaves (leaves)	Leaf width (cm)	Leaf length (cm)
Genotype			
G1	2.84	0.26 ab	9.52 cd
G2	3.00	0.27 ab	10.07 d
G3	3.04	0.31 c	10.36 d
G4	2.97	0.27 ab	9.25 c
G5	2.93	0.27 ab	10.01 d
G6	3.04	0.28 bc	9.33 c
G7	2.84	0.26 ab	7.91 b
G8	2.80	0.29 bc	9.64 cd
G9	2.75	0.24 a	7.06 a
G10	2.88	0.26 ab	9.53 cd
LSD 5%	ns	0.03	1.26
Stress			
C0 (Drought)	2.82 a	0.27	8.88 a
C1 (Non-drought)	3.00 b	0.27	9.63 b
CV (%)	0.11	14.21	0.56
LSD 5%	8.40	ns	13.58

Remarks: Means followed by the same letters are not significantly different (p > 0.05) based on LSD test at 5%. "ns" denotes no significant difference, and "CV" stands for coefficient of variation. G1: BP30411f, G2: B14039E-KA-15, G3: BP29790d-PWK-2-SKI-1-3, G4: BP29790d-PWK-SKI-1-5, G5: B13983E-KA-6-3, G6: B1398E-KA-7-3, G7: INPARI 38, G8: Salumpikit, G9: IR20, G10: IR64Dro1.

drought stress by rolling their leaves as a mechanism to avoid dehydration. This is due to their ability to adjust their leaf water potential, which allows them to absorb soil water more effectively than plants that cannot adjust their leaf water potential well under drought conditions. The regulation of stomatal function plays a crucial role in adjusting transpiration under water-limited conditions, which is facilitated by ion and water transportation through channel proteins across the plasma and vacuole membrane (Arve et al., 2013). Under drought, guard cell proteins transmit stress signals to regulate stomatal aperture, and studies indicate that ABA signaling, initiated by roots under drought, influences the opening and closing of stomata. Stomatal closure is a vital technique used by plants to conserve water under drought stress.

Morphological characteristics and root anatomy

The ability of plants to maintain root growth is crucial for water and nutrient absorption under drought stress (Wening and Susanto, 2021). Drought stress causes a decline in the rate of cell division in meristem, which halts the growth of roots (Nahar et al., 2016). Research has shown that plants with smaller root diameters and specific root lengths tend to have finer roots that are better suited to dry conditions (Henry et al., 2012). To cope with drought stress, plants use a mechanism called drought avoidance, which increases their ability to absorb water through a well-developed root system. This can be achieved by increasing rooting depth, root density, or root/shoot ratio (Fang and Lizong, 2015). Plants with deep roots tolerate water stress better and maintain productivity (Uga et al., 2013).

The primary root length of the rice plant provides information about the root's role in absorbing water under stress conditions. The Salumpikit variety has the longest primary root length (16.99 cm) as drought-stress-tolerant check (Table 3). Incomplete root growth causes the root system to become shallower and more drought-sensitive. If the primary roots are disrupted, the seminal roots will grow rapidly. Salumpikit variety has the longest seminal roots of 13.13 cm (Table 4). This is in line with the research of Banoc et al. (2000), reporting that drought-stressed rice plants at 11–17 DAT would lengthen their seminal roots, thus indicating that the ongoing drought stress resulted in the highly crucial development of seminal roots that are to support the plant growth. Hence, when the plant is re-watered, the role of the primary root and lateral roots become important factors in plant growth. Christopher et al. (2013) reported that the number of wheat seminal roots

Table 3. Interaction effect of genotypes and stress on primary root length, number of roots and root angle at 14 DAT

Genotype	Length of primary root (cm)		Number of seminal roots		Root angle (°)	
	C0 (Drought)	C1 (Non-drought)	C0 (Drought)	C1 (Non-drought)	C0 (Drought)	C1 (Non-drought)
G1	11.57 a A	13.15 abc A	3.54 ab A	5.25 b A	16.25 b A	15.00 bc A
G2	12.10 ab A	15.35 bcd B	3.75 ab A	4.75 ab B	4.25 a A	16.25 bc B
G3	13.58 abc A	14.19 bcd A	4.25 ab A	5.75 b A	17.50 b A	19.63 bc A
G4	13.80 abc A	14.90 bcd A	5.25 b A	5.33 b A	13.75 b A	15.00 bc A
G5	15.65 cd A	14.69 bcd A	5.00 b A	4.33 ab A	13.25 b B	6.25 ab A
G6	16.24 cd B	11.27 a A	4.37 ab A	4.75 ab B	2.00 a A	16.25 bc B
G7	14.68 bcd A	12.57 ab A	3.21 a A	5.67 b B	19.25 b A	15.00 bc A
G8	16.99 d A	16.68 d A	4.00 ab A	5.67 b A	17.25 b A	21.50 c A
G9	15.11 cd A	15.72 cd A	4.84 ab A	3.13 a A	12.00 b A	23.00 c B
G10	15.86 cd A	13.48 abc A	3.17 a A	5.46 b B	15.75 b B	5.00 a A
CV (%)	14.25		27.31		18.58	
LSD 5%	2.90		1.77		0.53	

Remarks: Means followed by the same uppercase letters in the same row and the same lowercase letter in the same column are not significantly different based on LSD test at 5%. The uppercase letters represent a comparison of stress conditions, while the lowercase letters represent a comparison of genotypes. G1: BP30411f, G2: B14039E-KA-15, G3: BP29790d-PWK-2-SKI-1-3, G4: BP29790d-PWK-SKI-1-5, G5: B13983E-KA-6-3, G6: B1398E-KA-7-3, G7: INPARI 38, G8: Salumpikit, G9: IR20, G10: IR64Dro1.

Table 4. The effects of genotype and stress treatment on the length of seminal roots and number of protoxylem at 14 DAP

Treatment	Seminal root length (cm)	Number of protoxylem
Genotype		
G1	10.73 b	6.00 b
G2	10.78 b	6.50 c
G3	10.28 b	6.25 bc
G4	10.23 b	6.13 bc
G5	9.01 b	6.00 b
G6	9.82 ab	6.50 c
G7	11.44 bc	6.00 b
G8	13.13 c	6.00 b
G9	8.15 a	5.38 a
G10	10.68 b	5.63 ab
LSD 5%	1.72	0.45
Stress		
C0 (Drought)	10.93 b	6.23 b
C1 (Non-drought)	10.10 a	5.85 a
LSD 5%	0.77	0.20
CV (%)	16.38	7.41

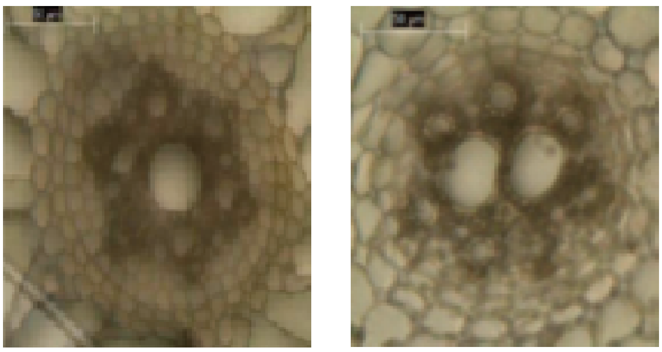
Remarks: Means followed by the same letters are not significantly different ($p > 0.05$) based on LSD test at 5%. "ns" denotes no significant difference, and "CV" stands for coefficient of variation. G1: BP30411f, G2: B14039E-KA-15, G3: BP29790d-PWK-2-SKI-1-3, G4: BP29790d-PWK-SKI-1-5, G5: B13983E-KA-6-3, G6: B1398E-KA-7-3, G7: INPARI 38, G8: Salumpikit, G9: IR20, G10: IR64Dro1.

under drought stress conditions was also a root characteristic reportedly associated with tolerance to drought stress, and the number of high seminal roots is related to root capacity to collect water under drought conditions. Lateral root formation increases under water stress, leading to a larger surface area for water absorption from shrinking water columns (Kim et al., 2020). This results in an increased volume of soil that can be explored for water and also enhances hydraulic conductance by reducing the apoplastic barrier to water entering the xylem (Comas et al., 2012). Additionally, a decrease in root diameter helps enhance water access, thereby increasing the productivity of plants even under water stress. The occurrence of drought stress will decrease the turgidity of cells, resulting in cell shrinkage. Rangappa

Table 5. Interaction effect of genotypes and stress on meta-xylem and meta-xylem diameter at 14 DAT

Genotype	Amount of meta-xylem		Diameter of meta-xylem (μm)	
	C0 (Drought)	C1 (Non-drought)	C0 (Drought)	C1 (Non-drought)
G1	1.50 abc A	1.00 a A	26.09 a A	31.58 cd B
G2	2.00 c B	1.00 a A	27.33 a A	30.69 bc A
G3	1.00 a A	1.75 b B	33.51 b A	36.89 e A
G4	2.00 c A	1.50 ab A	28.91 ab A	24.32 a A
G5	2.00 c B	1.00 a A	26.07 a A	30.25 bc A
G6	2.00 c A	1.50 ab A	28.21 a A	26.42 ab A
G7	1.75 bc A	1.75 b A	29.87 ab A	26.01 ab A
G8	1.50 abc A	1.00 a A	46.85 c B	36.07 de A
G9	1.25 ab A	1.00 a A	28.58 a B	24.18 a A
G10	1.50 abc A	1.00 a A	30.80 ab A	31.85 cd A
CV (%)	25.34		11.21	
LSD 5%	0.52		4.79	

Remarks: Means followed by the same uppercase letters in the same row and the same lowercase letter in the same column are not significantly different based on LSD test at 5%. The uppercase letters represent a comparison of stress conditions, while the lowercase letters represent a comparison of genotypes. G1: BP30411f, G2: B14039E-KA-15, G3: BP29790d-PWK-2-SKI-1-3, G4: BP29790d-PWK-SKI-1-5, G5: B13983E-KA-6-3, G6: B1398E-KA-7-3, G7: INPARI 38, G8: Salumpikit, G9: IR20, G10: IR64Dro1.



(a) (b)

Figure 3. Rice roots anatomy under normal conditions and drought stress of vegetative phase

Remarks: (a) B13983E-KA-7-3 under normal condition; (b) B13983E-KA-7-3 under drought stress conditions.

et al. (2016) stated that drought-tolerant sorghum has characteristics of greater metaxylem numbers and diameter than rice species under non-drought stress conditions. The genotype with the largest metaxylem diameter was Salumpikit, but the BP29790d-PWK-2-SKI-1-3 genotype also had a larger metaxylem diameter than the other genotype at 33.51 µm (Table 5) and Figure 3.

Characteristics of root and shoot weight

Plants absorb water and essential nutrients from the soil through their roots (Kim et al., 2020). Deficit water availability inhibits plant growth, thereby reducing photosynthetic yield. According to Taiz and Zeiger (2002), the average plant requires 500 grams of water, absorbed by roots and transported to all

Table 6. Effects of genotype and drought stress treatment on the fresh root weight, dry root weight, fresh shoot weight and dry shoot weight at 14 DAT

Treatment	Fresh root weight (g)	Dry root weight (g)	Wet shoot weight (g)	Dry shoot weight (g)
Genotype				
G1	0.220 bc	0.039	0.284 bc	0.079
G2	0.212 bc	0.034	0.311 bc	0.061
G3	0.256 c	0.049	0.405 c	0.077
G4	0.204 bc	0.032	0.306 bc	0.062
G5	0.240 bc	0.033	0.355 bc	0.064
G6	0.189 bc	0.054	0.255 b	0.046
G7	0.177 b	0.030	0.288 bc	0.048
G8	0.237 bc	0.048	0.362 c	0.071
G9	0.088 a	0.030	0.171 a	0.038
G10	0.160 b	0.023	0.250 b	0.049
LSD 5%	0.115	Ns	0.101	Ns
Stress				
C0 (Drought)	0.1313 a	0.029 a	0.2443 a	0.050
C1 (Non-drought)	0.2663 b	0.045 b	0.3540 b	0.069
LSD 5%	0.0515	0.028	0.0454	Ns
CV (%)	27.04	27.28	17.59	18.75

Remarks: Means followed by the same letters are not significantly different (p > 0.05) based on LSD test at 5%. "ns" denotes no significant difference, and "CV" stands for coefficient of variation. G1: BP30411f, G2: B14039E-KA-15, G3: BP29790d-PWK-2-SKI-1-3, G4: BP29790d-PWK-SKI-1-5, G5: B13983E-KA-6-3, G6: B1398E-KA-7-3, G7: INPARI 38, G8: Salumpikit, G9: IR20, G10: IR64Dro1.

Table 7. WINDEX values of characteristics

Genotype	Character															WINDEX
	NV	LL	LW	PRL	SRL	NSR	RA	NM	DM	NP	FWR	DWR	FWC	DWS	PH	
Correlation	0.46	0.87	0.82	0.71	0.69	0.67	0.03	0.01	0.62	0.53	0.90	0.67	0.89	085	1.00	
G1	0.89	0.98	0.94	1.10	1.40	0.87	2.20	0.96	0.91	1.03	0.41	0.09	0.51	0.25	1.03	7.62
G2	1.03	1.03	0.98	1.01	1.04	0.67	1.45	1.28	0.94	1.21	0.36	0.09	0.55	0.18	0.89	7.22
G3	1.03	1.16	1.33	1.11	1.27	1.10	2.41	1.12	1.36	1.16	0.52	0.33	0.75	0.24	1.23	9.25
G4	0.98	0.92	0.98	1.20	1.23	0.91	2.16	1.92	0.77	1.11	0.39	0.09	0.55	0.19	1.04	7.56
G5	0.95	1.12	0.98	1.32	1.19	1.13	1.79	1.28	0.87	1.03	0.48	0.09	0.61	0.19	0.96	7.99
G6	1.03	0.93	1.02	1.09	1.01	0.87	0.87	1.92	0.82	1.21	0.35	0.13	0.45	0.12	0.98	7.23
G7	0.90	0.63	0.90	1.01	1.29	0.50	2.31	1.92	0.93	1.03	0.29	0.08	0.37	0.12	0.64	6.17
G8	0.89	1.02	1.08	1.76	2.22	0.81	2.44	0.96	1.87	1.03	0.46	0.17	0.65	0.24	1.25	9.79
G9	0.85	0.48	0.76	0.82	0.63	0.62	2.32	0.80	0.76	0.86	0.12	0.05	0.29	0.08	0.42	4.69
G10	0.92	0.98	0.91	0.97	1.02	0.60	1.36	0.96	1.08	0.90	0.26	0.06	0.42	0.13	0.88	6.62

Remarks: G1: BP30411f; G2: B14039E-KA-15; G3: BP29790d-PWK-2-SKI-1-3; G4: BP29790d-PWK-3-SKI-1-5; G5: B13983E-KA-6-3; G6: B13983E-KA-7-3; G7: 38 Inpari variety; G8: Salumpikit variety; G9: IR20 variety; G10: IR64Dro1; PH: plant height; NV: number of leaves; LW: leaf width; LL: leaf length; PRL: primary root length; SRL: seminal roots length; NSR: number of seminal roots; RA: root angle; FWR: fresh weight of root DWR: dry weight of root; FWC: fresh weight of canopy; DWS: dry weight of shoot; NM: number of metaxylem; DM: metaxylem diameter; NP: number of protoxylem.

parts. Root hairs increase soil contact area, thereby absorbing soil water. Many plants associate root hairs with improved water and nutrient accumulation and responsiveness to stresses (Wasson et al., 2012). Fresh root weights are used to determine the capacity of plants to absorb water. The highest fresh root weight was produced by BP29790d-PWK-2-SKI-1-3 (0.2564 g). Dry root weight indicates the plant's ability to absorb water because plants with a higher dry root weight have more extensive roots and a higher tolerance to drought stress than those with a lower dry root weight (Kurniasih and Wulandhany, 2009).

Shoot growth indicates the potential of photosynthesis, and the lack of water will result in lower photosynthesis. The highest fresh shoot weight was produced by BP29790d-PWK-2-SKI-1-3 (0.4052 g). Roots experienced limited water and nutrient uptake due to decreased soil-water potential, slowing nutrient diffusion between soil matrix and root surface. When the availability of water is reduced, plants make adjustments to maintain some level of turgidity in their root system through osmotic adjustments. This helps re-establish the water potential gradient for water uptake. Additionally, plants use stomatal closure as another mechanism to cope with water stress.

Main component analysis, Stress Tolerance Index (STI), correlation analysis, and WINDEX analysis

The analysis of the main components identified four key components among the 15 characters observed. These components include plant height, number of leaves, leaf width, leaf length, number of seminal roots, fresh root weight, fresh shoot weight, and dry shoot weight. The second component consists of the length of the primary root, seminal roots, and the metaxylem diameter. The third component consists of the number of metaxylem and protoxylem. The fourth component consists of root angles and the dry weight of the root. Additionally, the stress tolerance index value for all genotypes in each character has been identified.

The correlation result indicates that there is a positive correlation between some characteristics and plant height, namely, leaf number, leaf length, leaf width, root length, seminal root, metaxylem diameter, protoxylem number, fresh root weight, fresh shoot weight, dry root weight and dry shoot weight. The WINDEX analysis selection method is highly effective for choosing breeding lines during the initial stages of segregation. It assigns weightings to desired traits, particularly agronomic traits, to help identify the best candidates for further breeding (Limbongan, 2008). Furthermore, based on WINDEX analysis, Salumpikit variety had the highest WINDEX value of 9.79. None of the tested genotypes had WINDEX values exceeding Salumpikit variety. There were genotypes having higher WINDEX values, greater than those of IR64Dro1, Inpari 38, and IR20 varieties. The genotypes predicted being tolerant of drought stress in the vegetative phase were BP29790d-PWK-2-SKI-1-3 (9.25), B13983E-KA-6-3 (7.99), and BP30411f (7.62) (Table 7). These genotypes had a greater WINDEX value than IR64Dro1.

CONCLUSIONS

BP29790d-PWK-2-SKI-1-3, B13983E-KA-6-3, and BP30411f are suspected drought-tolerant genotypes based on the WINDEX analysis. The root angle has an impact on rice's drought resistance. The principal root length is longer on plants with a steeper root angle. However, the length of seminal roots and the number of seminal roots are essential for plant growth and recovery. For future research, it is necessary to confirm the tolerance line.

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