Vol. 13, No. x (2024): 49 - 59 http://dx.doi.org/10.23960/jtep-l.v13i1.49-59

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Effect of Drought Periods on Rice Lines Growth and Yield

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Article History:

Received : 16 August 2023
Revised : 07 September 2023
Accepted : 21 September 2023

Keywords:

Drought periods,
Rice lines,
Growth,
Yield

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ABSTRACT

Numerous variables, such as drought period, growth stage, and varieties, influence rice growth and yield in response to drought. This study was conducted to determine the effect of drought periods on the growth and yields of several rice lines and varieties as well as to select drought-tolerant lines. Using a split-plot design with three replications, the pot experiment was carried out in the greenhouse from December 2015 to April 2016 at the Sukamandi Experimental Site of Indonesian Center for Rice Research (BB Padi). Drought periods were treated as the main-plot, while the rice lines/varieties were treated as sub-plots. The main-plot consists of four levels: control, drought at the maximum tillering stage, drought at the primordia stage, and drought at the grain filling stage. The rice lines used are expand lines of rainfed lowland rice and upland rice from the BB Padi breeding program. The results showed that of the 36 rice lines and 6 varieties tested, drought periods during maximum tillering and primordia affected plant height, while the tiller number was not affected by all drought periods. From the yield characters, drought periods increased unfilled grain percentage and decreased 1000 grains weight and also grain weight per plant. Jatiluhur is consistently tolerant and has the highest yield. There are 8 rice lines with consistent tolerance and not significantly different yields with Jatiluhur: B13650E-TB-80-2, B14168E-MR-6, B14168E-MR-10, B14168E-MR-11, B14168E-MR-12, B14168E-MR-13, B12480D-MR-7-1-1, and B12056F-TB-1-29-1.

1. INTRODUCTION

Water availability is crucial to the success of rice farming. However, drought and water scarcity caused by climatic factors may limit the high demand for water in rice agriculture (Bouman *et al*., 2007). Drought is a term to indicate that plants suffer from water deficiency due to the restriction of water in the growing media (Levitt, 1980). According to Zhang *et al*., (2018), the drought in recent years has decreased rice yields, and it is anticipated that future yields will be lower than they are now.

Rice response to drought depends on the level and duration of drought (Panda *et al*., 2021), growing stage, and genotype (Moonmoon & Islam, 2017). Drought in the vegetative stage can inhibit the plant height, the number of leaves, the number of tillers, and root growth, while in the reproductive stage it may decrease the 1000 grain weight, grains per panicle, panicle per hill, length of panicle, and the percentage of filled grains (Tubur *et al*., 2012; Akram *et al*., 2013; Zhang *et al*., 2018; Tiwari *et al*., 2021). According to Zhang *et al*. (2018), drought in the vegetative stage can decrease rice yields by 21–50.6%, drought during the flowering stage decreases rice yields by 42–83.8%, and drought in the reproductive stage may reduce rice yields by 51–90.6%.

Genetic improvement of rice to produce drought-tolerant varieties became an alternative to dealing with drought problems (Panda *et al*., 2021). Understanding the mechanisms of drought tolerance is essential for establishing a breeding strategy. Various changes occur in the morphological, physiological, biochemical, and molecular processes of plants in response to drought. Drought causes water balance problems, interferes with metabolic processes at the cellular level, disrupts membrane transport, and decreases ATP production and respiration, which causes seed germination to decline (Kadam *et al*., 2017). Drought has also been shown to decrease plant height, leaf area, and biomass (Mishra & Panda, 2017; Hussain *et al*., 2018).

Plants respond to drought with escape, avoidance, and tolerance mechanisms (Seleiman *et al*., 2021). Escape is defined as the ability of plants to complete their life cycles before groundwater deficits (Kumar *et al*., 2017). Escape mechanisms in rice included early flowering, early maturity, high leaf N2 levels, high photosynthesis capacity, and remobilization of assimilates (Panda *et al*., 2021). Kumar *et al*., (2017) defined avoidance as the ability of plants to maintain relatively high tissue water potential even at low soil humidity, such as deep roots, stomata closure, leaf rolling, tissue hydration, stay green, and high transpiration efficiency (Kim *et al*., 2020; Panda *et al*., 2021). While drought tolerance may refer to the ability of plants to maintain water potential and prevent dehydration in limited groundwater conditions (Shrestha, 2022). Some characteristics associated with tolerance mechanisms in rice include osmotic adjustment, high prolin, desiccation tolerant enzymes, high stomatal conductance, and maintenance of photosynthesis (Dien *et al*., 2019; Panda *et al*., 2021).

The development of drought-tolerant rice in Indonesia has been done for many varieties. However, drought tolerance screening is generally limited to drought periods in vegetative growth, while drought also has different effects on different plant growth stages. The development of new varieties should be a support for the limited availability of drought-tolerant varieties in other crucial growth stages. Therefore, screening the rice lines for drought in some critical stages of growth and its relationship with growth and yields is important to do (Swain *et al*., 2017). Tubur *et al*., (2012), Akram *et al*., (2013), Wening & Susanto (2014), Moonmoon & Islam (2017), and Vijayaraghavareddy *et al*. (2020) have tested the tolerance of rice plants to drought at various stages of growth. This study aims to find out the effects of drought at several stages of plant growth on the growth and yield of some rice lines. The research was also conducted to select drought-tolerant lines during one or more periods of drought.

2. MATERIALS AND METHODS

The pot experiment was carried out in the greenhouse at the Sukamandi Experimental Site of Indonesian Centre for Rice Research (BB Padi) from December 2015 to April 2016, using a split-plot design with three replications. Drought periods were treated as the main-plot, consists of four levels: control (P0), drought at the maximum tillering stage (P1), drought at the primordia stage (P2), and drought at the grain filling stage (P3). The rice lines/varieties were used as sub-plots (Table 1). The rice lines used are expand lines of rainfed lowland rice and upland rice from the BB Padi breeding program.

Water supply was cut off at 40 days after sowing (DAS) (maximum tillering stage), 55 DAS (primordia stage), and 66–85 DAS (grain filling). Ten days after treatment, the water supply was restored, and irrigation returned to normal. Irrigation on the control treatment continues indefinitely until harvest. During irrigation, the water surface is about 5 cm above the soil surface. The planting media used firstly dried and sifted using a 1 cm screen. Each pot contains 10 kg of soil. Planting was direct seeding with three seeds in each pot, and after 20 days, one plant was placed in each pot. Fertilizer dose is in accordance with the recommendation of Permentan No. 40 of 2007 for the Ciasem district, where the dose per pot was determined based on population in 1 ha. Pests and diseases were chemically controlled based on the level of attack.

Table 1. The rice lines/varieties used in experiment

No	Line/Variety	No	Line/Variety	No	Line/Variety
1	HHZ5-DT1-DT1	15	B13650E-TB-80-2	29	B12480D-MR-7-1-1
2	BP14352e-1-2-3Op-Jk-0	16	B11592F-MR-23-2-2	30	B14086D-TB-70
3	PR42096-B-4-1-SBY-0-CRB-0	17	B12165D-MR-8-1-1-2	31	B13642E-TB-71
4	BP17280-M-15D-IND	18	B11910D-MR-22-2	32	B11908F-TB-3-WN-1
5	BP17280-M-53D-IND	19	B14217F-MR-1	33	B12168D-MR-38-1-6-TB-1
6	B13031B-RS*^{1}-5-11-PN-5-1-3-MR-3	20	B14168E-MR-5	34	B12056F-TB-1-29-1
7	B12743-MR-18-2-3-5-PN-5-2-2-4	21	B14168E-MR-6	35	B12159D-MR-40-1
8	B12272D-MR-15-3-2	22	B14168E-MR-10	36	B12056F-TB-1-64-6
9	B13653G-TB-18	23	B14168E-MR-11	37	B11604E-MR-2-4
10	B14288F-MR-1	24	B14168E-MR-12	38	B13655E-TB-13
11	BP14034-2b-1-1-Trt-33-5-Ski-2	25	B14168E-MR-13	39	B12056F-TB-1-5-4-1
12	IR77674-3B-8-2-2-14-2-AJY4-Ind1	26	B14168E-MR-20	40	B12825E-TB-2-4
13	Inpari 10	27	Limboto	41	Inpago 5
14	Inpari 38	28	Sigambiri Putih	42	Jatiluhur

Rice responses were observed on plant tolerance based on leaf rolling, plant growth, yield, and tolerance index. The level of leaf rolling was observed visually based on a score of 0–9, as shown in Table 2. The drought tolerance index was calculated based on the following equation (Tubur *et al*., 2012):

$$\text{Tolerance index (IT)} = 1 - \frac{(Kn - Hnj)}{Kn}$$

Where: Kn = yield of rice line (1,2,..42) on the control treatment

Hnj = yield of rice line (1,2,..42) on the drought treatment (1,2,3)

The effects of drought on growth were observed on the plant height and number of tillers at 35, 49, and 63 DAS and before harvest. The drought effects on the yield were observed from the yield components and yields, including panicle number, panicle length, grain number per panicle, unfilled grain percentage, 1000 grain weight, and grain weight per plant. The collected data were analyzed using analysis of variance (ANOVA), and if there was a significant effect at 5% level, the least significant difference (LSD) was used. Cluster analysis was also performed to classify the rice lines into a number of different groups, with related participants placed in the same group (Sitaresmi *et al*., 2018). The agglomerative approach was employed for clustering, and euclidean distance was used to measure dissimilarity.

Table 2. Scores of the plant response to drought based on leaf rolling symptoms

Score	Description	Criteria
0	Leaves are healthy	Highly Tolerant
1	Leaves start to fold (shallow)	Tolerant
3	Leaves are folding (deep V-shape)	Moderate Tolerant
5	Leaves are fully cupped (U-shape)	Moderate Susceptible
7	Leaves margins are touching (0-shape)	Susceptible
9	Leaves are tightly rolled (V-shape)	Highly Susceptible

Source: IRRI (2014)

3. RESULTS AND DISCUSSION

The results showed that based on the leaf rolling score, the drought period at the maximum tillering and primordia stages resulted in 4 groups of tolerance categories: susceptible, moderate susceptible, moderate tolerant, and tolerant. At grain filling, a different response was seen, all rice lines were classified as susceptible at the end of the drought period (Table 3; Figure 1). Leaf rolling is the first response to drought, which is followed by leaf drying (Tubur *et al*., 2012). Leaf rolling is a mechanism associated with the ability to adjust the rate of transpiration to maintain high leaf water potential in dry conditions (Mackill *et al*., 1996). When drought occurs, rice plants will naturally develop defensive mechanisms by reducing the energy burden on their leaves (Chaturvedi *et al*., 2012) and rolling their leaves to suppress the effects of radiation on leaf surfaces (Swapna & Shylaraj, 2017). Varieties that are able to maintain high leaf water potential in dry conditions tend to have lower leaf rolling levels (Bouman & Tuong, 2001). Thus, a high leaf rolling score would be negatively associated with the ability of each variety to produce in dry conditions (Tubur *et al*., 2012). In rice, leaf rolling is one of the best criteria for estimating the level of tolerance to drought, especially in mass screening involving many lines or varieties (Pandey & Shukla, 2015).

The drought-tolerance can also be predicted by the value of the tolerance index for yield. Based on the experiment, the variability of the tolerance index ranges between 0.55 to 1.48 for drought periods at maximum tillering, 0.57 to 1.41 for drought periods at primordia stage, and 0.48 to 1.13 for drought periods at grain filling. According to Tubur *et al*. (2012), varieties with index values equivalen/equal to 1 under drought stress indicate that the varieties have a drought-tolerance index for high yielding. The GT-biplot analysis by Sabouri *et al*. (2022) using 3-year series data shows that the tolerance index has a strong and positive correlation with the yield both under and without a stress condition. This indicated that the tolerance index can be used to identify superior lines in both conditions using average yields. In this experiment, a tolerance index greater than 1 was obtained by 18 lines during the drought period at maximum tillering, 7 lines in the primordia stage, and 3 lines in the grain filling stage (Table 4, Figure 1). Inpari 10, IR77674-3B-8-2-2-14-2-AJY4-Ind1, and BP17280-M-15D-IND have a low tolerance index in any period of drought, while lines B14288F-MR-1, B11604E-MR-2-4, and B12056F-TB-1-29-1 have a higher tolerance index than others. Figure 2 shows various numbers of lines in each group.

Table 3. Tolerance categories of lines to drought in several growth stages based on leaf rolling symptoms

Category	Drought Periods		
	Maximum Tillering	Primordia	Grain Filling
Susceptible	6 Lines	1 Lines	36 Lines 6 Varieties
Moderate Susceptible	2 Lines	6 Lines	-
Moderate Tolerant	2 Lines	7 Lines 2 Varieties	-
Tolerant	26 Lines 6 Varieties	22 Lines 4 Varieties	-

Note: Susceptible: leaves margins are touching (0-shape); Moderat susceptible: leaves are fully cupped (U-shape); Moderate tolerant: leaves are folding (deep V-shape); Tolerant: leaves start to fold (shallow)

Table 4. Tolerance index by yield of test lines to drought in several growth stages

Tolerance index	Drought Periods		
	Maximum Tillering	Primordia	Grain Filling
>1.00	16 Lines 2 Varieties	6 Lines 1 Varieties	2 Lines 1 Varieties
0.75 – 1.00	20 Lines 3 Varieties	20 Lines 2 Varieties	9 Lines
< 0.75	1 Varieties	10 Lines 3 Varieties	25 Lines 5 Varieties

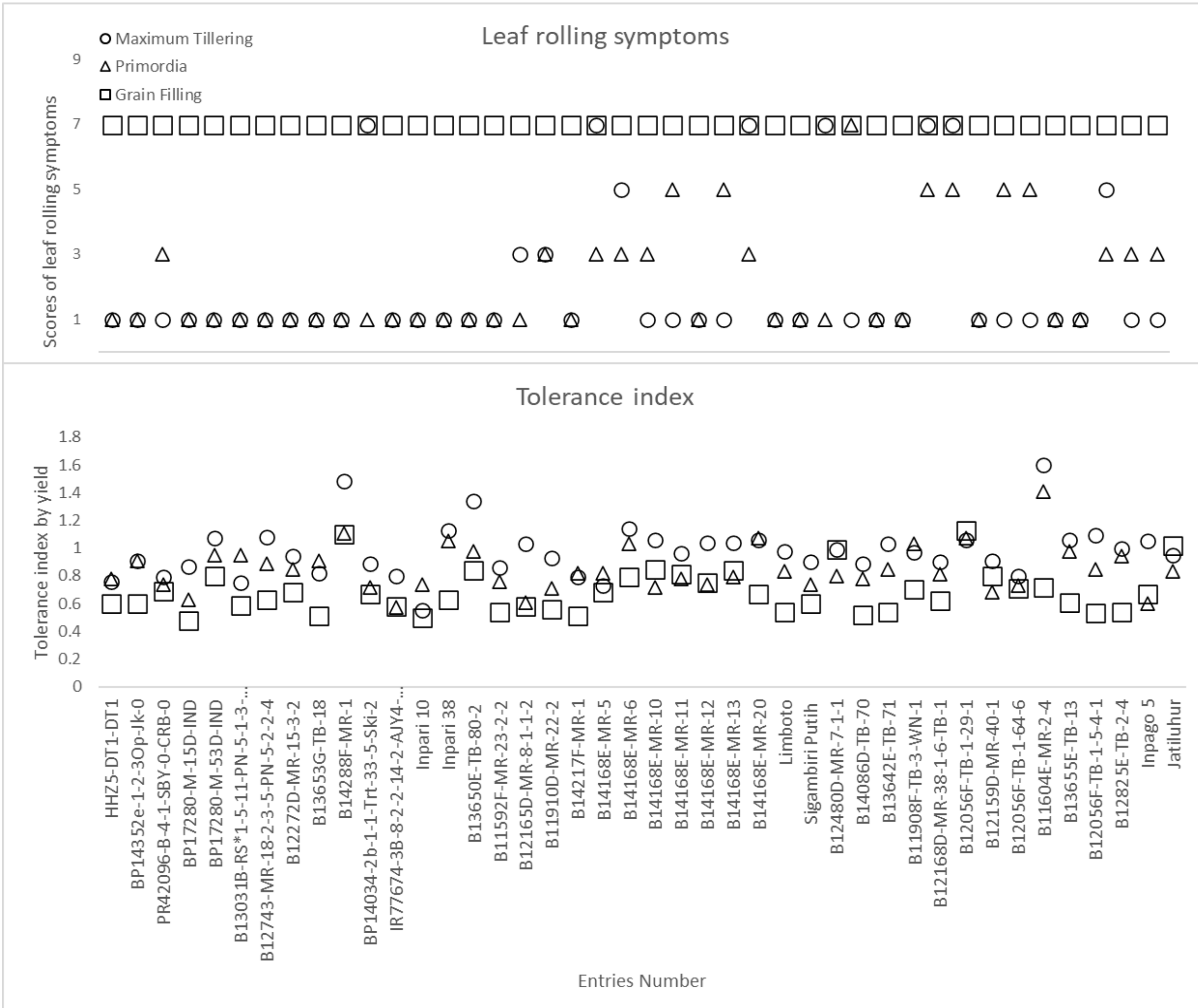


Figure 1. Scores of leaf rolling and tolerance index by yield to drought in several growth stages

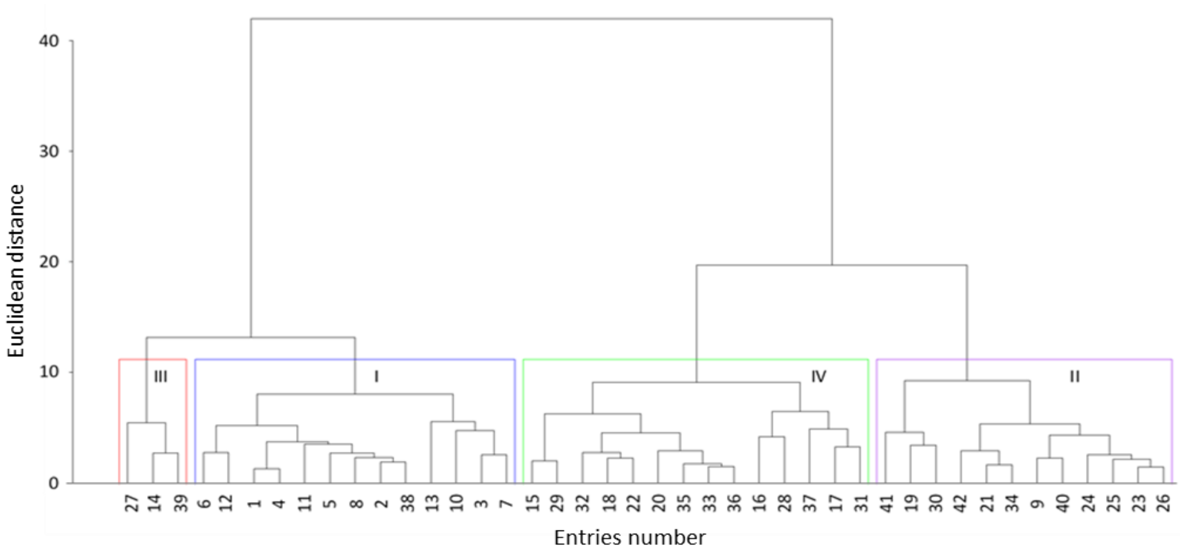


Figure 2. Grouping of test lines based on tolerance index, plant growth, and yield

Cluster analysis based on drought tolerance parameters, plant growth, and yield using Ward's method showed that of the 36 lines and 6 varieties tested, they were divided into four groups. There were various numbers of lines in each group (Figure 2). Cluster IV contains the most lines, while Cluster III contains the fewest. The similarity between the lines in the group was indicated by the value of the coefficient and a smaller value indicated that the lines were more similar to each other (Sitaresmi *et al*., 2018). This cluster was used to study the influence of drought periods on plant growth.

Plant height and tiller number are the characteristics that can describe the genetic and environmental influences on plant growth. Droughts in the vegetative stage can inhibit plant height and the development of the number of tillers (Davatgar *et al*., 2009). Chanu & Sarangthem (2023) report that the plant height and the number of tillers will be inhibited or decreased as the drought period increases.

The measurement of plant height during 35 days after sowing (DAS) until harvest is shown in Figure 3. The plant's height was observed to range from 104.33 cm to 170.50 cm. Cluster III has the lowest plant posture compared to the other clusters, whereas Cluster IV has the highest. According to variance analysis, the test lines and the drought period have a significant effect on plant height, but not the interaction. Based on measurements at maximum tillering and grain filling, the drought period had no significant effect on plant height. However, at the primordia stage, the drought period has a significant effect. Plant height on control and on the drought period at grain filling were not significant, but there is a significant difference in plant height between the drought period at primordia and at maximal tillering. It was indicated that drought periods at maximum tillering and at primordia inhibit plant height. According to Chanu & Sarangthem (2023), drought prevents cell division or cell enlargement. Plant posture was observed to be lower in lines treated with drought during maximum tillering. In all drought times, the lines showed significant differences.

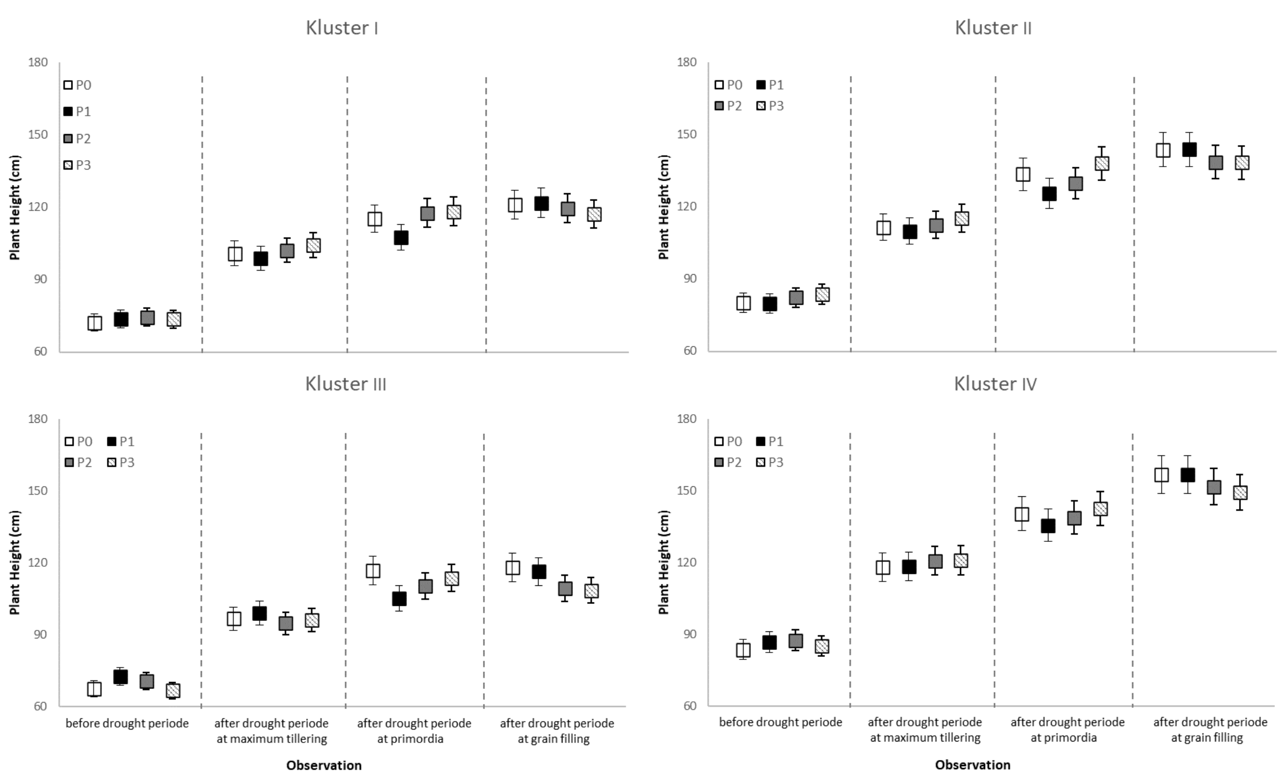


Figure 3. Plant height of test lines before and after drought periods at several growth stages (Note: P0: control; P1: drought at maximum tillering; P2: drought at primordia; P3: drought at grain filling)

Figure 4 depicts observations of the tiller number before and after the drought period. The observations revealed that the tiller number in this experiment varied between the tested lines and ranged from 9 to 19. In contrast to the drought period and interaction, test lines have an impact on the tiller number, according to variance analysis. This result shows that the tiller number of test lines has not decreased during the drought. This result contrasts with the findings of Chanu & Sarangthem (2023), which showed that the drought reduced the number of tillers, possibly as a result of less water being absorbed for photosynthesis and the restriction of systematic tissue cell division. Inpari 10 was the test line with the most tillers, and lines in Cluster I have more tillers than lines in other clusters.

The observations of yield component and yield are presented in Table 5. The results showed that only test lines showed a significant difference for panicle number, panicle length, and grain number per panicle. Since genotypic variations should have a stronger influence on that character than environmental factors, their responses to drought should not differ noticeably between drought periods. However, during a longer period of drought, panicle numbers per hill decrease (Chanu & Sarangthem, 2023). They hypothesized that the decrease in the number of panicles could be due to the minimal translocation of assimilation and water during panicle initiation and at the booting stage. According to Kato *et al*. (2008), the drought also increased secondary rachis abortion, which would reduce the amount of grain per panicle. According to the results, Inpari 10 had the highest panicle number, whereas B12165D-MR-8-1-1-2 had the longest panicle and the highest grain number per panicle.

The drought period and test lines had a significant effect on the unfilled grain percentage, 1000 grain weight, and grain weight per plant (Figure 5). The results of variance analysis showed that the percentage of unfilled grains and the 1000 grain weight were the same as to the control at the maximum tillering and primordia periods of drought. Drought periods at primordia reduced grain weight per plant by 16.87% in comparison to control plants, however drought periods at maximum tillering have observation values that do not statistically differ from the controls. Given that the yield loss is still less than 30%, the decreases suggest that the test lines have mild category decreases (Torres *et al*., 2012).

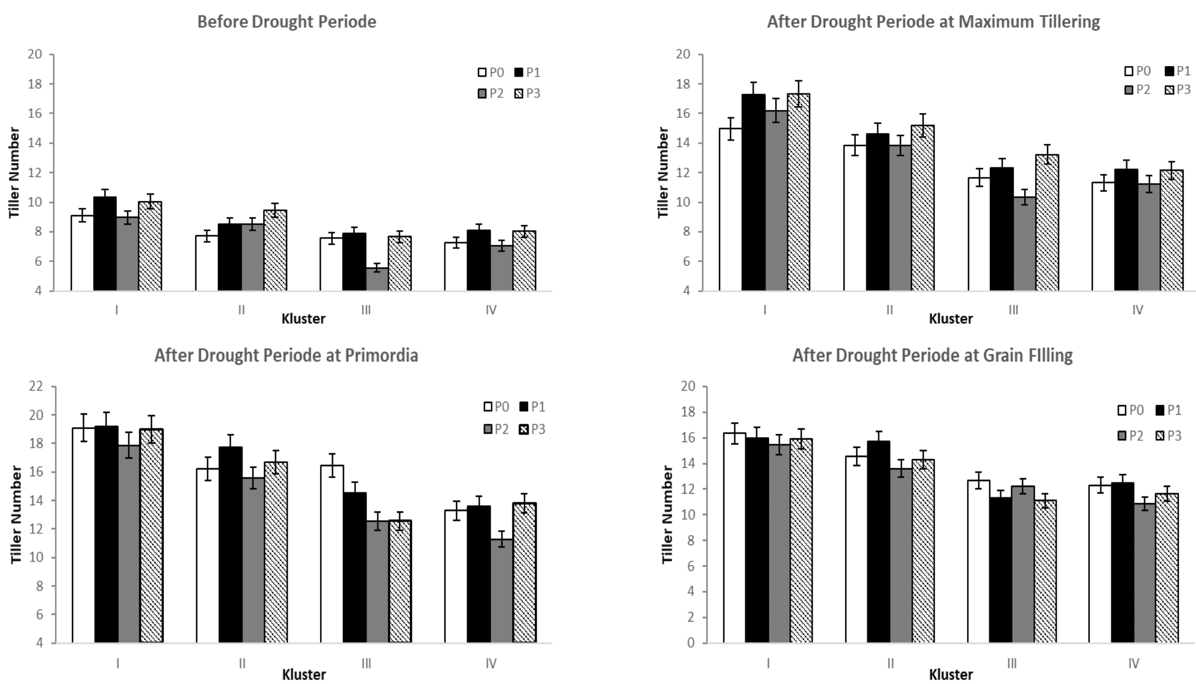


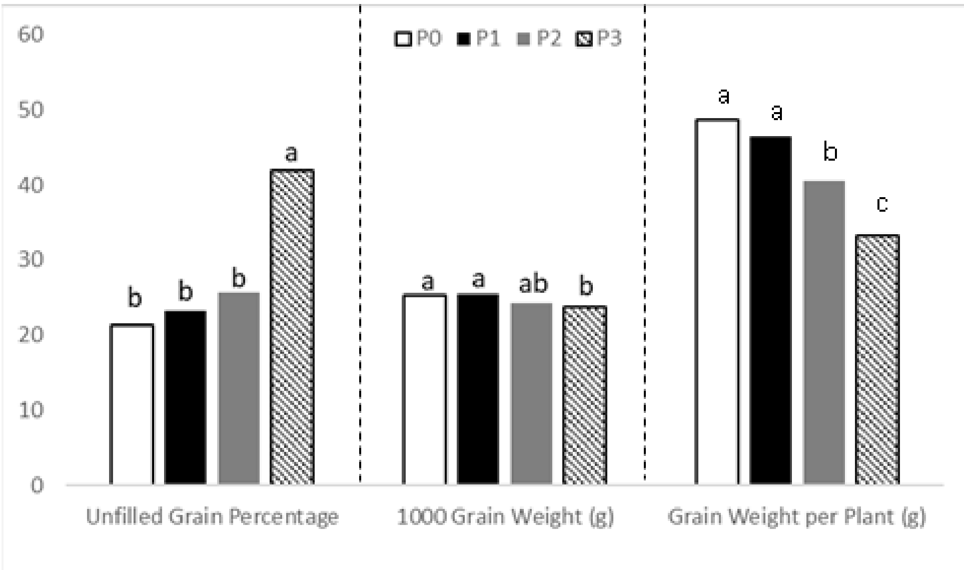
Figure 4. Tiller number of test lines before and after drought periods at several growth stages (Note: P0: control; P1: drought at maximum tillering; P2: drought at primordia; P3: drought at grain filling)

Table 5. Yield components and yield of test lines under drought stress

Lines	Panicle Number	Panicle Lenght (cm)	Grain Number per Panicle	Unfilled Grain (%)	1000 Grain Weight (g)	Grain Weight per Plant (g)
V1	17.25 a	24.22 a	113.02	21.02 a	22.42 a	38.29
V2	14.08	25.55 a	139.88 a	15.19 a	24.51 a	42.35
V3	17.73 a	24.39 a	129.78 a	23.21 a	22.25 a	44.51 a
V4	16.17 a	23.99 a	137.61 a	26.23 a	22.68 a	37.98
V5	17.00 a	25.25 a	132.18 a	28.69 a	24.05 a	41.12
V6	14.42 a	24.21 a	118.89	15.89 a	24.71 a	38.05
V7	16.00 a	25.62 a	154.40 a	26.21 a	22.30 a	40.08
V8	15.92 a	24.42 a	120.12	24.98 a	24.18 a	36.86
V9	14.00	26.27 a	148.17 a	36.12 b	25.92 a	41.75
V10	16.33 a	24.25 a	142.59 a	33.74 a	22.08 a	37.28
V11	18.00 a	24.29 a	121.43	21.17 a	23.39 a	44.19 a
V12	14.33 a	28.34 b	140.99 a	21.18 a	26.92 b	45.09 a
Inpari 10	19.58	22.64	101.01	25.44	25.28	36.52
Inpari 38	13.54	22.51	92.54	22.82	22.64	25.98
V15	12.00	26.09 a	225.83 b	37.04 b	22.39 a	42.58 a
V16	9.36	28.25 b	173.80 a	18.24 a	27.26 b	38.53
V17	10.83	32.92 b	255.63 b	44.53 b	26.75 b	47.73 a
V18	11.73	31.56 b	217.24 b	26.23 a	25.45 a	45.31 a
V19	12.00	28.04 b	162.29 a	25.29 a	22.69 a	37.18
V20	14.46 a	29.43 b	219.49 b	44.56 b	25.08 a	47.53 a
V21	17.00 a	25.81 a	159.42 a	30.61 a	24.24 a	46.63 a
V22	12.75	26.99 b	205.41 b	20.65 a	25.25 a	52.68 a
V23	13.50	26.92 b	176.78 a	26.37 a	25.02 a	49.63 a
V24	13.58	23.76 a	167.60 a	23.30 a	27.67 b	48.12 a
V25	14.17 a	24.68 a	181.92 a	22.57 a	24.62 a	53.13 a
V26	14.33 a	26.37 a	188.22 a	28.23 a	24.54 a	48.13 a
Limboto	10.67	30.12	162.08	24.43	25.09	34.35
Sigambiri Putih	12.17	28.58	155.73	37.34	28.97	35.70
V29	12.33	27.69 b	253.59 b	34.66 a	23.16 a	50.07 a
V30	17.00 a	27.48 b	149.06 a	32.74 a	22.04 a	41.86
V31	11.58	30.83 b	174.09 a	35.61 b	29.76 b	43.89 a
V32	10.67	27.53 b	174.12 a	19.04 a	27.18 b	42.79 a
V33	12.67	29.02 b	211.13 b	28.64 a	24.61 a	46.36 a
V34	15.91 a	25.14 a	176.91 a	32.29 a	24.28 a	49.31 a
V35	13.58	29.33 b	187.81 a	30.85 a	24.04 a	42.37
V36	12.46	29.24 b	212.39 b	39.93 b	24.95 a	44.86 a
V37	10.42	30.48 b	231.92 b	43.91 b	29.27 b	42.42 a
V38	15.17 a	24.95 a	127.71 a	17.92 a	23.56 a	40.07
V39	11.75	24.26 a	116.21	16.50 a	24.41 a	28.73
V40	14.58 a	25.46 a	166.79 a	30.35 a	22.64 a	42.02
Inpago 5	15.90	25.24	131.92	47.58	25.01	30.09
Jatiluhur	16.64	23.76	157.29	24.54	23.72	51.04

Note: Values followed by the letter a are not significant; the letter b are significant higher according to 5% LSD vs Jatiluhur variety
Jatiluhur is control variety with the highest grain weight per plant

Genotypes under severe drought stress during grain filling have the highest percentage of unfilled grains, the lowest 1000 grain weight, and the lowest grain weight per plant (Figure 5). The drought period at grain filling increased the unfilled grain percentage by 103.44% compared to control, while the 1000 grain weight and grain weight per plant decreased by 5.74% and 31.62%, respectively. This suggests that the primordia stage and the grain filling stage were the sensitive stages to drought. Similar to Yang *et al*., (2019), shows that drought has a significant impact on rice's physiological traits and yield during the generative phase, particularly during flowering. Unfilled grains typically result from low sink assimilation translocation rather than low biomass or sources (Moonmoon *et al*., 2020). Moonmoon *et al*., (2022) found that increased activity of invertase acid 21 induced by drought stress caused limited activity of photosynthesis in flag leaves that would further affect reproductive development. The rate of photosynthesis and chlorophyll content have been decreasing as drought occurs in the reproductive stage. Thus, drought in the reproductive stage leads to a decrease in both the rate of photosynthesis and the chlorophyll content during the reproduction stage. Akram *et al*., (2013) also note that the high percentage of unfilled grains and the low grain weight per plant are due to the failure to perfectly form ovaries and pollen, as well as further scanning against the formation of incomplete pollen tubes. Test lines had moderate drought stress since the percentage yield decline throughout the drought period at grain filling ranged from 31-64% (Torres *et al*., 2012). The results show that the test lines have genetic diversity, which were increases the possibility of drought-tolerant lines selection throughout different drought periods.



Note: P0: control; P1: drought at maximum tillering;
P2: drought at primordia; P3: drought at grain filling
Diagram followed by different letters are significant different according to 5% LSD

Figure 5. Unfilled grain percentage, 1000 grain weight, and grain weight per plant in different drought periods

4. CONCLUSIONS

Based on the results of the experiment series, we conclude that there were differences in genotype responses, such as:

1. Drought periods during maximum tillering and primordia affected plant height, while the tiller number was not affected by all drought periods.
2. According to yield characters, drought increased the unfilled grain percentage and decreased 1000 grain weight and grain weight per plant.
3. There is an opportunity to line selection that are drought-tolerances across various drought periods because of the genetic variety among the rice lines.
4. Jatiluhur is consistently tolerant and has the highest yield. There are 8 rice lines with consistent tolerance and not significantly different yields with Jatiluhur: B13650E-TB-80-2, B14168E-MR-6, B14168E-MR-10, B14168E-MR-11, B14168E-MR-12, B14168E-MR-13, B12480D-MR-7-1-1, and B12056F-TB-1-29-1.

ACKNOWLEDGEMENTS

The authors are grateful to the Indonesian Center for Rice Research of the Ministry of Agriculture for the funds and facilities for the research.

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