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Effect of Accession and Drought Stress on Growth and Adaptability of Pineapple (*Ananas comosus* (L.) Merr.) in Lowland Areas

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ABSTRACT: This research was conducted in the Greenhouse of the Agricultural Zone, Medan Baru, Kandang Limun, Muara Bangka Hulu Subdistrict, Bengkulu City. The study aimed to analyze the effect of different pineapple accessions (*Ananas comosus* (L.) Merr.) on the growth and adaptability of local pineapple under drought stress conditions. The experiment was arranged in a Completely Randomized Design (CRD) with two factors. The first factor was four pineapple accessions, and the second factor was the drought period, consisting of 15 and 30-day dry period. The results showed that the interaction between pineapple accessions and dry periods had a significant effect on shoot dry weight and stomatal density. Pineapple accession treatments had a significant effect on plant height, shoot fresh weight, and shoot dry weight. Dry period treatments significantly affected plant height and shoot dry weight. The results of the stress tolerance index (STI) at the 30-day dry period assessed during the vegetative stage indicated that pineapple accessions 19, 23, 24, and 25 all exhibited a similar level of drought tolerance and were classified as medium tolerant to drought stress.

KEYWORDS: Chlorophyll, Crassulacean acid metabolism, Drought stress, Pineapple, Stress tolerance index

INTRODUCTION

Pineapple (*Ananas comosus* (L.) Merr) is a fruit native to the South American region, encompassing tropical and subtropical areas [1]. Pineapple accounts for approximately 8% of total global fresh fruit production. Indonesia is one of the leading producers of fresh and processed pineapples, following Thailand and the Philippines [2]. Pineapple plants prefer fertile soil and humid climates, with annual rainfall ranging from 1,000 to 2,500 mm [3]. This plant can grow in tropical regions at elevations ranging from 100 to 800 meters above sea level, with ambient temperatures between 10 and 16°C [4]. Pineapples can grow in various soil types, provided there is good drainage, and thrive in lowland and highland areas [5]. Climate change in Indonesia's tropical regions has impacted fruit and vegetable crops by reducing yields, increasing disease incidence, and raising the risk of crop failure due to extreme weather. Developing stress-tolerant plant varieties is a key adaptation strategy [6].

Abiotic stress affects plant growth and development, leading to significant losses in global agriculture. One type of abiotic stress is drought stress, also called water deficit stress [7]. Drought stress results in plants being unable to meet their optimal water requirements [8]. Plants subjected to drought stress exhibit reductions in growth, development, and productivity [9]. The plant response to drought begins with physiological reactions, which involve a series of internal processes within the plant, followed by morphological changes that serve both as drought tolerance mechanisms and as consequences of the stress impact [10].

Naturally, pineapple is a xerophytic plant that can withstand drought conditions, as it belongs to the group of plants that utilize Crassulacean Acid Metabolism (CAM) [11]. Pineapple exhibits CAM-type stomatal that are more adaptive in hot and dry environments. stomatal in pineapple plants open at night and close during the day [12]. The CAM mechanism in pineapple improves water-use efficiency and enhances drought tolerance [13]. Variations in the appearance of pineapple plants can be attributed to several factors, including accession, environmental conditions, or the interaction between the two [14]. Accession is one of the key factors influencing the growth and adaptive capacity of pineapple plants under various environmental conditions, including drought stress. Certain plant accessions exhibit better adaptability to drought conditions compared to others, due to differences in their physiological or genetic characteristics. This study aims to investigate the effect of accession and the adaptive capacity of pineapple plants in terms of morphological and physiological responses under drought conditions in lowland areas.

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MATERIALS AND METHODS

This study was conducted in a greenhouse located in the Agricultural Zone of the University of Bengkulu, at an elevation of approximately 10 meters above sea level, from May to November 2024. The materials used included pineapple plantlets derived from slips, as well as base fertilizers such as NPK, Kieserite (Magnesium Sulfate), and DAP (Diammonium Phosphate). The experiment employed a Completely Randomized Design (CRD) with two factors and three replications. The first factor was four pineapple accessions. The accessions used in this study were based on the research by [15], consisting of one accession from the lowland area of Prabumulih and three accessions from the highland area of Kebawetan (Table I). The second factor was drought period, comprising three treatment levels: control (P0), 15-day dry period (P1), and 30-day dry period (P2). Each treatment combination was replicated three times, resulting in a total of 36 experimental units (four accessions × three treatments × three replications). Each experimental unit consisted of five plants, making a total of 180 plants used in this study.

Table I. Information on pineapple accessions based on their origin and collection location.

No.	*Accessions*	*Origins*	*Locations*
1	19	Prabumulih	Pangkul Village, Cambai Subdistrict, Prabumulih City
2	23	Kebawetan	Bukit Sari Village, Kabawetan Subdistrict, Kepahiang Regency
3	24	Kebawetan	Sidomakmur Village, Kabawetan Subdistrict, Kepahiang Regency
4	25	Kebawetan	Sidomakmur Village, Kabawetan Subdistrict, Kepahiang Regency

Preparation of planting media

The planting media used was a 1:1 (v:v) mixture of ultisol soil and manure. The mixed soil was air-dried before being placed into 30 cm × 30 cm polybags with a capacity of 5 kg.

Planting

The obtained pineapple plantlets were initially nursed in a seedbed plot for a period of four months. After the nursery period, transplanting was carried out into 30 cm × 30 cm polybags.

Fertilization

Fertilization was carried out by applying basal fertilizers such as NPK, Kieserite, and DAP at a dose of 0.2 grams per plant.

Treatment of dry period

The dry period treatment was applied in three levels: control, 15 and 30-day dry period. In the control treatment, irrigation was conducted every two days, from 90 days after planting (DAP) until 150 DAP, followed by a 10-day rewatering period until 160 DAP. In the15-day dry period treatment, irrigation was carried out four times, specifically at 105, 120, 135, and 150 DAP, followed by 10 days of rewatering until 160 DAP. In the 30-day dry period treatment, irrigation was conducted twice, at 120 and 150 DAP, followed by a 10-day rewatering until 160 DAP.

Observation variables

The variables observed in this study were plant height, number of leaves, root length, root diameter, root volume, root fresh weight, root dry weight, shoot fresh weight, shoot dry weight, stomatal density, relative leaf water content, leaf chlorophyll content.

Stomatal density

Stomatal density, according to [16], is calculated using the following formula:

$$\text{Stomatal Density} = \frac{Stomatal\ count}{Field\ of\ view\ area\ (mm^2)}$$

Relative leaf water content

According to [17], relative leaf water content is calculated using the formula:

$$\text{RLWC} = \frac{Fresh\ weight - dry\ weight}{Turgid\ weight - dry\ weight} \text{ x } 100$$

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Leaf chlorophyll content

Chlorophyll content in leaves was measured using the method described by [18], and calculated with the following equations:

Chlorophyll A = $12.7 \times A_{663} - 2.69 \times A_{645}$

Chlorophyll B = $22.9 \times A_{645} - 4.68 \times A_{663}$

Total = $20.2 \times A_{645} + 8.02 \times A_{663}$

Stress tolerance index (STI)

The drought tolerance of pineapple plants was assessed using the method described by [19], with the following formula:

$$STI = \frac{(Y_p)(Y_s)}{(Y_{\bar{p}})^2}$$

Note :

Yp : Yield of a genotype under non-stress conditions

Ys : Yield of a genotype under stress conditions

$Y\bar{p}$: Mean yield under non-stress conditions

RESULT

The analysis of variance indicated that the interaction between pineapple accessions and dry period had a significant effect on shoot dry weight and stomatal density. In addition, the analysis of variance revealed that pineapple accessions had a significant effect on plant height, shoot fresh weight, and shoot dry weight. Meanwhile, the dry period significantly affected plant height and shoot dry weight (Table II).

Table II. Analysis of variance results

Observation Variables	*F Calculated Values*			
	Accession (A)	*Dry Period (P)*	*Interaction (A x P)*	*CV (%)*
Plant Height	9.34^{**}	3.84^{*}	2.46^{ns}	19.22
Number of Leaves	0.74^{ns}	1.96^{ns}	1.28^{ns}	9.86
Root Length	2.75^{ns}	2.49^{ns}	0.48^{ns}	13.66^{T}
Root Diameter	0.96^{ns}	0.35^{ns}	0.46^{ns}	22.08
Root Volume	0.63^{ns}	2.42^{ns}	2.27^{ns}	20.77^{T}
Root Fresh Weight	0.22^{ns}	1.56^{ns}	0.59^{ns}	18.29^{T}
Root Dry Weight	1.11^{ns}	1.30^{ns}	0.36^{ns}	20.61^{T}
Shoot Fresh Weight	111.44^{**}	0.49^{ns}	1.86^{ns}	6.44
Shoot Dry Weight	255.82^{**}	113.33^{**}	10.14^{**}	6.48
Stomatal Density	2.60^{ns}	0.46^{ns}	2.58^{*}	15.74^{T}

Note : T = Transformation; ns = not significant; * = significant; ** = highly significant.

The results of the relative leaf water content analysis showed that the control treatment had the highest water content in accession 19, followed by accession 25, accession 23, and accession 24. Under the 15- and 30-day dry period, accession 19 maintained the highest relative water content, while accession 23 recorded the lowest. The greatest percentage reduction in relative leaf water content occurred in accession 23 at 15.48%, followed by accession 25 (10.25%), accession 19 (9.57%), and accession 24 (8.20%). The relative leaf water content of accession 24 under 15-day dry period was higher than that of the control, indicating that accession 24 was able to maintain its leaf water content during moderate drought conditions. According to [20], the accumulation of compatible osmolytes, such as proline, glycine betaine, and soluble sugars, helps maintain cellular osmotic pressure, allowing water to remain within plant tissues despite dry soil conditions.

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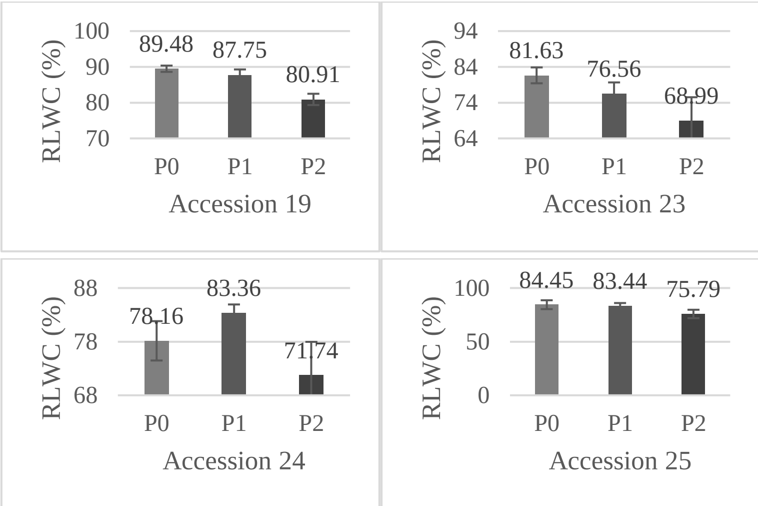

Figure 1. Percentage of relative leaf water content (RLWC) for each treatment combination

The interaction between pineapple accessions and drought periods showed a significant effect on shoot dry weight (Table III). The control treatment showed a significant difference compared to the 15- and 30-day dry period in accessions 19 and 23. Meanwhile, in accession 24, the control treatment was significantly different from the 30-day dry period but not significantly different from the 15-day dry period. Additionally, in accession 25, the 15-day dry period was significantly different from the control treatment but not significantly different from the 30-day dry period.

Accession 25 showed significant differences compared to accessions 24, 23, and 19 under the control treatment. In the 15-day dry period, accession 23 differed significantly from accessions 24 and 19 but was not significantly different from accession 25. Furthermore, in the 30-day dry period, accession 24 showed significant differences compared to accessions 25, 23, and 19.

Table III. Interaction between pineapple accessions and dry period on shoot dry weight variable

Dry	***Accession***			
Period	***19***	***23***	***24***	***25***
Control	9.56 a	15.65 a	19.61 a	20.92 a
	D	C	B	A
15-day dry period	6.25 b	13.56 b	19.37 a	13.53 b
	C	B	A	B
30-day dry period	5.40 c	11.16 c	14.67 b	13.05 b
	D	C	A	B

Note : Means in the same column followed by the same lowercase letters are not significantly different. Means in the same row followed by the same uppercase letters are not significantly different according to the Least Significant Difference (LSD) test at the 5% significance level ($\alpha = 0.05$). The LSD value difference for lowercase letters is 0.76, and for uppercase letters is 0.87.

The interaction between pineapple accessions and drought periods showed a significant effect on stomatal density (Table IV). In accession 19, the control treatment did not show significant differences compared to the 15- and 30-day dry period. Meanwhile, in accessions 23 and 25, the 30-day dry period was significantly different from the control treatment but not significantly different from the 15-day dry period. Additionally, in accession 24, the 30-day dry peirod showed significant differences compared to both the control treatment and the 15-day dry period.

Under the control treatment, accession 25 differed significantly from accessions 24 and 19, but not from accession 23. Under both 15- and 30-day dry period, no significant differences were observed among accessions.

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Table IV. Interaction between pineapple accessions and drought period on stomatal density variable

Dry Period	*Accession*			
	19	*23*	*24*	*25*
Control	23.81 a B	42.51 a A	17.01 c B	49.31 a A
15-day dry period	28.91 a A	25.51 b A	27.21 b A	30.61 b A
30-day dry period	25.51 a A	28.91 b A	34.01 a A	32.31 b A

Note : Means in the same column followed by the same lowercase letters are not significantly different. Means in the same row followed by the same uppercase letters are not significantly different according to the Least Significant Difference (LSD) test at the 5% significance level (α = 0.05). The LSD value difference for lowercase letters is 8.23, and for uppercase letters is 9.50.

The effect of pineapple accession showed a significant influence on plant height and shoot fresh weight variables (Table V). Accession 19 exhibited superior plant height performance and characteristics compared to the other two accessions. In contrast, accession 23 demonstrated the lowest growth performance and characteristics. Meanwhile, for the shoot fresh weight variable, accession 25 had the highest weight, followed by accessions 24, 23, and 19.

Table V. Results of the analysis of the effect of accessions on pineapple growth and adaptability

Accession	*Observation Variables*							
	PH (cm)	*NL (sheet)*	*RL (cm)*	*RD (cm)*	*RV (mL)*	*RFW (g)*	*RDW (g)*	*SFW (g)*
19	28.83 a	21.22	26.00	1.14	9.44	7.94	1.93	50.81 d
23	19.13 b	20.88	21.52	1.15	7.22	8.12	1.11	56.34 c
24	21.94 b	21.22	21.14	1.20	8.89	8.47	1.57	68.38 b
25	28.44 a	22.27	28.69	1.33	9.44	9.05	1.63	84.03 a

Note : PH = Plant height; NL = Number of leaves; RL = Root length; RD = Root diameter; RV = Root volume; RFW = Root fresh weight; RDW = Root dry weight; SFW = Shoot fresh weight. The LSD value difference for plant height is 4.86, and for shoot fresh weight is 4.18.

The effect of dry period showed no significant influence on most of the observed variables, but had a significant effect on plant height (Table VI). Plant height was highest under the 15-day dry period, followed by the control treatment and the 30-day dry period.

Table VI. Results of the analysis of the effect of dry period on pineapple growth and adaptability

Dry Period	*Observation Variables*							
	PH (cm)	*NL (sheet)*	*RL (cm)*	*RD (cm)*	*RV (mL)*	*RFW (g)*	*RDW (g)*	*SFW (g)*
Control	25.83 a	21.87	26.08	1.17	10.00	9.78	1.72	64.10
15-day dry period	26.41 a	21.91	25.90	1.26	9.58	8.14	1.75	64.78
30-day dry period	21.52 b	20.41	21.03	1.18	6.66	7.26	1.21	65.78

Note : PH = Plant height; NL = Number of leaves; RL = Root length; RD = Root diameter; RV = Root volume; RFW = Root fresh weight; RDW = Root dry weight; SFW = Shoot fresh weight. The LSD value difference for the plant height variable is 4.21.

The results of total chlorophyll analysis in pineapple plants showed that under the 15-day dry period, accession 25 had the highest total chlorophyll content, followed by accessions 19, 23, and 24. Meanwhile, under the 30-day dry period, accession 25 also exhibited the highest total chlorophyll content, followed by accessions 23, 24, and 19 (Table VII).

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Table VII. Chlorophyll content analysis results

Combinations	*Chlorophyll A (mg/g) FW*	*Chlorophyll B (mg/g) FW*	*Chlorophyll Total (mg/g) FW*
A19P0	0.69	0.21	0.90
A19P1	1.09	0.27	1.36
A19P2	0.54	0.11	0.64
A23P0	1.81	0.43	2.24
A23P1	0.79	0.16	0.95
A23P2	1.08	0.23	1.31
A24P0	1.01	0.23	1.23
A24P1	0.71	0.15	0.86
A24P2	1.04	0.24	1.27
A25P0	1.31	0.24	1.55
A25P1	1.52	0.35	1.87
A25P2	1.14	0.27	1.41

The drought stress tolerance index during the 15 and 30-day dry periods for pineapple accessions showed variation in the results. The classification criteria for determining the level of drought tolerance according to [21], are categorized as sensitive if STI < 0.5, medium tolerant if 0.5 < STI < 1.0, and tolerant if STI > 1.0.

Based on shoot and root dry weight of the four pineapple accessions, accessions 24 and 25 had higher STI values compared to accessions 19 and 23 under the 15-day dry period (Table VIII). Accordingly, accessions 24 and 25 are classified as tolerant due to STI values greater than 1.0, while accessions 19 and 23 are categorized as medium tolerant with STI values between 0.5 and 1.0.

Table VIII. Mean values of stress tolerance index at 15-day dry period

Accession	*SDW*	*RDW*	*Average*	*Result*
19	0.22	1.62	0.92	M
23	0.79	0.43	0.61	M
24	1.41	1.24	1.32	T
25	1.05	0.96	1.00	T

Note: SDW = Shoot Dry Weight; RDW = Root Dry Weight; S = Sensitive; M = Medium Tolerant; T = Tolerant

Meanwhile, under the 30-day dry period, all pineapple accessions had STI values between 0.5 and 1.0 (Table IX). Based on this, accessions 19, 23, 24, and 25 are classified as medium tolerant.

Table IX. Mean values of stress tolerance index at 30-day dry period

Accession	*SDW*	*RDW*	*Average*	*Result*
19	0.19	0.89	0.54	M
23	0.65	0.41	0.53	M
24	1.07	0.62	0.84	M
25	1.01	0.89	0.95	M

Note: SDW = Shoot Dry Weight; RDW = Root Dry Weight; S = Sensitive; M = Medium Tolerant; T = Tolerant

Accessions with higher total chlorophyll content tended to exhibit higher STI values, suggesting that these plants are more tolerant to drought stress. This is consistent with the findings of [22], who stated that genotypes with higher chlorophyll content tend to have superior yield performance and greater drought tolerance.

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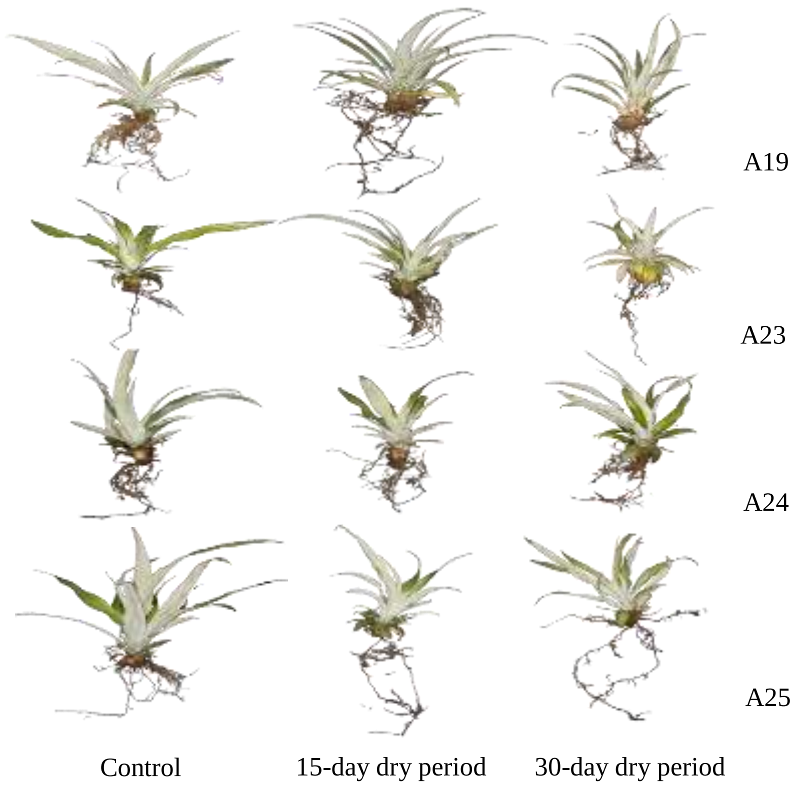

Figure 2. Appearance of pineapple plant accessions at 60 DAP (all accessions are classified as medium tolerant under the 30-day dry period).

DISCUSSION

Each pineapple accession tested exhibited different growth responses under dry period conditions. The 15 and 30-day dry period conditions resulted in varying growth responses among the pineapple accessions. Based on the observation of shoot dry weight, the control treatment showed significant differences compared to the 15 and 30-day dry period conditions in accession 19 and accession 23. Meanwhile, in accession 24, the control treatment showed a significant difference compared to the 30-day dry period condition, but not to the 15-day dry period condition. In accession 25, the 15-day dry period condition differed significantly from the control, but was not significantly different from the 30-day dry period condition. Accession 25 exhibited significant differences compared to accession 24, accession 23, and accession 19 under the control treatment. Additionally, accession 23 differed significantly from accession 24 and accession 19, but not from accession 25 under the 15-day dry period condition. Furthermore, under the 30-day dry period condition, accession 24 showed significant differences compared to accession 25, accession 23, and accession 19. These results suggest that each accession may possess a different level of drought tolerance. This response appears to depend on the interaction between accession characteristics and the duration of drought stress. This aligns with the findings of [23], which state that plant responses to abiotic stress, such as drought, are strongly influenced by genetic differences and each accession's specific adaptive mechanisms.

The results of the study showed that pineapple accessions differed significantly in plant height and shoot fresh weight. The plant height variable indicated that accession 19 exhibited the greatest height growth compared to the other accessions. In contrast, accession 23 had the lowest plant height, suggesting that genetic differences influence the growth response of pineapple plants. Additionally, accession 25 recorded the highest shoot fresh weight, followed by accessions 24, 23, and 19, respectively. Furthermore, the study revealed that the dry period treatments did not significantly affect most of the growth variables, except for plant height. The 15-day dry period condition resulted in the highest plant height, followed by the control, while the 30-day dry period condition showed the lowest plant height. This suggests that the 15-day dry period drought stress may have stimulated plant height growth, whereas the 30-day dry period treatment likely suppressed it. According to [24], each accession has genetic differences that can influence growth patterns, yield, and adaptive capacity to the environment..

The stress tolerance index analysis (Tables VIII and IX) revealed that pineapple accessions responded differently to drought stress. Under the15-day dry period treatment, accessions 24 and 25 were classified as tolerant, likely due to their better adaptive capabilities to drought conditions. Meanwhile, accessions 19 and 23 fell into the moderately tolerant category. However, under the 30-day dry period treatment, the response of the plants changed: accessions 25 and 24, which were previously categorized as tolerant, shifted to the moderately tolerant category. This suggests that the duration of stress influences each accession's response. According to [25], each genotype responds differently to drought, as reflected in the variation of mean values across various traits, including sensitivity to changes in biomass, root-to-shoot ratio, and fruit yield.

CONCLUSION

Accessions 19 and 25 exhibited the highest performance compared to the other two accessions. Under the15-day dry period condition, accessions 24 and 25 showed higher STI values than accessions 19 and 23. Accessions 24 and 25 were categorized as drought-tolerant, while accessions 19 and 23 were considered moderately tolerant. Based on these findings, accessions 24 and 25 have better drought tolerance than accessions 19 and 23 under the15-day dry period condition. However, under the 30-day dry period condition, accessions 24 and 25 experienced a decline in shoot and root dry weight, resulting in their reclassification as medium tolerant, and based on this finding, under the 30-day dry period condition, accessions 19, 23, 24, and 25 are possess a similar level of drought tolerance.

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