

Evaluation of Secondary Traits as Indicators of Drought Tolerance in Rice

ABSTRACT

Rice is susceptible to various abiotic stressors, including drought, heavy metals, salt, cold, and submergence. This research was conducted to evaluate the secondary traits of six rice varieties as indicators of drought tolerance. It was conducted from February 19 to July 6, 2024, in Paddaoan, Conner, Apayao, utilizing a factorial setup within a Randomized Complete Block Design composed of two water conditions (well-irrigated and water-stressed) applied to six varieties: PSB Rc10, NSIC Rc160, NSIC Rc506, NSIC Rc508, Mestizo 20, and Mestizo 73. This study focused on the identification of rice genotypes that are relatively higher yielding under drought condition as well as determination of the relationship between yield attributes and yield. Results showed that well-irrigated conditions significantly affected all parameters, with unstressed plants surpassing their stressed counterparts. Among the varieties, NSIC Rc160, NSIC Rc508, and Mestizo 73 shown exceptional performance in growth, fertility, and yield, especially under non-stress settings, with NSIC Rc160 achieving the highest metrics. In contrast, PSB Rc10 consistently exhibited the least favorable performance in both treatments, signifying inadequate drought adaption. Notable genotype-by-treatment interactions were recorded, underscoring varied varietal responses to drought. The research underscores the necessity of advancing drought-resistant cultivars for sustainable rice cultivation and advocates for the utilization of high-yielding genotypes in both irrigated and rainfed regions. Further study across many places and seasons is advised to validate these findings.

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Keywords: Drought stress, drought-tolerant, rice, irrigated

1. INTRODUCTION

Rice (*Oryza sativa* L.) is cultivated in diverse ecosystems, encompassing both flood- and drought-prone conditions. Given that rice serves as the primary sustenance for over fifty percent of the global population, reductions in rice yield represent a significant risk to food security. Rice is susceptible to various abiotic stressors, including drought, heavy metals, salt, cold, and submergence. Irrigated rice is a water-intensive crop, constituting 53% of the world's cultivated rice acreage. The availability and accessibility of freshwater influence global rice production.

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The Food and Agriculture Organization of the United Nations has acknowledged the Philippines as the eighth largest rice producer globally for 15 consecutive years (1999–2013), with a production of 18.439 million metric tons in 2013 (FAOSTAT 2015). Rice agriculture in the Philippines is categorized as either irrigated or rainfed. In 2015, rainfed rice cultivation

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constituted 30.56% of the total rice harvesting area in the country. Nonetheless, production in these regions amounted to only 4.211 million metric tons, representing 23.21% of the total rice output, in contrast to the 13.937 million metric tons harvested from irrigated areas (PSA 2015). The Philippines is a leading producer and consumer of rice in South-east Asia. In 2018, the nation generated 19.08 million metric tons (M mt), although this quantity was inadequate to satisfy domestic demand. Consequently, imports account for around 10% of annual consumption (PSA, 2018). Notwithstanding significant production improvements during the Green Revolution, supply has failed to match population increase after that period, particularly in underprivileged communities. The stagnation of rice yields, especially in regions with sufficient irrigation, intensifies the supply and demand dilemma. In 2003, the average production in irrigated regions was 3.5 tons per hectare, whilst rainfed upland areas achieved a significantly lower yield of 1 ton per hectare.

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Investigations into drought-resistant rice cultivars are fundamentally associated with multiple United Nations Sustainable Development Goals (SDGs), particularly SDG 2: Zero Hunger, which seeks to eliminate hunger, ensure food security, enhance nutrition, and foster sustainable agriculture. Rice serves as a fundamental food source for more than fifty percent of the global populace; thus, the advancement of drought-resistant types is a tactical measure to secure consistent food supply in the face of escalating environmental pressures, especially in areas susceptible to water deficiency. This research not only pertains to food security but also significantly advances SDG 13: Climate Action, by tackling the detrimental effects of climate change—particularly drought—on agricultural systems.

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Enhanced rice production must predominantly derive from elevated yields on a diminishing land area within irrigated and advantageous rainfed lowland habitats. This rice must be cultivated with reduced water, lower costs, and likely diminished manpower availability. The development and delivery of natural resource management technologies to improve the production of irrigated rice in an ecologically sustainable manner is essential. Hence, the present study will be carried out to find association between grain yield and drought related secondary traits and the inter correlation among these traits under managed stress condition.

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2. OBJECTIVES

This study was conducted to:

1. Evaluate the response of different rice genotypes to water stress at the reproductive stage;
2. Determine the association between secondary traits and yield under drought condition;
3. Identify drought tolerant inbreds and hybrids.

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3. REVIEW OF RELATED LITERATURES

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3.1. Responses of Rice to Drought Stress

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Rice productivity is extremely threatened under drought conditions. Drought-induced morpho-physiological damage and biochemical dysfunction are evident in rice plants, which curbs active plant growth and development. It is reported that drought stress affects rice yield by up to 90% depending on the intensity, duration, and crop growth stage (vegetative or reproductive) (Basnayake *et al.*, 2006; Venuprasad *et al.*, 2007). Crop plants tend to avoid, escape, tolerate, and recover from drought-induced implications; this phenomenon is collectively called drought resistance (Yue *et al.*, 2006; Luo, 2010; Shanmugavadivel *et al.*, 2019). On the other hand, drought avoidance is characterized as the ability of plants to sustain high water potential and continue optimal plant growth under moisture-stress conditions (Kumar *et al.*, 2017). Drought escape is the early completion of the plant growth cycle before the onset of local moisture deficit conditions (Manavalan *et al.*, 2009). Drought tolerance refers

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to a plant's innate capacity to survive in water-deficit conditions by sustaining physiological and biochemical activities with minimal plant damage (Luo, 2010). The ability of a plant to restore its metabolic activity and regain its vigour after being exposed to extremely high levels of drought stress and dehydration is known as drought recovery (Luo, 2010).

3.2. Morphological and Yield-Associated Responses

Unlike other cereals, rice is a water-loving plant susceptible to drought stress (Panda *et al.*, 2021). According to Fukai and Cooper (1995), roots, shoots, and leaves' responses to drought vary depending on the plant growth stage (early seedling, vegetative, or reproductive), the intensity of drought stress (mild to severe), and other environmental conditions. Various morphological parameters have been used to monitor plant responses to drought stress (Zaher-Ara *et al.*, 2016; Upadhyaya and Panda, 2019). Drought stress alters the anatomy and ultrastructure of the leaf (Upadhyaya and Panda, 2019). Drought-induced low-water potential limits leaf growth (Zhu *et al.*, 2020); additionally, reduced leaf area, leaf rolling, wilting, thickened leaf size, early senescence, stomatal closure, and cutinized layer on the leaf surface are some of the morphological traits associated with drought stress (Mishra and Panda, 2017; Hussain *et al.*, 2018; Panda *et al.*, 2021).

Root system efficiency is vital in combating drought stress conditions (Panda *et al.*, 2021). Comas *et al.* (2013) stated that root mass (dry) and length are used to forecast rice production under water stress. Rice cultivars with a deep and prolific root system perform better in drought conditions (Mishra *et al.*, 2019; Kim *et al.*, 2020). Extreme drought conditions limit secondary root growth, thicken primary root structures, disrupt water relations, and result in poor nutrient uptake, leading to poor or stunted plant growth (Hussain *et al.*, 2018; Panda *et al.*, 2021).

Rice has three sensitive growth stages concerning drought stress: early seedling, vegetative, and anthesis (reproductive) (Singh *et al.*, 2012). Water scarcity in the early seedling stage reduces drought stress, leading to unbalanced and poor stand establishment (Vibhuti *et al.*, 2015). Drought stress interrupted active seed germination, causing osmotic imbalance, membrane impairment, decreased respiration, and ATP production (Kadam *et al.*, 2017). Water constraint during the vegetative period causes delayed panicle initiation, followed by late maturity (Singh *et al.*, 2012), directly correlated with yield decline. The most damaging impact of drought stress on grain yield appears to be during the reproductive growth stage. However, plants tend to recover during the vegetative growth phase, but recovery from the drought stress during the flowering phase is more complicated (Pantuwan *et al.*, 2002; Alam Khan, 2012; Xangsayasane *et al.*, 2014). A short span of drought stress during the reproductive growth phase severely curbs the rice grain yield by diminishing panicle length, poor seed setting, reduced number of kernels per panicle, and poor spikelet development (Figures 1–3) (Sikuku, 2012; Wei *et al.*, 2017). It has been reported that drought stress during flowering has a detrimental impact on pollination, resulting in poor seed setting and reduced grain size and grain number; in severe drought cases, flowers abortion takes place, leading to a 100% yield decline (Kumar *et al.*, 2006; Davatgar *et al.*, 2009). It is therefore established that any intensity of drought stress (mild or severe) during the reproductive growth phase lowers the final grain production; this is because the translocation of assimilates from leaves to reproductive organs (panicle, kernel) is interrupted (Rahman *et al.*, 2002). Additionally, rice cultivars that recovered from temporary drought patches exhibited better yield responses than drought-sensitive cultivars (Singh *et al.*, 2012).

3.3. Physiological and Biochemical Responses of Rice to Drought Stress

Drought stress disrupts the normal physiological functioning of rice plants, followed by restricted growth and reduced productivity (Upadhyaya and Panda, 2019). Drought-induced malfunctioning of vital physiological processes includes diminished photosynthetic activity, decreased water use efficiency (WUE), low transpiration rate, poor stomatal conductance,

reduced CO₂ concentration, imbalanced water relations and membrane impairment (Figure 4) (Dash *et al.*, 2018; Zhu *et al.*, 2020; Panda *et al.*, 2021).

Plant water relations are attributed through various terminologies such as leaf water potential, relative water content (RWC), turgor pressure, WUE, and membrane stability index. The RWC and WUE are crucial metrics for determining rice's yield potential and performance in drought conditions (Farooq *et al.*, 2009; Panda *et al.*, 2021). Plant RWC is negatively impacted by moisture stress conditions, followed by osmotic imbalance, water exclusion, lipid peroxidation, membrane damage, and necrosis (Rao and Chaitanya, 2016). Drought-tolerant rice varieties can maintain adequate RWC and prevent membrane impairment. In a research investigation, Choudhary *et al.* (2009) exposed 28 days rice seedlings to water-scarce conditions for 72 hours. The results exhibited a uniform increase in RWC through osmotic adjustments (increased proline synthesis) and prevented membrane damage. The ability of crop plants to maintain membrane stability under drought-stress conditions is a vital feature of their tolerance mechanism (Pandey and Shukla, 2015). The Membrane stability index has been studied for its correlation with rice yield under drought conditions (Upadhyaya and Panda, 2019).

Photosynthesis (PS) is a vital physiological process that largely accounts for dry matter production in crop plants. Water-scarce conditions negatively influenced the status of RWC in plants; as water-saving tactics, stomatal closure occurs, reducing CO₂ influx, decreased transpiration rate, poor gaseous exchange, and electron transport. Drought stress lowers the efficiency of photosystems I & II (PSI and PSII), impairs rubisco activity and inhibits electron transport chain and ATP production (Farooq *et al.*, 2009; Mishra and Panda, 2017; Upadhyaya and Panda, 2019). Photosynthetic pigments (i.e., chlorophyll, phycobillin, and carotenoids) showed lower efficiency under water-deficient conditions, resulting in inadequate light absorption, reduced light harvesting, and poor quality photoprotection (Jahan *et al.*, 2013). Eventually causes limited photosynthesis and restricts photosynthates' production (Fahad *et al.*, 2017; Gupta *et al.*, 2020). Carotenoids also serve as a precursor for plant signaling under stress conditions, so a decrease in carotenoid contents has a negative impact on signal perception during drought stress (Ashraf and Harris, 2013; Panda *et al.*, 2021).

Nitrogen (N) metabolism is handy in combating water-deficient stress conditions, particularly in plants' tolerance response (Suresh *et al.*, 2015). Plants tend to regulate nitrogen metabolism under drought stress conditions by decreasing nitrate reductase activity (Xu *et al.*, 2015). Glutamate dehydrogenase (GDH), a stress-responsive enzyme, is vital in N metabolism and highly effective in detoxifying intracellular ammonia, synthesizing proline, and producing glutamate and soluble sugars (Zhou *et al.*, 2015). Zhong *et al.* (2017) conducted an experiment in which rice plants were exposed to water deficit conditions with treatments of varying N levels. According to this study, high N levels increase rice's ability to adapt to water stress by reducing stomatal restrictions on photosynthesis, maintaining higher Rubisco activity, and enhancing the assimilation of nitrate and ammonia. Another experimental study conducted by Cao *et al.* (2018) confirmed that nitrogen fertilization in rice improved the rice's ability to withstand drought conditions by influencing photosynthetic activity, hormonal balance, carbohydrate assimilation, and distribution to other plant parts.

Plant drought tolerance responses are mediated by balanced mineral nutrition. These vital minerals, such as nitrogen, silicon, magnesium, calcium etc. are taken up by plants through their roots via water absorption. The uptake of these essential elements is pivotal in balancing a plant's mineral homeostasis and acclimation responses to abiotic stresses (Waraich *et al.*, 2011; Zhong *et al.*, 2017). Drought limits the active uptake of these essential minerals, resulting in stunted plant growth (Upadhyaya *et al.*, 2013; Upadhyaya and Panda, 2019). It is reported that silicon fertilization increases the rate of photosynthesis, mineral absorption, and water use efficiency in rice, which helps counter the implications of drought stress more effectively (Chen *et al.*, 2011; Cooke and Leishman, 2016). It has been reported that silicon and selenium effectively combat drought adversities by increasing the contents of

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amylase, phenolics, carbohydrates, and proteins, thereby increasing final grain yield (Emam *et al.*, 2014; Suh *et al.*, 2015). Li *et al.* (2017) reported the role of aquaporins in regulating hydraulic conductivity and its assisted by nitrate nutrition. Hydraulic conductivity is critical because of its role in facilitating plant nutrient transportation.

Potassium (K) is also considered an essential nutrient having indispensable roles in plant physiology. It regulates the plant water potential and facilitates alleviating drought stress in tobacco and rice (Ahmad *et al.*, 2016; Chen *et al.*, 2017). Calcium (Ca) also effectively mitigates drought repercussions, particularly post-drought recovery responses (Devi and Kar, 2013). Zinc (Zn) nutrition is handy in ameliorating drought stress responses and post-drought recovery (Upadhyaya *et al.*, 2017; Upadhyaya *et al.*, 2020). It is directly and indirectly involved in various plant physiological activities, but any deviation from the optimum level results in toxicity and alterations in plant cell physiology, biochemistry, and anatomy (Alloway, 2013; Billard *et al.*, 2015; Mattiello *et al.*, 2015). The severe deficiency of Zn causes the disintegration of the cell membrane that hinders active plant growth and significantly dents the final grain yield; therefore, Zn fertilization is an effective way to overcome drought-induced complexities (Upadhyaya *et al.*, 2013; Upadhyaya *et al.*, 2017). Increased reactive oxygen species (ROS) accumulation under drought damages cellular structures because it interacts with lipids, proteins, nucleic acids, and pigments, impairing membrane function and causing lipid peroxidation that compromises cell viability. It can be avoided by increasing the scavenging response by antioxidant enzymes (Bartels and Sunkar, 2005; Pandey and Shukla, 2015). Under water-scarce conditions, the recommended fertilization of macronutrients (N, P, K, and Ca) and micronutrients (Si, Zn, and Mg) requires for activation of antioxidant defense mechanism and protection of plant cells from the harmful consequences of ROS accumulation (Dimkpa *et al.*, 2017; Khan *et al.*, 2017). Boron (B) is also thought to play a role in drought tolerance responses by promoting seed germination, mediating sugar transport, maintaining flower architecture, and developing pollen (Waraich *et al.*, 2011). Recent research studies revealed that employing nano-fertilizers (particularly for micro-nutrients) in paddy fields will effectively tolerate the detrimental impacts of drought stress (Adhikari *et al.*, 2016; Liu *et al.*, 2016).

Low precipitation and dry conditions undermine plant turgidity. In water-deficit conditions, plants maintain their turgor by accumulating osmolytes, i.e., proline, soluble sugars (SS), amino-acids, and phenolics (Anjum *et al.*, 2011); this phenomenon is called osmoregulation. Proline is a type of amino acid used as a protein building block in plants, considered a vital osmoprotectant (Hayat *et al.*, 2012). Increased proline content was first observed in ryegrass under water-scarce conditions. Mishra *et al.* (2018) found increased proline accumulation in rice under water deficit conditions compared to normal irrigated conditions. Increasing proline content is directly related to drought tolerance as it helps the plant continue stomatal conductance and maintain leaf turgidity (Kumar *et al.*, 2017). Soluble sugars are critical for optimizing various physiological functions, notably photosynthesis and mitochondrial respiration (Gill and Tuteja, 2010a). Soluble sugar accumulation under drought protects cell membrane integrity and acts as an Osmo protectant (Upadhyaya and Panda, 2019; Hassan *et al.*, 2021). There were rare studies conducted to investigate how soluble sugars relieve drought stress.

Rice exhibits a diversified molecular response to drought stress. The drought tolerance mechanism is initiated with signal sensing, followed by signal perception, transduction, genetic expressions, cellular regulation, and survival metabolic responses (Du *et al.*, 2011; Oladosu *et al.*, 2019). Drought is a multifaceted abiotic condition acclimated through regulating numerous genetic expressions (Kumar *et al.*, 2017). Rice exposure to water-deficit stress exhibited multiple differential gene expressions, with about 5000 up-regulated and 6000 down-regulated gene expressions (Bin Rahman and Zhang, 2016; Joshi *et al.*, 2016). These genes are categorized based on their localized functioning: (1) genes associated with membrane transport, (2) genes involved in signaling, and (3) transcriptional regulation (Kim *et al.*, 2020). These genetic expressions are responsible for most rice plants'

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drought-induced physiological, biochemical, and molecular acclimation responses (Dash *et al.*, 2018; Gupta *et al.*, 2020). Transcriptomic and proteomic studies on rice have identified the transcriptomic factors (i.e., *MYB*, *DREB/CBF*, *AREB/ABF*, *NAC*, etc.) and their role in regulating the transcription of drought inducible gene expressions (Nahar *et al.*, 2016; Zhang *et al.*, 2016). Kumar *et al.* (2012) also reported the number of gene expressions and transcription factors (TFs) responsible for the drought tolerance response in rice. Previous research studies advocated that there are two main regulatory pathways for the induction of gene expression patterns for drought resistance mechanisms, known as (1) ABA-dependent and (2) ABA-independent regulation pathways (Du *et al.*, 2011; Fu *et al.*, 2017). The *MYB*, *NAC*, and *AREB/ABF* TFs drive the ABA-dependent pathway, while ABA-independent pathways are regulated via *DREB* TFs. Rabbani *et al.* (2003) stated that the exogenous application of ABA in rice effectively induces genetic expressions for combating the negative impacts of drought stress. A study on upland rice reported the role of drought-responsive genes in various signaling pathways (i.e., Ca^{2+} , ABA, and ethylene-accompanied proteins kinases and inducive factors), reducing oxidative damage, maintaining cellular homeostasis and osmoregulation (Rabello *et al.*, 2008). The ABA-receptor complex regulates ABA-responsive transcription through *AREB/ABF*, and it involves *SnRK2*, which is integral for activating *ARB/ABF* by phosphorylation (Umezawa *et al.*, 2010). The function of *SnRK2* indicates the significance of the plant's drought-responsive mechanism via swift adaptive action by plants under stress (Upadhyaya and Panda, 2019). As we mentioned earlier, ABA-independent pathways are governed by *DREB* TFs. Transcription of various genetic expressions in plant tissues is activated by the *DREB* TFs (Upadhyaya and Panda, 2019). The TF, *C2H2*-type, regulates stomatal closure upon exposure to water-deficit stress; this TF is also responsible for the induction of gene expression for quenching ROS and H_2O_2 and maintaining their dynamic balance under drought stress (Huang *et al.*, 2009). Cominelli *et al.* (2005) stated that the expression of TFs, *AtMYB60* and *AtMYB60* primarily found in guard cells and controls the opening and closing of the stomatal aperture under drought tolerance responses.

3.4. Drought Tolerance in Rice

Drought tolerance in rice varies with variety, degree, duration of stress and growth stage. Rice's susceptibility to water stress is more pronounced at the reproductive stage and causes the greatest reduction in grain yield when stress coincides with the irreversible reproductive processes (Yue *et al.*, 2006). Some investigations noted that deep rooting and osmotic adjustment are associated with drought tolerance. Although drought tolerance is a complex trait, it is not always the case, and depending on the drought scenario, drought tolerance may be controlled by simple plant traits that can lead to simple and cheap breeding strategies. Experiments conducted at the International Rice Research Institute (IRRI) showed that withholding water for about 14 days from about 10 days before flowering until 4 days after flowering can reduce yield by 20 - 40% relative to the fully irrigated aerobic control treatment. Spikelet fertility was observed to be most sensitive to stress in rice if it occurs near flowering. Many processes involved in fertilization and grain filling, including the production of viable pollen, panicle exertion, pollen shedding and germination, and embryo development are reportedly affected by water stress, particularly when the onset of stress is sudden and severe. In some varieties, poor panicle exertion is often observed under stress during the reproductive stage. The stage of pollen meiosis has been suggested as a very drought sensitive stage. This stage occurs about 10 days before anthesis, and stress at that time is expected to reduce the number of normal pollen grains (Lafitte *et al.*, 2000).

Drought is among the major abiotic stresses on rice production that can cause yield losses of up to 100% under severe drought conditions (Thomas *et al.*, 2017). In these environments, a farmer can be considered lucky if he obtains 2.5 t ha^{-1} . Considering the vast hectareage planted to un-irrigated rice in the Philippines and the poor living conditions of the

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farmers in these places compared with their lowland counterparts, it is necessary to focus research efforts in upland areas.

So far, genetic improvement for drought tolerance is addressed by direct selection for yield and its stability over locations and seasons. Aside from selection for yield, however, yield improvement under water-limited environments can be achieved through selection for secondary traits that contribute to drought tolerance. These traits are considered as important determinants of yield under water-stress conditions. Selection for these traits in a breeding program may enhance chances for developing drought tolerant lines, or even hybrids that can give higher yield. This strategy is an important option in solving the problem of low rice production in the water-limited uplands, which recently is one of the primary concerns of rice scientists worldwide.

3.5. Secondary Traits of Rice

Combining selection based on yield with secondary traits into selection indices can improve selective response, if the physiological processes contributing to grain yield in the target environment are well understood and if the secondary traits can be repeatably and inexpensively measured (Araus *et al.*, 2002; Lafitte *et al.*, 2003). Secondary traits most commonly used by breeders are generally easily determined visually. The number of days to flower is normally measured under both stress and non-stress conditions. Selection may be performed for lines with ideal maturity dates in well-watered conditions and no large flowering delay under drought. Selection for lines that maintain a high spikelet fertility under drought stress and/or a low rate of leaf drying under drought stress is also common (Jongdee *et al.*, 2006; and Lafitte *et al.*, 2003). Also, Lafitte *et al.* (2003) reported that flowering delay and spikelet fertility have moderate heritability and a high correlation with grain yield under stress at flowering.

3.6. The Hydrological Status of Different Rice Ecosystems

Rainfed upland rice is grown in un-bunded fields where good soil drainage and/or uneven land surface renders the accumulation of water impossible. Upland rice is usually grown in systems where little or no fertilizer is applied, and is direct seeded into un-puddled, unsaturated soil (Atlin *et al.*, 2004). Most traditional upland rice varieties are low-yielding and prone to lodging, but are adapted to non-flooded soils. According to Atlin *et al.* (2006), upland rice encompasses 12% of global rice production area and is generally the lowest-yielding ecosystem. Upland rice has a proportionately greater importance in Africa and Latin America, where it accounts for around 40% and 45% of the rice growing areas, respectively (Fisher *et al.*, 2001; CIAT, 2007). In Asia and Africa, upland rice farmers are among the poorest in the world and their holdings are often less than 0.5 ha in size. The situation is different in Latin America since much of the upland rice production there is mechanized and farms are larger (Moncada, 2001).

Recently, improved upland rice varieties with higher harvest index, improved input responsiveness and higher yield potential have been developed at IRRI, in Brazil and in several Asian countries. Such 'aerobic rice' varieties combine the aerobic adaptations of traditional upland varieties with the input responsiveness, lodging tolerance and yield potential of irrigated varieties (Atlin *et al.*, 2006). Bouman *et al.*, 2006 stated that aerobic rice may replace irrigated rice and rainfed lowland rice in some parts of the world facing decreasing water supplies for agriculture.

In the irrigated and deep-water rice ecosystems, water shortage does not normally occur, but in both the rainfed upland and lowland cultivation systems drought stress is often the most important abiotic stress factor limiting yields (Babu *et al.*, 2004). Rainfed rice fields (both upland and lowland) within a given watershed usually drain into one another from the highest to lowest elevation. The upper fields are the most drought prone as they do not receive

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extra water from runoff or seepage from nearby fields. Upland rice is generally more prone to drought than lowland rice because water does not accumulate in the field, due to the lack of a bund or hard-pan layer and, often, due to irregular, sloping topography (Babu *et al.*, 2003; and Babu *et al.*, 2001).

4. MATERIALS AND METHODS

4.1. Source of Seeds and Number of Entries

Seeds were procured from the PhilRice – Malasin, San Mateo, Isabela. It was composed of 4 inbreds and 2 hybrids for a total of 6 entries.

4.2. Location of the Experimental Area

The study was conducted at Purok 6, Paddaoan, Conner, Apayao.

4.3. Collection of Soil Samples and Soil Analysis

Soil samples were randomly collected within the surrounding upland area with the use of shovel. The soil samples were spread in newspaper and air dried. One kilogram soil sample was thoroughly pulverized and was cleaned to separate foreign materials present in the soil sample. The soil sample was submitted at the Bureau of Soils and Water Management – Department of Agriculture, Carig Sur, Tuguegarao City, Cagayan for the soil analysis. The rate of 90–80–0 kg NPK ha⁻¹ was the basis for the study.

4.4. Preparation of Soil Media

Garden soil from the surrounding upland area of the research station at Paddaoan, Conner, Apayao was used in the study. It was thoroughly pulverized and 7 kg of soil was put on each 4-gallon black pail size.

4.5. Pulling and Transplanting of Seedlings

The beds were irrigated before pulling to facilitate easy uprooting of seedlings with minimum root damage.

Two seedlings per hill were planted per pot. Extra pots with two seedlings each were provided to replace seedlings that die to ensure equal number of plants per plot. One replication consisted of 10 samples with two seedlings each with a total of 360 pieces experimental pots.

4.6. Experimental Design and Analysis

The experimental treatments were randomly allocated following the procedure for Randomized Complete Block Design Factorial. It composed of Main Plot Factor (Factor A) which is divided into subplots factor (Factor B). The assign Factor A (Main plot) were the Factor A₁ – well irrigated (unstressed) and Factor A₂ – water stressed, while Factor B (subplots) were assigned to different varieties.

All data gathered were collated, tabulated and analyzed following the Analysis of Variance for the Randomized Complete Block Design Factorial and means comparison using Tukey's Honest Significant Difference (HSD) Test was generated using the Statistical Analysis System (SAS) software.

4.7. Experimental Treatments

The following treatments were evaluated in this study:

Main Plot: (Factor A)
A₁ – Well Irrigated
A₂ – Stressed

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Sub-Plot: (Factor B)

- V₁ – PSB Rc 10 (Inbred)
- V₂ – NSIC Rc 160 (Inbred)
- V₃ – NSIC Rc 506 (Inbred)
- V₄ – NSIC Rc 508 (Inbred)
- V₅ – NSIC Rc 204H/ Meztizo 20 (Hybrid)
- V₆ – NSIC Rc 446H/ Meztizo 73 (Hybrid)

4.8. Cultural Management

Pest and Disease Control. Maximum protection against pests and diseases were employed. Hence, manual control of insects was regularly performed, as they were easier to manage within the controlled environment of the greenhouse, where insect entry was minimized.

Irrigation. *Factor A₁ (well irrigated).* Irrigation was done by manually applying equal amounts (1.5 liters) of water per bag every 4 days or as often as needed until 5 days before flowering. After which, water application was stopped at 5 days before expected flowering until 5 days after flowering.

Factor A₂ (non-irrigated). Irrigation was done by manually applying equal amounts (1.5 liters) of water per bag every 4 days but water application was stopped 14 days before the flowering (based on Maturity Days) to let the plants undergo extreme strain but not let it die.

Harvesting and Threshing. Harvesting was done at approximately 85% maturity by cutting the panicles and manually threshed. As a basis, 80% maturity was reached when 20% of the grains at the base of the panicle are at hard dough stage. When a grain at the base of panicle was pressed between fingers, it should be hard enough although seedcoat color was still light green. At this stage, most of the grains in the panicle were already golden yellow.

Cleaning, Drying and Weighing. The samples were individually put into sacks with labels just after harvesting and sundried until 14% moisture content. A battery-operated Moisture Tester was used to determine moisture content every 5 hours during sun drying until 14% moisture content is reached. After drying, samples were weighed and then the grains were separated from other plant parts and also weighed to get the grain weight.

4.9. Data Gathered

The following data gathered were;

1. **Plant Height (cm).** This was measured in centimeters from the base of the plant to the tip of the panicle including awn, if any. It was taken from 10 sample plants per replication just before harvesting.
2. **Number of Productive Tillers per Plant.** It is the number of panicles bearing tillers. It was counted from 10 sample plants per replication.
3. **Number of Filled Grains per Panicle.** This was taken by counting the filled grains in a panicle. It was obtained from average of 10 panicles per replication.
4. **Total Number of Spikelets per Panicle.** The total number of spikelets per panicle was counted from 10 panicles per replication.
5. **Spikelet Fertility (%).** This was obtained by getting the number of filled grains per panicle divided by the total number of spikelets and then multiplied by 100. It was taken from 10 panicles per replication.
6. **1000 Seed Weight (g).** Weight of 1000 seeds were obtained from 10 sample plant per replication.
7. **Yield per Plant.** The average grain yield of 10 sample plants per replication at 14% moisture content was weighed using the digital weighing scale.

4.1.0. Well Irrigated Aerobic Companion Nursery

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As a reference, a well irrigated companion nursery using the same entries and cultural management was established. The data gathered was also the same as that of the stressed nursery. Since it was only use as a reference to determine reduction in yield under water stress, statistical analysis was no longer conducted. The test entries were subjected to water stress.

Yield reduction from well – watered to stressed nursery was computed per entry to identify drought tolerant inbreds and hybrids. Drought tolerance of entries was recorded based on the procedure outlined by Pinheiro as follows:

Yield Reduction (%)		Rating
≤ 30	-	Tolerant (T)
30 – 50	-	Moderately Tolerant (MT)
51 – 80	-	Moderately Susceptible (MS)
>80	-	Susceptible (S)

Source: Pinheiro, 2005

5. OBSERVATIONS, RESULTS AND DISCUSSION

5.1. Observation

1. Stand and Vigor of the Crop. The different 6 varieties at well-irrigated plants had uniform growth at early stage of growth. However, there were an apparent difference towards maturity in terms of growth and development. While, plants under stress condition led to stunted growth.

2. Number of Days to Maturity. The different varieties differed with each other in terms of number of days to maturity (Table 1). Under unstressed conditions, the days to maturity ranged from 106 days (PSB Rc10) to 122 days (NSIC Rc160), indicating inherent genetic differences in phenological development among the varieties. Notably, PSB Rc10 matured the earliest, suggesting it may be suitable for environments requiring early harvest, such as regions with tight planting windows or where double cropping is practiced.

When subjected to stress, most varieties displayed a variation in maturity duration, with either an increase or decrease in days to maturity. For instance, PSB Rc10 showed a delay in maturity under stress (112 days), reflecting possible sensitivity to the stress factor applied, which could be due to physiological disruptions such as delayed flowering or grain filling. Conversely, NSIC Rc160 exhibited a slight reduction in maturity duration from 122 to 118 days under stress, suggesting a level of adaptability or stress escape mechanism.

Similarly, NSIC Rc506 and NSIC Rc508 showed minor decreases in maturity duration under stress (from 111 to 106 days and 110 to 107 days, respectively). These reductions may indicate a hastening of the developmental process, potentially as a survival strategy under adverse conditions. The hybrid varieties Meztizo 20 and Meztizo 73 demonstrated delayed maturity under stress, extending their growth period by 6 and 7 days, respectively, which might imply a higher sensitivity to stress.

This variation in phenological response among rice genotypes under stress aligns with findings in existing literature. According to Fageria (2007), stress conditions such as drought can significantly alter the growth duration of rice, often hastening maturity in some varieties as a survival strategy. Similarly, Kumar *et al.* (2006) observed that drought stress during the reproductive stage can lead to earlier maturity in susceptible varieties, while tolerant genotypes may maintain or even extend their growth duration. Furthermore, Venuprasad *et al.* (2009) reported that genotypic differences in phenological traits such as days to maturity

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play a critical role in drought adaptation, with some varieties exhibiting phenological plasticity to avoid terminal drought.

Table 1. Number of days to maturity.

VARIETIES	Days to Maturity	
	Un-stressed	Stressed
V ₁ - PSB Rc10	106	112
V ₂ - NSIC Rc160	122	118
V ₃ - NSIC Rc506	111	106
V ₄ - NSIC Rc508	110	107
V ₅ - Meztizo 20	111	117
V ₆ - Meztizo 73	113	119

5.2. Discussion of Results

1. Plant Height (cm). The height of plants at maturity days of different rice varieties under stress condition is presented in Table 2. The analysis revealed significant difference between level of main plot wherein the Well irrigated (A₁) produced the taller plants with a mean value of 94.29 centimeters. Shorter plants were observed on the stressed plots (A₂) with a mean of 90.58 centimeters. This finding aligns with the work of Pantuwan *et al.* (2002), who reported that water stress significantly diminishes plant height due to constrained cell elongation and diminished metabolic activity in drought circumstances.

Significant variation was also observed on the sub plot composed of different varieties. The Meztizo 20 (V₅) was the tallest plants with mean of 109.20 centimeters. It was followed by Meztizo 73 (V₆), NSIC Rc508 (V₄), NSIC Rc506 (V₃) and NSIC Rc160 (V₂) having means ranging from 90.10 to 98.20 centimeters. The shortest variety was PSB Rc10 with 71.81 centimeters. The shortest plants were recorded in PSB Rc10 (V₁), with a mean height of 71.81 cm. The results align with the findings of Ingram and Bartels (1996), who highlighted that genetic heterogeneity among rice genotypes substantially affects their morphological responses in water-limited settings.

Insignificant result was noted on the interaction between the main plot and subplot, with means ranging from 73.54 to 110.13 centimeters. Lafitte *et al.* (2004) reached analogous conclusions, indicating that genotypic responses to drought frequently occur independently of their interactions with particular environmental treatments.

Table 2. Plant height (cm) of different rice varieties under stress condition.

TREATMENTS	Plant Height (cm)
Main Plot	Maturity
A ₁ - Well Irrigated	94.29 ^a
A ₂ - Stressed	90.58 ^b
ANOVA RESULT	**
Sub-Plot (Varieties)	
V ₁ - PSB Rc10	71.81 ^f
V ₂ - NSIC Rc160	90.10 ^e
V ₃ - NSIC Rc506	91.30 ^d
V ₄ - NSIC Rc508	94.00 ^c
V ₅ - Meztizo 20	109.20 ^a
V ₆ - Meztizo 73	98.20 ^b
ANOVA RESULT	**
Factor A x Factor B	
A ₁ V ₁	73.54
A ₁ V ₂	92.07
A ₁ V ₃	93.87
A ₁ V ₄	95.00

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A ₁ V ₅	110.13
A ₁ V ₆	101.13
A ₂ V ₁	70.08
A ₂ V ₂	88.13
A ₂ V ₃	88.73
A ₂ V ₄	93.00
A ₂ V ₅	108.27
A ₂ V ₆	95.27
ANOVA RESULT	ns
C.V. (%)	1.52

Note: Means with common letter/s are not significantly different with each other using Tukey's HSD.

ns – not significant

** – significant at 1% level

2. Number of Productive Tillers per Plant. The number of productive tillers of the different rice varieties under stress condition is shown in Table 3. There were highly results revealed significant variations in the number of productive tillers on the levels of the main plot. The well irrigated plots (A₁) had a mean of 7.92 obtained the greater number of productive tillers than stressed plants (A₂) with 5.15. This corresponds with the findings of Lafitte *et al.* (2004), who indicated that drought stress during the vegetative phase markedly diminishes tillering in rice, principally due to suppressed leaf emergence and tiller start.

Significant variations on sub-plots were also noted, wherein NSIC Rc160 (V₂) exhibited the highest number of productive tillers, followed by NSIC Rc508 (V₄) with 6.82, Meztizo 73 (V₆) with 6.50, NSIC Rc506 (V₃) with 6.50 and Meztizo 20 (V₅) with 6.20. The PSB Rc10 (V₁) obtained the least number of productive tillers with 6.07. Pantuwan *et al.* (2002) showed similar varietal differences in tillering capability under differing water availability, highlighting the genetic heterogeneity in drought response among rice cultivars.

No significant interaction was observed between the main plot and the sub-plot with means ranging from 4.57 to 8.37.

Table 3. Number of productive tillers of different rice varieties under stress condition.

TREATMENTS	Number of Productive Tillers
Main Plot	
A ₁ - Well Irrigated/ Unstressed	7.92 ^a
A ₂ - Stressed	5.15 ^b
ANOVA RESULT	**
Sub-Plot (Varieties)	
V ₁ - PSB Rc10	6.07 ^e
V ₂ - NSIC Rc160	7.14 ^a
V ₃ - NSIC Rc506	6.50 ^c
V ₄ - NSIC Rc508	6.82 ^b
V ₅ - Meztizo 20	6.20 ^d
V ₆ - Meztizo 73	6.50 ^c
ANOVA RESULT	*
Factor A x Factor B	
A ₁ V ₁	7.57
A ₁ V ₂	8.37
A ₁ V ₃	8.03
A ₁ V ₄	8.13

A ₁ V ₅	7.43
A ₁ V ₆	8.00
A ₂ V ₁	4.57
A ₂ V ₂	5.90
A ₂ V ₃	4.97
A ₂ V ₄	5.50
A ₂ V ₅	4.97
A ₂ V ₆	5.00
ANOVA RESULT	ns
C.V. (%)	7.80

Note: Means with common letter/s are not significantly different with each other using Tukey's HSD.

ns – not significant

* – significant at 5% level

** – significant at 1% level

3. Number of Filled Spikelets per Panicle. Table 4 shows the number of filled spikelets of the different rice varieties under stress condition. Highly significant differences were noted on the number of filled spikelets on the main plot, wherein the unstressed plants had the greater number of filled spikelets with a mean of 81.62. Lesser number of filled spikelets were recorded on the stressed plants (A₁) with 31.53. This finding aligns with the study by Kumar *et al.* (2014), which revealed that drought stress during the reproductive phase significantly diminishes spikelet fertility and grain filling, hence reducing overall output.

Likewise, significant differences were also observed on the number of filled spikelets in terms of sub-plot. Greater number of filled grains were exhibited on variety NSIC Rc160 (V₂) with a mean of 61.34. It was followed by the varieties Meztizo 73 (V₆) – 60.30, Meztizo 20 (V₅) – 59.28, NSIC Rc506 (V₃) – 55.34 and NSIC Rc508 (V₄) – 55.04, respectively. Least number of filled grains was attained by the variety PSB Rc10 (V₁) with 48.16. The varietal differences are consistent with the findings of Bernier *et al.* (2007), who highlighted that genetic heterogeneity among rice genotypes is essential for grain filling under drought stress. Genotypes possessing superior adaptation mechanisms, such as deeper root systems or osmotic adjustment, typically demonstrate enhanced spikelet fertility even in conditions of restricted water availability.

Furthermore, significant variations were also noted on the interaction of factor a and factor b, wherein, the NSIC Rc160 (V₂) obtained the greatest number of filled spikelets among all the treatments. Followed by the varieties Meztizo 73 (V₆), Meztizo 20 (V₅), NSIC Rc506 (V₃) and NSIC Rc508 (V₄). The variety PSB Rc10 (V₁) exhibited the least number of filled grains among the all varieties. According to Manickavelu *et al.* (2006), rice varieties exhibiting elevated spikelet fertility during drought stress are essential for breeding initiatives focused on enhancing drought resilience and yield stability.

Table 4. Number of filled spikelets per panicle of different rice varieties under stress condition.

TREATMENTS	Number of Filled Spikelets
Main Plot	
A ₁ - Well Irrigated/ Unstressed	81.62 ^a
A ₂ - Stressed	31.53 ^b
ANOVA RESULT	**
Sub-Plot (Varieties)	
V ₁ - PSB Rc10	48.16 ^f
V ₂ - NSIC Rc160	61.34 ^a
V ₃ - NSIC Rc506	55.34 ^d
V ₄ - NSIC Rc508	55.04 ^e

V ₅ - Meztizo 20	59.28 ^c
V ₆ - Meztizo 73	60.30 ^b
ANOVA RESULT	**
Factor A x Factor B	
A ₁ V ₁	69.70 ^e
A ₁ V ₂	87.97 ^a
A ₁ V ₃	79.97 ^d
A ₁ V ₄	79.53 ^d
A ₁ V ₅	85.57 ^c
A ₁ V ₆	87.00 ^b
A ₂ V ₁	26.62 ^e
A ₂ V ₂	34.71 ^a
A ₂ V ₃	30.70 ^d
A ₂ V ₄	30.55 ^d
A ₂ V ₅	32.99 ^c
A ₂ V ₆	33.60 ^b
ANOVA RESULT	**
C.V. (%)	0.77

Note: Means with common letter/s are not significantly different with each other using Tukey's HSD.

** – significant at 1% level

4. Spikelet Fertility (%). The percentage of spikelet fertility of different rice varieties under stress condition is shown in Table 5. The well irrigated plants obtained spikelet fertility of 90.04 percent while the stressed plants had 38 percent. The results of this study on spikelet fertility under both stress and non-stress conditions corroborate earlier research highlighting the vulnerability of rice reproductive development to water stress. In well-irrigated settings, elevated spikelet fertility rates (up to 95.57%) found among cultivars align with the anticipated optimal physiological performance when water is not a limiting factor (Kato *et al.*, 2008). Nonetheless, during drought stress, the significant decline in spikelet fertility—falling to as low as 35.65%—illustrates the adverse effects of water scarcity on panicle growth and pollination, a phenomenon extensively recorded in the literature (Lal *et al.*, 2006; Pantuwan *et al.*, 2002).

Significant results were also noted on the different varieties (sub-plot). Highest percentage of spikelet fertility was observed of variety NSIC Rc160 (V₂) with a mean of 68.79 percent. It was followed by the varieties Meztizo 73 (V₆) – 64.86 percent, Meztizo 20 (V₅) – 63.84 percent, PSB Rc10 (V₁) – 63.30 percent and NSIC Rc508 (V₄) – 62.12 percent, respectively. The lowest percentage of spikelet fertility was observed on NSIC Rc506 (V₃) with 61.22 percent. The superior performance of NSIC Rc160 under both conditions highlights the capacity of specific genotypes to sustain elevated reproductive efficiency in water-scarce environments, a finding reported by Kumar *et al.* (2006) in their assessment of drought-resistant rice cultivars. The varietal variations indicate intrinsic genetic pathways that provide stress resilience, highlighting the necessity of focused breeding initiatives to improve drought tolerance in rice (Serraj *et al.*, 2011).

Similarly, significant differences among the treatments were also recorded on the interaction of main plot and sub-plot (factor a x factor b). On the well irrigated plants, NSIC Rc160 (A₁V₂) obtained the highest percentage of spikelet fertility with 95.57 percent. Followed by Meztizo 73 (A₁V₆) had 91.72 percent, PSB Rc10 (A₁V₁) had 90.95 percent, Meztizo 20 (A₁V₅) had 89.49 percent and NSIC Rc508 (A₁V₄) had 87.50 percent. The lowest percentage was attained by the variety NSIC Rc506 (A₁V₃) with a mean value of 85.01 percent. While, on stressed plants, it was also observed that NSIC Rc160 (A₂V₂) obtained the highest spikelet fertility with 42 percent. Followed by variety Meztizo 20 (A₂V₅) and Meztizo 73 (A₂V₆) having comparable means of 38.18 and 37.99 percent. Then, NSIC Rc506 (A₂V₃) and NSIC Rc508 (V₄) with the mean values of 37.43 and 36.73 percent, respectively. The PSB Rc10 (A₂V₁)

variety gained the lowest percentage of spikelet fertility with 35.65 percent. The interaction effects observed further indicate that genotype-environment interactions significantly affect spikelet fertility, reinforcing the idea that both genetic potential and environmental factors should be taken into account in varietal selection for drought-prone ecosystems (Bernier *et al.*, 2008).

Table 5. Spikelet Fertility (%) of Different Rice Varieties under Stress Condition.

TREATMENTS	Spikelet Fertility (%)
Main Plot	
A ₁ - Well Irrigated	90.04 ^a
A ₂ - Stressed	38.00 ^b
ANOVA RESULT	**
Sub-Plot (Varieties)	
V ₁ - PSB Rc10	63.30 ^d
V ₂ - NSIC Rc160	68.79 ^a
V ₃ - NSIC Rc506	61.22 ^f
V ₄ - NSIC Rc508	62.12 ^e
V ₅ - Meztizo 20	63.84 ^c
V ₆ - Meztizo 73	64.86 ^b
ANOVA RESULT	**
Factor A x Factor B	
A ₁ V ₁	90.95 ^c
A ₁ V ₂	95.57 ^a
A ₁ V ₃	85.01 ^f
A ₁ V ₄	87.50 ^e
A ₁ V ₅	89.49 ^d
A ₁ V ₆	91.72 ^b
A ₂ V ₁	35.65 ^e
A ₂ V ₂	42.00 ^a
A ₂ V ₃	37.43 ^c
A ₂ V ₄	36.73 ^d
A ₂ V ₅	38.18 ^b
A ₂ V ₆	37.99 ^b
ANOVA RESULT	*
C.V. (%)	2.83

Note: Means with common letter/s are not significantly different with each other using Tukey's HSD.

* – significant at 5% level

** – significant at 1% level

5. Weight (g) of 1000 Grains. Table 6 shows the data on weight of 1000 grains of different rice varieties under stress condition. Significant result was existed on the weight of 1000 grains on the main plot. The unstressed plants (A₁) produced the heavier grains with mean value of 27.22 grams while lighter weight of grains was exhibited by the stressed (A₂) with mean value of 25.33 grams. This finding aligns with the research of Farooq *et al.* (2009), which indicated that drought stress during the grain-filling stage markedly reduces grain weight due to disrupted assimilate translocation and abbreviated grain development length.

Similarly, a significant difference was noted on the different varieties (sub-plots) wherein the variety NSIC Rc508 (V₄) produced the heaviest 1000 grains with a mean of 29.00 grams. It was followed by Meztizo 20 (V₅) with 27.33 grams, Meztizo 73 (V₆) with 26.50 grams, NSIC Rc506 (V₃) with 26.17 grams and NSIC Rc160 (V₂) with 25.00 grams, respectively. Lightest weight of grains was attained by PSB Rc10 (V₁) with 23.67 grams. The observed

differences correspond with the findings of Lafitte, Yongsheng, and Bennett (2006), who highlighted the significance of genotypic variation in sustaining grain weight under stress, as certain varieties exhibit superior adaptation through physiological and morphological traits that improve drought tolerance.

No significant result was found on the interaction of the two factors which obtained mean values ranging from 22.67 to 29.33 grams.

Table 6. Weight (g) of 1000 Grains of Different Rice Varieties under Stress Condition.

TREATMENTS	Weight (g) of 1000 Grains
Main Plot	
A ₁ - Well Irrigated	27.22 ^a
A ₂ - Stressed	25.33 ^b
ANOVA RESULT	**
Sub-Plot (Varieties)	
V ₁ - PSB Rc10	23.67 ^f
V ₂ - NSIC Rc160	25.00 ^e
V ₃ - NSIC Rc506	26.17 ^d
V ₄ - NSIC Rc508	29.00 ^a
V ₅ - Meztizo 20	27.33 ^b
V ₆ - Meztizo 73	26.50 ^c
ANOVA RESULT	**
Factor A x Factor B	
A ₁ V ₁	24.33
A ₁ V ₂	27.33
A ₁ V ₃	27.00
A ₁ V ₄	29.33
A ₁ V ₅	28.33
A ₁ V ₆	27.00
A ₂ V ₁	23.00
A ₂ V ₂	22.67
A ₂ V ₃	25.33
A ₂ V ₄	28.67
A ₂ V ₅	26.33
A ₂ V ₆	26.00
ANOVA RESULT	ns
C.V. (%)	5.23

Note: Means with common letter/s are not significantly different with each other using Tukey's HSD.

ns – not significant

** – significant at 1% level

6. Weight (g) of Grains per Plant. Table 7 shows the data on weight of grains per plant of different rice varieties under stress condition. Significant result was recorded on the weight of grains per plant on the main plot. Heaviest weight of grains per plant was obtained by well irrigated plants with 19.04 grams. Lightest weight of grains per plant was produced on stressed plants. Similar findings were reported by Kumar *et al.* (2006), indicating that drought-tolerant genotypes typically sustain greater grain weights under water-limited conditions owing to enhanced water utilization and superior physiological resilience.

Likewise, a significant variation was noted on the different varieties (sub-plots) wherein the NSIC Rc160 (V₂), Meztizo 73 (V₆) and NSIC Rc508 (V₄) produced the heaviest grains per plant having mean values of 13.64, 13.33 and 13.28 grams, respectively. It was followed by Meztizo 20 (V₅) and NSIC Rc506 (V₃) with means of 12.68 and 11.82 grams. The PSB Rc10 (V₁) obtained the lightest weight of grains having mean value of 8.89 grams. This

corresponds with the findings of Serraj *et al.* (2009), who highlighted that genotypic variation is pivotal in rice's response to drought, with specific genotypes capable of sustaining higher yields under restricted water conditions.

Similarly, highly significant variation was also recorded in terms of the interaction of the two factors. On the interaction of well irrigated plants and different rice varieties, the heaviest grains were recorded on NSIC Rc160 (A₁V₂) with 21.37 grams, Followed by Meztizo 73 (A₁V₆), NSIC Rc508 (A₁V₄), Meztizo 20 (A₁V₅) and NSIC Rc506 (A₁V₃) having mean values of 20.54, 20.35, 19.53 and 18.55 grams, respectively. Lightest weight of grains was obtained by PSB Rc10 (A₁V₁) with a mean of 13.89 grams. On the other hand (stressed), heaviest weight of plants was observed on NSIC Rc508 (A₂V₄) and Meztizo 73 (A₂V₆) having means of 6.20 and 6.12 grams. It was followed by the varieties NSIC Rc160 (A₂V₂), Meztizo 20 (A₂V₅) and NSIC Rc506 (A₂V₃) with the mean values of 5.90, 5.83 and 5.08 grams. The PSB Rc10 (A₂V₁) variety produced the lightest weight of grains with a mean of 3.88 grams, indicating that drought-tolerant genotypes typically sustain greater grain weights under water-limited conditions due to enhanced water utilization and superior physiological resilience. Lafitte *et al.* (2004) stated that such interactions should be taken into account while developing drought-resistant rice varieties, as performance in favorable conditions may not immediately correspond with performance under stress.

Table 7. Weight (g) of Grains per Plant of Different Rice Varieties under Stress Condition.

TREATMENTS	Weight of Grains per Plant
Main Plot	(g)
A ₁ - Well Irrigated	19.04 ^a
A ₂ - Stressed	5.50 ^b
ANOVA RESULT	**
Sub-Plot (Varieties)	
V ₁ - PSB Rc10	8.89 ^d
V ₂ - NSIC Rc160	13.64 ^a
V ₃ - NSIC Rc506	11.82 ^c
V ₄ - NSIC Rc508	13.28 ^a
V ₅ - Meztizo 20	12.68 ^b
V ₆ - Meztizo 73	13.33 ^a
ANOVA RESULT	**
Factor A x Factor B	
A ₁ V ₁	13.89 ^e
A ₁ V ₂	21.37 ^a
A ₁ V ₃	18.55 ^d
A ₁ V ₄	20.35 ^b
A ₁ V ₅	19.53 ^c
A ₁ V ₆	20.54 ^b
A ₂ V ₁	3.88 ^d
A ₂ V ₂	5.90 ^b
A ₂ V ₃	5.08 ^c

A ₂ V ₄	6.20 ^a
A ₂ V ₅	5.83 ^b
A ₂ V ₆	6.12 ^a
ANOVA RESULT	**
C.V. (%)	6.92

Note: Means with common letter/s are not significantly different with each other using Tukey's HSD.

** – significant at 1% level

7. Yield Reduction (%). Table 8 shows the percentage yield reduction of different rice varieties under stress condition. The percentage yield reduction of grains is organized in a descending order: A₂V₃ had 72.63 percent, A₂V₂ had 72.38, A₂V₁ had 72.09, A₂V₆ had 70.23, and A₂V₅ had 70.15 and A₂V₄ had 69.54.

Kumar *et al.* (2006) indicate that drought stress during the reproductive period might result in production losses of 60–80%, mostly due to spikelet sterility, diminished grain filling, and compromised physiological processes. Similarly, Serraj *et al.* (2011) emphasized that drought can significantly diminish grain output by restricting water availability, impairing root development, and modifying transpiration efficiency, particularly in vulnerable genotypes. The observed variation in yield reduction among the tested varieties aligns with the findings of Pantuwan *et al.* (2002), who indicated that genotypic variations in drought tolerance are crucial for sustaining output in water-limited environments.

Table 8. Yield Reduction (%) of Grains per Plant of Different Rice Varieties under Stress Condition.

TREATMENTS	Yield Reduction (%)
A ₂ - Stressed	
V ₁ - PSB Rc10	72.09
V ₂ - NSIC Rc160	72.38
V ₃ - NSIC Rc506	72.63
V ₄ - NSIC Rc508	69.54
V ₅ - Meztizo 20	70.15
V ₆ - Meztizo 73	70.23

6. CONCLUSION AND RECOMMENDATIONS

Based on the study, results clearly indicated that water availability plays a significant role in influencing the growth, development, and yield of rice. Across all measured agronomic parameters—including plant height, number of productive tillers, number of filled spikelets, spikelet fertility, 1000-grain weight, and grain yield per plant—well-irrigated conditions consistently produced superior outcomes compared to stressed environments.

Among the six varieties studied, NSIC Rc160, Meztizo 73, and NSIC Rc508 emerged as the most adaptable and high-yielding varieties across varying conditions. These varieties demonstrated better physiological resilience, higher spikelet fertility, and greater grain yield, particularly under well-irrigated scenarios. In contrast, PSB Rc10 exhibited significantly lower performance under both stress and non-stress conditions, suggesting limited adaptability.

It is recommended that rice farmers, particularly those in areas prone to water stress, adopt high-performing varieties such as NSIC Rc160, Meztizo 73, and NSIC Rc508, as these

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exhibited superior yield and physiological traits under both stressed and unstressed conditions. These varieties demonstrated resilience to water limitations, making them suitable for both rainfed and irrigated ecosystems. Additionally, the poor performance of PSB Rc10 across all measured parameters suggests that its use should be limited unless further improvement or breeding efforts are pursued to enhance its stress tolerance and yield capacity.

Further studies are recommended to be conducted to validate and strengthen the applicability of these findings in different environmental contexts.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I acknowledge that I have not used ChatGPT or Copilot for refining some of the sections in the document.

CONSENT (WHEREVER APPLICABLE)

The author has declared that no consent is needed in this study.

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

The author has declared that no ethical approval is needed in this study.

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