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# Effect of Drought Stress on Growth and Productivity of Local Rice Ciherang, and Aromatic Rice Sintanur

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## ABSTRACT

This study examined the morphological and physiological responses of two rice varieties to drought stress to identify adaptive characteristics that support plant resistance. Parameters analyzed included leaf rolling rate, stomatal density, chlorophyll content, proline accumulation, and the number of full and hollow grains per panicle. Results showed that increased drought stress triggered more intense leaf rolling, decreased stomatal density, and reduced chlorophyll content, which negatively affected photosynthesis and yield. Proline accumulation increased significantly, suggesting its important role in osmoregulation and stress tolerance. Variety Ciherang (V1) showed better adaptability than Variety Sintanur (V2), characterized by efficient stomatal adjustment and higher proline accumulation. The decreased number of full grains and increased hollow grains at high stress levels confirmed the impact of drought on productivity. These findings indicate that leaf rolling and proline accumulation can be used as indicators for the selection of drought-resistant varieties, supporting the development of adaptive rice in drought-prone areas due to climate change.

**Keywords:** Chlorophyll content; Leaf rolling; Proline accumulation; Stomatal regulation; Stress tolerance

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## INTRODUCTION

Climate change has a significant impact on the growth process and productivity of crops, especially food crops. One of the climate anomalies that contribute to global climate disruption is the El Nino phenomenon, which is an increase in sea surface temperatures above normal in the central region of the Pacific Ocean. The El Nino phenomenon results in increased convective activity but simultaneously causes a decrease in rainfall in the Indonesian region. The reduction in rainfall triggers widespread drought, which in turn increases the risk of crop failure (puso), especially in rice commodities. One of the main obstacles facing the national agricultural sector today is the limited availability of plant varieties that have high tolerance to drought stress (Maisura et al 2016).

According to data from Indonesian Statistics (2024), national rice production decreased in 2023, with a total output of 53.98 million tons of milled dry grain (MDG), a decrease of 767.98 thousand tons of MDG or equivalent to 1.4% compared to the achievement in 2022. This decline is closely related to the occurrence of extreme weather conditions, especially prolonged drought as a result of the El Niño phenomenon. Drought causes plants to experience physiological stress, thus inhibiting the process of growth and development, and reducing plant productivity.

Water plays a crucial role in the rice cultivation system, considering that rice plants have a high water demand. However, the availability of water in the agricultural sector often experiences constraints due to competition between sectors and climate change that results in drought (Sujinah and Ali 2016). In the face of drought stress, rice plants show several tolerance mechanisms, including shortening the growth cycle, reducing the leaf area index, increasing water absorption by roots in deeper soil layers, and accumulating osmoprotectant compounds such as sugar alcohols, betaine, proline, and glycine. In addition, rice plants also regulate the opening and closing of stomata to minimize water loss through leaf transpiration (Dama et al 2020).

The initial morphological response to drought stress is generally characterized by a decrease in leaf area index, which results in a reduced number of active stomata and photosynthetic rate. The decrease in leaf area is caused by disturbances in the process of cell division and expansion. Plants experiencing water deficit show obvious symptoms of drought stress (Widianti et al 2017).

Physiologically, water deficiency results in the degradation of photosynthetic pigments, a decrease in chlorophyll content, and a weakening of the

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photosynthetic system as a whole. This decrease is caused by damage to cell structures that accelerate the process of chlorophyll catabolism (Fathi and Tari 2016). Under stress conditions, an increase in proline content is an important indicator of plant tolerance to drought. Proline functions as a vital osmolyte and osmoprotectant that facilitates osmoregulation, stores nitrogen (N), and protects essential enzymes. Furthermore, its accumulation helps maintain cell turgor pressure, thereby supporting plant growth, particularly root development, under low osmotic potential conditions (Nurmalasari 2018).

Several superior rice varieties are cultivated and consumed by the Indonesian population, including both local and aromatic types. Ciherang is widely recognized as a high-yielding local variety with favorable agronomic performance, while Sintanur is valued for its distinctive aroma and increasing consumer preference (Elvi 2019). However, comparative information on the integrated morphological and physiological responses of these two contrasting varieties under controlled water deficit conditions remains limited, particularly in relation to their yield performance, highlighting the importance of further investigation.

This study aims to evaluate the morphological, physiological, and yield productivity responses of Ciherang and Sintanur rice varieties under different levels of water availability based on field capacity. By simultaneously examining key indicators such as leaf rolling, stomatal characteristics, chlorophyll content, and proline accumulation, this study provides a more integrative assessment of plant responses to water deficit. The results are expected to reveal specific adaptive traits associated with each variety and contribute to the development of practical selection criteria for drought-tolerant rice in climate-affected agricultural systems.

## MATERIALS AND METHODS

This research was conducted in the *Greenhouse* of Agronomy Study Program, Faculty of Agriculture, University of Jember, while the physiological analysis of plants was carried out in the Laboratory of Plant Analysis, Department of Agronomy and UPT Integrated Laboratory and Technology Innovation Center (CDAST), Universitas Jember. Materials used include loamy soil, Petroganik fertilizer, rice seeds of Ciherang and Sintanur varieties obtained from agricultural stores, ninhydrin acid, distilled water, $N_2$, and sulfosalicylic acid, The tools used were a chlorophyll meter, vortex, mortar, micropipette, centrifuge, test tube, spectrophotometer analytical balance. Polybag, watering can

The experimental design used a factorial completely randomized design (CRD). The first factor is rice variety which is symbolized (V): V1 = Ciherang and V2 = Sintanur. The second factor is the level of drought stress at different critical phases in rice plants with 5 levels of field capacity percentage symbolized (P), namely: P1 = Control, P2 = 100%, P3 = 80%, P4 = 60%, and P5 = 40% of field capacity. Each experiment was repeated 3 times so that a total of 2 x 5 x 3 = 30 experimental units were obtained. In each experimental unit, there were 2 polybags per sample plant, so in the experiment, there were 60 polybags per sample plant.

The experiment was conducted through several stages, namely: preparation of planting media, seedling and seedling preparation, planting, fertilization, drought stress treatment, weeding, pest control, and harvesting. Furthermore, first, measure the soil moisture content at field capacity conditions using the *gravimetric* method. Furthermore, soil moisture content was calculated using the formula (1 and 2):

$$DC = \frac{W-w}{T} x\ 100\% \quad (1)$$

Where $DC$ = dry matter content (%), $W$ = Weight of air-dried soil + weighing bottle (g), $w$ = weight of weighing bottle (g), and $T$ = weight of moist soil taken for oven (g).

$$SMC = (MC - DC)\% \quad (2)$$

Where $SMC$ = soil moisture content (%), $MC$ = moisture content.

### Stomatal density

Observations of stomatal density measurements were made once at the end of the vegetative phase. In each observation, 3 leaf samples were taken for each treatment. The leaf that was observed was the second leaf of the flag leaf. The method of measurement is that the leaf surface is cleaned of dust or dirt, then smeared with nail polish covering 1 cm at the tip, center, and base on the lower surface of the leaf. The following is the formula (3) for calculating stomatal density:

$$SD = \frac{SS}{VA} \quad (3)$$

Where $SD$= stomatal density, $SS$= sum of stomata, and $VA$= unit of field-view area

### Chlorophyll

Chlorophyll content in leaves was measured using a Chlorophyll meter (SPAD-10 $\mu$mol m content$^{-2}$). Data were taken twice, at the end of drought treatment in the vegetative phase, and the end of the flowering phase.

### Proline content

Proline content was analyzed at the end of the vegetative phase and the end of the flowering phase. Leaf samples were taken from the second leaf from the top, using a modified method (Bates et al 1973). Proline concentration was determined through a standard curve and calculated based on fresh weight using the following formula (4):

$$Proline\ content = \frac{[(\mu g\ proline/mL)\ x\ mL\ toluene]/115.5\ \mu g/mol}{gram\ sample/5} = \mu\ mol\ proline/g\ fresh\ weight \quad (4)$$

### Leaf rolling score

Leaf rolling score observations were made at the end of the drought stress phase in the vegetative phase. The level of leaf rolling was measured visually based on a score of 1-9 IRRI standards (IRRI 2002). The leaf rolling score is as follows: 0 = healthy leaves (showing no signs of folding), 1 = leaves begin to show signs of folding, 3 =

leaves fold in the shape of the letter V, 5 = leaves fold in the shape of the letter U, 7 = leaf edges touch each other to form the letter O, 9 = leaves roll up completely.

**Product observations**

Production observations of the weight of full grain per panicle and the weight of hollow grain per panicle. Carried out one day after harvest by calculating each production observation variable.

## RESULT AND DISCUSSION

### Morphological response

Traditional methods for assessing drought resistance traits such as leaf greenness, leaf senescence, and leaf curl, such as manual assessments are subjective, error-prone, less scalable, and time-consuming. Rice leaf curling is usually in response to the intensity of drought stress. The leaf rolling and senescence response of plants, especially plants of the Poaceae family, is associated with decreased leaf expansion, lower stomatal conductance, and transpiration rate. Therefore, leaf rolling and senescence scores may help in developing plants that are resistant to water stress. One form of early plant response to drought, according to (Veerala et al 2024), is leaf rolling. Under high-stress conditions, rice plants will roll up their leaves to reduce sun exposure, which reduces evaporation and water loss. According to Zou et al (2011), leaf rolling is caused by shrinking bulliform cells, which are a series of cells that are larger than other epidermal cells, and have thin walls, large vacuoles, and water. The task of bulliform cells is to protect the underlying tissue from being damaged by water stress.

The data in Figure 1 included in this study shows that the highest leaf rolling score occurred under drought stress at the 40% field capacity level. This proves that the higher the level of drought stress, the more rice leaves are rolled. In varieties that are more resistant to drought, leaf rolling may occur less because plants can manage water more efficiently. According to Ali et al (2022) increased drought stress caused by global climate change may impact the resistance of rice plants to water stress. Therefore, an understanding of the stomatal response and leaf rolling in different rice varieties may help in the selection of more drought-resistant varieties. Plants with low stomatal density and faster leaf rolling may be the best choice for planting in drought-prone areas.

Stomata are part of the leaf organelles in the form of small holes found on the surface of the upper and lower leaves of the plant. Stomata have several functions including as a way of exchanging carbon dioxide gas ($CO_2$) with oxygen ($O_2$) and functioning as a place for the transpiration process, which is the process of losing water from the plant body to the environment through evaporation. The efficiency of the photosynthesis process and the ability of plants to withstand environmental stress conditions are related to the density of stomata on the leaves. According to Pirasteh-Anosheh et al (2016) the decrease in the number of stomata is a change in plant morphology in response to drought stress. Stomata can be completely closed under severe drought stress and is highly dependent on the plant species. Tolerant plants can control their stomatal status to allow carbon fixation and photosynthesis and improve water use efficiency. Plants with modified low stomatal density can reduce transpiration rates in dry environments (Bertolino et al 2019). Plants turn to a variety of complex resistance and adaptation mechanisms, including physiological and biochemical responses, to cope with water stress, a process that is different for each type of plant. Sophisticated adaptation mechanisms and organized networks that enhance water stress tolerance and adaptation in plants. Growth patterns and structural dynamics, reduction of transpiration losses through changes in conductance, stomatal distribution, and leaf rolling (Seleiman et al 2021).

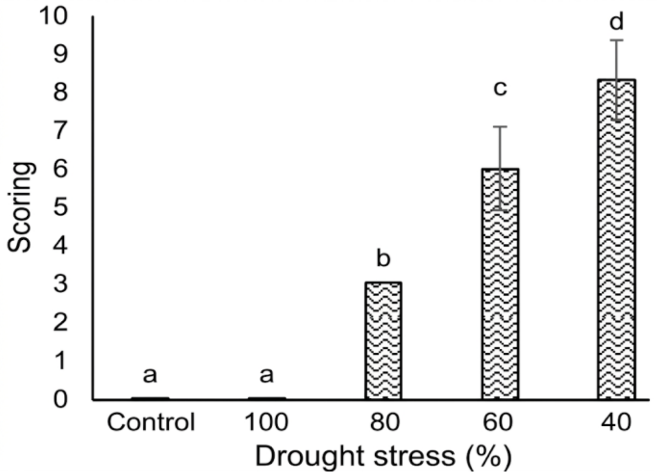


**Figure 1.** Effect of drought stress levels on rice leaf rolling

Based on Table 1, the stomatal density in the Ciherang and Sintanur rice varieties is strongly affected by drought stress. In Ciherang variety, stomatal density decreased significantly as drought stress increased, dropping from 41,353 stomata mm$^{-2}$ under normal conditions to only 23,666 stomata mm$^{-2}$. This indicates that plants adapt to drought by reducing the number of stomata located on the leaf surface. This is supported by statement Mudhor et al. (2022) that the less the field capacity, the lower the stomatal density. Black rice variety Jeliteng responded to drought stress caused by the application of water with 80% field capacity resulting in a decrease in the number of stomatal density by 30.85% when compared to the control. At 60% drought stress level, there was a 33.73% decrease in the number of stomata when compared to the control. This decrease in stomatal density may be a way to maintain the turgor of plant cells and tissues in a dry state. Based on the physiological mechanism of each variety, the response to drought stress can be different. In Sintanur variety, the decrease in stomatal density was less as drought stress increased, but there was still a decrease, indicating that this variety has a higher capacity to manage drought stress According to Jarin et al (2024) this shows that the response to drought stress can vary between varieties, depending on the physiological mechanisms possessed by each variety.

**Table 1.** Interaction between rice variety and drought stress on stomatal density

| Rice Variety | Drought stress (%) | | | | |
|---|---|---|---|---|---|
| | 100 | 80 | 60 | 40 | 20 |
| **Ciherang** | 41.37± 2.49 f | 37.06±1.60 e | 36.17±1.15 de | 30.38±1.32 bc | 23.67±1.22 a |
| **Sintanur** | 41.83±2.68 f | 41.35±1.22 f | 33.30±1.70 cd | 27.91±2.28 b | 27.34±1.22 b |

**Physiological response**

The generative phase of rice plants, which lasts from panicle formation to grain filling, is highly susceptible to environmental stress, especially drought. Drought during this phase can disrupt plant physiological processes, such as a decrease in chlorophyll content, which impacts photosynthetic efficiency and yield. One indicator of rice plant resistance to drought stress can be proven through the amount of chlorophyll content because chlorophyll biosynthesis is closely related to photosynthesis which is sensitive to water availability (Nio et al 2019). Based on the results of the study, due to drought stress caused a decrease in the amount of total chlorophyll in both varieties of rice plants (Ciherang) and (Sintanur). It can be seen in Figure 2 that the higher the drought stress, the lower the chlorophyll content. At the concentration of drought stress with 100% field capacity with the control, there is no significant difference, while between the control and 60% field capacity stress, there is a significant difference. The decrease in total chlorophyll between the control and 80% field capacity was 12.69%, while with 60% field capacity was 21.57%. In addition, drought stress causes a decrease in total chlorophyll content in various rice genotypes (Kumar et al 2021). Drought-tolerant genotypes such as Nagina 22 (N22) and DTY1.1 experienced a decrease in chlorophyll of 9-16%, while sensitive genotypes such as IR64 experienced a decrease of more than 25%.

The difference in proline content in rice varieties due to the accumulation of proline in plants is proven to correlate with drought stress tolerance. Based on Table 2, it can be seen that the interaction between varieties and drought stress treatment has a significant effect on proline content. The highest proline content was found in the P5 treatment, which is the highest stress condition. This may indicate that proline accumulation increases when plants experience stress. Plants that experience biotic or abiotic stress, including drought stress will accumulate proline (Larasani and Violita 2021). The level of proline accumulation varies depending on the variety, duration of stress, plant growth phase, and plant tolerance. Plants with a high level of tolerance to drought stress will accumulate proline tends to be higher than susceptible plants (Palupi and Dedywiryanto 2008). Proline is a protective molecule that accumulates in plants during drought stress, as a mechanism to prevent or overcome these stress conditions (Joanna et al 2023). Proline contributes significantly to the process of osmoregulation, which is the process of regulating the balance of water and solutes, in this case, sodium and chloride. Based on this, it can be seen that in this study, Ciherang variety have a higher level of tolerance to drought stress than Sintanur variety.

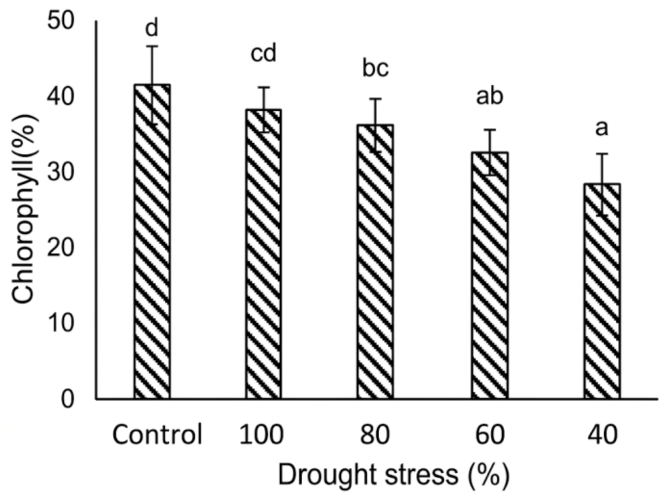


**Figure 2.** Effect of drought stress on chlorophyll content in the generative phase

**Production**

Drought stress has a significant effect on the number of full grains per panicle. Based on Figure 3, shows that both varieties experienced a decrease in the number of full grains per panicle. The lower the stress, the higher the number of full grains per panicle. Conversely, the higher the level of drought stress, the lower the number of full grains per panicle. Lack of water in the generative phase of flower formation can cause a decrease in the number of full grains, resulting in a decrease in production yield (Trisnawaty et al. 2024). This happens because the disruption of the photosynthesis process will affect the production of assimilates for panicle filling. These results are in line with the findings in the study which stated that drought stress that occurs during the grain filling process from anthesis to maturity has a very negative effect (Moonmoon and Islam 2017). Because it can cause a large decrease in the rate of photosynthesis, which impacts the production of assimilates that play an important role in panicle growth and grain filling. Thus, this mechanism reduces grain production significantly.

**Table 2.** Interaction between rice varieties and drought stress on proline content

| Rice Variety | Drought stress (%) | | | | |
|---|---|---|---|---|---|
| | 100 | 80 | 60 | 40 | 20 |
| **Ciherang** | 0.62±0.04 d | 1.24± 0.03 e | 1.27± 0.03 e | 1.27± 0.03 e | 1.30±0.03 e |
| **Sintanur** | 0.12±0.03 a | 0.13± 0.03 a | 0.32± 0.03 b | 0.41± 0.03 c | 1.28± 0.01 e |

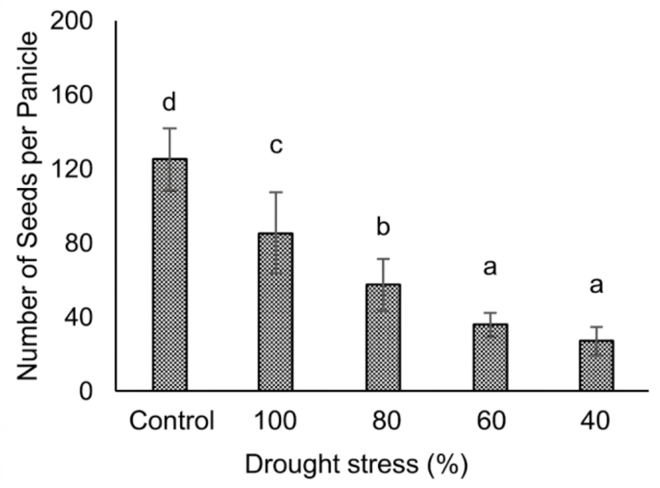


**Figure 3.** Effect of drought stress on the number of blossoms per panicle

### Number of empty grain per panicle

Based on Figure 4, it can be seen that drought stress treatment significantly affects the number of empty grains per panicle. The higher the stress, the higher the number of empty grains per panicle. This can be influenced by the low rate of photosynthesis, which results in a decrease in the amount of photosynthate that can be translocated to seeds. Photosynthesis is a vital physiological process that plays a role in the production process of food crops (Hassan et al 2023). Drought conditions can hurt plants, including less than optimal seed filling. Drought stress in rice plants can affect the low translocation of assimilates from leaves to reproductive organs such as panicles and seeds (Rahman et al 2002).

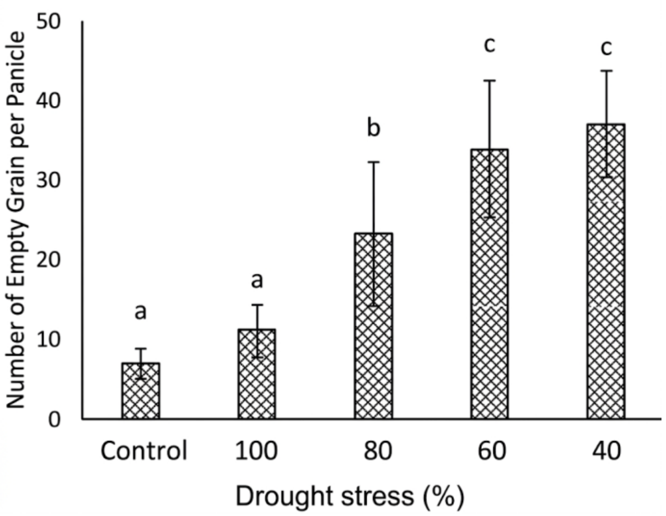


**Figure 4.** Effect of drought stress on the number of empty grain per panicle

## CONCLUSIONS AND SUGGESTIONS

This study shows that the response of rice plants to drought stress is complex and involves interactions between morphological, physiological, and yield factors. Leaf rolling and decreased stomatal density play a role in reducing water loss. Photosynthesis decreases due to the presence of decreased chlorophyll content so the assimilated yield from photosynthesis decreases which leads to decreased production. Proline content increased as an adaptive response, the Ciherang variety showed an adaptive response compared to the Sintanur variety with higher tolerance and water use efficiency, so the results of this study are important for the selection of candidates for assembling drought-tolerant rice varieties.

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