Drought tolerant rice breeding lines developed for rainfed lowland areas

A Hairmansis*, Yullianida, R Hermanasari, A P Lestari, P Sasmita and Suwarno

Indonesian Center for Rice Research, Indonesian Agency for Agricultural Research and Development, Jalan Raya 9 Sukamandi, Subang, West Java, 41256, Indonesia
*Corresponding author’s e-mail: a.hairmansis@gmail.com

Abstract. Drought is a major problem in rice production in rainfed areas. Climate change has exacerbated the negative effect of drought on the sustainability of rice production. Development of drought tolerant rice varieties is important strategy to minimize rice yield losses in drought prone areas. This study aimed to determine drought tolerance of twenty-five advanced rice breeding lines under artificial drought environment and to evaluate their agronomic performance in rainfed lowland rice areas. Evaluation of drought tolerance was carried out at seedling stage in greenhouse. Yield trial was conducted in rainfed rice area in Indramayu district, West Java province, during wet season 2017-2018. The trial was designed in randomized complete block design with four replications. Result from this study indicated a variation in drought tolerance of twenty-five breeding lines. Two lines showed highly tolerant response to drought in seedling stage namely B15231-MR-10-1 and B15143C-TGB-12. The grain yield of highly drought tolerant rice line B15231-MR-10-1 (4.81 t ha⁻¹) was comparable to popular rice varieties Situ Bagendit (4.56 t ha⁻¹) and Ciheryang (5.09 t ha⁻¹). Drought tolerant rice breeding lines identified from this study have potential to be adopted by farmers in drought prone rainfed areas as an adaptation strategy to the impact of climate change.

1. Introduction

Rice is served as the main food for nearly half world population [1]. About 75% of world rice production was supplied from irrigated lowland area, while about 19% and 4% were contributed by rainfed lowland and upland areas, respectively [1]. As the second largest rice ecosystem, rainfed lowland covered about 52 million ha worldwide [1]. Rainfed lowland rice areas are characterized as a fragile environment with drought as the major constraint [2,3]. It was estimated that more than 13 million ha of rainfed lowland areas throughout Asia affected by drought stress [4]. In Indonesia, drought-prone rainfed lowland areas is one of major contributors to the national rice production accounted for about 2.08 million ha distributed throughout the country [2].

Drought impacts on rice production in rainfed area would be worse due to global climate change [5]. The climate change is predicted to delay the onset of rainy season and decrease the precipitation [6]. It was estimated about 50% of agricultural areas in Indonesia has been experienced shorter rainy season and longer dry season and therefore increased the frequency of drought events [7]. Rice production in rainfed lowland areas which relied on rain would be heavily affected by the drought impacts of global climate change.

The damage caused by drought possibly occur in seedling, vegetative and reproductive stages of rice [8]. Drought has the most severe effect when occur during reproductive stage of rice [8,9]. Rice plants respond to drought stress through different adaptive mechanism including physiological and phenological mechanisms. Physiological responses of rice plants against drought stress including
improving water uptake system, increasing water use efficiency, reducing transpiration, and osmotic adjustment; while phenological response of rice plants through adjusting their flowering time [10].

Development of drought tolerant rice cultivars is one of important strategies to improve the rice productivity and production in drought-prone rainfed lowland [3]. However, progress in the breeding program to improve drought tolerance in rice remains slow due to the complexity of genetic determinant of drought tolerance [11]. Direct selection on grain yield character of rice in stress environment is suggested to be the most effective strategy to develop drought tolerant rice [11,12]. This study aimed to evaluate drought tolerance of advanced rice breeding lines in vegetative stage and to evaluate agronomic performance of the materials in rainfed lowland rice areas.

2. Materials and methods

2.1. Plant materials
A total of 25 rice breeding lines and three check varieties (Situ Bagendit, Ciherang and Dodokan) were evaluated for their drought tolerance and yield trial. Situ Bagendit and Ciherang are popular rice varieties grown by farmers in rainfed lowland areas. Dodokan is short duration rice variety released for rainfed lowland rice areas. Most of the materials has popular varieties genetic background such as Ciherang, Situ Patenggang, Inpago 8 and Batutegi (Table 1).

2.2. Drought tolerance evaluation
Evaluation of drought tolerance was carried out at seedling stage using concrete tank method (Figure 1) following the previous study [13]. Rice seeds were directly sown in a concrete tank (L 5.5 m x W 1.3 m x H 0.6 m) filled with soil collected from paddy field. Ten seedlings were grown for each line with plant spacing of 20 cm within lines and 20 cm between lines. Drought tolerant check variety Salumpikut and susceptible check variety IR20 were grown in each 20 rice breeding lines. Soil was watered until the seedling were two weeks old. Watering was then stopped until the susceptible check variety was died. Scoring was performed following [14] when the susceptible check was died (score 9).

2.3. Replicated yield trial.
Yield trial was conducted in rainfed rice area in Indramayu district, West Java province, during wet season 2017-2018. The trial was designed in randomized complete block design with four replications. Twenty-one days old rice seedlings were transplanted at a plant spacing of 20 cm × 20 cm. Each genotype was planted in a 2 m × 5 m plot. Observation were made for agronomic characters of rice
including plant height, number of productive tillers, flowering time, harvesting time, panicle length, number of filled grains, number of empty grains, grain filling percentage, 1000 grain weight and grain yield.

Table 1. Drought tolerance score and level of rice breeding lines under drought treatment in green house during vegetative stage

| Lines           | Parentage                        | Score | Level            |
|-----------------|----------------------------------|-------|------------------|
| B15143C-TGB-12  | B13654G-MR-3/Jatiluhur          | 1     | Highly tolerance |
| B15175C-TGB-12  | B11423G-MR-1/ Jatiluhur/B11423G-MR-1 | 3     | Tolerance        |
| B15862-1-3      | Ciherang*4/Inpari 13//IRBL m-6   | 5     | Moderately tolerance |
| B15862-5-1      | Ciherang*4/Inpari 13//IRBL m-6   | 5     | Moderately tolerance |
| B15862-6-1      | Ciherang*4/Inpari 13//IRBL m-6   | 7     | Susceptible      |
| B15209B-MR-1-2  | Inpago 8*2/PTB33/IR64          | 3     | Tolerance        |
| B15209B-MR-12-5 | Inpago 8*2/PTB33/IR64          | 3     | Tolerance        |
| B15209B-MR-12-6 | Inpago 8*2/PTB33/IR64          | 3     | Tolerance        |
| B15231-MR-10-1  | Inpago8*4/Phb33/IR64           | 1     | Highly tolerance |
| B15053F-PWR-2   | Batutugi*2/Memberamo           | 7     | Susceptible      |
| B14958-MR-11-25-1-1-1 | Batutugi*4/Conde | 7     | Susceptible      |
| B14958-MR-11-25-1-1-2 | Batutugi*4/Conde | 7     | Susceptible      |
| B14949-MR-2-1-1  | Inpari 5*5/Conde              | 7     | Susceptible      |
| B14949-MR-2-2-1  | Inpari 5*5/Conde              | 7     | Susceptible      |
| B15227-MR-5-2   | Inpari 30*4/Conde             | 7     | Susceptible      |
| B15227-MR-5-3   | Inpari 30*4/Conde             | 5     | Moderately tolerance |
| B15195B-MR-7-3  | Inpari 30*3/Conde             | 5     | Moderately tolerance |
| B15056C-MR-1-1  | Sintanur/Conde               | 9     | Highly susceptible |
| B15056C-MR-1-2  | Sintanur/Conde               | 9     | Highly susceptible |
| B14948-MR-3-15-3-2 | Inpara 2*4/Conde | 9     | Highly susceptible |
| B14948-MR-3-15-3-3 | Inpara 2*4/Conde | 7     | Susceptible      |
| B14191E-MR-3-61 | Situpatenggang/IR68144-2B-2-2-3-2 | 7     | Susceptible      |
| B14192E-MR-2    | Situpenggang/IR73571-2B-14-2  | 7     | Susceptible      |
| B14192E-MR-33   | Situpenggang/IR73571-2B-14-2  | 7     | Susceptible      |
| B10580E-KN-28-1-1 | TB154E-TB-1/Kapuas       | 7     | Susceptible      |
| Situ Bagendit   | Improved rice variety         | 7     | Susceptible      |
| Dodokan         | Improved rice variety         | 3     | Tolerance        |
| Ciherang        | Improved rice variety         | 7     | Susceptible      |
| Salumpikit      | Drought tolerant check        | 1     | Highly tolerance |
| IR20            | Drought susceptible check     | 9     | Highly susceptible |

3. Results and discussion

3.1. Drought tolerance of rice genotypes in seedling stage

A total of 25 advanced rice breeding lines have been screened for their responses to drought stress in seedling stage. The materials showed variation in their tolerance to drought in seedling stage (Table 1). Two lines showed highly tolerant response to drought (score 1) namely B15143C-TGB-12 and B15231-MR-10-1 which were comparable to the tolerant check variety Salumpikit. Salumpikit has been intensively used as a standard check variety for drought tolerance experiment [15]. However, the variety...
has poor agronomic performance. The lines B15143C-TGB-12 and B15231-MR-10-1 were derived from improved upland rice variety Jatiluhur and Batutegi, respectively. There were four lines which showed tolerance response to drought (score 3) and five lines showed moderately tolerance response (score 5). The remaining breeding lines were categorized as susceptible (score 7) or highly susceptible (score 9). Drought stress caused detrimental effect on rice plants in all growth stage from seedling until reproductive stage [16]. The ability of rice genotype to adapt against drought stress during seedling stage is important when early-season drought occur [15].

**Table 2.** Agronomic performance of rice breeding lines in rainfed lowland rice area of Indramayu, West Java, Wet Season 2017-2018

| Lines             | PH  | NPT | FT  | HT  | PL  | NFG | NEG | GF  | GW  | GY  |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| B15143C-TGB-12    | 126.8 | 10.7 | 75  | 106 | 26.0 | 167.2 | 54.3 | 77.1 | 27.7 | 4.10 |
| B15175C-TGB-12    | 111.6 | 12.2 | 76  | 105 | 27.0 | 131.6 | 24.6 | 83.8 | 32.9 | 5.13 |
| B15862-1-3        | 109.2 | 12.0 | 86  | 117 | 26.3 | 130.1 | 44.7 | 74.4 | 26.7 | 4.30 |
| B15862-5-1        | 109.3 | 12.8 | 84  | 117 | 25.0 | 127.0 | 40.9 | 74.7 | 27.2 | 4.56 |
| B15862-6-1        | 104.0 | 13.6 | 83  | 118 | 25.2 | 144.2 | 40.2 | 78.1 | 27.1 | 4.64 |
| B15209B-MR-1-2    | 122.5 | 12.3 | 83  | 115 | 26.1 | 165.4 | 47.4 | 78.9 | 27.1 | 4.01 |
| B15209B-MR-12-5   | 114.1 | 13.0 | 82  | 112 | 27.1 | 166.6 | 41.6 | 83.4 | 27.3 | 4.33 |
| B15209B-MR-12-6   | 114.4 | 12.3 | 81  | 114 | 27.5 | 158.6 | 56.0 | 77.6 | 27.1 | 4.54 |
| B15231-MR-10-1    | 131.7 | 11.0 | 92  | 117 | 26.6 | 150.0 | 36.1 | 83.7 | 32.1 | 4.81 |
| B15053F-PWR-2     | 107.9 | 9.8  | 89  | 117 | 24.9 | 174.2 | 101.9 | 62.8 | 24.1 | 3.24 |
| B14958-MR-11-25-1-1 | 115.4 | 10.0 | 82  | 116 | 28.2 | 228.5 | 41.7 | 85.7 | 26.8 | 5.06 |
| B14958-MR-11-25-1-1-2 | 116.7 | 10.1 | 82  | 114 | 28.5 | 209.0 | 48.6 | 79.3 | 25.4 | 4.15 |
| B14949-MR-2-1-1   | 110.2 | 12.2 | 80  | 114 | 26.0 | 127.6 | 48.1 | 73.1 | 26.4 | 2.97 |
| B14949-MR-2-2-1   | 111.0 | 13.4 | 83  | 112 | 26.5 | 137.5 | 52.3 | 72.3 | 26.6 | 3.93 |
| B15227-MR-5-2     | 108.4 | 13.3 | 84  | 117 | 24.9 | 124.4 | 41.1 | 75.4 | 26.7 | 3.96 |
| B15227-MR-5-3     | 110.2 | 13.5 | 83  | 118 | 25.6 | 125.6 | 32.6 | 77.1 | 26.8 | 4.01 |
| B15195B-MR-7-3    | 107.7 | 12.3 | 93  | 117 | 25.9 | 147.5 | 28.1 | 82.8 | 27.7 | 4.59 |
| B15056C-MR-1-1    | 110.7 | 12.3 | 81  | 116 | 27.5 | 170.4 | 36.1 | 81.5 | 27.2 | 5.35 |
| B15056C-MR-1-2    | 106.5 | 12.2 | 80  | 118 | 24.8 | 133.8 | 38.4 | 75.9 | 27.5 | 3.92 |
| B14948-MR-3-15-3-2 | 116.3 | 14.0 | 87  | 118 | 25.3 | 142.1 | 17.6 | 88.3 | 29.9 | 5.16 |
| B14948-MR-3-15-3-3 | 118.6 | 13.4 | 86  | 117 | 25.5 | 142.1 | 16.6 | 90.1 | 29.2 | 5.22 |
| B14191E-MR-3-61   | 123.8 | 12.4 | 75  | 104 | 24.3 | 136.7 | 49.0 | 74.4 | 26.2 | 3.22 |
| B14192E-MR-2      | 129.0 | 12.9 | 78  | 106 | 27.5 | 139.2 | 44.2 | 78.6 | 30.8 | 4.20 |
| B14192E-MR-33     | 137.9 | 11.0 | 86  | 115 | 24.9 | 153.8 | 19.4 | 87.7 | 30.2 | 4.97 |
| B10580E-KN-28-1-1 | 116.9 | 11.3 | 84  | 117 | 27.2 | 205.2 | 22.7 | 90.9 | 27.4 | 3.63 |
| Situ Bagendit     | 107.4 | 13.7 | 81  | 107 | 26.9 | 123.8 | 45.2 | 75.5 | 27.9 | 4.56 |
| Dodokan           | 105.6 | 15.7 | 72  | 101 | 23.5 | 98.4 | 53.1 | 66.8 | 25.4 | 3.20 |
| Ciberang          | 109.4 | 13.5 | 82  | 118 | 25.2 | 142.6 | 27.5 | 85.0 | 28.0 | 5.09 |

**Mean**

| CV (%) | 3.7 | 11.9 | 4.9 | 2.1 | 2.6 | 13.3 | 29.8 | 7.6 | 2.8 | 14.1 |
| LSD (5%) | 5.8 | 2.2 | 5.6 | 3.3 | 0.9 | 27.3 | 16.8 | 8.4 | 1.0 | 0.85 |

Abbreviation: PH= Plant height (cm), NPT= Number of productive tiller, FT= Flowering time (d), HT= Harvest time (d), PL= Panicle length (cm), NFG= Number of filled grain per panicle, NEG= Number of empty grain per panicle, GF= Grain filling percentage, GW= 1000 grain weight (g), GY= grain yield (ton ha⁻¹), CV= Coefficient of variance, LSD= Least significant difference
3.2. Agronomic performance of rice genotypes in rainfed lowland area

Agronomic performance of drought tolerance rice breeding lines was evaluated in rainfed areas in Indramayu during WS 2017-2018. Analysis of variance on agronomic characters of 25 advanced breeding lines showed variation among the lines for all characters (Table 2). Several rice lines had higher plant height compared to popular rice varieties Situ Bagendit (107.4 cm), Dodokan (105.6 cm) and Ciherang (109.4 cm). Most of the lines had comparable number of productive tillers to Situ Bagendit (13.7) and Ciherang (13.5), but mostly had lower number compared to check variety Dodokan (15.7). Flowering time of rice breeding lines were mostly comparable to Situ Bagendit (81 d) and Ciherang (82 d), while only three lines which showed early flowering similar to Dodokan (72 d) including B15143C-TGB-12 (75 d), B15175C-TGB-12 (76 d) and B14191E-MR-3-61 (75d).

The grain yield of rice breeding lines ranged from 2.97 to 5.35 t ha$^{-1}$ (Table 2). The grain yield of highly drought tolerant rice line B15231-MR-10-1 (4.81 t ha$^{-1}$) and drought tolerant rice line B15175C-TGB-12 (5.13 t ha$^{-1}$) were comparable to popular varieties Situ Bagendit (4.56 t ha$^{-1}$) and Ciherang (5.09 t ha$^{-1}$). Selection on grain yield character of rice genotype in target areas was considered as the primary approach to select drought tolerant rice [11,12,17]. The line B15175C-TGB-12 also had early maturity (105 d) which was important trait in rainfed lowland areas to escape from drought in generative stage by completing rice life cycle before drought occur [11].

The intensity of drought events in the future is predicted to be more frequent as the impact of climate change [5,6]. Rainfed lowland rice areas which has significant contribution to the national rice production in Indonesia will be the most suffered from drought in near future. Cultivation of high yielding drought tolerant rice cultivars developed in this study will be a potential adaptation strategy to the impact of climate change in rainfed lowland rice areas and maintaining the sustainability of rice production.

4. Conclusion

This study has identified two lines which were highly tolerant to drought namely B15231-MR-10-1 and B15143C-TGB-12. The grain yield of highly drought tolerant rice line B15231-MR-10-1 was comparable to popular rice varieties Situ Bagendit and Ciherang. Drought tolerant rice breeding lines developed in this study has potential to be adopted by farmers in drought prone environments as an adaptation strategy to the impact of climate change and to increase rice productivity in rainfed lowland areas. Further studies are needed to evaluate the adaptability of the selected lines in more diverse drought-prone environment.

References

[1] GRiSP 2013 Rice Almanac 4th Edition (Los Banos: International Rice Research Institute)
[2] Hairmansis A, Rumanti I A, Nugraha Y, Kato Y and Jamil A 2016 Reaping gains with less rain: best management practices for drought-prone rice areas in Indonesia Climate-ready technologies: Combating poverty by raising productivity in rainfed rice environments in Asia ed D Manzanilla, R K Singh, Y Kato and D Johnson (Los Banos, Philippines: International Rice Research Institute) p 204
[3] Haefele S M, Kato Y and Singh S 2016 Climate ready rice: Augmenting drought tolerance with best management practices F. Crop. Res. 190 60–9
[4] Mohanty S, Wassmann R, Nelson A, Moya P and Jagadish S V K 2013 Rice and climate change: significance for food security and vulnerability (Los Banos, Philippines)
[5] Li T, Angeles O, Radanielson A, Marcaida M and Manalo E 2015 Drought stress impacts of climate change on rainfed rice in South Asia Clim. Change 133 709–20
[6] Naylor R L, Battisti D S, Vimont D J, Falcon W P and Burke M B 2007 Assessing risks of climate variability and climate change for Indonesian rice agriculture. Proc. Natl. Acad. Sci. U. S. A. 104 7752–7
[7] MOA 2015 Strategic planning of Ministry of Agriculture year 2015-2019 (Jakarta: Ministry of Agriculture Republic of Indonesia)
[8] Sandhu N and Kumar A 2017 Bridging the Rice Yield Gaps under Drought: QTLs, Genes, and their Use in Breeding Programs Agronomy 7 27
[9] Garrity D P and O’Ttoole J C 1994 Screening rice for drought resistance at the reproductive phase F. Crop. Res. 39 99–110
[10] Li Z and Xu J 2007 Breeding for drought and salt tolerant rice (oryza sativa L.): progress and perspectives Adv. Mol. Breed. Towar. Drought Salt Toler. Crop. 531–64
[11] Dixit S, Singh A and Kumar A 2014 Rice Breeding for High Grain Yield under Drought: A Strategic Solution to a Complex Problem Int. J. Agron. 2014 1–15
[12] Bernier J, Atlin G N, Serraj R, Kumar A and Spaner D 2008 Breeding upland rice for drought resistance J. Sci. Food Agric. 88 927–39
[13] Hairmansis A, Warsono, Yullianida, Trisnaningsih and Suwarno 2018 Combining of drought tolerance and brown planthopper resistance traits into elite rice cultivars targeting rainfed area Proceedings of PERIPI-2017 International Seminar ed Y Wahyu, D Wirnas, Trikoesoemaningtyas, A W Ritonga and S Marwiyah (Bogor: PERIPI (Indonesian Breeding Science Society)) pp 83–90
[14] IRRI 2014 Standard Evaluation System for Rice (Los Banos: IRRI)
[15] de Datta S K, Malabuyoc J A and Aragon E L 1988 A field screening technique for evaluating rice germplasm for drought tolerance during the vegetative stage F. Crop. Res. 19 123–34
[16] Oladosu Y, Rafii M Y, Samuel C, Fatai A, Magaji U, Kareem I, Kamarudin Z S, Muhammad I and Kolapo K 2019 Drought Resistance in Rice from Conventional to Molecular Breeding: A Review Int. J. Mol. Sci. 20 3519
[17] Fischer K S, Fukai S, Kumar A, Leung H and Jongdee B 2012 Field Phenotyping Strategies and Breeding for Adaptation of Rice to Drought† Front. Physiol. 3 282

Author Contributions
A.H., SW. conceived and designed the experiments. A.H., P.S. supervised the project. A.H., Y.L. R.H. A.P.L. performed the experiments. A.H., Y.L. analysed the data. A.H. wrote the manuscript with the input from all authors. All authors read and approved the final manuscript.

Acknowledgement
This study was funded by Research Partnership Program KP4S 2017 under the Sustainable Management of Agricultural Research and Technology Dissemination (SMARTD) Project of Indonesian Agency for Agricultural Research and Development (IAARD).