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Responses of Growth and Yield of Rice Varieties to Contrasting Hydrothermal Regimes during Vegetative and Reproductive Growth Phases in Akure, a Rainforest Zone of Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author AS designed the study, while authors AS and AM performed the statistical analysis and wrote the protocol and author AS wrote the first draft of the manuscript. Authors AS and AM managed the analyses of the study. Author AM managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Experiments were conducted in the screenhouse to determine the effects of watering and temperature regimes on the growth, seed yield and yield components of rice. The experiment was a split-plot scheme involving 4 x 3 x 2 factorial combinations of rice varieties (Igbemo, Millina, Cherie and Nerica 7), watering regimes, ambient and high temperature conditions arranged in Completely Randomized Design with four replications. Watering regimes (40, 70 and 100% field capacity (FC) consisted of water application at 1.5, 1.0, 0.6 litres of water per pot at 4 days interval) were imposed two weeks after germination. At the onset of flowering, a set of experimental materials grown under the watering regimes were retained under ambient temperature (29-32°C) and atmospheric dryness (vapour pressure deficit: 2.3 – 2.8 kPa: moderate humidity) and another set were grown under conditions of high temperatures (35-42°C) and VPD (3.2 - 3.8 kPa: low humidity). Data were collected on root and shoot weights, number of green and dead leaves, tillers/stand,

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spikelets/panicle, seed and panicle weights. The tested rice varieties differed in growth and yield characters. In general, the landraces (Igbemo and Benue types) produced a higher number of tillers and filled grains and heavier seeds/panicle. The 100 and 70% FC watering enhanced rice performance: height, leaf area, number of tillers and panicle and seed yield, 100 seeds weight compared to the 40% FC soil moisture conditions. However, compared with growth under field capacity moisture, rice had declined growth and yield characters under 70 and 40% FC. The chlorophyll and soluble carbohydrate contents in leaf and stem which differed among the varieties were also affected by watering regimes and growing environment conditions. The responses of rice varieties varied under conditions of high temperature and low humidity during the reproductive phase in combination with variable root zone moisture. Under low humidity and high temperature conditions during reproductive phase: Compared with the landraces, Nerica 7 was best for leaf area and 100 seed weight and lowest unfilled grains/panicle. High air temperatures and low humidity during reproductive phase enhanced leaf senescence and sterility of spikelets and seeds (empty seeds). The strong interplay between soil moisture deficit and temperature stress especially during the reproductive phase depressed rice growth and yield. High temperature and low humidity appeared to have accentuated soil moisture deficit constraints on the growth and yield of rice.

Keywords: Global change; stress; agriculture; rice; food security.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereals and is a major source of food for a large number of the people worldwide [1,2]. Rice is a major staple food crop in many parts of the world., it provides food for more than three billion people and constitutes 50-80% of daily calorie intake (23% percent of the global human per capital energy and 16% per capita protein) [3]. It is planted on about one-tenth of the earth's arable land. About 85% of total rice production is for human consumption while most of the rice in the world is grown and consumed in Asia [4,5] where it is the dominant staple food accounting for more than 70% of caloric intake [3]. Rice forms a major part of the diet of most Nigerians and by extension other in the developing countries [6]. Global demand for rice is rising because of population growth, increasing affluence and changing dietary habits [7]. World rice consumption increased 40% in the last 30 years, from 61.5 kg per capita to about 85.9 per capita (milled rice), and FAO forecasts that global rice production will need to increase by over 40% by 2030 and 70% by 2050 [8].

Rice is probably the most diversely cultivated crop under varied environments including: (i) irrigated, (ii) rainfed uplands and (iii) rainfed lowland to deep water conditions. Among the abiotic stresses, drought constitutes a major factor affecting growth and yield of crops [9,10]. Water limited condition affects 23 million ha of rice is a condition related to insufficient soil moisture available to support average crop production. Water limited conditions (also referred to as drought), affect vast rice growing agroecologies worldwide [11]. Drought is a condition related to insufficient soil moisture to support crop production. Drought affects physiological processes during the flowering stage, such as spikelet fertility, anther dehiscence [1] and poor pollen germination [5,12]. The response of plants to water stress depends on the duration and severity of the stress [13,14] and the developmental stage [15]. Rice is sensitive to drought stress particularly during the flowering stage, resulting in severe yield losses [1,16]. The dysfunction in physiological processes during the sensitive flowering stage, negatively affect anther dehiscence and spikelet fertility under water stress [1] and pollen germination [7].

The effects of water stress are similar to high-temperature stress [17,18]. High temperature stress induced spikelet sterility has been attributed to abnormal anther dehiscence [19], impaired pollination and poor pollen germination [7]. Matsui and Omasa [19] reported that high temperatures of 39ºC given a day before flowering resulted in poor anther dehiscence during anthesis. High-temperature stress is defined as the rise in temperature beyond a critical threshold ranging from 33 – 35ºC for a period of time sufficient to cause irreversible damage to plant growth and development [11]. Rice responses to high temperature differ according to the developmental stage, with the highest sensitivity recorded at the reproductive stage. Temperature above 35ºC at anthesis and lasting for more than one hour can lead to high panicle sterility in rice [20]. Male sterility as a consequence of heat stress is widely observed in plants, for rice in particular, the impairment of pollen development has been the main factor involved in reduced yield under heat stress [21,22]. In many temperate, cereal crops, both grain weight and grain number are reported to be impacted by heat stress, with a decline in grain number directly proportional with increasing temperatures during flowering and grain filling [23,24]. For example, high temperature during wheat reproductive development hastens the decline in photosynthesis and leaf area, decreases shoot and grain mass as well as weight and sugar content of kernels, and also reduces water-use efficiency [25]. As a consequence, heat stress results in an altered nutritional flour quality [26]. The simultaneous occurrence of multiple abiotic stresses rather than one particular stress is commonly experienced by crops under field conditions [27]. The combination of high temperature and water stress represents an example of multiple abiotic stresses occurring concomitantly in the field. High temperature and water stress cause about 60% decline in rice yield and hence global food insecurity [28]. Hence, overcoming the effects of high temperature and water stress on rice production is essential for food security in the future. Wassmann et al. [29] identified hotspots for combined high temperature and water stress occurring at the sensitive flowering and grain-filling stage of rice using data from the rice almanac and spatial analysis using geographical information system.

Global climate models predict increases in mean temperatures by 2 - 4.5ºC and doubling agricultural land area affected by water stress by the end of this century [30]. Most studies of temperature and global warming effects on crop growth and grain yield are based on daily mean and maximum and minimum temperatures air temperatures, and the influence of day versus night temperature [31]. Although the effects of projected climate change on crop yields have been variously evaluated by using crop-simulation models, more studies are needed on the effects of changes in climate and weather factors on crop growth and yield [31].

The specific objectives of this study are to determine the interaction of soil moisture regimes and temperatures on growth, seed setting efficiency and yield of rice landraces in particular, ambient and high temperatures at reproductive phase on seed yields of rice. This study provided information useful in the identification of rice landraces with higher drought and temperature tolerance for production in the study area. The results will enhance knowledge of the tolerance of rice landraces and improved varieties to separate and concurrent occurrence of soil moisture deficit stress drought and high temperature stresses.

2. MATERIALS AND METHODS

2.1 Plant Material, Environments, Crop Husbandry and Experimental Design

Drought tolerance and yield traits of four rice landraces were studied between March 2016 and February 2017. The study was conducted at the screenhouse of the Department of Crop, Soil and Pest Management and the Greenhouse of the Central Laboratory, the Federal University of Technology, Akure, Nigeria. Akure is within the rainforest zone of Nigeria with an average annual rainfall of 1500mm and annual mean temperature of about 30ºC.

The experiment was a split-plot scheme involving 4 x 3 x 2 factorial combinations of rice landraces, watering and temperature regimes arranged in Completely Randomized Design (CRD) with four replications. Watering regimes 40, 70 and 100% field capacity (FC) constituted of application of water at (1.5, 1.0 and 0.6 l/plot) imposed two weeks after germination. At the onset of flowering (6 weeks after transplanting), a set of experimental materials of rice landraces grown under the watering regimes (variable root zone soil moisture regimes) were retained under the ambient temperature (29-32ºC) and humidity conditions of the screenhouse. Another set of the experimental materials were transplanted to the Greenhouse conditions of high temperatures (35 – 42 ºC) and low humidity. Watering regimes consisted of application of 1.5, 1.0 and 0.6 litre of water pot at 4 days interval. Millina, Cherie (varieties) were acquired from Benue, Igbemo from Ekiti State while the improved variety (Nerica 7) was acquired from Africa Rice Center Ibadan, Nigeria.

2.2 Cultural Practices

Five (5) litres capacity pots perforated pots at the base for easy drainage were filled with top soil and wetted to saturation. Rice seeds were sown at 2-3 seeds per pots after pre-germinated for two days. Water application was measured using measuring cylinder. The watering was done every four days interval in the greenhouse environment then at the screen house environment it was changed to three days interval due to high temperature and low humidity. Weeding was done manually throughout by handpicking of weeds around the potted plants.

2.3 Data Collection on Plant Growth and Yield Parameters

Data collection started six weeks after planting. Eighteen plants were randomly selected and tagged on which the growth and yield parameters for proper monitoring and sampling were collected. Data were collected on plant parameters at crop harvest which are total shoot weight and total root weight. Number of green leaves at harvest, number of tillers and leaf area. At fortnight intervals, data were collected on the number of leaves and tillers, flag leaf length, number of spikelets. Observation was made on chlorophyll concentration at 50% flowering, soluble carbohydrates content of leaves and stem at 50% flowering and grain maturity, number of tillers/plant, plant leaf area, flag leaf length, onset of flowering, days to 50% flowering, number of spikelets/panicle, panicle weight (filled and unfilled grains) and 100 seed weight/plant. Plant leaf area was measured using meter rule for the flag leaf length from its points of attachment on the plant and the breadth was measured at the main centre of the leaf.

2.4 Extraction of Leaf Chlorophyll Content and Determination

Chlorophyll extraction and its determination were done at two laboratories the first is the Laboratory of the Department of Crop, Soil and Pest Management, Federal university of Technology, Akure and Institute of Agricultural Research and Training, Moor Plantation, Ibadan, Nigeria. The two uppermost leaves of rice plant from each treatments were harvested. One gram of the fresh plant samples were cut into pieces and chopped in a mortar. The samples were put in a fresh tube and its chlorophyll content was repeatedly extracted with successive volume of 100ml acetone/water (80:20v/v) until no traces of green colour were noticed (residue became white).While adding the solvent (acetone), the test tubes containing the samples were kept boiling in a hot water bath. The total volume of the extract was also recorded at the end of the extraction. Three millimeter (3 ml) of the extract was taken and the absorbance was determined with a 663 nm and 645 nm that corresponds to maximum absorption of chlorophyll 'a' and 'b' respectively.

Total Chlorophyll content (mg/100 g tissue) = (20.2 A645 +8.02 A663) (V/10W)

where, A645= absorbance at 645 nm wavelength, A663=absorbance at 663 nm wavelength, V=final volume (cm^3) of chlorophyll extract in 80% acetone, and W=fresh weight (g) of tissue extracted

2.5 Determination of Water Soluble Carbohydrate/Reagents

0.5 g plant samples were ground and transferred into 250 ml test tube and 200 ml of water was added. The bottle was capped and shaken on a shaker for about an hour and filtered. The first few ml was ejected and the filtrate was retained for the determination of soluble carbohydrate using Anthrone reagents.760 ml of concentrated H_2SO_4 was added to 330 ml of distilled water, in addition to 1g of thiourea, 1 g of anthrone, stirred until dissolved and was stored in a refrigerator. Glucose stock solution, 1 g of anhydrous D (+) glucose in water and dilute to one litre prepared immediately before use. From the glucose working standard solutions, 10 ml of stock to 100 ml was diluted to produce 100 ppm. From these, 0,5,10,20,40,80 ml was pipetted and made up to 100 ml and these produced 0,5, 10, 20, 40, 80 ppm. Samples of 2 ml of each glucose working standard solutions were pipetted into the glass test tube and rapidly, 10 ml of anthrone reagent was added and mixed by shaking. The test tube was loosely covered with a glass bulb stopper and placed immediately in boiling water for 20 minutes. The absorbance was measured using spectrophotometer device in a 10mm optical cell at 620 mm.The graph of absorbance was plotted against glucose concentration in ppm and standard graph was prepared with each batch of extracts examined. The glucose standard becomes 0, 0.81, 7, 3, 3, 6, 7 and 13.3 ppm respectively.

2.6 Examination of Extracts

About 2 ml of extracts was pipetted into a test tube to which 10 ml of anthrone reagent was rapidly added and mixed by shaking and placed in a boiling water bath. The absorbance was measured using a 10 mm diameter curvette.

2.7 Harvesting

At 90-150 days after planting, matured grains were harvested and the plants were carefully uprooted to avoid root breakage from the pots and transported to the laboratory for further data collection. At the laboratory, the following data were taken on the sampled plants per pot: fresh root weight and fresh shoot weight.

2.8 Statistical Analysis

Data collected were subjected to Analysis of Variance (ANOVA) to test the significance of the treatment means using Minitab version 17.The means were separated using Duncan's Multiple range test (DMRT).

3. RESULTS

The trends of temperature and vapor pressure deficits (VPD) in the screenhouse during rice growth is presented in Fig. 1. The figure showed the range of maximum and minimum values of air temperatures (29.6 and 41°C) and vpd (2.9 and 3.1 kPa) during period of experiment. The comparative trends of temperature and vapor pressure deficits in both the screenhouse and greenhouse during rice growth are presented in Fig. 2a and b. The figures showed the range of maximum and minimum values of air temperatures (20 and 39°C for screenhouse; and 34 and 40°C in greenhouse) and VPD (2.3 and 3.0 kPa and 2.9 and 4.0 kPa) in the respective screenhouse and greenhouse environments during reproductive phase of rice. Rice varietal growth and yields responses to these growing environment conditions were further evaluated.

The results also showed that watering at field capacity soil moisture enhanced growth, yield and yield components of rice across varieties (Tables 1 and 2). Cherie and Millina at 70% FC had heaviest root and shoot weight while Nerica 7 had the lowest even at field capacity. In general, the landraces (Igbemo and Benue types) were taller in height and better in tillering and leaf production, Millina had highest seeds/panicle and unfilled grains/panicle, Igbemo had highest filled grains/panicle while the improved Nerica 7 was best for leaf and seed production. Well and moderate watering (100 and 70% FC) enhanced rice performance: height, leaf area, number of tillers and panicle and seed yield, 100 seeds weight compared to the 40% FC soil moisture conditions (Tables 3 and 4). At FC watering regime, Millina had highest number of spikelets and heaviest panicle and seeds, Nerica had heaviest 100 seeds while Igbemo had the lowest number of spikelets. For days to onset of flowering, Nerica7 at 70% FC watering regime flowered earlier while Cherie flowered late. Across the varieties and watering regimes, Cherie and Millina at 100, 70 and 40% FC watering had the greatest number of functional green leaves before and at 50% flowering while Nerica7 had lowest at all levels of watering. With respect to number of grains per plant, Millina at FC watering had significantly ($P < 0.05$) higher values while Nerica 7 had the lowest.

The effects of rice varieties and watering regime varied on leaf chlorophyll concentration and leaf and stem nutrient contents differed significantly ($P<0.005$) among the treatments. Under high temperatures and low humidity condition, Cherie at 100%FC watering regime had the lowest chlorophyll content. The interactions between variety and watering regime were significant for growth, yield and yield components of rice (Tables 5 and 6). The interactions were significant for plant height, leaf area and number of days to 50% flowering and tillers per plant (Table 5) and for varieties Igbemo and Millina and Cherie (Benue types) which were best for panicle weight, number of spikes and spikelets, seed yields while 100 seed weight was best for Nerica 7 (Table 6).

Differences in the growing environment conditions (temperature and humidity) were significant for most of the parameters measured on rice varieties (Tables 7 and 8). Rice yield and yield components were significantly ($P<0.05$) affected by high temperature and low humidity conditions during post-flowering phase. Under ambient (moderate temperature and high humidity; screenhouse environment) condition, varieties displayed significant differences for plant leaf area and shoot weight at 50% flowering and maturity. Nerica 7 had the highest leaf area followed by Millina, Igbemo and Cherie at 50% flowering and maturity. Millina and Cherie (Benue type) had the highest number of spikelets Igbemo a local upland rice had the highest mean number of grains per panicle followed by Millina (Benue type) (Table 7). For rice plants grown under high temperature and low humidity conditions, Nerica 7 had best performance while at Obanla location Millina (Benue type) and Cherie, Igbemo didn't flower at all. Across growing environments, Cherie (a local landrace) had significantly higher number of tillers and functional green leaves before flowering and at maturity compared with other varieties while Nerica7 had poorer performance. Under ambient temperatures and humidity, Igbemo had highest chlorophyll concentration of about 50% increase especially for Nerica 7 at 100 and 70% FC watering regimes (Table 7). Watering at 70% FC and ambient environment condition promoted leaf development, number of functional green leaves at 50% flowering and number of tillers and spikelets while 40% FC watering regime had the least performance (Table 8). Rice plants at 100 %FC has higher leaf area at 50% flowering and maturity compared with other watering regimes under ambient and high temperature and low humidity) conditions. Although, the performance of rice in terms of tillering, weight of spikelets, panicle and seeds at maturity was similar at 100 and 70% FC but were significantly different compared with 40% FC. Rice plants were grown under moderate temperature and high humidity environment had better growth and seed yield characters and the highest contents of chlorophyll and soluble carbohydrates compared with high air temperatures and low humidity conditions (Table 8). Rice at ambient temperatures produced heaviest seed weight, at 70% FC, Millina had significantly higher leaf area at 50% flowering and Nerica 7 at maturity. Compared with growth under field capacity moisture, rice had declined growth and yield characters under 70 and 40% FC both under ambient and high temperature and low humidity conditions in the screenhouse. High air temperatures and low humidity during reproductive phase enhanced leaf senescence and sterility of spikelets and unfilled (empty) seeds. In addition growth and seed yields characters of rice were poorer under soil moisture deficit stress combined with high temperatures and low humidity during the reproductive phase.

The responses of rice varieties varied under conditions of high temperature and low humidity combined with variable root zone moisture (Tables 9 and 10). Under low humidity and high temperature conditions during reproductive phase: Nerica 7 was best for leaf area and had heaviest 100 seeds and lowest unfilled grains/panicle (Tables 9 and 10). In general, Nerica 7 even at 40% FC had significantly higher leaf area when compared with other varieties across watering regimes and environment. The interactions between variety and environmental conditions (air temperatures and humidity) were significant for plant height, leaf area, number of tillers per plant and seed yields (Table 10). Igbemo and Millina and Cherie (Benue types) were best for panicle weight, number of spikes and spikelets, seed yields while 100 seed weight was best for Nerica 7. High air temperatures and low humidity during reproductive phase depressed rice yields.

4. DISCUSSION

In this study, the significant differences found in the response of rice to watering regime and growing environment conditions showed that the performance of rice varieties was determined by the status of moisture in the root zone. Reduction in the growth and yields of crop under field or green house conditions due to drought stress or deficit irrigation were reported [1,9,12]. The growth characters of rice varieties differed significantly among the 100, 70 and 40% FC watering regimes. Reduction in the growth and yields of crops due to high temperature stress was reported [5,7,32]. Under the condition of high temperatures and low humidity, and at 40% FC watering regime (severe moisture stress and high temperature), rice plants wilted and some varieties did not even flower at all.

The findings from the study showed that rice varieties responded differently to root zone soil moisture status and growing environment condition (temperature and humidity). Ambient (moderate temperatures and humidity) enhanced vigour of growth compared with high temperatures and low humidity at reproductive growth phase. These results agree with literature reports that ambient temperature significantly improved rice growth by increasing leaf area, shoot and root weight [33,34,35]. Environmental conditions defined by critical temperatures (low and high temperatures below 20°C and above 30°C) determine plant performance [36,37]. Hartfield et al. [36] reported that rate of plant growth and development is dependent upon the temperature surrounding the plant and each species has a specific temperature range represented by a minimum, maximum and optimum under which optimum growth is attained. At different times during the life cycle, rice plant is differentially sensitive to temperature stress, hence the critical temperatures vary from one growth stage to another [7,31,37]. This may explain differences in rice varietal performance under ambient and unfavourable (extreme temperature and humidity conditions). The results of this study showed that the measured growth variables of rice responded differently to watering regimes imposed. Bartels and Souer [14] and Zhu et al. [15] reported that the response of plants to water stress depends

Table 1. Effects of variety on leaf development and senescence, tillering and root and shoot biomass of rice

Varieties	Leaf area (cm³) @ 50% flowering	Leaf area (cm³) @ maturity	No of green leaves before flowering	No of green leaves @ 50% flowering	No of green leaves @ maturity	No of tillers before flowering	No of tillers @ 50% flowering	No of tillers @ maturity	Root weight (g)	Shoot weight (g)
Nerica7	70.82a	58.70a	4.74c	7.11c	6.83c	3.24c	5.78c	4.28b	7.12b	22.69c
Millina	54.64b	46.93b	13..41a	26.11b	26.83b	5.31b	8.94b	9.94a	12.69a	56.20a
Cherie	46.44c	49.96b	14.09a	31.67a	33.22a	6.41a	11.33a	10.83a	15.00a	39.17b
Igbemo	27.46d	26.64c	8.46b	25.28b	25.94b	4.18b	7.44bc	8.61a	8.25b	29.81b

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

Table 2. Effects of variety on panicle and spikelets, grain filling and seed yield of rice

Varieties	Panicle weight (g)	100 Seed weight (g)	No of spikelets	Grain yield/ plant (g)	Filled grain	Unfilled grains
Nerica7	9.72c	2.92a	75.50b	391.06d	234.44c	197.56c
Millina	12.73a	2.09b	110.17a	772.06a	443.83a	418.06a
Cherie	10.84b	2.04b	96.94a	610.39b	303.89b	322.83b
Igbemo	10.02bc	1.29c	49.50c	521.06c	328.83b	216.11bc

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

Table 3. Effects of watering regime on leaf development and senescence, tillering and root and shoot biomass of rice

Watering regime	Leaf area (cm³) @ 50% flowering	Leaf area (cm³) @ maturity	No of green leaves before flowering	No of green leaves @ 50% flowering	No of green leaves @ maturity	No of tillers before flowering	No of tillers @ 50% flowering	No of tillers @ maturity	Fresh root weight (g)	Fresh shoot weight (g)
100FC	53.22a	48.65a	7.82a	18.46b	23.50a	3.87a	6.75b	7.88a	11.18a	48.25a
70FC	50.56ab	45.55a	7.86a	24.13a	23.13a	3.71a	8.88a	9.04a	14.06a	35.00b
40FC	45.74b	42.48a	7.62a	25.04a	23.00a	3.69a	9.50a	8.33a	7.05a	25.66c

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

Table 4. Effects of watering regime on panicle and spikelets, grain filling and seed yield of rice

Watering regime	Panicle weight (g)	100 seed weigth (g)	No of spikelet	Grain yield/plant (g)	Filled grains	Unfilled grains
100FC	16.00a	2.26a	89.13a	795.46a	476.88a	388.21a
70FC	9.55b	2.05ab	87.96ab	572.63b	315.00b	279.08b
40FC	6.93c	1.95b	72.00b	352.83c	191.38c	198.63c

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

Table 5. Interactions of variety and watering regimes on leaf development and senescence, tillering and root and shoot biomass of rice

Varieties	Watering regime	Leaf area (cm³) @ 50% flowering	Leaf area (cm³) @ maturity	No of green leaves before Flowering	No of green leaves @ 50% flowering	No of green leaves @ maturity	No of Tillers before flowering	No of tillers @50% flowering	No of tillers @ maturity	Fresh root weight (g)	Fresh shoot weight (g)
Nerica7	100FC	77.23a	65.05a	7.00c	7.00d	7.83bcd	6.00bcd	5.67e	5.33bcd	9.41a	32.89d
Nerica7	70FC	66.85ab	53.05ab	5.50c	7.33d	5.67d	5.00cd	5.83de	3.17d	6.91a	20.01e
Nerica7	40FC	68.38a	58.00ab	5.50c	7.00d	7.00cd	3.00d	5.83de	4.33cd	5.04a	15.18f
Millina	100FC	50.70bc	49.06ab	19.75ab	19.50c	29.67a	7.00abcd	7.00cde	9.50abc	14.89a	66.59a
Millina	70FC	62.44abc	47.76ab	23.00a	32.33ab	27.17a	10.00ab	10.17bc	10.83ab	14.31a	54.91b
Millina	40FC	50.78bc	43.99bc	24.50a	26.50bc	23.67abc	9.75abc	9.67bcd	9.50abc	8.87a	47.10bc
Cherie	100FC	49.15bc	52.58ab	20.50a	25.00bc	27.83a	9.25abc	7.67cde	9.00abc	10.67a	52.75b
Cherie	70FC	46.84bc	53.05ab	25.00a	29.67abc	34.83a	11.25a	11.67ab	12.17a	27.04a	42.18c
Cherie	40FC	43.32cd	43.80bc	24.25a	40.33a	37.00a	10.00ab	14.67a	11.33a	7.28a	22.59e
Igbemo	100FC	35.80d	27.90cd	14.00abc	22.33bc	28.67a	6.25bcd	6.67cde	7.67abcd	9.34a	40.70cd
Igbemo	70FC	26.09de	27.90cd	14.75abc	27.17bc	24.83ab	6.00bcd	7.83bcde	10.00ab	7.99a	30.89d
Igbemo	40FC	20.48e	24.13d	10.25bc	26.33bc	24.33abc	5.75cd	7.83bcde	8.17abcd	7.03a	17.77ef

Table 6. Interaction of variety and watering regimes on panicle and spikelets, grain filling and seed yield of rice

Varieties	Watering regime	Panicle weight(g)	100 seed weight (g)	No of spikelets	Grain yield/panicle (g)	Filled grains	Unfilled grains
Nerica7	100FC	12.79b	3.00a	84.50abc	621.67d	365.00bc	275.00cd
Nerica7	70FC	9.49c	2.95a	72.83bc	405.00f	206.67d	232.50cd
Nerica7	40FC	6.89d	2.81ab	69.17bc	146.50g	131.67e	85.17d
Millina	100FC	18.44a	2.36b	119.67ab	967.50a	660.33a	555.00a
Millina	70FC	11.90b	2.03bc	129.83a	798.33bc	433.33b	377.50bc
Millina	40FC	7.85cd	1.89cd	81.00bc	550.33e	237.83d	321.67bc
Cherie	100FC	16.61ab	2.27bc	94.17abc	865.67b	443.50b	432.83b
Cherie	70FC	9.29c	1.98c	108.00ab	604.33d	290.50cd	343.00bc
Cherie	40FC	6.63d	1.40cd	88.67abc	361.17fg	177.67de	192.67cd
Igbemo	100FC	16.20ab	1.40d	58.17bcd	727.00c	438.67b	290.00c
Igbemo	70FC	7.50cd	1.25de	41.17d	482.83ef	329.50c	163.33cd
Igbemo	40FC	6.37d	1.22e	49.17cd	353.33fg	218.33d	195.00cd

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

Table 7. Growth parameters (leaf development and senescence, tillering and root and shoot biomass of rice grown in the screenhouse and greenhouse environment

Environment	Leaf area (cm³) @ 50% flowering	Leaf area (cm³) @ maturity	No of green leaves before flowering	No of green leaves @ 50% flowering	No of green leaves @ maturity	No of tillers before flowering	No of tillers @ 50% flowering	No of tillers @ maturity	Fresh root weight (g)	Fresh shoot weight (g)
Screenhouse	60.97a	54.77a	10.83a	22.17a	27.44a	5.51a	8.25a	7.92a	16.67a	43.17a
Greenhouse	38.70b	36.35b	11.24a	22.92a	18.97b	5.59a	8.50a	8.92a	4.86b	30.77b

Means that do not share a letter are significantly different from each other t 5% level of probability by Tukey method

Table 8. Yield components (panicle and spikelets, grain filling and seed yield) of rice grown in the screenhouse and green house environment

Environment	Panicle weight (g)	100 seed weight (g)	No of spikelet	Grain yield/plant (g)	Filled grains	Unfilled grains
Screenhouse	15.74a	2.50a	102.28a	823.56a	547.58a	303.67a
Greenhouse	5.92b	1.66b	63.78b	323.72b	107.92b	273.611b

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

Table 9. Interaction of variety and environment conditions on leaf development and senescence, tillering and root and shoot biomass of rice

Varieties	Environment	Leaf area (cm³) @ 50% flowering	Leaf area (cm³) @ maturity	No of green leaves before flowering	No of green leaves @ 50% flowering	No of green leaves @ maturity	No of tillers before flowering	No of tillers @50% flowering	No of tillers @ maturity	Fresh root weight (g)	Fresh shoot weight (g)
Nerica7	Screenhouse	72.22a	59.64a	7.67c	7.22d	6.67d	5.33ab	5.56e	3.89c	10.65ab	23.82cd
Nerica7	Greenhouse	69.42a	57.75a	6.83c	7.00d	7.00cd	4.67c	6.00de	4.67bc	3.59b	21.56d
Millina	Screenhouse	67.07ab	55.40a	22.42a	30.00ab	33.33ab	8.92ab	9.00abc	9.33a	13.99ab	47.90b
Millina	Greenhouse	42.20c	38.47b	14.58b	22.22bc	20.33bc	6.58ab	8.89abcd	10.56a	11.38ab	64.51a
Cherie	Screenhouse	49.68c	50.75ab	23.25a	30.78ab	41.00a	10.17a	11.78a	9.56a	25.53a	41.34bc
Cherie	Greenhouse	43.19c	49.19ab	15.17a	32.56a	25.44b	7.83a	10.89ab	12.11a	4.46b	37.01c
Igbemo	Screenhouse	54.91bc	53.29a	13.00a	20.67c	28.78ab	6.00bc	6.67cde	8.89ab	16.50ab	59.62ab
Igbemo	Greenhouse	0.00d	0.00c	12.58abc	29.89ab	23.11b	6.25b	8.22bcde	8.33ab	0.00b	0.00e

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

Table 10. Interaction of variety and environment on panicle and spikelets, grain filling and seed yield of rice

Varieties	Environment	Panicle weight(g)	100 seed weight (g)	No of spikelets	Grain yield/panicle (g)	Filled grains	Unfilled grains
Nerica7	Screenhouse	12.56b	2.41bc	71.89b	440.22d	360.00c	113.00e
Nerica7	Greenhouse	6.89cd	3.43a	79.11b	341.69e	108.89d	282.11d
Millina	Screenhouse	16.70ab	2.51b	119.33a	947.44ab	607.11ab	342.78c
Millina	Greenhouse	8.76c	1.67bc	101.00ab	596.67c	280.56cd	493.33a
Cherie	Screenhouse	13.64b	2.51b	118.89a	864.44b	565.56b	326.67c
Cherie	Greenhouse	8.04d	1.56c	75.00b	356.33e	42.22e	319.00c
Igbemo	Screenhouse	20.05a	2.58b	99.00ab	1042.11a	657.67a	432.22b
Igbemo	Greenhouse	0.00e	0.00d	0.00c	0.00f	0.00f	0.00f

Means that do not share a letter are significantly different from each other at 5% level of probability by Tukey method

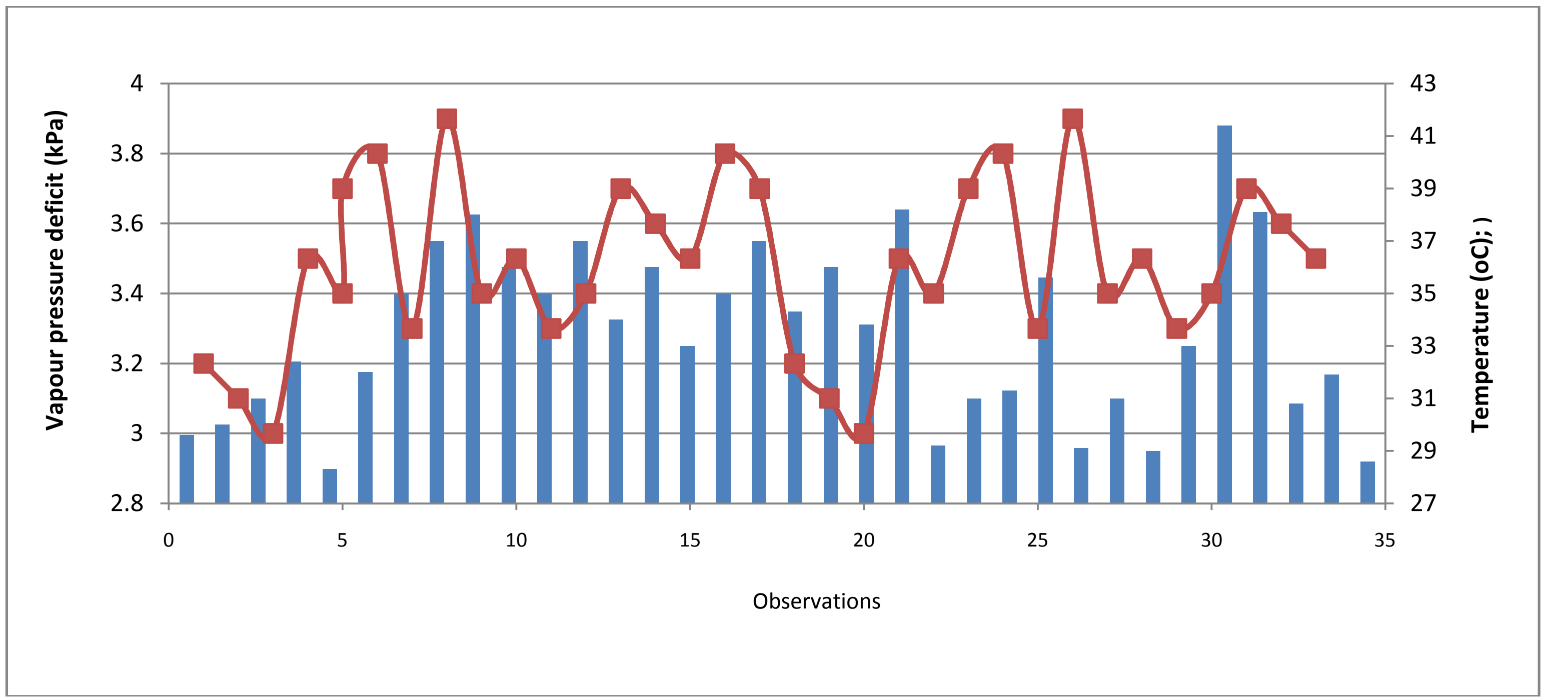

Fig. 1. Temperature and atmospheric dryness (VPD) in screenhouse

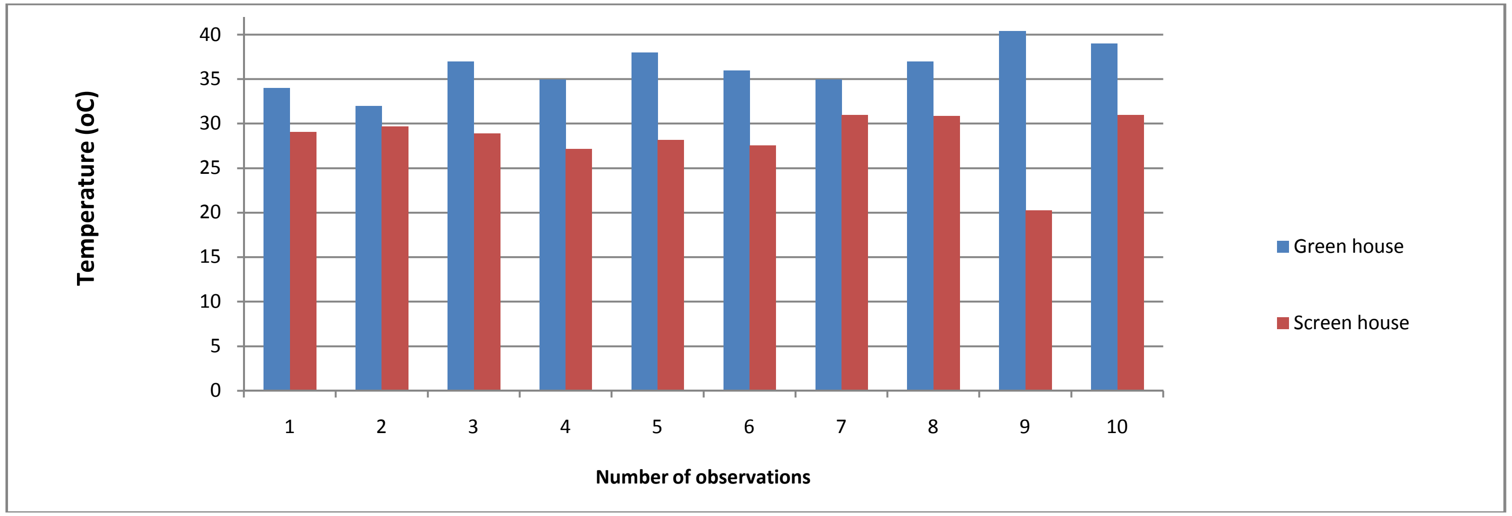

Fig. 2a. Temperature trends in the greenhouse and screenhouse environments

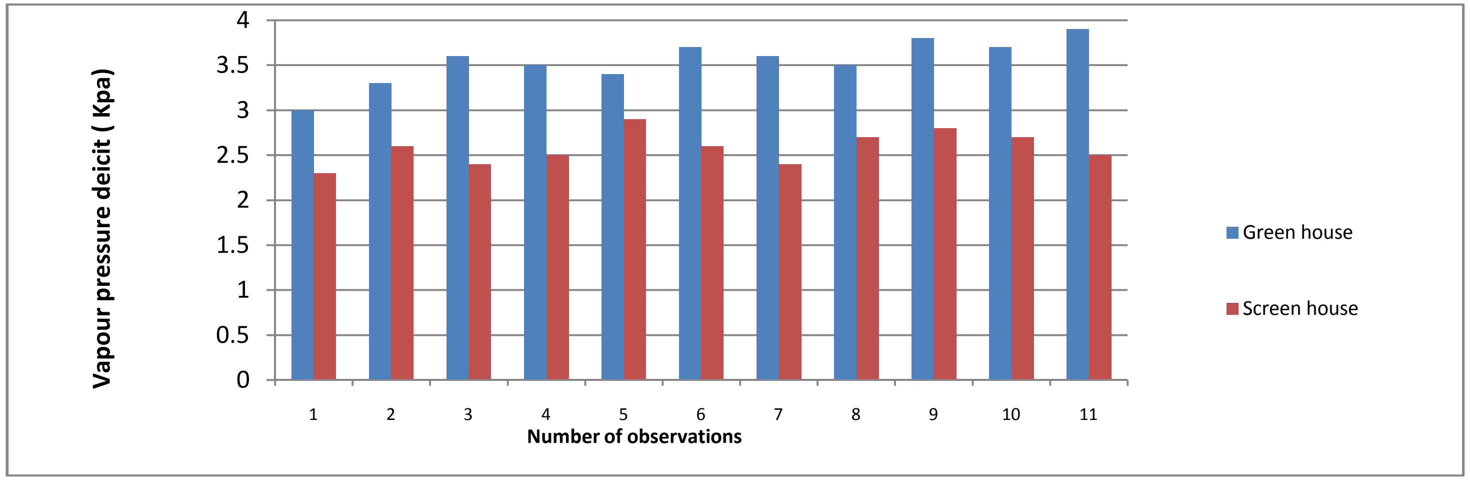

Fig. 2b.Vapoure pressure trends in the greenhouse and screenhouse environments

on the duration and severity of the stress and the developmental stage. Watering regime affected the growth of rice especially the number of functional green leaves and tillers at 50% flowering which is lower at 40% watering regime compared with others. Rice is sensitive to drought stress particularly during the flowering stage, resulting in severe yield losses [1]. The increase in yield parameters (Panicle weight, filled spikelets and seeds, 100 seed weight, grain yield/panicle, number of spikelets) under ambient condition decreased under high temperature [38,39]. Jagadish et al. [35] reported that the rate of increase in dry matter in the panicle after heading decreased under high temperature.

Rice performance was superior at 100 and 70% FC watering regime compared with 40% FC watering regimes. The physiological processes during the sensitive growth phase such as flowering and seed filling and spikelet fertility affected by water stress. Anther dehiscence [1]; pollen germination [12,35] were also influenced. The simultaneous occurrence of multiple abiotic stresses rather than one particular stress is commonly noticed under field conditions [40]. The combination of high temperature and water stress represents an excellent example of multiple abiotic stresses occur concomitantly in the field. It was found that combined stress had significant detrimental effect on growth and yield than exposure to single stress in crops [5].

Findings from this study provided more evidence of decreased rice yields from increases in temperatures and atmospheric dryness (va pour pressure deficit). Various physiological mechanisms had been advanced, Jagadish [5] attributed increased plant maintenance respiration with increasing temperature and that a greater rate of maintenance respiration reduces the amount of assimilates available for growth and yield. Current crop-growth models will need further refinement to account for the differential effects of high temperatures on respiration, morphological traits, and phenological development and thus more accurately simulate the influence of increased temperature under climate-change scenarios.

5. CONCLUSION

Rice landraces differed from the improved variety, Nerica 7 in growth and yield characters. In general, the landraces (Igbemo and Benue types) had better performance in terms of number of tillers, Millina had highest seeds/panicle and unfilled grains/panicle, and Igbemo had highest filled grains/panicle. Igbemo, and Millina and Cherie (Benue types) were best for panicle weight, number of spikes and spikelets, seed yields while 100 seed weight was best for Nerica 7.The 100 and 70% FC watering regimes enhanced rice performance compared to the 40% FC soil moisture conditions. The responses of rice varieties varied under conditions of high temperature and low humidity combined with variable root zone moisture. Compared with growth under field capacity moisture, rice had declined growth and yield characters under 70 and 40% FC both under ambient and high temperature and low humidity conditions in the screenhouse. High air temperatures and low humidity during reproductive phase enhanced leaf senescence and sterility of spikelets and seeds (empty seeds i.e. decreased seed setting). Under low humidity and high temperature conditions during reproductive phase: Nerica 7 was best for leaf area and had heaviest 100 seeds and lowest unfilled grains/panicle. Rice plants grown under moderate temperature and high humidity environment had better growth and seed yield characters and the highest contents of chlorophyll and soluble carbohydrates compared with high air temperatures and low humidity. Growth and seed yields characters of rice were poorer under soil moisture deficit stress combined with high temperatures and low humidity during the reproductive phase. The interactions between variety, watering intervals and environmental conditions (air temperatures and humidity) were significant on rice performance. Findings showed that rice productivity declined when soil moisture deficit stress combined with high temperatures and low humidity occurred especially during the reproductive phase. The strong interplay between soil moisture deficit and temperature stress especially during the reproductive phase had implications for rice performance Therefore, high temperatures and low humidity during reproductive phase of rice appeared to have accentuated soil moisture deficit constraints to growth and yield of rice.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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