**Analysis of submergence tolerance index in selected rice (*oryza sativa* l.) Cultivars grown in kebbi state, Nigeria**

**ABSTRACT**

**Aims:** Submergence is a major abiotic stress limiting rice production in flood-prone regions such as Kebbi State, Nigeria. This study evaluated the submergence tolerance of six rice cultivars (*MAI HIJABI, CP 60, FARO, FARO 40, SWARNA-SUB1,* and *IR64*) based on survival rate, shoot elongation, elongation rate, and Submergence Tolerance Index (STI).

**Study design:** The experiment was laid down in a completely randomized design consisting of six cultivars and each replicated three times.

**Methodology**: The experiment was conducted using a completely randomized design in pots under controlled submergence (14 days), followed by a 7-day recovery period.

**Results:** Results showed that SWARNA-SUB1 exhibited the highest survival rate (100%), longest shoot elongation (53.76 cm), highest elongation rate (3.28 cm/day), and superior STI (66.67%), confirming its high tolerance due to the presence of the *Sub1A* gene. CP 60 and Faro 40 recorded moderate STI values (33.34%) and showed some submergence resilience. Conversely, Mai Hijabi, Faro, and IR64 recorded 0.00% STI and low survival, indicating high susceptibility. While shoot elongation contributed to tolerance, excessive elongation, as seen in Mai Hijabi, did not correlate with survival, suggesting energy depletion.

**Conclusion:** This study highlights the potential of Swarna-Sub1 for cultivation in flood-prone areas and recommends its use in breeding programs to improve rice resilience to submergence stress.

Keywords: Submergence, Rice, Tolerance, Index, Cultivars,

1. **INTRODUCTION**

Rice, a major cereal food for many peoples of the world, is vulnerable in production, especially in the wetlands and flooding areas (Fukao & Bailey-Serres, 2008) The flooding, or full or partial inundation of the rice crop, is a major risk factor that affects the stability of yield, especially in lowland zones and in areas subjected to poor drainage conditions (Bailey-Serres & Voesenek, 2008). For example, in Southeast Asia, flooding-related loss in rice production is problematic, threatening food security. Due to the significance of these yield losses, breeding submergence-tolerant rice varieties is an important task to ensure stable rice yield in flood-prone areas (Dipak et al. 2024). Kebbi State, Nigeria, like other parts of Africa and Asia, is prone to intermittent flooding, making rice cultivation particularly vulnerable.

Rice (*Oryza sativa* L) is one of the most important food crops worldwide, with over a third of the world's population relying on it as staple food (Singh et al. 2010). Globally, several biotic and abiotic factors affect rice production. As many as half of these yield losses can be attributed to abiotic stress alone. Soil salinity is the simplest of all abiotic stresses and is thought to be a common limiting factor in rice production (Bharti et al. 2024). Submergence where rice plants are partially or completely submerged under water for prolonged periods results in the potential for depletion of O₂, decreased photosynthetic rates, and ultimately death of the plant if it is allowed to persist for too long according to the crop's tolerance level of being submerged, i.e., flooded. The effect on the plant is termed a chronic effect. This abiotic stress is highly damaging to rice plants, especially during the early vegetative stage, and most traditional and improved rice varieties exhibit a very high level of susceptibility (Bailey-Serres & Voesenek, 2008). Rice plant is naturally tolerant of water; it cannot survive prolonged periods of complete submersion in water (Bharti et al. 2024). The occurrence and severity submergence events in Nigeria have been compounded by climate change, inadequate drainage infrastructure, and deforestation, a situation that results to massive yield losses, especially in states such as Kebbi, Niger, Kogi, and Anambra where rice farming is dominant. In 2018, flooding destroyed over 200,000 hectares of rice farms, contributing to a domestic supply shortfall and increased dependence on imports (NIMET, 2024).

To mitigate these effects, research institutions in Nigeria have collaborated with international bodies like the International Rice Research Institute (IRRI) to introduce submergence-tolerant rice varieties, notably those carrying the *Sub1A* gene. These varieties, such as FARO 66 (also known as Swarna-Sub1), have shown enhanced survival under 10–14 days of complete submergence, offering hope for stabilizing yields in flood-prone areas (Ismail et al. 2013; AfricaRice, 2020). One of the primary hurdles to rice production in flood-prone areas, such as Nigeria's Kebbi State, is submersion stress. Finding rice cultivars that can withstand submersion is essential for climate-resilient agriculture. The Nigerian Meteorological Agency (2024) reported that flooding devastated thousands of rice farmlands every year, resulting in the loss of thousands of tons of rice. Few native rice cultivars are submersion tolerant, but no research on the analysis of rice with a high level of submersion resistance in the study area has been published to date. The Submergence Tolerance Index (STI), elongation characteristics, and survival are assessed in this study for a few chosen cultivars. The results shed light on breeding initiatives aimed at agro-ecologies impacted by flooding.

**2. MATERIALS AND METHODS**

**2.1. Description of Study Area**

Birnin Kebbi city of Kebbi State is located on 12.4539° N latitude and 4.1975° E longitude. (Nigerian Meteorological Agency. Birnin Kebbi’s vegetation is Sudan Savanna, with hot, dry season starting from October to April and a rainy season from May to September are the two different seasons that define this region's semi-arid climate. The city's average yearly temperature ranges from 24°C to 34°C, with March and April seeing the highest temperatures. The wettest months are July and August, with an average of 500 to 800 mm of rain falling per year (Ja’afar et al. 2024).



Figure 1: A: Map of study Nigeria, B: Map of Kebbi State C: Map of Birnin Kebbi

2.2 **Plant Materials and Preparation**

The research was carried out in the Biological Garden at the Department of Biological Science, Federal University Birnin Kebbi, Kebbi State. The seeds of selected rice cultivars were obtained in Yauri town (Swarna-Sub1, Mai hijabi, CP 60, Faro, and Faro 45). The seeds were transported to the biological garden at Federal University Birnin Kebbi. The four cultivars were surface sterilized by soaking in 5% hypochlorite and then rinsed three times with distilled water. The seeds were first sown in a nursery bed, and uniformly germinated seedlings (14 days) were selected and transferred into pots of 15-liter size containing a mixture of loamy soil and organic manure in a 3:1 ratio (Kawono et al. 2009).

**2.3 Plant Growth Condition and Experimental Design**

The research was carried out in the Biological Garden at the Department of Biological Science, Federal University Birnin Kebbi, Kebbi State. The seeds of selected rice cultivars were obtained in Yauri town in March, 2024 (Mai hijabi, IR64, CP 60, Faro 60, and Faro 45). The seeds were transported to the biological garden Federal University Birnin Kebbi. The seeds were identified and deposited in the Herbarium of Department of Biological Sciences and voucher number was given; (FUBK\_2024-87, FUBK\_2024-88, FUBK\_2024-89 and FUBK\_2024-90). The four cultivars were surface sterilized by soaking in 5% hypochlorite and then rinsed three in running water. The seeds were first sown in a nursery bed, and uniformly germinated seedlings (14 days old) were selected and transferred into plastic pots of 15-liter size containing a mixture of loamy soil and organic manure in a 3:1 ratio (one seedling per pot) (Ja’afar et al. 2018)

The experiment was laid down in a completely randomized design (CRD) was used with three replications to assess the submergence tolerance of different rice genotypes. The experiment includes both tolerant (Swarna-Sub1) rice varieties as controls and susceptible (IR64) rice varieties as controls.

**2.4 Submergence of rice cultivars**

Submergence is carried out in a controlled pots filled with clean water to a depth of at least 60–80 cm to ensure full submergence. The submergence period lasts for 14 days as this is the standard for screening *Sub1* tolerance. Water temperature, light intensity, and dissolved oxygen levels are monitored daily to simulate natural flood conditions (Septiningsih, 2009; Singh et al. 2009).

**2.5 Submergence recovery and Determination of survival rate**

After 14 days of submergence, the water is drained, and the plants are allowed to recover for 7 days under normal conditions. During the recovery period, the surviving seedlings are monitored and allowed to produce new leaves. Submergence survival rate was analysed using the formular below:

Survival percentage (%)**=**$\frac{Number of surviving seedlings after recovery}{Total number of seedlings before submergence}×100$ **\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_1**

(Septiningsih, et al. 2009).

**2.6 Determination of Shoot elongation during submergence (cm)**

Length of seedlings were measured with cm rule before submergence (L1). After the submergence period, the seedlings were gently removed from water and allow excess water to drain. Final shoot length (L₂) in the same seedlings you measured initially. Initial shoot length (L₁). Shoot elongation during submergence

Is determine the following formula (Ja’afar et al. 2024).

Shoot Elongation (cm)=L2​−L1​\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_2

Shoot Elongation Rate (cm/day) =$\frac{L2-L1}{ Number of submergence days}$\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_3

**2.7 Analysis of Submergence Tolerance Index (STI)**

The Submergence Tolerance Index (STI) is calculated based on survival rate using the following equation:

**STI =**$\frac{Survival (\%) of genotype}{Survival (\%) of susceptible control}×100$ **\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**4

**2.8 Statistical Analysis**

The data obtained was subjected to one way analysis of variance (ANOVA). Using SPSS statistical package (version 20). The mean was separated using Duncan’s multiple range.

**3. RESULTS AND DISCUSSION**

 **3.1** **Effect of submergence on survival rate, shoot elongation and shoot elongation rate of Selected Rice Cultivars**

Swarna-Sub1 had the highest survival rate (100%), indicating excellent submergence tolerance. This cultivar is significantly (P= .05) different from other cultivars. The cultivar shows significant different (P=.05) from the others. CP 60 and Faro 40 showed moderate tolerance of 66.67%, indicating some level of adaptive traits to submergence. Mai Hijabi, Faro, and IR64 all had low survival rates of 33.33%, suggesting poor tolerance to submergence stress (Table 1). Swarna-Sub1 had the highest shoot elongation of 53.76 cm, suggesting a vigorous elongation response to escape submergence. Followed by Mai Hijabi with 48.00 cm, although it had low survival, suggesting elongation alone does not guarantee survival. Faro, Faro 40, CP 60, and IR64 had moderate elongation in the 33–36 cm range, indicating a moderate growth response to flooding (Table 1). The ability of a rice plant to survive 10-14 days of complete submersion and renew its growth when the water subsides" is the definition of submersion tolerance (Bharti et al. 2024).

Survival under submergence is a critical trait for rice grown in flood-prone environments. The present study revealed that cultivar Swarna-Sub1 showed the highest survival rateof 100.00%, significantly outperforming others. This high tolerance is attributed to the presence of the *Sub1A* gene, known to enhance submergence tolerance by suppressing excessive elongation and conserving energy reserves during submergence (Xu et al. 2006). In contrast, Mai Hijabi, Faro, and IR64 all showed low survival rates of 33.33%, suggesting poor submergence tolerance, possibly due to the absence of *Sub1* QTLs or less effective anaerobic survival strategies. A study by Manasa et al. (2024) demonstrated that improved restorers hold promise for developing rice hybrids with tolerance to both submergence and phosphorus.

Swarna-Sub1 led with the highest elongation rate with 3.28 cm/day, showing a strong and sustained escape mechanism. MAI HIJABI had the second highest rate of 2.98 cm/day but did not survive well, possibly due to energy depletion from rapid elongation. Faro 40 and Faro had moderate elongation rates of ~2.5 cm/day, while IR64 had the lowest rate of 2.13 cm/day, correlating with its low survival (Table 1).

Under submergence, rice plants adopt either a quiescence strategy (limiting elongation to conserve energy) or an escape strategy (rapid elongation to reach the water surface). Swarna-Sub1 had the highest shoot elongation of 53.76 cm and highest shoot elongation rateof 3.28 cm/day, indicating a mixed strategy, though in many reports, *Sub1A* genotypes restrict elongation (Kawano et al. 2009; Septiningsih et al. 2009). This discrepancy could arise from genetic background interactions or stress duration. Mai Hijabi also showed high elongation of 48.00 cm, but with a low survival rate, indicating an inefficient escape strategy, where rapid elongation depletes carbohydrates without guaranteeing emergence from water, leading to mortality (Fukao & Bailey-Serres, 2008; Singh et al. 2009). Similarly, IR64 and CP 60 displayed moderate elongation, but CP 60 had better survival, possibly due to partial tolerance mechanisms.

The Submergence Tolerance Index (STI) is a valuable quantitative trait used to assess the ability of rice cultivars to withstand complete or partial flooding. It reflects a cultivar’s capacity to survive and maintain growth under submerged conditions. The table above presents STI values (with statistical groupings) and corresponding tolerance classifications for six rice cultivars under submergence stress.

Table 1: Influence of submergence on survival rate, shoot elongation and shoot elongation rate in rice.

|  |  |  |  |
| --- | --- | --- | --- |
| **Cultivars** | **Survival rate (%)** | **Shoot elongation (cm)** | **Shoot elongation rate (cm/day)** |
| MAI HIJABI | 33.33a±6.88 | 48.00 d±6.88 | 2.98cd±14.24 |
| CP 60 | 66.67b±0.95 | 35.25 abc±0.95 | 2.21 ab±3.75 |
| FARO | 33.33a±7.42 | 33.75 ab±7.42 | 2.51b±4’99 |
| FARO 40 | 66.67b±4.44 | 36.50bc±4.44 | 2.58bc±3.79 |
| SWARNA-SUB1 | 100.00c±5.89 | 53.76e±2.56 | 3.28c±2.43 |
| IR64 | 33.33a±6.88 | 35.45ab ±1.98 | 2.13b±3.21 |

Values presented in the table are mean±sandard deviation, values in a column with same superscript are the same

**3.2 Effect of submergence on submergence tolerance index in rice**

SWARNA-SUB1 shows significant (P= .05) different on STI it recorded 66.67% STI which indicates superior submergence tolerance. This high STI reflects its genetic resilience, likely due to the SUB1A gene, which confers controlled elongation and better survival (Table 2). CP 60 and Faro 40 Both recorded an STI of 33.34%, indicating moderate tolerance to submergence. Their performance suggests some adaptive capacity, though not as effective as Swarna-Sub1. Mai Hijabi, Faro, and IR64 shows STI values of 0.00% which indicate complete susceptibility. These cultivars are unable to survive or recover from submergence, making them unsuitable for flood-prone environments (Table 2)

Swarna-Sub1 demonstrated the highest STI, of 66.67 % confirming its high submergence tolerance. This aligns with existing research, as Swarna-Sub1 carries the Sub1A gene, a key factor in quiescence-based submergence tolerance. The Sub1A gene limits shoot elongation and preserves carbohydrate reserves, enhancing post-submergence survival (Xu et al. 2006; Bailey-Serres & Voesenek, 2008). CP 60 is classified as moderately tolerant, supported by its STI of 33.34%. This suggests it possesses partial adaptive traits under submergence, possibly through moderate elongation and energy use efficiency. Faro also shows an STI of 0.00% but is labelled “moderate tolerant. This classification raises concerns as STI typically directly reflects survival. Inconsistent classification may arise from varied submergence durations, incomplete recovery data, or environmental factors. Normally, an STI of 0% implies total sensitivity (Singh et al. 2010).

Mai Hijabi, Faro 40, and IR64 cultivars had STI values of 0.00% or 33.34%, and were largely classified as not tolerant, which agrees with prior studies by (Fukao et al., 2006; Dipak et al. 2024) which reported that in rice, plant survival rates, growth, and development are adversely affected by submergence. IR64, a widely studied variety, is known to be submergence-sensitive, with rapid elongation and energy depletion under flood conditions. Faro 40, despite having the same STI as CP 60, is classified here as “not tolerant,” which may be due to poor post-submergence recovery, carbohydrate exhaustion, or physiological damage and Mai Hijabi had 0% STI, accurately classified as not tolerant, indicating complete failure under submergence.

Quiescence strategy restricts elongation and conserves energy. Controlled by the Sub1A gene, found in tolerant varieties like Swarna-Sub1. Escape strategy involves rapid elongation to reach the water surface, common in sensitive varieties like IR64 but often results in energy exhaustion and low survival (Fukao & Bailey-Serres, 2008; Septiningsih, 2009).

Table 2: Salinity tolerance index of different rice cultivars

|  |  |  |
| --- | --- | --- |
| **Cultivars** | **STI (%)** | **Interpretation**  |
| MAI HIJABI | 0.00a±6.88 | Not tolerant |
| CP 60 | 33.34b±0.95 | Moderate tolerant  |
| FARO | 0.00a±7.42 | Moderate tolerant |
| FARO 40 | 33.34b±4.44 | Not tolerant |
| SWARNA-SUB1 | 66.67c±5.89 | High tolerant |
| IR64 | 0.00a±6.88 | Not tolerant |

Values presented in the table are mean±sandard deviation, values in a column with different superscript are significantly different.

**CONCLUSION**

Under submergence stress, rice cultivars respond differently. Swarna-Sub1 demonstrates superior performance and is a good candidate for cultivation in flood-prone areas. In contrast, varieties like IR64, Faro, and Mai Hijabi show poor adaptation and would require improvement through breeding or genetic modification for better submergence tolerance.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

The authors hereby attest that the usage of generative AI technology COPILOT was limited to the editing and proofreading of the article in order to improve readability.

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