



RESEARCH ARTICLE

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Influence Stress Drought to Anatomy and Morphology of Leaf Chilli (*Capsicum annuum* L.) Local West Sumatra

Tri Budiyanthi^{1,2,*}, Irfan Suliansyah¹, Dini Hervani¹, Rinda Kirana²

Abstract

Drought stress is a primary limiting factor affecting the growth and productivity of chili pepper (*Capsicum annuum* L.), particularly in dryland regions. This study evaluated the effects of drought stress on the anatomical and morphological characteristics of local chili pepper genotypes from West Sumatra. The experiment used a randomized block factorial design with two factors: water availability (80% and 50% field capacity) and three genotypes (Bonsai Tanah Datar, Kampung Manangah, and Tali). Results indicated that drought stress significantly reduced leaf count, fruit number, leaf size, and stomatal characteristics. Specifically, plants subjected to 50% field capacity exhibited smaller guard cells, reduced stomatal dimensions, and decreased leaf area compared to those under optimal watering conditions. A significant decline in fruit number was also observed. Among the tested genotypes, Kampung Manangah demonstrated superior adaptability. These morphological and anatomical changes reflect adaptive responses to water deficit. The findings provide critical selection criteria for breeding drought-tolerant chili genotypes. Consequently, the Kampung Manangah genotype warrants further investigation to develop varieties with enhanced drought tolerance.

Keywords: Adaptation, Physiological Stress, Stomata, Water Tolerance

1. Introduction

Chilli red curly (*Capsicum annuum* L.) is one of the types of chili developed in Indonesia, in accordance with the preferences of Indonesian consumers in general. Availability of chilli, continuously and fluctuatingly, is one of the problems nationwide. Improvement of chilli production nationally can be done through the expansion of planting areas, utilizing marginal land and planting in areas that are kept dry. Chili plants are very sensitive to water shortages, as they significantly reduce production (Rosmaina et al., 2019).

Drought stress occurs when the soil water supply is insufficient to meet plant needs, resulting in a water deficit in plant tissues. This condition can reduce cell turgor pressure, inhibit cell division, and disrupt photosynthesis and plant metabolism (Hussain et al., 2020; Ahanger et al., 2021).

In dryland areas, drought stress occurs when the water supply cannot meet a plant's needs. Drought stress that occurs at various stages of growth and development can

reduce plant yields. The extent of yield reduction depends on the severity and duration of the stress, the growth phase at which it occurs, and the plant genotype (Seleiman et al., 2021; Oguz et al., 2022). During the vegetative growth phase, water availability affects several physiological and morphological aspects, including reduced photosynthetic rate and leaf area. If plants are exposed to drought stress, leaf water potential will decrease, leaf chlorophyll formation will be disrupted, and chloroplast structure will be disrupted (Sallam, 2019; Pei et al., 2019). Rosmaina et al. (2019) reported that drought stress in chili plants can reduce yields by 30% to 100%, depending on the genotype tested. The difference in the percentage of reduction indicates that each chili genotype has a different level of tolerance to water shortages.

Water limitations reduce the rate of photosynthesis, inhibit the transport of photosynthetic products, and reduce the energy available for the formation of reproductive organs. Drought can also disrupt photosynthesis by impairing photosystems, the electron transport chain, and

*Correspondence: tri_budiyanthi@yahoo.com

1) Universitas Andalas - Jl. Dr. Mohammad Hatta, Limau Manis, Kec. Pauh, Kota Padang, Sumatera Barat 25163, Indonesia

2) Badan Riset dan Inovasi Nasional (BRIN) - Jl. Raya Jakarta-Bogor Km 46, Cibinong, Bogor 16915, West Java, Indonesia

chloroplast activity, resulting in decreased plant growth and yield (Qiao *et al.*, 2024). At the cellular level, water loss can cause changes in osmotic compound concentration, decreased cell volume, loss of turgor, membrane disruption, and protein damage. Furthermore, drought stress can accelerate leaf senescence and reduce photosynthetic efficiency, preventing photosynthetic organs from functioning optimally (Tan *et al.*, 2023; Munné-Bosch, 2025). Consequently, yield reductions can differ between susceptible and tolerant plants. Tolerant plants generally have better adaptation mechanisms, such as stomatal regulation, reduced water loss, osmotic adjustment, and the ability to maintain leaf function during drought (Zhao *et al.*, 2022; Alghamdi *et al.*, 2024). Morphological or phenotypic characters (conventionally) are generally used to estimate plant tolerance to drought stress, namely by visually observing symptoms at the *in vitro* level (Budyanti *et al.*, 2023) and in the field (Safitri, 2024). In chili plants, drought stress is known to reduce vegetative growth, leaf area, and fruit production (Widuri *et al.*, 2020; Hernández *et al.*, 2022; Ntanasi *et al.*, 2025).

Plants have various adaptation mechanisms to survive water shortages, including physiological, morphological, and anatomical changes. Morphological changes in plants are one of the initial responses observed when plants experience drought stress. Some common morphological changes include decreases in leaf area and leaf number, and changes in leaf shape and thickness, which aim to reduce water loss through transpiration (Seleiman *et al.*, 2021; Fahad *et al.*, 2021; Ullah *et al.*, 2023).

In addition to morphological changes, drought stress also alters leaf anatomy. Leaves are the most sensitive plant organs to water shortages because they play a direct role in photosynthesis and transpiration. Under drought stress, plants often exhibit changes in stomatal structure, cuticle thickness, and the composition of leaf mesophyll tissue as adaptations to maintain water balance (Li *et al.*, 2022; Zhang *et al.*, 2021; Arena *et al.*, 2025). Stomata play a crucial role in regulating gas exchange and transpiration, which contribute to water loss. Under drought conditions, plants tend to reduce stomatal aperture or alter stomatal size and density to minimize water loss (Li *et al.*, 2025). Furthermore, changes in vascular tissue structure and epidermal thickening can occur as part of plant adaptation mechanisms to drought stress (Pang *et al.*, 2024; Khan *et al.*, 2022).

Several previous studies have examined the morphological and anatomical responses of leaves to drought. Li *et al.* (2021) found that leaf anatomy plays a crucial role in maintaining the balance between water supply and CO₂ diffusion responses in stressed tomato plants. Furthermore, changes in vascular tissue structure and epidermal thickening may occur as part of plant adaptation mechanisms to drought stress (Pang *et al.*, 2024; Khan *et al.*, 2022). Research on the effects of drought on

stomata and leaves in local chili peppers from West Sumatra has not been conducted. This study aims to determine the morphological and anatomical responses of three local chili genotypes from West Sumatra to drought stress.

2. Material and Methods

2.1. Place and Time

The research was conducted at the farmer's Screen House in Solok Regency, at an altitude of 450 m above sea level, at coordinates -0.7651 S, 100.6330 E. Stomata observations were conducted at the Central Laboratory of Andalas University from June to December 2024.

2.2. Tools and Materials

The tools used were an object glass, tweezers, a microscope, a hoe, a watering can, a meter, a tensiometer, a thermometer, a camera, and scales. The materials used were three genotypes of local chili seeds from West Sumatra, polybags, soil, manure, fertilizer, and insecticide.

2.3. Research Methods

The experiment was conducted using a factorial randomized block design (RAK) with two factors: the first factor was 2 watering conditions, namely the Field Capacity (KL) control and 50% KL, and the second factor was 3 types of local West Sumatran chilies, namely Bonsai Tanah Datar (BO), Kampung Manangah (KM), and Tali (TA), repeated three times. Watering and observation treatments were carried out during the early generative phase, when the plants began to flower.

2.4. Research Procedures

Chili seeds are soaked in lukewarm water for approximately 2 hours. This aims to accelerate seed germination and also to separate submerged seeds from floating seeds. Chili seeds are planted in 15 x 10 cm polybags. The planting medium is a mixture of sifted topsoil and compost in a 3:1 volume ratio. Sowing continues until the seedlings are 4 weeks old. Next, the seedlings are transferred to polybags (25 cm x 30 cm) filled with planting medium (manure and mineral soil in a 1:1 ratio, up to 5 kg per polybag).

Field capacity was determined two days before the seedlings were transferred to the media. Each prepared medium was weighed (initial weight). The gravimetric method was used to determine field capacity. This method was carried out by pouring water onto the media until it was saturated, then leaving it until the water stopped dripping from the polybag. Then, the weight of each medium was weighed (final weight). 100% field capacity was determined by subtracting the final weight of each medium from its initial weight. The media weight at 50% and 100% KL was determined based on the average 100% field capacity.

Drought stress or watering treatments were administered one day after transplanting for vegetative

stress and one week after flowering for generative stress. Polybags (soil + plants) were weighed every two days. Watering treatments were administered according to the tested water availability level.

2.5. Observation

Morphological observations consisted of the number of leaves/plant, the number of fruits/plant, leaf length, and leaf

width. Morphological observations were carried out when the plants were 3 months old after planting. Anatomical observations of leaf sample preparations were carried out according to Gärtner and Schweingruber (2013) at the Central Laboratory of Andalas University using a microscope with 40X magnification and a PC with Labscope software version 3.3.1. For observations of stomatal size, ImageJ (<https://imagej.nih.gov/ij/>) was used.

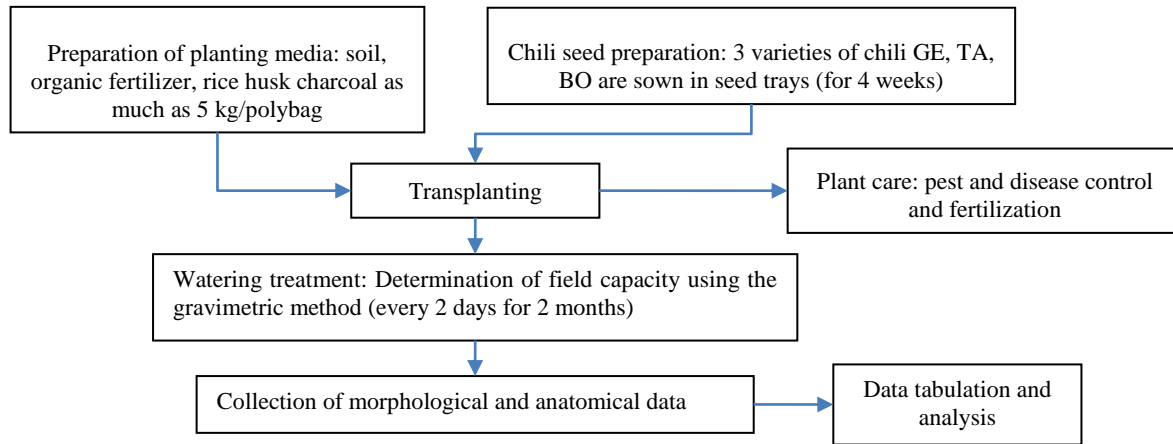


Figure 1. Research flow diagram

3. Results and Discussion

Based on Table 1, stress drought affects the number of leaves and fruit in three chilli varieties from West Sumatra. Plants that get 50% capacity treatment rooms show a lower amount of leaf compared to the 80% capacity condition field. A decline in leaf area indicates that limited water availability hinders the growth of vegetative plants. A

water deficit causes a decline in cell turgor pressure, so that the processes of cell division and cell enlargement become disturbed. This aligns with research showing that stress and drought, in turn, significantly reduce plant growth, causing physiological disturbances and consequences (Hussain et al., 2020; Sihotang et al., 2024).

Table 1. Average number of leaves and number 3 varieties of fruit local chilies from West Sumatra in good condition, watering at 80% capacity, spacious and 50% capacity spacious.

Variety	Amount leaf			Amount fruit		
	80% FC	50% FC	Average	80% FC	50% FC	Average
TA	29.00 ±3.91	18.33 ±2.02	23.67 ±6.47	22.33 ±2.52	5.33 ±0.58	13.83 ±9.45 ^b
KM	29.00 ±1.33	17.17 ±1.26	23.08 ±6.58	25.33 ±4.04	2.33 ±1.53	13.83 ±12.89 ^b
BO	33.67 ±2.02	18.5 ±1.80	26.08 ±8.48	74.00 ±44.68	7.67 ±3.06	40.83 ±20.00 ^a
Average	30.56 ±3.27 ^a	18.00 ±1.62 ^b	-	40.56 ±15.00 ^a	5.11 ±2.89 ^b	-

^a Numbers followed by the same letter in the same column are not significantly different based on the LSD test at the 5% level.

A decline in the amount of leaves under stress and drought is also a form of adaptation that reduces water loss through transpiration. Plants tend to reduce leaf area and quantity as a mechanism to avoid drought. Adaptation is important for maintaining water balance in network plants. Besides that, stomatal closure under drought conditions reduces photosynthesis, thereby hampering leaf growth (Pamungkas et al., 2022).

For the number parameter fruit, it is evident that stress due to drought causes a further drastic decline in the number of leaves. This shows that the reproductive system is more sensitive to water stress. Decrease amount fruit at 50 % capacity roomy, caused by disruption of the flowering and pollination processes, as well as formation fruit consequence limitations photosynthesis. The latest shows

that stress drought can lower the efficiency of photosystem II and the rate of photosynthesis, so that impact is directly reflected in the bottom results in fruit (Mushtaq et al., 2024).

The difference in response between varieties is also clear in the table, where BO varieties have the highest fruit yield compared to KM and TA varieties, under both normal and stress conditions. This shows genetic variation in tolerance to drought stress. More varieties are tolerant, capable of maintaining physiological activity (e.g., photosynthesis and stomatal conductance) are higher, Good, compared to varieties sensitive. Research on chili peppers shows that genotypes tolerant of drought can maintain physiological performance and yield better under drought conditions (Poudyal et al., 2024).

In a way, overall, results show that stress drought influences growth, vegetative and reproductive, in chilli plants through changes in physiological and anatomical traits. A decrease in leaf and fruit amount is an indicator of the main impact of drought on plants. Besides that, ability variations in maintaining fruit quantity show potential tolerance to drought stress, which can be utilized in the breeding program for plants. This is supported by various studies that show that plant responses to drought involve complex interactions among morphological, physiological, and genetic factors (Sulaman et al., 2025; Al Toriq & Puspitawati, 2023).

Based on Table 2, stress drought give influence real to length and width of leaves in three varieties of chilli from West Sumatra local. At 50% capacity, the roomy happen decline long leaf compared to the 80% capacity condition, which is spacious. This shows that low water availability limits growth in leaf cells. Lack of water causes a decline in turgor pressure, so that expansion cells are hampered, which ultimately impacts leaf size, making more leaves smaller. Phenomenon This phenomenon occurs in plants, such as chilies, that experience drought stress (Hussain et al., 2020; Molla et al., 2023).

Decline in longleaf is one of the adaptive responses of plants to drought conditions. Plants tend to reduce leaf size to increase transpiration rate and maintain water balance in the network. Research previously showed that stress during drought causes a wide range of consequences, including decreased activity of photosynthesis and cell division (Widuri et al., 2020). Besides that, water limitations also

affect chlorophyll synthesis, so that growth slows down in leaves (Haris et al., 2020).

The width parameter shows that stress drought also causes a significant decrease. Average wide leaves at 50% capacity; roomy, more low compared to 80% capacity, spacious. This shows that stress drought not only influences leaf elongation but also the lateral expansion of the leaves. The decrease in wide leaf is related to a decline in physiological activity, such as photosynthesis and stomatal conductance, which impacts the growth of leaves (Ntanasi et al., 2025).

Difference in response between varieties shows genetic variation in tolerance to drought stress. The KM variety has long leaves, the largest among the varieties, both under normal and stress conditions, which indicates greater adaptation ability. Meanwhile, BO and TA varieties show size more leaves small so that allegedly more sensitive to drought. Variation in accordance with the report that genotype plants exhibit different responses to drought stress depending on their physiological and morphological adaptation (Siaga et al., 2024).

In a way, overall, results show that stress drought causes a decline in leaf size, good long and wider as part of a mechanism of adaptation to reduce water loss. Although thus, the decline in size also affects photosynthesis, resulting in potentially lower productivity plants. Therefore, the election varieties that can maintain a larger leaf size under stress-drought conditions become important in the development of chilli tolerant to drought (Syafriani et al., 2024).

Table 2. Average length and width of 3 varieties of leaves of local chilies from West Sumatra in good condition, watering at 80% capacity, spacious and 50% capacity spacious.

Variety	80% FC	50% FC	Average	80% FC	50% FC	Average
Leaf length (cm)			Leaf width (cm)			
TA	11.50±1.39 ^{ab}	5.42±0.14 ^b	8.46±3.44 ^b	4.58±0.36	3.43±1.01	4.01±0.92 ^a
KM	13.92±0.80 ^a	8.42±0.72 ^a	11.17±3.08 ^a	4.3±0.13	2.57±0.20	3.43±0.96 ^b
BO	8.75±2.46 ^b	7.53±0.82 ^{ab}	8.14±1.77 ^b	3.75±0.05	2.7±0.13	3.23±0.58 ^b
Average	11.39±2.67 ^a	7.12±1.44 ^b	-	4.21±0.41 ^a	2.90±0.65 ^b	-

^a Numbers followed by the same letter in the same column are not significantly different based on the LSD test at the 5% level.

The function of stomata in plants is very important: controlling CO₂ absorption for photosynthesis and water loss through transpiration, as well as balancing both processes. Stomatal opening is controlled by a pair of guard cells that actively and reversibly change their turgor pressure to regulate the degree of stomatal pore opening. Stomatal performance is strongly influenced by the regulation of ion transport capacity in the cell membrane as well as changes in subcellular organization within the guard cells. The guard cells in three local West Sumatran chili varieties under normal watering conditions appear to differ in length and width. Kampung Manangah (KM) chili has larger guard cells than those of the other two chili types. This study shows that the size of guard cells in chili plants stressed by drought at 50% field capacity is smaller than in

watering conditions at 80% field capacity. This is also accompanied by a reduction in leaf stomatal size, which becomes smaller and narrower under drought stress at 50% field capacity.

Based on the results in the table, stress drought has a significant effect on the size of guard cell stomata in three varieties of chilli from West Sumatra. In general, a decline in average long cell stomata guard from 29.56 to 24.98 and wide from 20.58 to 17.73 at 50% capacity roomy compared to 80% capacity field. Decline: This shows that water stress causes a decrease in turgor pressure in cells, which reduces the ability of cells to expand. Condition: This is in line with the draft physiology plant, which states that water deficit will lower leaf water potential, so that cell guard loss of turgor and stomata size become smaller (Hussain et al.,

2020; Ahanger *et al.*, 2021).

Table 3. Average length and width of cell stomata guards on 3 varieties of local chilies from West Sumatra in good condition, watering at 80% capacity, spacious and 50% capacity roomy.

Variety	Cell length stomatal guard			Cell width stomatal guard		
	80% FC	50% FC	Average	80% FC	50% FC	Average
TA	29.64±1.48 ^b	24.71±0.82 ^a	27.17±2.90 ^b	20.41±0.29 ^b	16.86±0.55 ^a	18.64±1.98 ^b
KM	35.08±1.73 ^a	26.16±1.80 ^a	30.62±5.13 ^a	22.60±2.04 ^a	18.18±1.20 ^a	20.39±2.84 ^a
BO	23.95±0.88 ^c	24.08±0.57 ^a	24.01±0.68 ^c	18.74±1.66 ^b	18.14±0.38 ^a	18.44±0.88 ^b
Average	29.56±4.97 ^a	24.98±1.49 ^b		20.58±2.13 ^a	17.73±0.68 ^b	

^a Numbers followed by the same letter in the same column are not significantly different based on the LSD test at the 5% level.

If analyzed further for each variety, the KM variety has the largest size cell guard at optimal conditions (35.08 length and 22.60 width at 80% FC) and remains the highest in condition stress (26,16 and 18,18). This indicates that KM varieties have greater capacity for maintaining stomatal function compared to other varieties. Meanwhile, TA varieties experience declines from 29.64 to 24.71 (length) and from 20.41 to 16.86 (width), while BO varieties show relatively low values in both normal conditions (23.95 and 18.74) and stress (24.08 and 18.14). Difference: This shows variation in genetics in response to stress and drought, which is an important factor in determining plant tolerance to extreme environmental conditions (Fahad *et al.*, 2021; Poudyal *et al.*, 2024).

Decline in cell stomata guard at 50 % capacity roomy is form of structural plant to reduce loss of water through transpiration. More stomata, small, tend to have more openings, narrow, so that capable of reducing water loss. Mechanism: This is controlled by hormonal signals such as the plant hormone abscisic acid (ABA), which increases under drought conditions and triggers stomatal closure. In addition, changes in stomatal size are also related to a decline in stomatal conductance, which directly impacts plant water-use efficiency (Li *et al.*, 2022; Zhang *et al.*, 2021). However, this adaptation has its own consequences in the form of a decline in CO₂ diffusion into the leaf, so that potential photosynthesis rates are lower.

Table 4. Average length and width of stomata on leaves of 3 varieties of local West Sumatra chilies under watering at 80% capacity, spacious and 50% capacity. roomy

Variety	Stomata length			Stomata width		
	80% FC	50% FC	Average	80% FC	50% FC	Average
TA	19.12±0.50 ^b	17.05±1.02 ^a	18.09±1.19 ^b	7.93±0.31 ^{ns}	7.24±0.39 ^{ns}	7.59±0.49 ^b
KM	22.65±1.56 ^a	17.35±1.15 ^a	20.00±3.15 ^a	10.17±1.77	7.42±0.09 ^a	8.79±1.88 ^a
BO	15.64±1.02 ^c	17.02±0.20 ^a	16.33±0.88 ^c	7.81±1.96	6.30±0.85 ^a	17.05±1.53 ^b
Average	19.14±3.18 ^a	17.15±0.68 ^b		8.63±1.76 ^b	6.99±0.64 ^b	

^a Numbers followed by the same letter in the same column are not significantly different based on the LSD test at the 5% level.

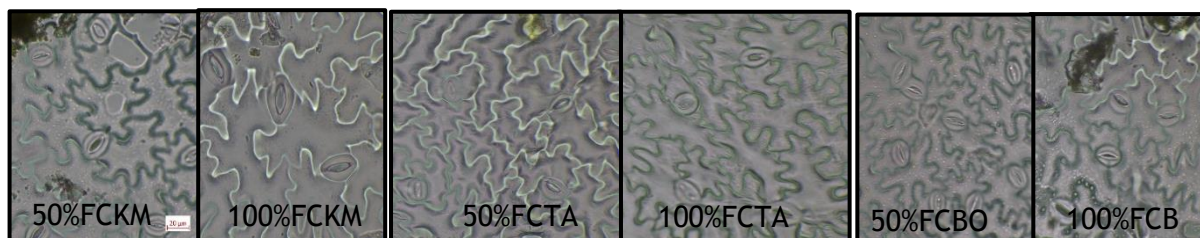


Figure 2. Performance leaf 3 and leaf stomata in 3 genotypes of chilli with treatment watering 50% capacity space and roomy capacity

In a way, physiological changes in stomata anatomy were observed in the study. This can be separated from changes in metabolic processes in plants in a way overall. Decrease in stomata size in TA and BO varieties is greater than in KM, showing that the second varieties tend to be more sensitive to drought stress. Sensitive plants generally respond quickly, with excessive stomatal closure, so photosynthesis is disturbed. On the other hand, the more varieties tolerant, like KM, are capable of arranging stomatal opening more efficiently, so that they still

maintain a balance between water loss and CO₂ absorption (Ntanasi *et al.*, 2025).

Besides that, the size of the stomata is also closely related to the efficiency strategy of water use (water use efficiency/WUE). Plants with more stomata, small but distributed optimally, tend to have higher water-use efficiency. In this context, although stomata size decreases under conditions of stress, KM variety still shows a marked average (30.62 length and 20.39 width), which indicates that varieties have their own mechanism for

better adaptation in maintaining physiological balance. This is supported by research, the latest stating that stomatal characters, such as density, size, and response to stomatal openings, together with physiological responses like photosynthesis, stomatal conductance, transpiration, and water use efficiency, can be used as important indicators in selection plant tolerant to drought (Haghpanah et al., 2024; Fernando et al., 2025; Li et al., 2025)

In a way, overall, results show that stress drought causes significant changes in the dimensions of guard cells as part of the mechanism of adaptation in plants. Decline in stomatal size is a strategy to reduce water loss, but it also affects the decline in photosynthetic capacity. Therefore, the variety is capable of maintaining relative stomatal size more stable, like KM and has greater potential for development as varieties tolerant of drought. Integration between character anatomy, morphology, and physiology

become important approach in support of breeding programs for plant chilies in the field dry (Ahanger et al., 2021; Fahad et al., 2021; Zhang et al., 2024).

4. Conclusion

Research results show that stress drought, in a way, significantly reduces the number of leaves, the number of fruits, leaf size, and stomatal characteristics. Plants in condition capacity 50% field shows size cell more guards small, the size of the stomata is reduced, and the size of the drooping leaves compared to with plant in a normal watering. Stress drought causes a significant decline in the amount. Between genotypes, This is Manangah Village shows greater relative adaptation, which is good. Change observed morphology and anatomy in the study. This reflect response adaptive plant to water deficit conditions.

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