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Evaluation and Selection of High Biomass Rice (*Oryza sativa L.*) for Drought Tolerance

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Abstract

Biomass production is important in increasing yield not only for food but also for bio-fuel production that depends on high dry matter. Due to climate change, occurrence of drought may be prevalent and this affects both grain and biomass yields in crops including rice. The objectives of this study were to determine the performance of selected high biomass breeding rice lines to different levels of drought and use several drought tolerance indices to identify best genotypes that could be grown in unfavorable water stressed areas. A rainfed and flooded trial was conducted to evaluate 20 selected breeding lines for biomass production and ten entries from the same set were grown in the greenhouse at three different field capacities (FC, 50%, 75%, 100%). Most of the genotypes performed well under non-stressed conditions (flooded and 100% FC) but some genotypes performed well in water stressed condition. The plants had lower plant height, tiller plant^{-1}, and total biomass at maturity under rainfed conditions and their flowering was delayed compared to flooded conditions. In the greenhouse, water stress slowed the rate of increase in height, and produced lower shoot and root weight, percent dry matter (% DM) and total biomass. However, drought enhanced the rate of tiller production. Two genotypes were found to more tolerant to drought stress and could be used for cultivation under water stress condition to get optimum biomass yields. These genotypes can be identified using drought tolerance indices, particularly stress tolerance index (STI), geometric mean productivity (GMP), mean productivity (MP) and harmonic mean (HARM), as these have a similar ability to separate drought sensitive and tolerant genotypes. Genetic and molecular analyses, and detailed characterization of these genotypes will help understand their inheritance pattern and the number of genes controlling the traits and determine specific leaves and root traits important in developing high biomass rice.

Keywords

High Biomass Rice, Water Stress, Selection Indices

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1. Introduction

Rice (*Oryza sativa*) is the staple food for a large part of the world's human population, which is the most consumed cereal after wheat. *Javanica* known also as "tropical japonica" [1] (Mae, 1997) is the type of rice commonly grown in the U.S. Rice has been grown in several states in the U.S., but currently large rice areas can be found in six states including Arkansas, California, Louisiana, Mississippi, Missouri and Texas. Long and medium grain rice is the major grain type but none is grown mainly for fodder or biomass.

Different environments have different effects on the production of rice grain and biomass. Rice which is grown in humid tropics in rainfed (dry land) areas covers 19% of the total rice production areas and the 15 million hectares of rain dependent rice fields contribute about 4% of total world rice production [2] (GRiSP, 2013). These areas generally suffer from drought but may also have acidity of soil and deficiency of phosphorus and zinc. Drought is one of the most important limiting factors in the production of the major crops in the world and affects 20% of the total rice-growing area in Asia [3] (Pandey and Bhandari, 2008). The percentage of drought affected land areas has doubled from 1970 to the early 2000 [4] (NCAR-UCAR, 2005). Furthermore, the global warming increases the occurrence of drought [5] (Farooq *et al.*, 2009) and that in turn results in global water shortage. Improving drought tolerance of crops along with water management will have an impact on production [6] (Long and Ort, 2010). Drought causes yellowing of leaves, reduces number of tillers, height of plant, number of panicles and overall vegetative weight and increases number of unfilled grains. It has been shown that there are more productive tillers plant^{-1} under flooded than non-flooded (rainfed) conditions [7] (Chaudhry and McLean, 1963). The current drought resistance levels and those needed for rice grain yield stability are significantly different as rice is very sensitive to water scarcity [8] (Xiao *et al.*, 2007).

The rise in concerns about the environment and price of volatile oils has diverted the attention of the world to using alternative energy resources [9] (Lim *et al.*, 2012). One of the most important sources for renewable energy is crop biomass [10] (Kirubakaran *et al.*, 2009) or agricultural biomass like rice husk, straw and bagasse and it has received attention as it does not threaten the food supply (Lim *et al.*, 2012). One third of the primary energy sources after coal and oil are biomass [11] (Werther *et al.*, 2000). Rice is a potential source of feedstock for bio-refinery since it can produce a lot of biomass; however, it should not compete for the areas which are favorable for grain production. There are many unfavorable areas for rice production that can be tapped for high biomass production. Hence, our goal is to study the response of high biomass rice grown under stress conditions so that adapted genotypes can be grown in unfavorable environments for biomass and grain production. The main impact of this study is the generation of base information on high biomass rice genotypes which is important for the future bioenergy related research activities. The evaluation of agronomic traits will be useful in crop improvement and in basic research to understand their relationship with high biomass production. It will help us understand the science needed to achieve high stable biomass yields under unfavorable environments.

One of the objectives of this study was to determine the response of selected high biomass rice genotypes to drought and rainfed growing condition. Specifically, the study aimed to determine growth and biomass yield of selected *O. sativa* lines under two levels of drought and their agronomic response in rainfed and flooded conditions. Six selection indices were used to identify best genotypes that could be grown in unfavorable areas. Drought tolerance indices provide a measure of drought based on yield loss under drought conditions as compared to normal conditions and hence they are used to screen drought tolerant genotypes [12] (Nazari and Pakniyat, 2010).

2. Materials and Methods

2.1. Source of Test Entries

The materials for evaluation were obtained from high biomass rice project of Texas A&M AgriLife Research and Extension Center, Beaumont, Texas which was aimed to identify high biomass rice as alternative source of feedstock for bioenergy generation. These breeding lines were generally late maturing, with large tiller or with many tillers, leafy and taller than conventional rice. These were derived from breeding populations developed for breeding high grain yield thus these were undesirable for high grain yield but has potential for high biomass production.

2.2. Response of Selected High Biomass Rice to Different Percentages of Field Capacity

Ten selected genotypes were used in pot experiments aimed to evaluate biomass production in water-limited environment. Five seeds of each genotype were seeded in six inches in diameter and six inches deep plastic pots with equal amount of soil arranged in a completely randomized design with three replications. Equal amount of water was used until germination. At 20 days after sowing (DAS), thinning to one plant was done and the following treatments were used; 50%, 75% and 100% FC. These water levels were maintained throughout the experiment by weighing the pots every other day while the evaporated water was compensated by adding extra water. One extra pot without plant for 75% and 50% FC was maintained and the water evaporated from those pots was used to add water in the experimental pots at the same FC. Nitrogen fertilizer was applied in two splits; first at planting at the rate of 57 $kg\cdot ha^{-1}$ and second at tillering at the rate of 91.2 $kg\cdot ha^{-1}$. The final data gathering was done 85 DAS.

The data collected were the days to first tiller emergence, weekly tiller count, weekly increase in plant height, shoot fresh weight (FW) and dry weight (DW), root FW and DW, total fresh and dry biomass. Tiller emergence was the day when the first tiller with one fully expanded leaf appeared at the base of the plant. Tiller count was gathered by counting the tillers including the newly emerged tillers with one fully expanded leaf while plant height was gathered by measuring the length of the plant from soil surface to the tip of the longest leaf. The shoot and root weights were collected by weighing the upper part of the plant and root including the node where the upper most roots originated after carefully removing soil at the end of the experiment (85 DAS). These samples were air dried for 30 days to obtain the shoot and root dry weights. Rate of tiller production, rate of leaf production and rate of increase in plant height were computed by finding the slope of number of tillers and leaves, and plant height at weekly intervals.

2.3. Response of Selected High Biomass Rice to Rainfed and Flooded Conditions

This experiment was conducted in the field of Texas A&M AgriLife Research and Extension Center at Beaumont, Texas (30.06˚N, 94.29˚W). Twenty selected high biomass rice genotypes were field planted to evaluate their biomass production in rainfed and flooded environment. Ten of these were included in the pot experiment on field capacity. The soil for direct seeding was prepared using disc harrow and rotavator to pulverize the soil, and was laser leveled. Before planting, levees were made to facilitate water control. Urea was applied in three splits; 57 $kg\cdot ha^{-1}$ at planting, 91 $kg\cdot ha^{-1}$ at flooding and at panicle differentiation at the rate of 80 $kg\cdot ha^{-1}$. The P_2O_5 fertilizer was applied at planting at the rate of 34 $kg\cdot ha^{-1}$. A split-plot design with two replications was used, with the flooded and rainfed environments as the main plot, and high biomass rice genotype as sub-plot. Each sub-plot had three rows that were 3 m long and 25 cm apart. Seeds were sown using a planter at the rate of 2 - 3 grams row^{-1}. The flooded treatment had permanent flood starting from 30 days after seedling emergence while rainfed treatment was flush flooded when rain water was not enough to avoid severe soil cracking and wilting of the plants. In most cases, flushing of irrigation water was done when high noon leaf rolling was observed in some of the test entries. The rainfall received during emergence to harvest was 11.57 inches.

The data collected were average height, tillers $plant^{-1}$ at 105 DAS, days to 50% heading and total fresh biomass yield ($kg\cdot ha^{-1}$) at maturity. The plant height at maturity was measured from the soil level to the tip of the tallest panicle. The number of tillers $plant^{-1}$ at 105 DAS was computed by dividing the total number of tillers/750 cm^2 by number of plants/750 cm^2. Flowering date was gathered when 50% of the panicles of plants in a plot had opened florets. The total fresh weight of above ground biomass of all the plants in a plot at maturity was gathered along with the date at which the crop was harvested.

2.4. Statistical Analysis

All the data gathered were statistically analyzed using analysis of variance (ANOVA; SAS software). The means were separated using Duncan's t test at an alpha level of 0.05.

2.5. Screening Methods (Drought Tolerance Indices)

Drought tolerance indices were calculated using the following equations:

Drought Tolerance Indices	Formulae	References
Stress Tolerance Index (STI)	$(Y_P \times Y_S)/(\bar{y}_p)$	[13] (Fernandez, 1992)
Tolerance Index (TOL)	$Y_P - Y_S$	[14] (Rosielle and Hamblin, 1981)
Geometric Mean Productivity (GMP)	$\sqrt{(Y_P)(Y_S)}$	[13] (Fernandez, 1992)

Continued

Mean Productivity	$(Y_P + Y_S)/2$	[14] (Rosielle and Hamblin, 1981)
Stress Susceptibility Index (SSI)	$(Y_P/Y_S)/\left(1-\left(\overline{Y_P/Y_S}\right)\right)$	[13] (Fernandez, 1992)
Harmonic Mean (HARM)	$2(Y_P \times Y_S)/(Y_P + Y_S)$	[15] (Fischer and Maurer, 1978)

where *Ys* and *Yp* are yield under stress and non-stress yield of a given genotype, respectively.

$\overline{Ys}$ and $\overline{Yp}$ are average yields of all genotypes under stress and non-stress conditions, respectively.

3. Results and Discussion

3.1. Experiment 1: Response of Selected High Biomass Rice to Different Percentages of Field Capacity

The analysis of variance showed that the differences in the number of days to first tiller, rates at which tillers were produced, shoot and root fresh and dry weight as well as the total fresh and dry biomass in three levels of FC and in genotypes was significantly different. The variations in plant heights at 43 DAS and 85 DAS and the rates of height increase in three levels of FCs and 10 genotypes, however, were highly significant. The number of tillers at 43 and 85 DAS varied significantly among genotypes but it varied only with FC at 43 DAS but not at 85 DAS. The interaction of genotype x FC for these parameters was non-significant except for the plant height at 85 DAS.

The genotypes grown at 100% FC had significantly faster tiller emergence and the rate of increase in plant height than those grown at 75% and 50% FC but plant grown at 50% FC had fastest rate of tiller production (**Table 1**). The fresh and dry weights of shoot, root and total biomass were always significantly higher at 100% FC than those obtained in 50% and 75% FC. Percent dry matter, however, was significantly higher at 75% than both 50% and 100% FC. Relative to 100% FC, 50% less available water reduced both FW and DW of shoot by 64%, 75% for root FW, 70% for root DW, and 65% for both FW and DW of total biomass. The 25% reduction of available water caused 33% reduction in shoot FW, 28% in shoot DW, 13% in root FW, 16% in root DW, 35% in total biomass FW and 26% total biomass DW. Sixteen percent and 5% more dry biomass were obtained in 75% and 50% FC, respectively compared to plants at 100% FC indicating plant succulence in fully saturated soil. These results further suggest that a full field capacity is not needed to produce high dry biomass for high biomass rice and severe drought (50% FC) may not severely affect dry biomass production. The increase dry biomass at 50% FC could be attributed to faster tiller production, even though the total tiller number was reduced.

Among the ten genotypes studied, genotype 12 had the lowest number of days to first tiller emergence (early tiller production) but it was statistically comparable to genotype 10 and 11 (**Table 2**). The early tillering ability of genotype 11 may have originated from the parent 'Zhe 733' which is known to produce tillers earlier than conventional U.S. rice varieties [16] (Tabien *et al.*, 2005). Genotype 11 also had the fastest rate of tiller production that was comparable to genotype 12 and fastest rate of increase in plant height. The shoot FW and DW was highest in genotype 12 having 40% and 71.06 % increases, respectively when compared to Banks. The root FW and DW was highest in genotype 11 showing 37.9% and 43% increase compared to Banks, respectively. However the total fresh (43.71 g) and dry (11.94 g) biomass is highest in genotype 12 having 34% and 64% increase

Table 1. Means of days to first tiller emergence, rate of tiller production, rate of increase in plant height, shoot and root fresh and dry weights, total fresh and dry biomass and % dry matter in three percentages of field capacity across ten genotypes in Beaumont, Texas.

% Field capacity	Days to first tiller emergence	Rate of tiller production	Rate of increase in plant height	Shoot weight (g)		Root weight (g)		Total biomass (g)		% Dry matter
				Fresh	Dry	Fresh	Dry	Fresh	Dry	
50	45.59a	0.1117a	0.3044a	15.01c	3.99c	2.08c	0.44c	17.08c	4.44c	26.52b
75	41.32b	0.0785b	0.4518a	27.37b	7.94b	5.05b	1.25b	32.41b	9.19b	29.27a
100	36.67c	0.0731b	0.4564b	41.26a	10.90a	8.15a	1.48a	49.41a	12.39a	25.14b

Means in each column followed by the same letter are not significantly different at 5% level of significance.

Table 2. Means of the days to first tiller emergence, rate of tiller production, rate of increase in plant height, shoot and root fresh and dry weights, total fresh and dry biomass and % dry matter across drought levels of nine high biomass rice and cultivar Banks at Beaumont, Texas.

Genotypes	Days to first tiller emergence	Rate of tiller production	Rate of increase in plant height	Shoot weight (g)		Root weight (g)		Total biomass (g)		% Dry matter
				Fresh	Dry	Fresh	Dry	Fresh	Dry	
4	42.56abc	0.0408e	0.3160b	24.77c	6.27d	5.67abc	1.02abcd	30.44bcd	7.28d	24.17cd
5	42.88abc	0.0605de	0.3721b	24.06c	7.28bcd	4.45bc	0.95bcd	28.51cd	8.23bcd	28.89ab
6	41.33bc	0.0419e	0.3704b	31.71ab	8.58bc	5.26abc	1.19abc	36.97abc	9.78abc	26.27bcd
7	40.67cd	0.0941cd	0.3894b	24.23c	6.94cd	5.11bc	0.94bcd	29.33cd	7.88cd	26.83bcd
10	38.89cde	0.1247bc	0.3653b	33.66ab	9.25ab	5.63abc	1.31a	39.29ab	10.56ab	26.56bcd
11	36.89de	0.1757a	0.6216a	33.99a	8.32bcd	7.74a	1.46a	41.73a	9.78abc	23.52d
12	36.11e	0.1439ab	0.2942b	37.80a	10.64a	5.91ab	1.30ab	43.71a	11.94a	27.43abc
14	42.00abc	0.0623de	0.4569b	21.72c	6.34d	3.14c	0.80cd	24.86d	7.14d	30.60a
16	45.22ab	0.0674de	0.4240b	21.99c	6.54d	3.18c	0.66d	24.18d	7.20d	31.09a
Banks	46.14a	0.0553de	0.4398b	26.83bc	6.22d	5.61abc	1.02abcd	32.44bcd	7.24d	23.12d

Means in each column followed by the same letter are not significantly different at 5% level of significance.

when compared to the check. The % DM was highest in genotype 16 having 34.4% more than Banks and genotype 11. Being best in all the parameters measured, genotype 12 has the best potential for higher biomass production in any FCs. For high % DM, however, genotypes 5, 14 and 16 are the best together with genotype 12. Genotype 6, 10 and 11 showed similar pattern but all were included in the group with lower % DM.

The amount of available water affected the growth and development of the ten high biomass rice lines. The observed reduction in tiller production under stress could be due to limited assimilates produced from inhibited photosynthesis which is directly caused by drought [17] (Mostajeran and Rahimi-Eichi, 2009) while the significant differences in rate of increase in plant height can be due to differences in cell elongation, internode elongation and number of nodes, the traits shown to be affected by drought and genotypes [18] (Guevarra and Chang, 1965). Furthermore, the reduction in available water or the increase in stress was shown to reduce the rate of growth of stems, thereby affecting plant height [19] (Bunnag and Pongthai, 2013). Several studies have shown that water stress can reduce shoot growth [20] [21] (Price *et al.*, 2002; Suralta and Yamauchi, 2008). In drought stress, the reduction in shoot fresh and dry matter can be attributed to the reduction of leaf area and slow photosynthesis rate [22] [23] (Sinaki *et al.*, 2007; Zubaer *et al.*, 2007). Like the shoot, root growth is also affected by limited water supply. Reference [21] reported that the nodal root production was reduced in drought condition and this influenced the formation of root biomass. In soils which are water stressed, there is reduced oxygen supply, physical barrier like hardpans and poor adaptation of roots to aerobic condition that limit exploitation of deeper soil layers hence reducing root biomass [24] (Samson and Wade, 1998). Similar to the root and shoot of the 10 genotypes, the total biomass was also affected by the amount of available water. The observed reduction in total biomass in water stressed condition might be attributed to low net photosynthesis and low nutrition associated oxidative damage to shoot tissues [25] (Zhang and Kirkham, 1996) in drought environment. Drought stress suppresses leaf expansion, tillering and midday photosynthesis [19] (Bunnag and Pongthai, 2013) that can lead to lower production of biomass.

Limited water availability can cause cascade of signals mediated by phytohormone ABA [26] (Christmann *et al.*, 2007). Higher % DM at 75% FC could be due to mild stress signal that caused faster accumulation of photoassimilates [27] (Matsuo *et al.*, 2007).

3.2. Experiment 2: Response of Selected High Biomass Rice to Rainfed and Flooded Conditions

Analysis of variance indicated significant differences between the two environments and 20 genotypes. The genotype x environment interaction was highly significant for average height, tillers plant^{-1} at 105 DAS and days to 50% heading but not for biomass yield (**Table 3**) indicating that some genotypes varies in heading, plant height and tiller count depending on the field condition. The tallest genotype was genotype 2 in flooded field and it was the shortest genotype in the rainfed condition. The mean height of genotypes at harvest across two environments ranged between 100.83 and 115.29 cm with a mean of 109.79 cm. The number of tillers plant^{-1} at 105 DAS in flooded was 16.13 and this was significantly higher than in rainfed with 13.18 tillers. The highest tillers plant^{-1} was from genotype 11 in flooded field and lowest from genotype 8 in flooded condition. Among the genotypes across the two environments, the number of days to 50% heading ranged from 93 to 113 with a mean of 102.54 days. Genotype 18 and 10 flowered the earliest in flooded and rainfed condition, respectively.

Among the genotypes, there were significant differences for tiller plant^{-1} at 105 DAS, days to 50% heading and biomass yield (kg·ha^{-1}) but not for plant height (**Table 4**). Average plant height ranged from 100.83 - 115.29 cm, and these are generally closer to the commercial rice varieties like Banks. Plant height could be critical to avoid lodging that may cause lower biomass harvest. Taller plant should have big tillers to minimize lodging. Number of tillers plant^{-1} at 105 DAS was highest in genotype 11 (22 tillers) and lowest in genotype 17 (9 tillers). The tillers count of genotype 11 was statistically comparable to other 10 genotypes while the low tiller count of genotype 17 was similar to the majority of the genotypes. Genotype 10 attained 50% heading fastest (93 days) and this was not significantly different to the heading of four other genotypes. Genotype 12 was last to

Table 3. Average height, tillers plant^{-1} at 105 Days after sowing (DAS), days to 50% heading and biomass yield (kg·ha^{-1}) of selected high biomass rice lines and Banks in two environments in Beaumont, Texas.

Genotype	Average height (cm)		Tillers plant^{-1} at 105 DAS		Days to 50% heading		Fresh biomass yield (kg·ha^{-1})	
	Environment		Environment		Environment		Environment	
	Rainfed	Flooded	Rainfed	Flooded	Rainfed	Flooded	Rainfed	Flooded
1	102.25abc	125.17abc	14.67abcde	15.42abcde	109.50defgh	92.50lmno	25,178.72	30,148.16
2	93.67c	135.00a	8.48de	12.79abcde	111.00def	96.50jklmn	26,147.52	23,175.60
3	108.00abc	118.17abc	11.38bcde	22.50ab	121.50ab	95.50jklmno	26,209.68	43,963.92
4	95.50bc	106.17abc	18.46abcde	17.67abcde	110.00defg	93.00lmno	27,890.24	36,733.76
5	98.67bc	114.33abc	10.13cde	13.83abcde	122.50ab	101.00ghijkl	17,171.84	24,788.96
6	103.50abc	120.33abc	13.88abcde	10.13cde	109.50defgh	96.50jklmn	31,699.92	42,868.56
7	103.50abc	122.67abc	15.58abcde	17.67abcde	112.00cde	90.00mno	28,985.04	22,402.24
8	110.83abc	111.50abc	14.00abcde	9.70cde	102.50fghijk	88.00no	20,786.08	31,052.56
9	110.33abc	111.75abc	13.40abcde	16.13abcde	114.50abcd	97.50ijklm	23,046.80	26,469.52
10	119.92abc	110.67abc	12.95abcde	15.08abcde	97.00ijklmn	89.00mno	13,297.76	20,530.72
11	111.33abc	105.83abc	20.17abcd	24.00a	122.00ab	101.00ghijkl	45,065.44	45,193.68
12	99.92bc	127.17abc	15.00abcde	18.33abcde	123.50a	102.50fghijk	18,592.56	39,513.04
13	108.00abc	101.33abc	6.60e	17.00abcde	114.00bcd	93.50klmno	26,663.28	37,767.52
14	97.67bc	118.42abc	8.28de	13.50abcde	106.00defghi	93.00lmno	27,436.08	23,046.80
15	109.33abc	111.67abc	12.38abcde	19.50abcd	111.00def	96.50jklmn	19,107.76	25,114.32
16	103.50abc	112.33abc	15.13abcde	18.58abcde	104.00efghij	89.50mno	35,378.00	23,758.56
17	100.50bc	107.42abc	8.60cde	10.50bcde	100.50hijkl	89.00mno	14,460.32	29,503.60
18	96.00bc	128.33ab	8.75cde	13.88abcde	101.00ghijkl	86.50o	15,497.44	13,880.72
19	95.50bc	125.17abc	17.33abcde	20.75abc	120.50abc	94.00klmno	31,117.52	26,988.08
Banks	108.08abc	102.33abc	18.50abcde	15.67abcde	110.50def	93.50klmno	24,984.96	30,405.20

Means in each column followed by the same letter are not significantly different at 5% level of significance.

flower (113 days) and this heading was comparable to genotype 3, 5, 11 and 19. The highest fresh biomass yield was from genotype 11 (45,129.56 kg·ha^{-1}) followed by genotype 6 (37,284.24 kg·ha^{-1}) and these were not significantly different from yields obtained from seven genotypes including Banks. The lowest biomass was obtained from genotype 18. Late heading produce more tiller and higher biomass. Genotypes having more tillers had higher biomass.

Evaluation of plant agronomic traits in stressed and non-stressed environment, can give an insight on how that genotype performs under stress. Previous studies have showed that plants grow taller in flooded condition than non-flooded condition [28] [29] (Kamoshita and Abe, 2007; Patel *et al.*, 2010). Reduction in plant height under rainfed condition may be due to water stress which limits cell elongation resulting in reduction of internodal length and eventually giving shorter plant height [29] (Patel *et al.*, 2010). Moreover, plant height and tiller plant^{-1} were reduced under conditions of water deficit because plants are unable to absorb soil water resulting in essential elements being less available [19] (Bunnag and Pongthai, 2013). In an experiment conducted by [30] Owusu-Sekyere, (2005), the number of tillers in flooded plants was significantly greater than that for rainfed plants. Delay in flowering in rainfed plots compared to flooded plots was reported by [31] Bouman and Tuong, (2001). Reference [32] Lilley and Fukai, (1994) showed that the delay in flowering and the magnitude of this delay was associated with severity of drought conditions. [33] Yan *et al.*, (2010) reported that biomass was significantly affected by water regime.

Simple correlations indicated that biomass yield was significantly and positively correlated with tillers meter^{-1} at 56 DAS, 105 DAS and number of tillers plant^{-1} at 105 DAS (**Table 5**). The tillers at 56 DAS were found

Table 4. Mean of plant height, tillers plant^{-1} at 105 days after sowing (DAS), days to 50% heading and biomass yield (kg·ha^{-1}) across two environments of nineteen high biomass rice lines and cultivar Banks in Beaumont, Texas.

Genotype	Plant height (cm)	Tillers plant^{-1} at 105 DAS	Days to 50% heading	Fresh biomass yield (kg·ha^{-1})
1	113.71	15.04abcd	101.00efgh	27,663.44abc
2	114.33	10.63cd	103.75cdef	24,661.56bc
3	113.08	16.94abcd	108.50abc	35,086.80ab
4	100.83	18.06abc	101.50defg	32,312.00abc
5	106.50	11.98bcd	111.75ab	20,980.40bc
6	111.92	12.00bcd	103.00cdef	37,284.24ab
7	113.08	16.62abcd	101.00efgh	25,693.64bc
8	111.17	11.85bcd	95.25hij	25,919.32bc
9	111.04	14.76abcd	106.00bcde	24,758.16bc
10	115.29	14.01bcd	93.00j	16,914.24c
11	108.58	22.08a	111.50ab	45,129.56a
12	113.54	16.67abcd	113.00a	29,052.80abc
13	104.67	11.80bcd	103.75cdef	32,215.40abc
14	108.04	10.89cd	99.50fghi	25,241.44bc
15	110.50	15.94abcd	103.75cdef	22,111.04bc
16	107.92	16.85abcd	96.75ghij	29,568.28abc
17	103.96	9.55d	94.75ij	21,981.96bc
18	112.17	11.31cd	93.75ij	14,689.08c
19	110.33	19.04ab	107.25abcd	29,052.80abc
Banks	105.21	17.08abcd	102.00defg	27,695.08abc

Means in each column followed by the same letter are not significantly different at 5% level of significance.

significantly and positively correlated with tillers meter^{-1} at 105 DAS, number of tillers plant^{-1} at 105 DAS and days to 50% heading. Average height was significantly and negatively correlated with days to 50% heading. These results suggest the importance of tiller number in biomass production and it can be taken earlier (56 DAS) or later (105 DAS) to estimate biomass yield.

3.3. Drought Tolerance Indices to Identify Tolerant Genotypes

Different drought tolerance indices were calculated for total fresh and total dry weight at a mild drought stress (75% FC), severe drought stress (50%) and for total fresh biomass in rainfed condition. The three superior and inferior genotypes for each of the drought indices are shown in **Table 6**. Based on SSI and TOL indices computed using the greenhouse data, in both total fresh and dry weights, genotype 7 was identified as a tolerant genotype in mild stress. Genotype 11 was identified as a tolerant genotype based on SSI in severe stress in both total fresh and dry weights and Banks and 11 in total fresh and dry weight, respectively based on TOL. Based on the indices values, it seems that TOL can succeed in selecting genotypes with high yield under stress, but cannot select genotypes with good yield under both stress and non-stress condition [34] (Golbashy *et al.*, 2010). Using SSI, for fresh weights genotype 16 and Banks were selected as sensitive ones in mild and severe stresses, respectively and for dry weights, Banks and genotype 16 in mild and severe stress, respectively (**Table 6**) as they had higher values of SSI [12] (Nazari and Pakniyat, 2010). SSI could not identify genotypes having high yields under both stressed and non-stressed condition [34] (Golbashy *et al.*, 2010) for e.g., genotype 12 in mild stress for both fresh and dry weights. Higher values of STI, GMP, MP and Harm indicate stress tolerance [13] (Fernandez, 1992). Based on these indices, genotype 12 and genotype 10 were identified as tolerant genotypes in mild stress for both fresh and dry weights (**Table 6**) and genotype 11 and genotype 12 for fresh weights and genotype 12 and genotype 11 for dry weight in severe stress based on STI, GMP and HARM whereas genotypes 12 and 10 based on MP. Based on SSI and TOL, in % DM genotypes 16 and 14 are identified as tolerant whereas genotypes 4 and 5 are sensitive and in severe stress genotype 14 and Banks as tolerant and genotypes 10 and 4 as susceptible. Based on STI, GMP, MP and HARM, genotypes 16 and 14 are superior in % DM in mild stress and genotypes 14 and 5 in severe stress.

Table 6 similarly shows the three superior and inferior genotypes based on different indices in rainfed and flooded condition. Based on SSI and TOL, genotypes 16 and 7 were identified as tolerant, however using the other calculated indices i.e. STI, GMP, MP and HARM, genotypes 11 and 6 were identified as tolerant genotypes. As mentioned earlier, SSI and TOL are not very successful in identifying genotypes having high yield in both stressed and non-stressed condition [14] [35] (Jafari *et al.*, 2009; Rosielle and Hamblin, 1981).

4. Conclusion

In the green house and field experiments, the availability of water affected the agronomic traits and biomass production. Most of the genotypes performed better under non stressed conditions. The best performing genotypes were impressive as these genotypes had the best traits measured in this study that could be the determinants

Table 5. Correlation among various traits of high biomass rice genotypes grown in rainfed and flooded environments at Beaumont, Texas.

Trait	Average height	Tiller meter^{-1} at 56 DAS	Tiller meter^{-1} at 105 DAS	Rate of tiller production	Tillers plant^{-1} at 105 DAS	Days to 50% heading
Average height						
Tiller meter^{-1} at 56 DAS	-0.01					
Tiller meter^{-1} at 105 DAS	-0.06	0.80^{**}				
Rate of tiller production	-0.09	0.02	0.60^{**}			
Tillers plant^{-1} at 105 DAS	0.14	0.46^{**}	0.57^{**}	0.34^{**}		
Days to 50% heading	-0.43^{**}	0.24^{*}	0.24^{*}	0.09	-0.11	
Biomass yield (kg·ha^{-1})	0.04	0.32^{**}	0.27^{*}	0.04	0.45^{**}	0.01

*Significance at $p \le 0.05$; **Significance at $p \le 0.01$; DAS, days after sowing.

Table 6. Selected superior and inferior genotypes using the six drought tolerance indices at mild and severe drought stress based on percent field capacity, and in rainfed condition.

Indices	Genotypic group	Drought condition						
		Mild drought stress (75% FC)			Severe drought stress (50%)			Rainfed
		Total FW	Total DW	% DM	Total FW	Total DW	% DM	Total fresh biomass
Y_P	Superior	12, 10, 11	12, 10, 11	5, 14, 12	12,10,11	12, 10, 6	5, 14, 12	11, 3, 6
	Inferior	4, 5, 7	4, Banks, 7	Banks, 11, 4	4, 5, 7	4, Banks, 7	Banks, 11, 4	18, 10, 7
Y_S	Superior	12, 6, 10	12, 6, 10	16, 14, 5	11, 12, 10	12, 11, 10	14, 5, 16	11, 16, 6
	Inferior	16, Banks, 14	Banks, 16, 14	4, Banks, 11	Banks, 4, 14	4, banks, 7	11, 4, Banks	10, 17, 18
SSI	Superior	7, 4, 12	7, 6, 12	16, 14, 6	11, 12, 6	11, 12, 6	14, Banks, 16	16, 7, 14
	Inferior	16, Banks, 14	Banks, 16, 14	4, 5, 12	Banks, 14, 4	16, 14, 7	10, 4, 6	12, 17, 3
STI	Superior	12, 10, 11	12, 10, 6	16, 14, 5	11, 12,10	12, 11, 10	14, 5, 12	11, 6, 3
	Inferior	16, 5, 14	Banks, 16, 4	Banks, 11, 4	4, Banks, 14	4, Banks, 7	11, Banks, 4	18, 10, 5
TOL	Superior	7, 4, 6	7, 6, 4	16, 14, 6	5, 7, 11	11, 4, Banks	14, Banks, 16	16, 7, 14
	Inferior	16, Banks, 14	16, Banks, 14	4, 5,12	Banks, 10, 12	10, 16, 12	10, 4, 6	12, 3, 17
GMP	Superior	12, 10, 11	12, 10, 6	16, 14, 5	11, 12, 10	12, 11, 10	14, 5, 12	11, 6, 3
	Inferior	16, 5, 14	Banks ,16, 4	Banks, 11, 4	4, Banks, 14	4, Banks, 7	11, Banks, 4	18,10, 5
MP	Superior	12, 10, 11	12, 10, 6	16, 14, 5	11, 12, 10	12, 10, 11	14, 5, 12	11, 6, 3
	Inferior	5, 16, 14	Banks, 4, 5	Banks, 11, 4	4, 7, 5	4, Banks, 7	11, Banks, 4	18, 10, 5
HARM	Superior	12, 10, 11	12, 10, 6	16, 14, 5	11, 12, 10	12, 11, 10	14, 5, 12	11, 6, 3
	Inferior	16, Banks, 14	Banks, 16, 5	Banks, 11, 4	Banks, 4, 14	4, Banks, 7	11, Banks, 4	18, 10, 17

Y_P: Potential yield; Y_S: Stress yield; SSI: Stress susceptibility index; STI: Stress tolerance index; TOL: Tolerance index; GMP: Geometric mean productivity; MP: Mean productivity; HARM: Harmonic mean.

of biomass yield. The high biomass genotypes like conventional rice were affected by drought and performed better under flooded field conditions. However, some genotypes had comparable response under stress environment. These genotypes can be identified using STI, GMP, MP and HARM drought tolerance indices as they have a similar ability to separate drought sensitive and tolerant genotypes. These genotypes can be used for cultivation under stress condition to get optimum biomass yields. In conclusion, genotype 11 and genotype 12 are more tolerant to drought stress. Genetic analysis and detailed characterization of both shoot and root rates of such genotypes will help us understand the inheritance pattern and the number of genes controlling the traits and determine specific leaves and root traits important in developing high biomass rice.

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