Original Research Article

Effect of Water Stress Duration on the Growth Characteristics and Yield Components of Upland Rice Varieties in Kenya

ABSTRACT

Drought stress is a major problem in upland rice grown areas under rainfed conditions. It affects plant growth and development, and eventually leads to a considerable yield reduction. The study was carried out with the aim of evaluating the effect of drought stress duration on the growth characteristics and yield components of upland rice varieties. The experiment was conducted at the University of Eldoret with Sixteen upland commercial and local rice varieties were used in the study obtained from Kenya and Liberia. Rice plants were subjected to drought stress treatments at tillering and flowering stages in the green house. The experiment was layout in a complete randomized design (CRD) in a split plot arrangement with five treatments and replicated three times. The results of leaf rolling, plant height, days to 50% flowering, days to maturity, panicle number, spikelet sterility, biological yield, leaf relative water content,1000-grain weight, harvest index and grain yield revealed that there were significant differences as a result of water stress on the treatments ($p \leq 0.001$) and rice varieties ($p \leq 0.05$). All the sixteen varieties were significantly affected by the treatments when compared with the control. The results also revealed that MWUR, Dourado, L-22, Komboka, Jaowo, LAC-23, Kpatawee, MWUR, White rice and Red Youmo varieties were significantly affected by the water stress treatments at leaf rolling, flowering and maturity then that of NERICA 1,2 ,3, 4, 10,11 and 14 at tillering and flowering stages. The findings of this study indicated that NERICA 1, 2, 3, 4, 10 varieties were less affected by soil water stress treatments amongst the tested varieties, followed by NERICA 11 and14 respectively. Thus, NERICA varieties had the best performance in most of the parameters that were measured. Therefore, these varieties can thus be used by breeders to develop varieties adapted to areas with limited rain fall and insufficient soil moisture for rice production.

Key words: Drought stress, Upland rice, Growth stages and yield components. Response, growth

1. INTRODUCTION

Rice (*Oryza Sativa*) is the main staple food and grown in over 75% of the African countries, with a total population of close to 800 million people [1]. In Africa, it has been identified as a source of food to support the population growth, based on similar successes in Asia [1]. Rice provides nutrition for more people in the world than any other crop, especially in developing countries [1]. It is, however, the most popular food crops in the world, and are the basis of staple food in most of the developing countries [2] Rice is also recognized as a crop that can feed large populations based on several of its attributes, including good storability and requiring less energy to prepare.

Despite rice being an important crop, drought stress is one of the most crucial abiotic constraints that obstructs its production, and contributes to yield certainty in Sub-Saharan Africa [3]. It is projected that the overall effects of drought stress accounts for over 50% of losses incurred in crop production [4]. It affects rice plant physiological processes and impacts the performance of agronomic traits, which ultimately results in low grain productivity. Water plays a major role in agriculture and food production [5], and its deficit threatens food security by reducing crop yields and increasing variability every year.

Over the last decade, the number of people affected by the drought in Kenya is gradually increasing from an average of 1.5 million to 4.5 million people affected annually [6]. The 2011 Post Disaster Needs Assessment (PDNA) conducted by the Government of Kenya, showed that drought incidents during 2008-2011 resulted in USD 2.1 billion worth of damages and losses to the economy of Kenya, with 85% occurring in the main livelihood sectors of livestock and agriculture. A severe and prolonged drought from 2008-2011 affected 3.7 million people, caused $12.1 billion in damages and losses, and cost over $1.7 billion in recovery and reconstruction needs [7].

According to [8] more than 70% of natural disasters in Kenya are associated to extreme climate variations. Over the recent past, droughts have become a regular phenomenon with the number of affected people increasing. However, in order for Kenya to increase its rice production and be able to meet the country’s rice demand, there is a need to identify drought tolerant upland rice varieties to improve grain yield of upland rice varieties grown in areas with limited water supply. Therefore, the study was carried out to establish the effect of drought stress duration on upland rice variety on the growth characteristics and yield components in Kenya.

2. MATERIALS AND METHODS

2.1 Planting materials

Sixteen upland rice varieties were selected for the study, seven varieties were selected from Liberia and nine were from Kenya (Table 1).

Table 1: List of rice varieties and their sources used in the study

No.	Variety Name	Sources	Origin
1	Dourado	Kenya	Commercial
2	Jaowo	Liberia	Local
3	Komboka	Kenya	Commercial
4	Kpatawee	Liberia	Local
5	L - 22	Liberia	Local
6	LAC-23	Liberia	Local
7	MWUR	Kenya	Commercial
8	NERICA 11	Kenya	Africa Rice
9	NERICA 1	Kenya	Africa Rice
10	NERICA 10	Kenya	Africa Rice
11	NERICA 14	Liberia	Africa Rice
12	NERICA 2	Kenya	Africa Rice
13	NERICA 3	Kenya	Africa Rice
14	NERICA 4	Kenya	Africa Rice
15	White rice	Liberia	Local
16	Red Youmo	Liberia	Local

2.1.2 Experimental Site

The experiment was conducted at the University of Eldoret, which is situated 9 kilometers along the Eldoret-Ziwa Road from Eldoret town, Usain Gishu County, Kenya, with the longitude of 35^{o} 18’ E and 0^{o} 34’N latitude at altitude of 2153 meters above sea level. The area has the average annual rainfall of approximately 1295mm, and annual minimum and maximum temperatures of 15 and 28 ^{0}C, respectively. The soil is rhodic ferralsol with a pH range of 5.5 to 6.2.

2.1.3 Experimental Treatments and design

Sixteen rice varieties (sub-plots) were subjected to five watering regimes (main plots) using a Complete Randomized Design in a split plot arrangement with three replications in the greenhouse. Moisture content of the soil from (zero) to 15 cm depth in each pot was measured at the time of planting and before subjecting some of the treatments to water stress. The soil volumetric water content was monitored and determined using the soil moisture meter; control (100%) field capacity (FC) and water stress (40 %) was imposed on rice plant at maximum tillering and 50% flowering stages and discontinued when each stage was over [9]. The water stress was subjected at maximum tillering stage (Treatments 2 and 3) and at 50% flowering stage (Treatments 4 and 5) by withholding water application for different periods (Table 2).

Table 2: Description of water stress duration applied on rice varieties at maximum tillering and at 50% flowering stages at different days.

Water Stress	Watering duration
T1	Continuous watering till harvest (control)
T2	Stop watering at maximum tillering for 10 days
T3	Stop watering at maximum tillering for 15 days
T4	Stop watering at 50% flowering for 10 days
T5	Stop watering at 50% flowering for 15 days

The soil used was taken from the University of Eldoret main campus, solarized for five days at the temperature of 60°C at of depth 5cm, after which the soil was filled into a 30 cm diameter and 30 cm height plastic pot filled with 10 kg of soil (dry weight basis) perforated bottoms up to ¾ full. The seeds were soaked with plain water for 24 hours prior to planting to accelerate the germination rate. Rice was planted in experimental pots, divided into fifteen plots. The spacing within each plastic pot were 15 cm between rows and 15 cm between hills. Four seeds were planted per hill in each pot using the dibbling method. Nitrogen fertilizer were applied at the rate of 50kgN/ha in split doses, 50 % basally and 50 % as topdressing.

3. Data collection

This commenced 45 days from planting date and was done before and after every stress period till the end of the experiment. Four rice plants from each pot were randomly selected for data collection.

3.1 Leaf rolling

Data was collected on leaf rolling was determined visually on the basis of the degree of folding [10]. and after 10 and 15 days of water stress, using the scale from 0 – 9, the standard evaluation system for rice [11]. The extent of leaf rolling was considered as an alternative means of showing the leaf water status.

Table 3: Description of the scale for leaf rolling

Scale	Description
0	Healthy leaves
1	Leaves start to fold along the margins
3	Leaves folded into V- shape
5	Leaves fully cupped (V- shaped)
7	Leaf margins touching each other (O - shaped)
9	Leaves tightly rolled

Data were collected on number of tillers per hill, Plant height (cm); Days to 50% flowering and days to maturity; Number of panicles per hill; 1000 grain weight; grain yield in gram; The RWC was recorded according to the following formula {RWC (%) = (fresh weight – dry weight) / (turgid weight – dry weight) X 100} [12]. Biological yield was determined by weighing the rice plants along with ears obtained from each plot. Harvest index (%) was calculated basing on the ratio between grain yield and biological yield × 100 using the formula: Harvest Index (%) = (Grain yield / Biological yield) x 100. Spikelet Sterility was computed by dividing the number of unfilled grains by the total number of filled grains and was expressed as percentage as follows:

$$\text{Spikelet Sterillity (\%)} = \frac{\text{Unfilled grains}}{\text{filled grains}} \times 100.$$

3.1.2 Statistical analysis of data

All the data collected were summarized in Microsoft excel and subjected to analysis of variance (ANOVA) using GENSTAT 14th - edition (VSN International Limited, 2011). Treatment means for the different parameters were separated using Fisher's protected least significant difference (LSD) procedure at 5 % level of significance.

4. RESULTS AND DISCUSSION

The results analyzed were to ascertain the performance of upland rice varieties on growth characteristics, yield and yield components under drought stress conditions at different growth stages.

4.1 Leaf rolling at tillering and flowering stages

The results on leaf rolling indicated that there were significant differences among the treatments (*P<.001)* and the varieties (*P* < .001), and their interactions were significant as presented in Table 4. The sixteen varieties were affected by the water stress at tillering stage when compared with the control (T1). However, the effect of the stress was severe on, MWUR, Dourado, Komboka, L-22 followed by, LAC- 23, White rice, Red youmo, Kpatawee when the varieties were subjected to stress for 10 and 15 days at tillering stage, except NERICA 1, 2, 3 followed by NERICA 10, 11, 4 and Jaowo varieties which were less affected. (Table 4). All the rice varieties were significantly affected when subjected to drought stress at flowering stage for 10 days (T4) and 15 days (T5) as compared with the control (T1). (Table 4). Leaf rolling was significantly different (*P*<.001) in all the varieties, and was highest in all the varieties except NERICA 1, 2, 3, 4, 14, 10 and 11 varieties which were least affected when subjected to drought stress for 10 and 15 days at flowering stage. When the sixteen rice varieties subjected to water stress at tillering stage are compared with those of flowering stage, NERICA varieties were the least affected at both tillering and flowering stages.

Table 4: The response of sixteen upland rice varieties on leaf rolling, tiller numbers relative water content and plant height under water stress at tillering and flowering stages

Variety Name	LRT	LRF	TN	PHT	PHF	RWC (%)	RL (cm)
MWUR	3.2^{a}	2.1^{bcd}	10.5^{b}	44.1^{gh}	72.1^{fg}	72.0^{defgh}	21.6^{d}
Dourado	2.7^{a}	3.4^{ab}	8.9^{bcde}	54.0^{abc}	83.5^{e}	77.3^{cdefg}	23.2^{d}
L- 22	2.2^{a}	3.5^{ab}	9.5^{bcde}	53.2^{abcd}	95.9^{abc}	87.1^{abc}	21.6^{d}
Komboka	1.4^{b}	2.7^{abc}	13.4^{a}	31.10^{i}	56.2^{h}	50.2^{i}	21.3^{d}
LAC 23	1.3^{b}	3.7^{a}	8.8^{bcde}	57.4^{ab}	98.9^{ab}	90.0^{abc}	22.5^{d}
White rice	1.2^{b}	2.7^{abc}	10.3^{b}	48.10^{def}	94.4^{abc}	85.7^{abcd}	22.9^{d}
Kpatawee	1.1^{b}	4.1^{a}	8.1^{def}	51.1^{abcde}	99.3^{a}	90.7^{abc}	21.8^{d}
Red youmo	1.1^{b}	3.8^{a}	8.6^{bcdef}	54.1^{abc}	92.3^{bcd}	91.4^{abc}	21.9^{d}
NERICA 10	0.9^{c}	1.0^{de}	9.5^{bcde}	45.4^{fgh}	70.3^{fg}	63.2^{ghi}	28.2^{bc}
NERICA 14	0.7^{c}	0.8^{de}	9.7^{bcd}	42.2^{h}	75.5^{f}	72.2^{defgh}	27.5^{bc}
Jaowo	0.7^{c}	3.2^{ab}	7.6^{ef}	54.1^{abc}	93.8^{bc}	82.7^{abcd}	23.3^{d}
NARICA 11	0.5^{c}	0.3^{e}	9.5^{bcde}	47.2^{efg}	67.1^{g}	84.6^{abcd}	29.7^{ab}
NERICA 4	0.2^{c}	0.8^{de}	10.2^{bc}	41.7^{h}	70.7^{fg}	59.8^{hi}	28.1^{bc}
NERICA 1	0.1^{d}	1.5^{cde}	10.1^{bcd}	44.6^{fgh}	70.8^{fg}	68.3^{fgh}	26.c
NERICA 2	0.1^{d}	0.8^{de}	6.7^{f}	47.0^{efg}	74.4^{f}	70.0^{efgh}	28.1^{bc}
NERICA 3	0.1^{d}	0.5^{e}	6.8^{f}	55.2^{abc}	70.10^{fg}	72.2^{defgh}	31.9^{a}
Stress Treatment							
T1	0.0^{b}	0.0^{c}	9.3^{a}	53.5^{a}	84.1^{a}	71.6^{b}	25.9^{a}
T2	3.1^{a}	2.7^{ab}	8.6^{a}	46.8^{b}	85.4^{a}	65.2^{b}	24.5^{b}
T3	2.4^{a}	3.4^{a}	8.9^{a}	45.3^{b}	82.4^{a}	65.1^{b}	23.9^{b}
T4	0.0^{b}	2.7^{b}	9.8^{a}	51.1^{a}	80.1^{a}	98.1^{a}	23.7^{b}
T5	0.0^{b}	3.2^{ab}	8.8^{a}	52.2^{a}	80.6^{a}	94.7^{a}	24.5^{b}
Means	**1.100**	**2.47**	**9.06**	**49.8**	**82.5**	**78.9**	**24.4**
($LSD_{0.05}$) variety	0.99***	1.320***	1.659***	4.21**	6.24***	7.60**	2.54***
Stress Treatment	1.1020***	0.605***	1.787ns	2.44**	5.21ns	12.62***	1.13*
Stress Treatment ×Variety	2.3635***	2.921***	3.933ns	9.40ns	14.32ns	28.25***	5.63*

Data means followed by the same superscripts within a column for treatment and variety are not significantly different at (*P*=.05). ns= significant, * = significant at *P* =.05, ** = significant at *P*<.01 and *** significant at *P* <.001. LRT= Leaf rolling at tillering, LRF= leaf rolling at flowering, TN= Tiller number, PHT= plant height at tillering, PHF= plant height at flowering, RWC= Relative water content, RT= Root length; T1=Continuous watering till harvest (control), T2=Stop watering at maximum tillering for 10 days, T3=Stop watering at maximum tillering for 15 days, T4 = Stop watering at 50% flowering for 10 days, T5= Stop watering at 50% flowering for 15 days

Leaf rolling can reduce further loss of water by ensuring that the air trapped by rolled leaf becomes saturated so as to reduce the water potential gradient between the water in the leaf and air in trapped by the leaf. [13]. reported that leaf rolling is correlated with internal water status of the leaf tissue and it is also related with the stomatal closure and decreases transpiration from leaves. [14] found that leaf rolling began at higher midday leaf water potentials and turgor pressures in upland rice than in low land adapted varieties.

The degree of leaf rolling of rice plant is dependent on the ability of the plant to adjust osmotically. In plants, osmotic adjustment refers to the maintenance of turgor by reducing the tissue osmotic potential, ascending from the net accumulation of solutes in the cell sap in response to the water potential of the cell's environment. Leaf rolling greatly helps grasses, including rice, in reducing transpirational water loss during water stress [15]. However, when leaves roll, the effective leaf area for light interception is reduced and the diffusive resistance to CO_2 is increased, both of which will reduce photosynthesis.

Leaf rolling can be used as a visual score for selecting for water stress tolerance in rice [16]. [16] observed that the degree of leaf rolling at a particular leaf water potential was dependent on the variety and, thus, care must be taken into consideration when using leaf rolling as an index of the degree of water stress or dehydration avoidance. This denotes that screening for water stress tolerance for rice on the basis of leaf rolling should be conducted based on the degree of leaf rolling since different varieties have different genetic traits and leaf water tissue status.

4.1.2 Number of tillers

Table 4 showed that there was significant effect among the varieties ($P<.001$) on the tiller numbers. The interaction between the water stress treatments ($P=.05$) was not significant. Komboka rice variety had increased or highest number of tillers (13.4) when all the varieties were stressed for 10 and 15 days. Differences in tiller production under soil water stress levels might be due to the fact that under water stress plants were not able to produce enough assimilates because of inhibited photosynthesis. The results agreed with those of [17] who reported that differences in tiller numbers could be due to soil water stress. [18] also reported that water stress during vegetative and reproductive stages reduced tillering.

The reduction in tiller numbers in some varieties could be as a result of limited water supply which in turn resulted in reduced amounts of carbohydrate assimilates and the chlorophyll contents. It could also be due to less amount of water uptake that led to inhibition of cell division of the meristematic tissues [19]. The leaf size declined leading reduced tiller numbers. [20] stated that significant reductions in tiller and panicle numbers were observed when water stress was imposed at tillering stage. Generally, all the local varieties produced higher number of tillers than that of NERICA varieties which could be genetic or environmental.

4.1.3 Plant height at tillering and flowering in (cm)

The response of different timings of water stress and rice varieties on plant height at tillering stage was highly significant ($P<.01$) as presented in Table 4. The interaction between the treatments and the varieties was not significant. When rice plants were subjected to drought stress at tillering for 10 and 15 days, plant heights of Dourado, LAC-23, NERICA 3, L-22, Jaowo, Kpatawee and Red youmo were similar but significantly higher than the MWUR, NERICA 1, 2, 4, 10, 11, 14 and white rice varieties while Komboka produced the lowest plant height at tillering stage.

At flowering stage, rice varieties had significant effect (*P* <.001) on plant height at various water stress. The effect of different lengths of water stress periods on plant height at growth stages was significant (*P* <.001) (Table 4). The interaction between the varieties and the water stress treatments was not significant. Exposing to water stress at flowering stage caused a significant variation in plant heights at flowering stage. Kpatawee, L-22, White rice and LAC-23 had the highest plant height at flowering followed by Red youmo and Jaowo. While Komboka obtained the shortest plant height.

The significant variation in rice plant height when all the varieties were subjected to stress for 10 and 15 days, it could be due to insufficient soil moisture for cell expansion. However, when the stress length increased to 10 days, the plants tried to recover and their heights significantly increased in some of the varieties. A further increase in the stress duration to 15 days significantly reduced plant height again for all the varieties. Dourado, LAC-23, Narica 3, Red Youmo and Jaowo rice varieties performed better in terms of plant height at tillering as compared to other varieties.

The variation in plant height when subjected to drought stress at anthesis could be due to inhibition of cell enlargement under water stress conditions. The differences in plant heights as a result of the water stress treatments both at vegetative and reproductive stages is in agreement with [21]. The depression of plant height could also have resulted from a reduction in plant photosynthetic efficiency as reported by [22].

4.1. 4 Leaf Relative Water Content (%)

The leaf relative water content of the sixteen upland rice varieties was significantly different at (*P* <.01), water stress at *P* <.001and the interaction between the treatments and the rice varieties (*P*< .001*)*, (Table 4). The interaction between the stress and the rice varieties (Table 4) was highly significant (*P* <.001). When rice plant was exposed to drought stress at tillering and flowering stages for 10 and 15 days caused a significant variation in the relative water content. Jaowo, L-22, LAC- 23, Kpatawee, Red youmo White rice and Nerica 11 Producing the highest relative water content of the leaves. However, there were no statistical differences among the rest of the varieties with Komboka producing the lowest relative water content percentage. Leaf relative water content is one of the important indicators of water status in plants, it reflects the balance between water supply to the leaf tissue and transpiration rate [23]. It is also considered the best integrated measurement of plant water status, which represents the variations in water potential and turgor potential of plants [24]. There was a greater decreased in the leaf relative water content at tillering and flowering stages, it could be due to the water stress, rice plants were not able to increase its water content in the cells under drought stress conditions. This is in agreement with [25] who reported that osmotic adjustments affect relative water content depends on the response of varieties to water stress, the longer the osmotic adjustment water stress is greater relative water content increased or can be maintained [2]. Plant tolerance to drought stress could be associated with different systems, including the ability to retain the high relate water content [26].

4.1. 5 Root length (cm)

The root length analysis indicated significant difference among varieties *at (P* <.001), the effect on water stress and their interactions were significant at (*P* =.05) (Table 4). This showed that there were differences among the varieties for the root traits under the five watering stress regimes. Introducing these varieties to water stress at tillering and flowering stages for 10 and 15 days showed that NERICA 3 and 11 varieties had the longest root length, followed by NERICA 2, 4, 10 and 14. However, when the stress period was prolonged to 15 days, caused significant reduction in the root diameter of MWUR, Dourado, Komboka, L-22, LAC-23, Kpatawee, White rice, Red youmo and Jaowo (Table 4). The access of water to rice plant is determined by its root system, properties, structure, and distribution, thus improving root traits to increase the uptake of soil moisture and maintain productivity under water stress is of huge interest [27]. Water stress reduces root growth and development of rice because of the increased soil resistance and low water availability [27].

Some studies have demonstrated that during the adaptation process to the water stress conditions, plant roots have evolved a stronger water uptake capacity [28]. [27] reported that the longer the root of rice plants the more branch roots they produce, the stronger their capacities to absorb and transport water, thereby displaying more resistance to water stress. [29] Stated that the capacity of roots to absorb water and nutrients mainly depends on root morphological and anatomical traits. Extensive studies on rice roots have identified many root traits that provide drought resistance.

Rice plants with deep rooting can access water from deeper soil layers, which enables the plants to avoid drought stress [30]. A well-developed root system can help plant in maintaining high plant water status under water stress, upland rice develops deep and thick root systems to improve the hydraulic properties of its roots. These features greatly enhance the drought resistance of upland rice varieties by allowing the absorption of more water stored in deep soil layers ([31].

4. 1. 6 Days to 50% flowering

Table 5 revealed that there were significant differences (*P <.001*) among rice varieties regarding to the number of days to 50% flowering while watering regimes and their interaction was not significantly different. The longer the stress period, the longer the number of days to flowering. The Kpatawee, L-22, White rice and Jaowo varieties took the longest time to attain 50% flowering followed by MWUR, Komboka, LAC-23, Red youmo and White rice. While NERICA varieties significantly performed better in terms of days to 50% flowering (Table 5). [32] observed that rice plants exposed to water stress can advance flowering by up to one week or more with a corresponding decrease in the number of spikelets and pollen fertility leading to yield reduction. Ontogenic characters especially appropriate flowering time play a major role in moisture stress avoidance of rainfed upland rice [33].

Timing, intensity and occurrence of water stress have been associated with the delay of heading or flowering (Lanceras *et al*. 2004). If the stress occurred in the vegetative stage and is not severe, there might not be much effect on the heading or flowering. However, if the occurrence is at the end of the vegetative stage, there may be a delay in panicle initiation that may affect grain yield [33]. [34]. reported that the longer the flowering period, the less grain yields. The growing period of flowering causes plants to run out of energy to produce optimally due to water deficit stress.

4. 1. 7 Days to maturity

The watering regimes affected the number of days taken by the rice plants to reach harvesting. Imposing water deficit stress on Dourado, Kpatawee, Jaowo, L-22 and White rice at tillering and flowering stages for 10 and 15 days, significantly increase in the number of days to maturity followed by MWUR, Komboka, LAC- 23 and Red youmo (Table 5). While NERICA 2, 3, 10, 4, 14, had the shortest days to maturity followed by NERICA 1 and 11.

Significant increase in the number of days to maturity in rice varieties showed that water stress causes retardation in the growth of these varieties. However, since NERICA varieties are fast maturing, they can be planted early to escape drought. It has been reported that under severe water stress conditions, early flowering feature is a very important mechanism to escape from drought stress [35]. But selection based on time of flowering or maturing, does not occur at the same time with water deficit period will be very effective method to improve drought tolerance in upland rice variety [36].

Table 5: Effect of water stress duration on yield and yield attributes of sixteen upland rice verities at tillering and flowering stages

Variety Name	**DTF**	**DTM**	**PN**	**GY (g)**	**1000-GW**	**SS (%)**	**BY (g)**
MWUR	138.7^{c}	168.1^{b}	9.2^{abc}	62.3^{bcd}	10.9^{ef}	35.7^{abc}	261.4^{cde}
Dourado	143.7^{bc}	173.7^{ab}	5.9^{h}	57.8^{d}	13.1^{de}	38.2^{a}	303.9^{abcd}
L- 22	146.5^{abc}	176.5^{ab}	6.2^{gh}	82.4^{a}	8.1^{fg}	31.0^{abcd}	332.2^{ab}
Komboka	141.6^{bc}	171.6^{b}	6.6^{fgh}	55.8^{d}	10.9^{ef}	34.0^{abcd}	265.4^{cde}
LAC 23	143.1^{bc}	173.1^{b}	6.3^{fgh}	75.6^{abc}	7.5^{fe}	29.5^{abcd}	345.4^{a}
White rice	158.3^{a}	188.3^{a}	6.2^{gh}	61.3^{cd}	6.5^{g}	39.8^{a}	249.5^{e}
Kpatawee	158.2^{ab}	183.2^{ab}	7.6^{cdefg}	58.7^{d}	9.0^{fg}	32.8^{abcd}	309.3^{abc}
Red Youmo	139.1^{bc}	169.1^{b}	8.3^{cde}	77.4^{abc}	6.0^{g}	33.4^{abcd}	293.3^{bcde}
NERICA 10	103.3^{d}	133.3^{cd}	10.7^{a}	81.5^{ab}	16.3^{bcd}	31.6^{abcd}	289.7^{bcde}
NERICA 14	102.9^{d}	133.7^{d}	7.9^{cdef}	81.7^{ab}	18.5^{abc}	24.4^{d}	278.7^{cde}
Jaowo	150.7^{abc}	180.7^{ab}	7.1^{efgh}	72.9^{abc}	6.8^{g}	26.4^{bcd}	298.9^{abcde}
NARICA 11	105.0^{d}	148.3^{c}	8.8^{bcd}	78.2^{abc}	19.9^{ab}	27.1^{bcd}	276.3^{cde}
NERICA 4	101.9^{d}	131.2^{d}	8.8^{bcd}	79.1^{abc}	18.0^{abc}	36.2^{ab}	347.0^{a}
NERICA 1	99.9^{d}	129.3^{c}	10.3^{ab}	86.5^{a}	15.3^{cd}	25.2^{cd}	251.9^{de}
NERICA 2	104.5^{d}	133.3^{d}	6.7^{efgh}	81.3^{ab}	20.6^{a}	25.5^{bcd}	272.1^{cde}
NERICA 3	104.3^{d}	134.3^{d}	7.5^{defgh}	79.4^{abc}	17.2^{abc}	27.2^{bcd}	290.1^{bcde}
Stress Treatment							
T1	102.4^{a}	128.1^{a}	6.0^{a}	58.2^{a}	11.4^{a}	22.8^{a}	282.6^{a}
T2	102.4^{a}	126.4^{a}	6.4^{a}	61.5^{a}	10.1^{ab}	29.8^{a}	305.2^{a}
T3	100.5^{a}	125.9^{a}	6.3^{a}	54.9^{a}	10.1^{ab}	24.4^{a}	296.1^{a}
T4	101.4^{a}	125.4^{a}	5.9^{a}	54.8^{a}	10.1^{ab}	23.4^{a}	281.1^{a}
T5	102.5^{a}	126.2^{a}	6.5^{a}	54.2^{a}	9.5^{b}	24.1^{a}	281.9^{a}
Means	**101.84**	**126.4**	**6.2**	**58.6**	**10.24**	**24.9**	**289.4**
(LSD$_{0.05}$) variety	12.376***	13.84***	1.43**	12.85***	3.302***	4.51***	44.01***
Stress Treatment	6.442ns	8.07ns	0.86ns	10.57ns	1.473ns	3.86ns	35.45ns

Stress Treatment ×Variety	27.522ns	30.93ns	3.21ns	29.43ns	7.305ns	10.55ns	100.62ns

Data means followed by the same superscripts within a column for treatment or variety are not significantly different at (*P*=.05). ns= significant, * = significant at *P*=.05, ** = significant at *P* <.01 and *** significant at *P* <.001.DTF= Days to 50% flowering, DTM= Days to maturity, PN= panicle numbers, GY= grain yield, 1000 GW= 1000 grain weight, SS= spikelet sterility, BY- biological yield; T1=Continuous watering till harvest (control), T2=Stop watering at maximum tillering for 10 days, T3=Stop watering at maximum tillering for 15 days, T4 = Stop watering at 50% flowering for 10 days, T5= Stop watering at 50% flowering for 15 days

4. 1. 7 Panicle numbers/plant

The effect of water stress on the number of panicles was significant at (*P < 0.01)* among the varieties (Table 5), but the interaction between the varieties and watering regimes were not significant. Subjecting Kpatawee, NERICA 1, 10 and MWUR to water stress at tillering and flowering stages significantly increased the number of panicles, followed by NERICA 4 and 11. The performance of the varieties across all the water stress treatments were significantly different on the number of panicles, this was due to the stressful conditions. [37]. reported that water stress at or before panicle initiation reduced panicle number regardless of the growth stage of the crop at which stress occurred. This might be due to the fact that moisture stress reduced the rate of cell division and growth of the individual cells. [38]. also reported that water stress at both tillering and reproductive growth stages reduced the panicle numbers.

Water deficit affected panicle number of rice at maturity. Well-watered treatments produced highest number of panicles than water stressed treatments with panicle number decreasing with increasing water stress. The result is in agreement to that of [17] who reported that water stress led to decreased panicle number, different varieties reacted differently to soil water stress. The variation in panicle number under soil water stress agrees with the findings of [39] who reported that varietal differences existed in panicle number under different water stress regimes.

4.1. 8 Grain yield (g)/(pot)

The results depicted that the effects of water stress on grain yield of upland rice varieties were significant at (*P* < .01) among the varieties, but the watering regimes and the interaction between the varieties were not significant (Table 5). The varieties of 10 and 15 days' stress at tillering and flowering stages, the grain yields were significantly different across all the watering regimes. However, Jaowo, MWUR, Dourado, Komboka, Kpatawee and white rice had similar grain yield, but significantly lowest than that of LAC- 23, L-22 NERICA 1, 2, 3, 4, 10, 11 and Red youmo. The grain yields varied meaningfully among the varieties, the variation was as a result of the stress, environment and the genetic makeup of the varieties.

The magnitude of grain yield loss depends on the growth stage at which the stress occurs and the severity of the stress. Water stress at the flowering stage, reduced chances of grain filling resulting in decreased grain yield. For Komboka, Jaowo, Kpatawee, Dourado, Komboka MWUR and white rice, when exposed to water stress, there was significant reduction in grain yield for all the treatments in relation to the control. The yield decreased with the increase in soil water stress. [40]. reported that rice grain yield severely reduced under water stress. Reduction in 1000-grain weight and an increase in spikelet sterility was also observed by [41]. under water stress condition. Water stress at vegetative growth stage, especially booting stage can interfere floret initiation, causing spikelet sterility and slow down grain filling, resulting in reduced grain yield and ultimately poor yield. Water stress reduced grain yield probably by shortening the grain filling period, disrupting leaf gaseous exchange properties, limiting the size of the source and sink tissues, impaired phloem loading and assimilate translocation [42].

The deterioration in grain yield could also be due to stress induced reduction in CO_2 assimilation rates, reduced stomatal conductance, photosynthetic pigments, small leaf size, reduced stem extension, disturbed plant water relations, reduced activities of sucrose and starch synthesis enzymes and reduced assimilate partitioning, leading to a reduction in plant growth and productivity [43]. The magnitude of grain yield loss depends on the length of water stress, the phase of crop growth and the severity of the stress [2]. The reduction in yield largely resulted from the reduction in fertile panicle number and filled grain percentage.

[44] reported that in as much as varieties differ greatly in inherent yielding ability, they could not rely on grain yield difference as the only criterion of water stress tolerant. On the other hands, yield losses from the normal conditions due to water stress are useful in assessing water stress tolerance. [45]. stated that grain yield can be significantly reduced if water stress occurs during flowering time. Evaluating the effect of different duration of water stress at various growth stages showed that water stress at any stage would reduce yield [44]. However, yield reduction was more closely related to the duration of the stress than to the stage at which the stress occurred. Water stress during at vegetative stage reduced tiller number while stress at the reproductive and grain-filling stage reduced grain number.

4.1. 9 1000 - Grain weight (g)

The response of water stress on the 1000 - grain weight was highly significant ($P <.001$) with in the varieties (P <.001) (Table 5), but the interaction between the varieties and treatments was not significant. The weight of 1000-grains decreased with the increased of water stress intensity. When the stress was imposed at tillering and flowering stages for 10 and 15 days, NERICA 2, 3 4, 10, 11,14 produced the highest 1000-grain weight, followed by NERICA 1,10 and Dourado however, the smallest 1000-grain weight was found in LAC -23, Kpatawee, L-22, White rice, Red youmo, MWUR, Komboka and Jaowo. It shows that water stress influenced the grain weight and the rate of reduction depends on the type of variety. [17] showed that the reduced soil moisture can inhibit photosynthesis and decreased translocation of assimilates to the grain which lower grain weight and 1000- grain weight.

Slow grain filling, reduction in 1000-grain weight, and an increase in spikelet sterility under drought stress conditions was also reported by (Raman *et al*., 2012. Drought stress can also reduce grain yield by disrupting leaf gaseous exchange properties especially CO2 assimilation rates and stomatal conductance, limiting the sizes of source and sink tissues, impairing phloem loading and assimilate translocation, and reducing the activities of sucrose and starch synthesis enzymes [43].

Significant increase of 1000- grain weight started to happen when rice plant was stressed for 10 days, however, when the stress was extended for 15 days, there was a significant reduction in the 1000- grain weight. The results of 1000-grain weights indicated that the reduction in grain size with drought stress imposed on rice plant in all the varieties. Similar results on1000 - grain-weight under water stress had been reported by [46].) that drought stress during different stages of rice growth might decrease translocation of assimilate to the grain which lowered grains weight and increased the empty grains.

4.1.10 Spikelet Sterility (%)

Rice varieties had significant (*P*<.001) influence on spikelet sterility, but water stress levels and their interactions were not significant (Table 5). The increased in spikelet sterility was due to the fact that water stress slowed down carbohydrates synthesis leading to the abortion of fertilized ovaries. The results showed that NERICA 1, 2, 3, 11, 14 and Jaowo measured the smallest percentage of Spikelet sterility. Spikelet sterility of grains from different rice varieties was significantly influenced by water stress conditions. These results are in agreement with those of [47] who observed that water stress disrupted most developmental stages of rice including both ovule and pollen abortion resulting in increased spikelet sterility, decreased grain weight and hence yields. Water stress at flowering caused flower abortion, grain abscission and increased the percentage of spikelet sterility [48].

Increased unfilled grains per panicle under lower soil moisture levels could be due to inactive pollen grains, incomplete development of pollen tube and inadequate assimilates production and its distribution to grains due to drought stress. The results agreed with [2] who conducted an experiment under different drought stress regimes and observed that the number of spikelet sterility was increased with stress duration. The findings also agreed with those of [49]. who observed that water stress during reproductive stage increased the sterility percentage and the number of empty spikelets.

[50] reported that low temperature can induced spikelet sterility, particularly during the reproductive period, it could be related to the physiological response mechanisms in the anther, pollen, and stigma. Previous studies have indicated that short anther dehiscence, poor pollen grains, and low pollen germination on stigmas were associated with high spikelet sterility under drought induced stress. The low temperature might have caused chilling stress to the late flowering and maturing, resulting in heading difficulty, poor spikelet fertility, which inhibits the transportation of photosynthetic products, and leads to the decrease in seed setting rate, high spikelet sterility and yield reduction [51].

4.1. 11 Biological Yield/gram/pot

There were significant (*P* <.001) differences among the varieties of the biological yield, but the watering regimes and the interactions between the varieties and watering regimes on biological yield were not significant (Table 5). When rice plants were introduced to water stress at various growth stages for 10 and 15 days, the biological yields were significantly different in all the varieties. NERICA 4, Jaowo, LAC-23, Dourado, Kpatawee and L-22 produced the largest number biological yield followed by Red youmo, NERICA 10 and 3.

The differences in biological yield were due to the decline in the ability of different varieties in absorbing nutrients, composing and transferring assimilates due to water shortage that led to a reduction in biological yield [52]. The increase in biological yield of rice plants under favorable soil moisture conditions could be due to the expansion of leaf area and also its higher durability that leads to higher biological yield.

Based on the results of the analysis on the variety means, there were significant differences in the biological yield of different varieties. It has been reported that usually the varieties which have longer growing season have higher biological yield. [37] also reported that some traits including the number of days to maturity, biological yield, grain weight, grain yield and harvest index in varieties of rice are significantly different under moisture stress condition. However, among all the varieties, NERICA 4, Dourado, L-22, LAC-23, Kpatawee and Jaowo rice varieties obtained the largest biological yield indicating they had the best performance in terms of biological yield (Table 5).

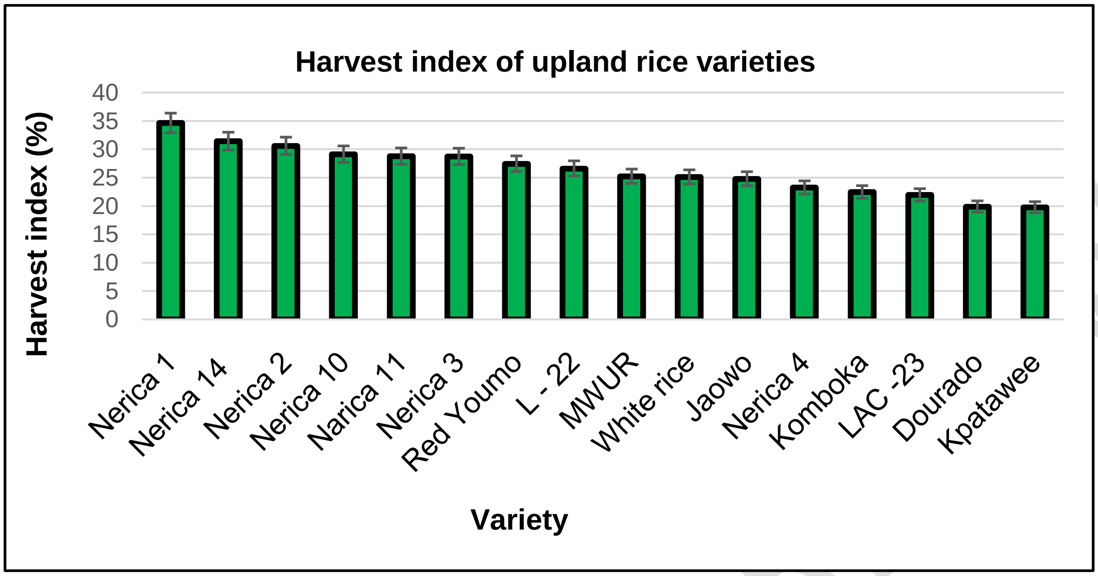

Figure1: The effect of water stress on harvest index of upland rice.
Error bars represent means ± standard error of the means.

5. Harvest index (%)

The effect of water stress and variety on Harvest index of sixteen upland rice varieties is presented on (Figure 1). The analysis of variance revealed that the stress effect on rice varieties was significant on harvest index at P≤*0.001* (Figure 1). The interaction effect between varieties and water stress on harvest index was not significant (*P =.05*). When the water stress treatments were imposed at tillering and flowering stages for 10 and 15 days, NERICA 1 obtained the highest harvest index followed by NERICA 2 and 14. Dourado and Kpatawee produced the lowest harvest index.

The reduction in harvest indices of Kpatawee and Dourado (figure 1), could be largely due to water stress which led to the decrease in carbohydrate accumulation in the grains [53]. High harvest index indicates the efficient transport of assimilates towards the sink. Lower harvest index values under water stress at flowering and grain filling stages indicate that it was more harmful in translocation of assimilates towards the grains ([54]. The results of water stress on rice varieties showed that Kpatawee differed significantly (*P < .001*) with lower harvest index, while for NERICA 3 10, 11, and Red youmo harvest indices did not differ significantly from each other.

6. Conclusion and Recommendations

The study indicated that NERICA 1, 2 ,3, 4, 10 rice varieties were less affected by water stress treatments and had outstanding performance in terms of leaf rolling, grain yield, biological yield,1000-grain weight, early maturing, harvest index (%) and spikelet sterility (%). These varieties can be used by breeders and farmers to develop varieties adapted to areas with limited rain fall and insufficient soil moisture for rice production.

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