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Chlorophyll Stability and Photosynthesis Efficiency as Indicators of Drought-Tolerant Brown Rice Rice Selection

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ABSTRACT

Drought stress is one of the major limiting factors in rice production, particularly for red rice varieties that are commonly cultivated in dryland areas. Water deficiency leads to a reduction in chlorophyll content, disruptions in the photosynthetic system, and an increase in the formation of reactive oxygen species (ROS) that damage chloroplast structures. Drought-tolerant plants are able to maintain the stability of photosynthetic pigments through enhanced antioxidant activity, the accumulation of osmotic compounds, and improved water-use efficiency. This paper discusses the role of chlorophyll content and photosynthetic efficiency as key physiological indicators for assessing plant drought tolerance. Findings indicate that plants with higher chlorophyll content, stable chlorophyll fluorescence values (Fv/Fm), and good photosynthetic efficiency exhibit greater adaptive capacity under water deficit conditions. Therefore, these physiological parameters can be used as selection criteria in breeding programs for drought-tolerant red rice to support sustainable productivity in suboptimal lands.

Keywords: Drought stress, chlorophyl, photosynthetic efficiency, antioxidants, red rice

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INTRODUCTION

Brown rice is a functional food that has constituent components including protein, fat, crude fiber (cellulose, hemicellulose, and lignin), low mineral content, and carbohydrates. Brown rice also contains bioactive compounds of the carotenoid group, tocopherols, anthocyanins, and tocotrienol that act as antioxidants. The antioxidant content functions to ward off free radicals in the body (Pangerang et al., 2022). In addition, regular consumption of brown rice has been associated with various health benefits such as lowering cholesterol levels, controlling blood sugar, and protecting against degenerative diseases. The red color in this rice comes from the anthocyanin pigment which also provides an anti-inflammatory effect and is able to increase the body's immune system. However, the production of brown rice that is usually cultivated on dry land is still relatively low.

The low production of brown rice is caused by suboptimal cultivation, especially in dry land. Indonesia has 144.47 million hectares of dry land, with 99.65 million hectares potentially for agriculture. Of these, 29.39 million hectares are considered suitable for the development of food crops (Ritung et al., 2015). Therefore, the use of suboptimal land needs to be increased as an alternative solution in the midst of the limited expansion of rice fields that reach 100,000 hectares per year (Dahiri, 2021). Intensification and extensification efforts on drylands are very important to support national food security, especially with the management of water, fertilizers, and varieties that are adaptive to environmental stress conditions. The development of soil and water conservation technology, as well as the implementation of sustainable agricultural systems, also has the potential to increase the productivity of brown rice in marginal areas.

The productivity of brown rice is still relatively lower than white rice. The causative factors include longer plant lifespan, limited yield potential, and low adaptability to environmental stresses (Putri et al., 2019; Singh et al., 2020). In addition to genetic factors, low productivity can also be influenced by unfavorable agroecological conditions, such as water availability, soil fertility levels, and suboptimal cultivation practices. One of the most common forms of environmental stress in rice plants on dry land is water scarcity. Drought control is a major limiting factor in plant growth and yield because it directly affects vital metabolic processes.

Drought stress affects all aspects of plant growth, which includes physiological, biochemical, anatomical and morphological processes. During drought stress, some leaf stomata close so that there is an inhibition of CO_2 entry and decreases photosynthesis activity. In addition to inhibiting photosynthetic activity, water deficiency also inhibits protein synthesis and cell walls (Salisbury and Ross, 1992). Lack of water can lead to a decrease in chlorophyll. A further impact of this condition is a decrease in the efficiency of light energy utilization and disruption in the formation of plant biomass. In the long term, plants that experience heavy water stress can show symptoms of chlorosis, a decrease in leaf area, and the death of photosynthetic tissues.

Chlorophyll is the main pigment in chloroplasts which plays a role in capturing light energy for the photosynthesis process. Decreased chlorophyll levels can reduce the ability of plants to absorb sunlight energy so that it can reduce the efficiency of photosynthesis (Li et al., 2006). In addition, chlorophyll levels are also one of the indicators of plant tolerance to drought stress because chlorophyll biosynthesis is closely related to photosynthesis which is sensitive to drought stress (Nio et al., 2019). Thus, the relationship between chlorophyll content and photosynthesis efficiency in brown rice under drought conditions is important to support the selection of genotypes tolerant to water stress. This paper aims to establish the role of chlorophyll content and photosynthesis efficiency as effective indicators in selecting brown rice rice genotypes that are tolerant to drought stress and support the development of adaptive and productive varieties in dry land. Through this research, it is hoped that genotypes that are able to maintain optimal photosynthetic activity even in water deficit conditions can be found, so that it can be the basis for breeding superior brown rice rice in the future.

METHODS

This paper is a literature review that aims to analyze the role of chlorophyll content and photosynthesis efficiency as an indicator of drought tolerance in rice plants, especially brown rice varieties. The study method was carried out systematically following the approach of Snyder (2019) and Kitchenham & Charters (2007), through the stages of identification, selection, analysis, and synthesis of literature from reliable scientific sources such as Google Scholar, ScienceDirect, ProQuest, and ResearchGate. The literature was selected based on its relevance to the topics of plant physiology, chlorophyll content, photosynthesis efficiency, and adaptation to drought. The analysis was carried out in a qualitative descriptive manner by examining the results of previous research to identify plant patterns and mechanisms in maintaining the stability of photosynthetic pigments under drought stress, referring to the thematic analysis method of Braun & Clarke (2006).

RESULT AND DISCUSSION

The Impact of Drought on the Growth and Physiology of Brown Rice

Drought is one of the main abiotic factors that can reduce the productivity of rice crops, including brown rice rice varieties. Water scarcity interferes with various physiological processes, and plant growth. Drought stress can reduce production even if the results are not significant in the yield component. Lack of water can reduce protein synthesis and cell wall formation, so plants that are exposed to water stress generally have a smaller size than plants that grow normally. In addition, water scarcity also interferes with the absorption of essential nutrients from the soil. Nutrients that are not optimally absorbed will affect the growth of roots, stems, and leaves. As a result, the process of formation of reproductive organs is disrupted and plant productivity decreases significantly (Salisbury and Ross, 1992).

Plant tolerance to stress is influenced by the adaptive response of the variety, both at the morphological and anatomical levels. The physical response most quickly demonstrated by rice is leaf rolling, which serves as an effort to reduce surface area exposed to the sun and minimize water loss through transpiration (Opalofia et al., 2018). Leaf curling occurs due to the shrinking of bulliform cells or commonly called fan cells where these fan cells are a series of cells that are larger than other epidermal cells, have thin walls, large vacuoles and water. The function of the fan cell itself is to protect the tissue underneath it from being damaged due to lack of water (Zou et al. 2011).

Water deficiency in rice plants triggers complex physiological changes, especially with regard to photosynthetic pigments. One of the impacts is a decrease in the chlorophyll content in the leaves due to the inhibition of the biosynthesis process and the increase in pigment degradation. Drought stress during the germination stage has been shown to decrease the expression of genes encoding important enzymes in the chlorophyll biosynthesis pathway (Dalal & Tripathy, 2012). Decreased chlorophyll levels are also a form of plant adaptation to limit excess light absorption and slow down the flow of electrons in photosynthesis systems. This mechanism helps reduce the formation of Reactive Oxygen Species (ROS) which are toxic and can damage cells (Dalal & Tripathy, 2012).

Chlorophyll content and pigment stability due to water deficiency

Chlorophyll content is an important physiological parameter that reflects the plant's ability to carry out photosynthesis. The high chlorophyll content indicates optimal photosynthetic activity. This value can be used as an indicator to assess the effect of water scarcity on plant growth and development. Drought stress lowers chlorophyll content in various plant species with varying degrees of decline between varieties, depending on the defense mechanism against water stress. Plants with the ability to survive using drought escape strategies can complete their life cycle faster before water scarcity reaches critical levels (Farooq et al., 2009; Abdullah et al., 2010).

High-level plants synthesize four types of tetrapirol, namely chlorophyll, heme, cyroheme, and phytochromomobilins. Chlorophyll is a macrocycle of tetrapyrol containing magnesium (Mg) and phytile chains. Under drought conditions, the synthesis of tetrapirol is disrupted so that the formation of chlorophyll decreases (Tanaka & Tanaka, 2007). Water deficiency also leads to pigment photooxidation and chlorophyll, exacerbated by reduced absorption of essential nutrients such as nitrogen (N) and magnesium (Mg) that play a role in the formation of chlorophyll (Jayaweera et al., 2016; Syafi, 2008). Water stress triggers the formation of reactive oxygen species (ROS) such as superoxide (O_2^-) and hydrogen peroxide (H_2O_2). ROS accumulation induces lipid peroxidation on the chloroplast membrane which accelerates chlorophyll breakdown and decreases the efficiency of photosynthesis (Ahmadikhah & Marufinia, 2016). Drought-tolerant plants usually have more active antioxidant systems, such as increased activity of the enzymes superoxide dismutase (SOD), catalase (CAT), as well as the accumulation of proline which plays a role in maintaining the stability of photosynthetic pigments (Hussein et al., 2022).

Drought also causes an imbalance between chlorophyll a and chlorophyll b, where chlorophyll b decreases faster so that the ratio of chlorophyll a/b increases. This change shows a disturbance in the photosynthetic antenna complex that functions to capture light energy (Biotech Asia, 2019). The decrease in protective pigments such as carotenoids and xantophylls also worsens the damage to the photosynthetic system due to reduced protection against photooxidation (Photosynthetica, 2020). The decrease in chlorophyll content and pigment degradation reflect physiological disturbances in the biosynthesis pathways and photosynthetic systems of plants. Plants with high levels of drought tolerance are able to maintain more stable levels of chlorophyll and carotenoids through efficient water use and improved antioxidant mechanisms. Chlorophyll content can be used as a physiological indicator to assess water stress levels as well as the potential resistance of plants to drought.

Plant mechanisms of efficient photosynthesis in the face of drought

Water scarcity is one of the main factors that reduce the efficiency of plant photosynthesis. Drought conditions inhibit biochemical processes in leaf tissue, especially in reactions that occur in photosystem II (PSII). Decreased water availability leads to disruption of carbon dioxide (CO_2) absorption as the stomata close to reduce water loss through transpiration. The closure of these stomata limits the diffusion of CO_2 into the chloroplasts so that the rate of photosynthesis decreases (Fitter & Hay, 1994; Ju & Zhang, 1999). The results of Karami and Shiran et al.'s (2025) research show that drought stress affects the expression of genes that play a role in chlorophyll metabolism and photosynthesis. C_4 plants have the ability to maintain photosynthesis efficiency better than C_3 plants due to a stronger photoinhibition protection system.

Stomata play an important role in the process of photosynthesis efficiency. In water-deficit conditions, plants close most of the stomata to suppress the rate of transpiration, but this action also reduces the supply of CO_2 required in the process of photosynthesis. The decreased water potential due to drought stress has a direct impact on plant physiological processes and metabolism, including a decrease in the activity of enzymes that play a role in carbon fixation (Sumadji, 2020). Drought-tolerant plants adapt through increased accumulation of osmotic compounds such as proline, glycine betaine, and soluble sugars to maintain turgor pressure and protect chloroplasts from damage due to oxidative stress. This osmotic adjustment mechanism helps plants maintain cell stability and photosynthesis efficiency under conditions of water deficiency (Hussein et al., 2022). In addition, the efficiency of photosynthesis in water deficit conditions is also measured through increased water use efficiency (WUE), which is the ability of plants to produce biomass with minimal water loss (Flexas et al., 2013).

The density of the stomata is one of the important factors in the adaptation of plants to drought. Drought-sensitive plants show a decrease in stomata density as water availability decreases, while tolerant plants are able to maintain relatively high stomata density to maintain CO_2 diffusion and photosynthesis efficiency (Dama et al., 2020). Environmental factors such as temperature, light intensity, humidity, and water availability also affect the formation and function of stomata (Al Toriq & Puspitawati, 2023).

Plants develop three main mechanisms to deal with drought stress, namely escape, avoidance, and tolerance. The escape mechanism is characterized by morphological changes such as narrow leaves, thick cuticles, and the ability of the stomata to close quickly when the water deficit increases. This adaptation serves to reduce water loss while maintaining photosynthesis efficiency in dry environmental conditions (Sumadji & Purbasari, 2018). Overall, the efficiency of photosynthesis under drought conditions is highly dependent on the plant's ability to adjust the opening of the stomata, maintain water balance, and maintain the activity of enzymes and photosynthetic systems.

The Role of Chlorophyll and Photosynthesis Efficiency as Indicators of Drought Tolerance

The density of the stomata is an important parameter in determining the level of tolerance of plants to drought stress. Plants with high stomata density are generally able to maintain photosynthetic activity and exhibit lower levels of stress, while decreased stomata density reflects the plant's efforts to reduce water loss through transpiration (Riaz et al., 2013).

Chlorophyll plays an important role in the process of photosynthesis, especially in capturing light energy and converting that energy into chemical energy through reactions in photosystems I and II. The high chlorophyll content indicates the ability of plants to maintain the integrity of the photosynthetic system under drought conditions, so it can be used as a physiological indicator of tolerance to water stress (Putri et al., 2022). Plants that are able to maintain higher levels of chlorophyll during periods of drought tend to have more efficient photosynthesis systems and are resistant to oxidative stress. This is due to the ability of plants to suppress pigment degradation and maintain the stability of the thylacoid membrane, so that the electron transfer process in chloroplasts remains optimal. In contrast, the decrease in chlorophyll levels in drought-sensitive plants is related to the increased formation of reactive oxygen species (ROS) that can damage the structure of chloroplasts (Apherta et al., 2025). Tolerant plants have a more active antioxidant system to neutralize ROS and maintain the stability of photosynthetic pigments (Ahmadikhah & Marufinia, 2016).

The efficiency of photosynthesis can also be assessed through fluorescence measurements of chlorophyll, especially the variable to maximum fluorescence (Fv/Fm) ratio, which describes the efficiency of photosystem II. A high Fv/Fm value indicates that the photosynthesis system is still functioning optimally even under drought conditions (Badr & Brüggemann, 2020). This decrease in value is an early indicator of physiological stress due to disturbances in light energy transfer in chloroplasts (Mohammadi et al., 2015). Therefore, Fv/Fm measurements can be used as a fast and accurate method to evaluate drought tolerance between plant varieties. Thus, the measurement of chlorophyll content and photosynthesis efficiency can be used as the basis for the selection of brown rice rice genotypes that are adaptive to dry land conditions.

CONCLUSION

Drought stress is a major environmental factor that decreases the efficiency of photosynthesis and growth of rice plants. This condition inhibits the synthesis of chlorophyll, accelerates pigment degradation, and increases the formation of reactive oxygen species (ROS) that damage the structure of chloroplasts. Drought-tolerant plants are able to suppress these impacts through increased antioxidant activity, osmotic compound accumulation, as well as the regulation of stomata opening and water use efficiency. Chlorophyll content and photosynthesis efficiency have proven to be effective physiological indicators for assessing the level of tolerance of plants to drought stress. Plants with stable chlorophyll levels and high photosystem II (Fv/Fm) efficiency showed better ability to maintain photosynthetic activity. Therefore, parameters such as chlorophyll content, photosynthesis efficiency, and water use efficiency can be used as the basis for the selection of drought-adaptive brown rice rice genotypes to support breeding programs of superior varieties with high yielding power on dry land.

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