Physiological characteristic of 10 sorghums genotypes under water stress in greenhouse

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Abstract. Selection to screen sorghum accessions tolerance to drought condition was conducted. The experiment was conducted in the glasshouse on 10 sorghum accession using a Randomized Block Design, on July to October 2017. Three water treatments were used i.e., 30% of field capacity (FC), 50% FC and 80% FC, with 3 replicates for each treatment. The results indicated that N6.12 was very sensitive to drought with water potential of -6.45 MPa at 30% FC and -6.22 MPa at 50% FC, while Jagung Rote was very resistant with water potential of -4.23 at 30% FC, followed by Suri 3 with -3.33 at 50% FC. The two accessions with the lowest photosynthetic rates were Super 1 and WR with 8.61809455 and 8.1580396 µmol m⁻² s⁻¹, respectively. The three highest photosynthetic rates were shown by Suri 3 (14.32254207 µmol m⁻² s⁻¹), Jagung Rote (15.37299675 µmol m⁻² s⁻¹), and UPCA (11.87406017 µmol m⁻² s⁻¹). Sorghum with the lowest biomass production were Buleleng Empok (26.61 g plant⁻¹) and the highest was WR (57.17 g plant⁻¹). The lowest plant height was UPCA and the highest was Suri 4. We concluded that Jagung Rote and Suri 3 were the most tolerant sorghum accessions to drought according to their leaf water potentials and photosynthetic rates.

1. Introduction

Sorghum (Sorghum bicolor (L) Moench), is the fifth most important cereal after rice, wheat, maize, and barley [1]. It is the major food grain for over 750 million people who live in the semi-arid tropics of Africa, Asia, and Latin America. The producers mostly are small-scale subsistence farmers with minimal access to production inputs such as fertiliser(s), pesticides, improved seeds (hybrids or varieties), good soil and water, and credit facilities for their purchase [2].

The growth and development of sorghum are comparable to those of most determinate species, in that three major development periods exist in the life cycle. The period from emergence until the apical meristem conversion from a vegetative stage, leaf producing system to a reproductive apex, and grain filling period and grain maturity can be categorized as growth stage 1 (GS-1), growth stage 2 (GS-2) and growth stage (GS-3), respectively [3-5]. However, although sorghum is known as a minor crop, sorghum is very important because they are very adaptive to dry areas and simple to cultivate. Moreover, since water shortage was a serious problem particularly in the dry area of Indonesia, which is worsen by the global climate change [6], sorghum cultivation is more desirable [6]. Recently, different sorghum cultivars were widely distributed in Indonesia [7].

The study on the roles of moisture on plants, especially in the area of the plant water relations, relative water content, stomatal regulation, photosynthesis, respiration, protein metabolism, hormone and membrane integrity are very important for crop cultivation management through plant breeding [3,8], [9]. Research to select sorghum accessions that is resistant to drought to be develop in the dry area was
very important since water shortage is a serious problem because of the global climate change impact, particularly in the dry area of Indonesia [6]. To meet the needs, a research to screen sorghums tolerance to drought condition was performed.

Research of leaf water potential to screen sorghum genotypes that sensitive to water stress had already been conducted previously. This research was also supported by observation on plant height and leaf width [10]. Previous research that observed the effect of water supply to the physiological characteristic and production of Basil (*Ocimum basilicum* L.) showed that the driest condition (30% soil water content) will be reduced 20% of relative water content (RWC) in the plants and reduced to 45% of water potential compared to the control plants (water supply to 70% soil water content) [11]. Another research [12] on wheat cultivars (*Triticum durum*) grown in Saudi Arabia indicated that water deficit on plant growth depend on the combination of water stress regime and wheat cultivars. This research was a continuation of our initial research [10] mentioned above. This research observed leaf photosynthetic rate and water potential as a rapid test to understand crops response to water stress. These methods were combined with the agronomics observation such as plant height, biomass weight and root length. The specific objective of this research was to characterize physiological response of 10 sorghum accessions due to water stress in the greenhouse.

2. Material and methods

2.1. Research location

The research was part of SATREPS LIPI-JICA Programme, conducted on July to October 2017, in the greenhouse of Research Center for Biotechnology, Indonesian Institute of Sciences, Cibinong Science Center. In this research, light intensity as photosynthetic photon flux density (PPFD) or Qinleaf, relative humidity (RH), and temperature were automatically set using the Licor-6800 Portable Photosynthesis System.

2.2. Materials

Ten sorghums genotypes used in this research were N6.12, WHP, Buleleng Empok, Suri 4, Super 1, Samurai 1, WR, UPCA, Jagung Rote, and Suri 3. Sorghum seeds were obtained from Cereal Crop Research Institute in Maros, South of Sulawesi. The seed were then propagated at the Research Center for Biotechnology, Indonesian Institute of Sciences in Cibinong.

2.3. Equipment

Leaf water potential was measured using WP4-Water Potential Meter (WP4). WP4 is able to measure water potential from 0 to -300 MPa. However, its accuracy is different based on the value of potential, ±0.1 MPa and ±1% for 0 to -10 MPa and -10 to -300 MPa, respectively. The operational procedure to observe the leaf water potential using WP4 was as described previously [13]. Licor-6800 Portable Photosynthesis System (LI-COR, USA) was used to observe gas exchange including photosynthetic rate (A), transpiration rate (E), and stomatal conductance to water vapour (gsww). It was operated under the photosynthetic photon flux density (PPFD) or Qinleaf from open sunlight as a light source. The measurements were performed between 09.30 to 10.30 AM. The settings used were as follows: flow rate: 500 µmol s⁻¹, RH: 50 %, CO₂ reference: 400-500 µmol L⁻¹, fan speed: 8000 rpm, control temperature/TxCh: 27-28°C, and leaf constant: 3 cm x 3 cm [14].

2.4. Design and application

Randomized Block Design was used in this research. The total number of sorghum accession used was ten (10). Three water treatments were 30% of field capacity (FC, severe stress), 50% FC (moderate stress) and 80% FC (control), with 3 replications. Thus, the samples measured in this research were 270 plants samples (Figure 1). Sorghum seeds were planted in pot with a medium composed of soil, organic fertilizer and sand. Sorghum was irrigated to match the field capacity design from the germination stage until 2 weeks after planting. Plants were then irrigated twice a week with water volume according to
the water treatment. The parameters observed were leaf water potential (MPa), leaf relative water content, leaf photosynthetic rate (µmol m⁻² s⁻¹), leaf transpiration rate (in mol m⁻² s⁻¹), plant height (cm), stem diameter (cm), root length (cm), root weight (g) and biomass weight (g). Data were then analysed statistically using MS Excel and SPSS.

Figure 1. Research layout with 30%, 50% and 80% of field capacity in greenhouse, Research Center for Biotechnology, Indonesian Institute of sciences July to October 2017.

3. Results and discussion

3.1. Leaf water potential
Leaf water potential is an important indicator for plant water status and can be applied in consideration to the irrigation schedule [15]. It is crucial to maintain the optimum plant water status. If the plant water status declines beyond a certain limit (threshold level), there is a severe decline in yield and quality of vegetable crops [16]. Soil and water salinity also affected leaf water status that can be measured by their leaf water potential [17].

The means of leaf water potentials of 10 sorghum accessions at 21 days after planting of plants under 100% (-4,037 MPa) was almost similar than that of under 80% field capacity at 45 days after planting (-4,207). The mean of leaf water potential tends to be more negative under the 50% of field capacity (-4,663 MPa), and even more negative under 30% of field capacity at 45 days after planting (-5,009 MPa) (Figure 2).

Observation on leaf water potential in the lab was performed using descriptive statistics as shown in Table 1. Research indicated that N6.12 was very sensitive to drought with water potential of -6.45 MPa in 30% FC and – 6.22 MPa in 50% FC. Jagung Rote was considered very resistant with - 4.23 in 30% FC, followed by Suri 3 with - 3.33 in 50% FC (Table 1). These results were in accordance with the previous results [9], showing that the more negative value of leaf water potential, the more sensitive the sorghum to water stress. It happened in sorghum under water stress treatment, with range of water potential value between -4.435 MPa to -2.69 MPa. However, control sorghum plants showed less negative water potential in the range of -3.53 MPa to -1.67 MPa.
Figure 2. Leaf water potential (LWP) of sorghums under water stress with 30%, 50%, 80% of field capacity were observed at 45 days after planting (dap), and initial observations with 100% of field capacity was observed at 21 days after planting.

Table 1. Leaf water potential of 10 sorghum accessions under water stress with 30%, 50% and 80% of field capacity in the greenhouse

| Sorghum accession/Cultivar | 100% 02/08/2017 21 dap | 80% 23/08/2017 45 dap | 50% 23/08/2017 45 dap | 30% 23/08/2017 45 dap |
|----------------------------|------------------------|-----------------------|-----------------------|-----------------------|
| N6.12                      | 3.61                   | 4.01                  | 6.22                  | 6.45                  |
| WHP                        | 4.15                   | 5.46                  | 5.46                  | 5.72                  |
| Buleleng                   | 3.74                   | 3.77                  | 4.73                  | 4.06                  |
| Suri 4                     | 3.96                   | 3.96                  | 5.80                  | 4.35                  |
| Super 1                    | 4.81                   | 4.07                  | 4.5                   | 4.05                  |
| Samurai                    | 3.7                    | 3.7                   | 3.76                  | 5.58                  |
| WR                         | 4.12                   | 4.82                  | 4.95                  | 5.35                  |
| UPCA                       | 4.45                   | 4.45                  | 5.46                  | 6.02                  |
| Jagung Rote                | 3.78                   | 3.78                  | 3.56                  | 4.23                  |
| Suri 3                     | 4.05                   | 4.05                  | 3.33                  | 4.28                  |
| Average/mean               | 4.037                  | 4.207                 | 4.663                 | 5.009                 |
| Deviation standard         | 0.372                  | 0.556                 | 0.976                 | 0.909                 |
| Maximum                    | 4.810                  | 5.460                 | 6.220                 | 6.450                 |
| Minimum                    | 3.610                  | 3.700                 | 3.330                 | 4.050                 |

Plants that experience water stress will have more negative leaf water potential, and this was dependent on the applied irrigation. In cotton leaf water potential will reach minimal values of between -2.18 and -2.31 MPa when plant was under water stress [18]. The more negative values of leaf water potential indicated that plant experience of water stress. These phenomena can be observed in the research of sorghum, pearl millet, and corn under deficit irrigation [19]. Leaf water potential dramatically decreased when temperature increases or plants experiencing temperature stress, as can be
seen in a research on wheat [20]. Leaf water potential was also influenced by micro-climatic condition. In the research of young Quercus petraea (M.) Liebl. coppice sprouts and seedlings during favourable and drought conditions, indicated that when microclimatic was warm but not wet leaf water potential was \(-1.1\) MPa, when it was hot and dry leaf water potential \(<-1.4\) MPa, and when it was cool and wet leaf water potential was \(-0.98\) MPa [21].

3.2. Photosynthetic rates

Relationship between photosynthetic rate and Qleaf in was shown in Figure 3. Photosynthetic rate in the greenhouse were highly influenced by light intensity absorbed by sorghums leafQ (Qleaf in), which was indicated by \(R^2 = 0.666\). Photosynthetic rates in the morning were higher than that of in the afternoon, and sorghum that received more light intensity tend to have high photosynthetic rates. The photosynthetic rates of sorghum in the field were higher than that of in the greenhouse due to the shading effects of the glasshouse.

\[
y = 0.0405x - 0.2836 \\
R^2 = 0.6668
\]

![Figure 3](image)

**Figure 3.** Relationship between Qleaf in and photosynthetic rate of sorghums in the greenhouse

Figure 4 showed that the two sorghum with the lowest photosynthetic rates was Super 1 and WR,8.61 and 8.15 \(\mu\text{mol m}^{-2}\text{s}^{-1}\), respectively. Their Qleaf in were, 210.72 and 266.99 \(\mu\text{mol m}^{-2}\text{s}^{-1}\), respectively. The three sorghum with the highest photosynthetic rateswere Suri 3 (14.32 \(\mu\text{mol m}^{-2}\text{s}^{-1}\)), Jagung Rote (15.37 \(\mu\text{mol m}^{-2}\text{s}^{-1}\)), and UPCA (11.87 \(\mu\text{mol m}^{-2}\text{s}^{-1}\)). While their Qleaf in were:Suri 3 (370,64 \(\mu\text{mol m}^{-2}\text{s}^{-1}\)), Jagung Rote (326.04 \(\mu\text{mol m}^{-2}\text{s}^{-1}\)), and UPCA (299.81 \(\mu\text{mol m}^{-2}\text{s}^{-1}\)).

Photosynthetic and transpiration rates in the plant follow plant water balance rule and basically it is controlled by plant water balance. When the water lost to the atmosphere from the mesophyll and inner surface of the epidermal cells of the leaf, the water potential of the cells falls and gradient in water potential was then established between plant leaves and the soils [22].
Drought stress can be simply defined as a shortage of water which induces dramatic morphological, biochemical, physiological, and molecular changes. Drought stress can occur at any growth stage and depends on the local environment. When plants are exposed to drought stress, they physiologically change to tolerate this stress. Drought-tolerant plants try to have less reduction in water content, membrane stability, and photosynthetic activity. Photosynthesis is the main driver of grain yield and plant growth. It is well known that drought decreases the photosynthetic rate of cereals [23].

Drought stress disrupts the biosynthesis of chlorophyll contents, carotene and decreases photosynthesis in plants. It gradually reduces CO2 assimilation rates owing to decrease in stomatal conductance. In addition, drought affects cell membrane stability and disrupts water relations of a plant by reducing water use efficiency. To cope with these situations, plants adopt different mechanisms such as drought tolerance, avoidance and escape [24,25].

Drought stress resulted in a reduction in photosynthetic rate, intercellular carbon dioxide concentration, stomatal conductance and transpiration. Additionally, drought stress reduced dry matter production, leaf area index, number of pods per plant, number of seeds per plant, hundred seed weight and grain yield [26].

3.3. Plant height and stem diameter
Drought adversely affects growth and yield of crops to various extents. The experiment was laid out in a split plot design with three replications. The plants were grown under three drought levels viz. 100% FC (control), 70% FC and 40% FC. Growth and yield of the Sorghum varieties were found to be decreased gradually with gradual increase in drought levels as compared to the control. This reduction was associated with decreased yield components [27].

Plant height and stem diameter of sorghum at 30% of field capacity was significantly different from 50% and 80% of field capacity, in observation of 50 and 70 days after planting. Although, leaf number of the three treatments were not significantly different. The highest plant was Suri 4 (232.55 cm), and the lowest was UPCA (162.57 cm). However, N6.12 and Suri 4 sorghums had the highest stem diameter 55 day after planting (Table 2).
Table 2. Plant height, stem diameter, leaf number of sorghums at the 55 and 77 days after planting under 30%, 50% and 80% of field capacity

| Sorghum Number | Sorghum Accessions | Plant height at 55 dap. (cm) | Stem diameter at 55 dap. (cm) | Leaf number | Plant height at 70 dap. (cm) |
|----------------|-------------------|------------------------------|------------------------------|-------------|-----------------------------|
| 1              | N6.12             | 194.88 c                     | 12.222 b                     | 92.222 b    | 205.11 b                    |
| 2              | WHP               | 190.77 c                     | 11.667 ab                    | 86.667 b    | 195.55 b                    |
| 3              | Buleleng empok    | 187.88abc                    | 10.444 a                     | 87.778 b    | 201.77 b                    |
| 4              | Suri 4            | 202.77 c                     | 11.778 ab                    | 83.333 b    | 232.55 c                    |
| 5              | Super 1           | 182.11abc                    | 10.778 ab                    | 82.222 b    | 187.66 b                    |
| 6              | Samurai 1         | 166.89abc                    | 10.556 a                     | 90.000 b    | 185.66 b                    |
| 7              | WR                | 186.55abc                    | 11.111 ab                    | 90.000 b    | 202.33 b                    |
| 8              | UPCA              | 166.57ab                     | 11.571 ab                    | 87.143 b    | 162.57a                     |
| 9              | Jagung Rote       | 191.09 c                     | 10.545 a                     | 87.273 b    | 208.81 b                    |
| 10             | Suri 3            | 188.66 bc                    | 12.222 b                     | 73.333 a    | 187.66 b                    |

Humidity | Field capacity
---|-------------------
1 | 30% | 175a | 10.900a | 84.667a | 175.63a |
2 | 50% | 190 b | 11.200ab | 85.667a | 205.26 b |
3 | 80% | 194 b | 11.700 b | 87.667a | 216.66 b |

3.4. Root length, root weight, and biomass weight
Sorghum root length at 30% field capacity was the longest, and significantly different from that of at 50% and 80% of field capacity, although their root weights were not significantly different. N612 had the shortest root length, but its root weight was the heaviest. On the other hand, UPCA had the shortest root length and lowest root weight. WR and N612 had the highest biomass weight, and Buleleng Empok had the lowest biomass (Table 3).

Table 3. Root length, root weight, and biomass weight at harvesting 90 days after planting under 30%, 50% and 80% of Field capacity

| Number | Sorghum accession | Root length (cm) | Root weight (g) | Biomass weight (g) |
|--------|-------------------|------------------|-----------------|--------------------|
| 1      | N612              | 31.29 a          | 10.22a          | 55.44a             |
| 2      | WHP               | 21.13bc          | 7.11ab          | 39.89ab            |
| 3      | Buleleng          | 22.25bc          | 4.94b           | 26.61b             |
| 4      | Suri 4            | 26.708abc        | 6.72ab          | 47.72ab            |
| 5      | Super 1           | 22.54abc         | 6.11ab          | 34.61ab            |
| 6      | Samurai 1         | 24.00abc         | 6.55ab          | 40.83ab            |
| 7      | WR                | 27.71abc         | 8.11ab          | 57.17a             |
| 8      | UPCA              | 19.667c          | 4.83b           | 38.89ab            |
| 9      | Jagung Rote       | 28.42abc         | 8.22ab          | 48.72ab            |
| 10     | Suri 3            | 28.96ab          | 6.56ab          | 41.83ab            |

Humidity | Field capacity
---|-------------------
1 | 30% | 27.56a | 5.950a | 30.63b |
2 | 50% | 25.50ab | 7.517a | 46.02a |
3 | 80% | 22.74b | 7.350a | 52.87a |

Sorghum biomass weight vary widely. The measurements of Suri 3 (V1), Kawali (V2), Super 2 (V3) and Suri 4 (V4), indicated that the highest amount of biomass include the stem height (301.28 cm), stem Dry Weight (DW) is 23.48 t ha–1, leaf DW (4.65 t ha–1), panicle DW (11.35 t ha–1) and biomass DW
(39.98 t ha⁻¹) were shown by Super 2. The highest sugar content (16.93 %) was observed from Suri 3 and the highest juice production (2742.86 L ha⁻¹) was observed from Suri 4 [28]. Sorghum biomass was proven to be a valuable crop under limited water supply. The mechanisms of plant adaptation to the drought stress vary according to genotype, morphological and physiological characteristics. Both morphological and physiological characteristics of sorghum were involved in plant adaptation to drought [29].

4. Conclusion
We concluded that Jagung Rote and Suri 3 were the most tolerance sorghum to drought based on their leaf water potentials and photosynthetic rates. Although Suri 3 was not the longest in terms of plant height and the heaviest of biomass, but with the biggest stem diameter, Suri 3 worth noticing for biomass production.

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