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# Drought adaptation level of maize genotypes based on leaf rolling, temperature, relative moisture content, and grain yield parameters

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**Abstract** The adaptation level among maize genotypes under drought stress is strongly affected by morphology and physiology aspects. To assess the adaptation level of maize hybrids to drought weight, an experiment was conducted in the dry season of 2016 (June to September) at Maros Experimental Station. A total of 70 maize hybrids candidates were evaluated under drought stress at generative (flowering stage) until physiological maturity. The results indicated that leaf rolling scores were negatively correlated with grain yield under drought stress conditions. The hybrid 26/B11209 and P 31 that experienced early leaf moving and a higher leaf rolling score ranged from 4.3, and 3.9 had grain yield of only 1.3 t/ha and 1.2 t/ha respectively, lower compared to the hybrid 34/Mal 03 and Bisi 18 that experienced a delayed leaf rolling and lower leaf rolling score (<2.5) with yields of 4.3 t/ha and 3.9 t/ha respectively. The hybrids 34/Mal 03 and Bisi18 had mechanisms to reduce the area of leaves affected by radiation and maintain relatively higher leaf moisture content compared to hybrids 26 / B11209 and P 31. Leaf relative moisture content of hybrid maize 34/Mal 03 and Bisi 18 were higher viz., 79.9% and 78.7% respectively and lower leaf temperatures (39.4-39.8 °C) as compared to hybrids 26/ B11209 and P 31. The effective score assessment time of leaf rolling of the hybrid genotypes was when the whole hybrid genotypes experienced leaf rolling with  $\pm 50\%$  genotype had leaf rolling scored 2 and  $\pm 50\%$  of other genotypes scored 3.

## 1. Introduction

The rising temperatures due to the global climate change cause greater water loss from both land (evaporation) and plants (transpiration), this increases the risk of crops affected by drought stress [1]. The average decrease in maize production due to drought stress is about 40% globally [2]. In Indonesia, the reduction of maize production due to drought stress is about 30-80% [3]. Therefore, improving the adaptability of hybrid maize in drought stress conditions is an alternative to reduce yield loss. To achieve that, the information of the characteristics of hybrid maize plant related to its ability to adapt to drought stress conditions is required [1, 4, 5].

Drought tolerance is controlled by multiple genes and involving various physiological processes [6], so the selection criteria for drought-tolerant plants is not only based on results but also includes other morphological and physical characteristics related to the drought stress tolerance mechanism, so that the selection of drought-tolerant hybrid maize genotypes became more active.

The alterations of the orientation of leaf movement due to drought stress in maize plants such as leaf rolling are easily observable plant responses. In the condition of the leaf-rolling due to drought stress, the cell turgidity or water potential of maize leaf are lower, ranges between -1,5 to -2,5 MPa [7, 8, 9, 10, 11].



Leaf rolling in plants is a mechanism to reduce transpiration, exposure to solar radiation, and dehydration [9, 11, 12, 13]. However, one of the breeding activities is to select maize genotype in drought stress condition; leaf rolling is a criterion of the plants that have experienced drought stress and contradicted the result. Plants that experience delayed leaf moving in drought stress conditions showed the ability to maintain the leaf turgor by increasing the uptake of water or by the osmotic regulation [9], whereas plants that experience leaf rolling earlier indicate that the plants are more sensitive to drought stress [10, 14, 15, 16].

Leaf rolling in severe drought stress condition plays an important role to reduce the exposure of solar radiation and transpiration through stomatal closure. However, reducing transpiration through stomatal closure has an impact on increasing leaf temperature [17, 18] and triggering the formation of *reactive oxygen species* that can damage the chloroplasts [19]. Plants suppress the increase of leaf temperature by keeping the water content of the leaf high, supported by the high ability of soil water absorption by roots [20].

Several studies have shown that leaf rolling is negatively correlated with yield [8, 9] and can be used as a characteristic selection of the drought-tolerant maize hybrid [21, 16], but the active observation time of leaf rolling and its correlation to temperature and relative water content in leaf have not been explained much. The objectives of this study were to determine the effective leaf is rolling observation time for selection of tolerant hybrid maize and its correlation to temperature and relative water content in leaf and also seed yield in drought stress conditions.

## 2. Materials and Methods

The experiment was conducted in the dry season at the end of June-Beginning of September 2016 in Indonesian Cereals Research Institute experimental station at Maros, South Sulawesi. The genetic materials of the 70 hybrid maize genotypes evaluated under drought stress conditions with the repeated randomized block design. The drought stress treatment was done according to the CIMMYT method [22] where the drought stress period occurs during the flowering phase ( $\pm 50$  dap) to physiological maturing ( $\pm 100$  dap). The supply of water was given after the plants were planted until 40 daps. The last water supply was given when the plants were 40 daps, so the plants suffer from drought stress right before flowering until physiological maturing phase.

The data collected were soil water content every 10 days, daily rainfall, leaf rolling score and temperature at 50, 55, 65, 70, 75 and 80 dap. The scoring of leaf rolling was done through visualization using the scale of 1-5, score of 1 means the leaf is not rolled up, the score of 2 leaf began to roll, the score of 3 leaf is rolled with the middle parts of the leaves meet each other so that the tip of the leaf is shaped like a reversed V letter, a score of 4 leaves is rolled over the leaf blade, and scores of 5 leaf is rolled like an onion leaf. The scores of leaf rolling were used if the percentage of drought on each plot were  $\geq 50\%$ . Scoring time of leaf rolling was conducted at 12.00-14.00. The leaf relative water content (RWC) was measured when the plants were 75 daps. The leaf relative water content sample was measured using the third leaf with a size of 3 x 3 cm which was taken at 1/3, 1/2 and 2/3 of the leaf tip. The RWC of three plants /genotype were measured. Fresh leaf samples were weighed to obtain fresh leaf weight (FW), then soaked for 24 h in distilled water and then weighed again to obtain turgid leaf weight (TW), then dried with an oven at 80°C for 3 days [23]. The following formula calculates the relative leaf water content:

$$\text{RWC} = \frac{(\text{FW} - \text{DW})}{(\text{TW} - \text{DW})} \times 100\%$$

Observation of leaf temperature was done at 12.00-14.00 hours using infrared thermometer model IT-550N. The temperature of leaf surface samples that were measured the third leaf above the cob. Leaf temperature was measured from the tip of the leaf to the base of 1/3-2/3 the tip of the leaf, as much as 12 points. The temperature of the three plants /genotype were measured. The collected data were processed using SAS ver.9.1 and Sigma Plot ver. 12.3.

## 3. Result and Discussions

### 3.1. Rainfall, Soil Water Content and Percentage of Crops Experiencing Malignant Symptoms

The rainfall during planting period until the initial vegetative growth phase (0-30 dap) ranges from 0.2 to 53.6 mm with 15 days of rain and average rainfall/day of 8.2 mm. In the period of continued vegetative growth until the hardening phase of the seeds (31-85 dap) there was no rain, so the treatment of drought stress can go well without the addition of rainwater (Figure 1), so that the drought stress indicator was started to show up right before the flowering phase (45 daps) in which a number of test hybrid maize genotypes have undergone leaf rolling. During the flowering phase (50-55 day), the soil water content decreased to 21.1%, the hybrid maize test genotypes that had been experienced drought stress indicated by leaf rolling scored 2-3, were as much as 75% of all test hybrid genotypes (Figure 2).

The intensity of drought stress increased along with decreased soil water content to 16.1%, whereas all hybrid maize genotypes tested scored 3-5 in leaf rolling during the seed hardening phase or at 85 daps (Figure 2). The period of stress experienced by some hybrid genotypes tested during the flowering stage until the hardening phase of the seed will negatively impact the yield. Several studies had shown that seed yield decreased by more than 60% when maize plants experienced drought stress during flowering phase-hardening seed [24, 25, 8, 26, 27].

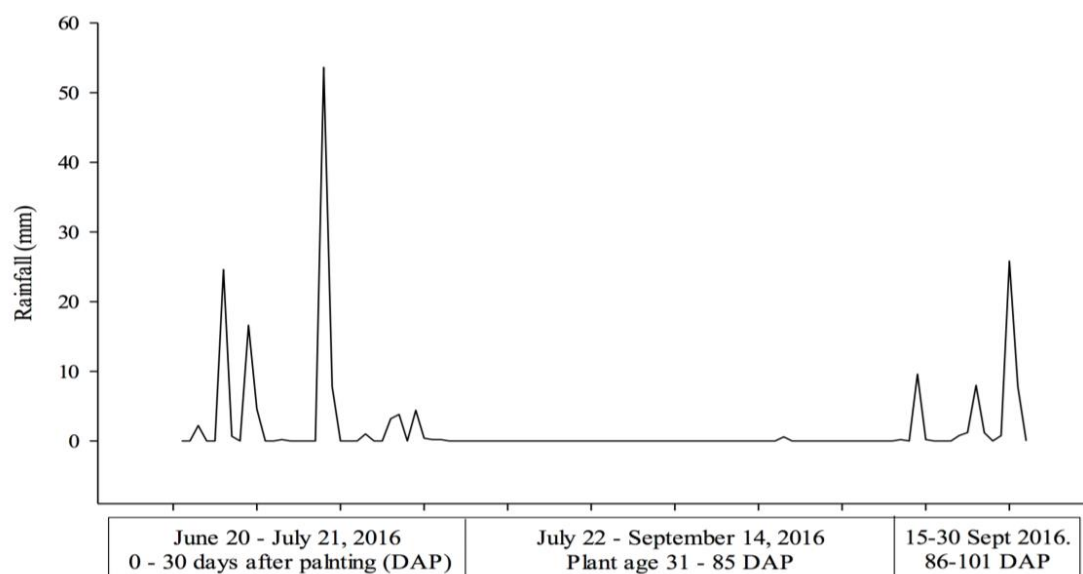


**Figure 1.** Rainfall pattern during the drought stress trials

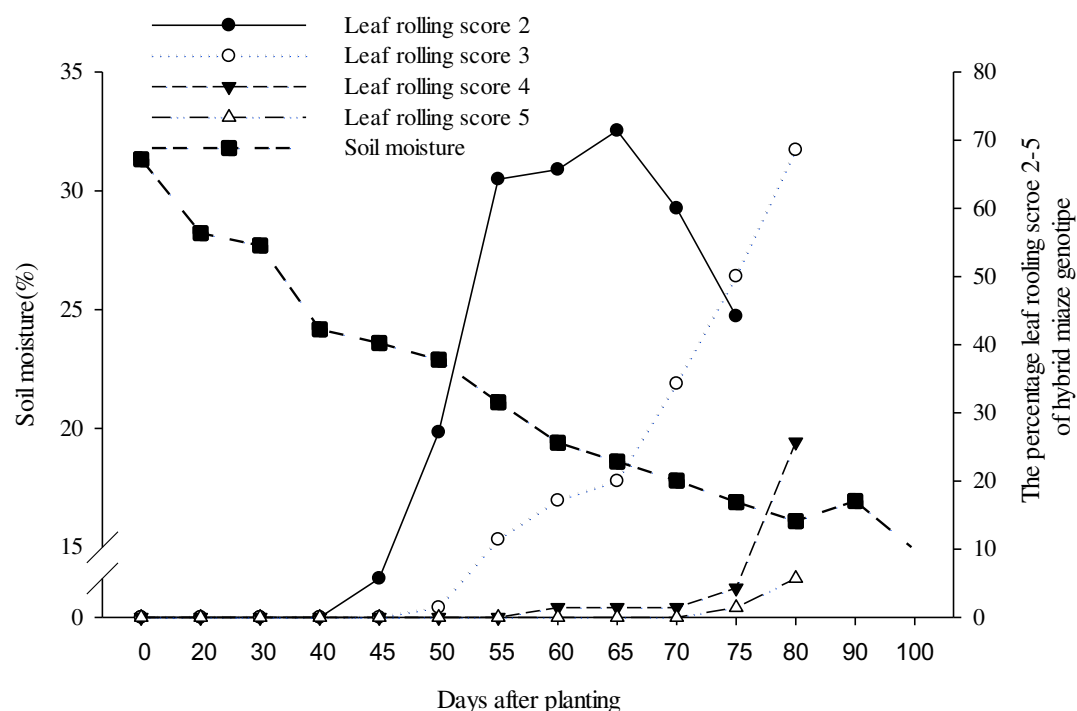


**Figure 2.** Moisture content variation and leaf rolling score during 0 -100 dap observation

### 3.2. Level of Leaf Rolling and Its Correlation with The Yields

The leaf-rolling scores among test hybrids due to drought stress at 50-75 DAP plant varies considerably (Table 2). This indicates that there were different levels of drought stress intensity experienced. The higher the score of leaf rolling experienced by a genotype of maize shows the greater the intensity of the drought stress experienced. Variance analysis showed that leaf rolling scores on drought stress conditions were significantly influenced by differences in test hybrid genotypes (Table 1). According to [28], different responses of some maize genotypes to drought stress are due to morphological, anatomical, and plant metabolism differences. The difference in response to some hybrid genotypes evaluated in drought stress conditions is indicated from the difference in leaf rolling scores. This difference is due to some test hybrid genotypes were derived from lines of different genetic backgrounds.

The hybrid maize 34/Mal 03 and Bisi 18 showed a slower leaf rolling rates compared to 26/B11209 and P 31 hybrid. The average score of leaf moving in hybrid 34/Mal 03 and Bisi 18 at 50 daps were 1,3 and 1,4 respectively, and when plants were aged 75 daps the score were 2,3 and 2,4, the score is lower compared to hybrid 26/B11209 and P 31 with an average score of leaf rolling at 50 daps scored 2.3 and 2.2, and each scored 4.3 and 3.9 respectively when the plants were aged 75 daps (Figure 3). Maize genotypes with delayed leaf rolling in drought stress conditions (34/Mal 03 and Bisi 18) showed more tolerance of drought stress than maize genotypes that experience leaf rolling earlier (26/B11209 and P 31). Some studies showed that drought tolerant maize hybrid could absorb enough soil water and can suppress water loss through transpiration, whereas drought-sensitive hybrids show greater water loss through transpiration than soil water absorption by roots [29, 7, 21, 8, 15, 10].

**Table 1.** Analysis of variance for grain yield and leaf rolling score under drought conditions.

| Source     | Df  | Mean square<br>yield | Mean square leaf rolling score (dap) |         |         |         |         |         |
|------------|-----|----------------------|--------------------------------------|---------|---------|---------|---------|---------|
|            |     |                      | 50                                   | 55      | 60      | 65      | 70      | 75      |
| Replicates | 2   | 4.69                 | 9.95                                 | 12.72   | 9.99    | 11.36   | 7.39    | 4.76    |
| Hybrid     | 69  | 1.11 **              | 0.49 **                              | 0.67 ** | 0.98 ** | 0.96 ** | 1.02 ** | 1.08 ** |
| Error      | 138 | 0.67                 | 0.19                                 | 0.29    | 0.32    | 0.33    | 0.32    | 0.33    |
| Total      | 209 | 0.86                 | 0.38                                 | 0.53    | 0.63    | 0.65    | 0.62    | 0.62    |

\*, \*\* Significant at 1 and 5% level of probability

**Table 2.** Grain yield, relative moisture content, leaf temperature and leaf rolling score under drought stress treatment

| Ranking | Hybrid     | Yield<br>(t/ha) | Relative moisture content<br>* (%) | Leaf Temperature<br>* (°C) | Leaf rolling score* (Score) |
|---------|------------|-----------------|------------------------------------|----------------------------|-----------------------------|
| 1       | 34/MAL03   | 4.3             | 79.9                               | 39.5                       | 2.3                         |
| 2       | Bisi18     | 3.9             | 78.8                               | 37.1                       | 2.2                         |
| 3       | 30/MAL03   | 3.6             | 79.3                               | 36.2                       | 2.2                         |
| 4       | 17/CY11    | 3.4             | 83.3                               | 37.3                       | 2.6                         |
| 5       | 9/CY11     | 3.3             | 85.3                               | 38.5                       | 2.2                         |
| 6       | 34/B11209  | 3.3             | 80.6                               | 37.2                       | 2.4                         |
| 7       | 10/CY11    | 3.2             | 79.6                               | 36.1                       | 2.3                         |
| 8       | 30/B11209  | 3.2             | 84.6                               | 37.7                       | 2.7                         |
| 9       | 7/CY11     | 3.2             | 79.2                               | 36.9                       | 2.4                         |
| 10      | 24/CY11    | 3.1             | 76.9                               | 35.4                       | 2.5                         |
| 61      | 25-2/MAL03 | 1.8             | 73.1                               | 40.9                       | 3.8                         |
| 62      | 15/MAL03   | 1.7             | 68.4                               | 40.5                       | 3.7                         |
| 63      | 17/MAL03   | 1.7             | 70.3                               | 41.0                       | 3.5                         |
| 64      | 28/B11209  | 1.7             | 71.2                               | 40.0                       | 3.3                         |
| 65      | 5/B11209   | 1.7             | 71.0                               | 40.5                       | 3.7                         |
| 66      | 26/B11209  | 1.6             | 59.7                               | 40.1                       | 4.3                         |
| 67      | 26/Nei9008 | 1.6             | 63.7                               | 41.7                       | 3.6                         |
| 68      | 7/B11209   | 1.5             | 74.6                               | 41.6                       | 3.7                         |
| 69      | 12/Nei9008 | 1.3             | 75.1                               | 39.4                       | 5.0                         |
| 70      | P31        | 1.2             | 71.3                               | 39.9                       | 4.0                         |
| Average |            | 2.2             | 74.1                               | 34.6                       | 3.0                         |
| LSD     |            | 1.0             | 11.3                               | 4.7                        | 0.9                         |
| CV      |            | 19.7            | 9.5                                | 9.8                        | 15.5                        |

\* Observation data at 75 dap and 16,9% moisture content

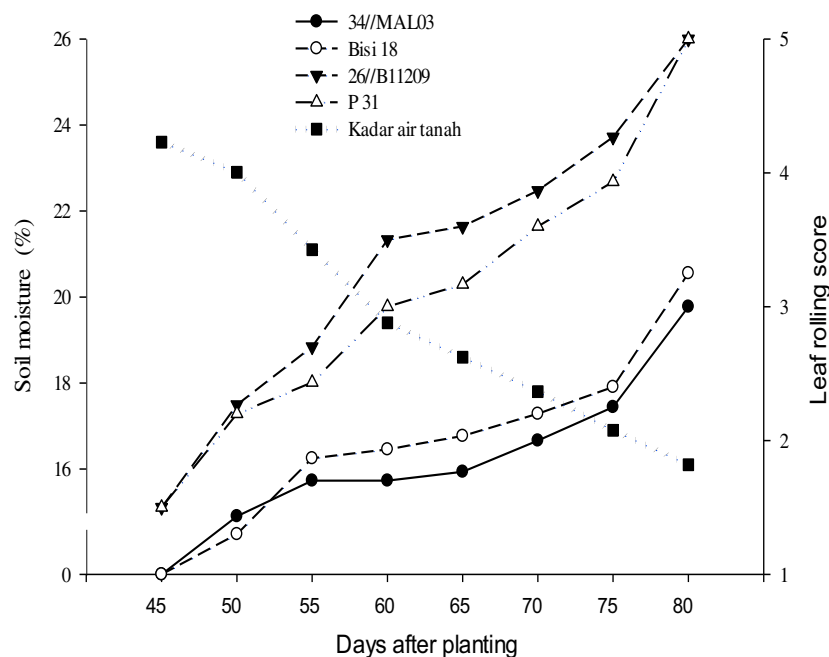


**Figure 3.** Diurnal variation of moisture content and leaf rolling score of four leaves

The correlation analysis between leaf rolling score and seed yield showed that leaf rolling was significantly negatively correlated with seed yield with correlation coefficient value ( $r$ ) of -0.54 (Table 3). The value of negative correlation coefficient shows that the greater the score of leaf rolling, the smaller the yield obtained during the drought stress conditions. Hybrid 26/B11209 and P 31 which had higher average leaf rolling score of 4.4 and 3.8 productivity were significantly lower with yield 1.2-1.3 t/ha, compared to hybrid 34/Mal 03 and Bisi 18 that had lower average leaf rolling score of 2.3 and 2.4 with yield 3.9-4.3 t/ha (Figure 3 and Table 2). According to [10], the leaf rolling in maize during drought stress conditions resulted in the intra-cell stomatal conductions and  $\text{CO}_2$  being reduced which negatively impacted the rate of photosynthesis and the production of assimilates. This resulted in the lower production of seeds from hybrid (26 / B11209 and P 31) that experienced early leaf rolling compared to a hybrid (34 / Mal 03 and Bisi 18) which were experienced a delayed leaf moving.

### 3.3. Score Assessment of Hybrid Leaf Rolling

Leaf rolling began to appear on some hybrid maize right before the flowering phase (45 dap) and then the whole hybrid maize genotype underwent leaf rolling at 75-80 dap. Determination effective scoring time of the test hybrid genotype can be seen based on its correlation level with the results.

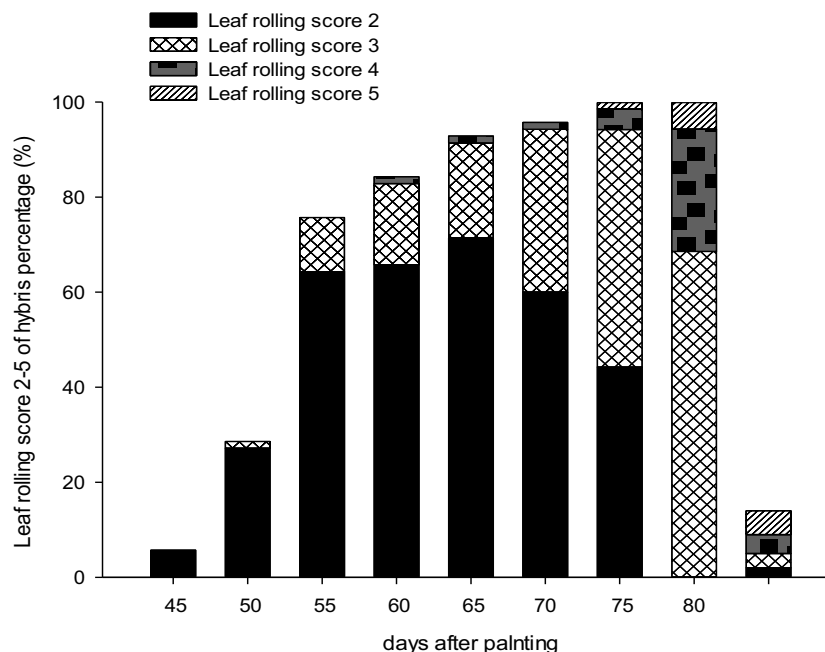


**Figure 4.** Percentage of maize genotypes attacked by leaf rolling stress at 45-80 dap

The correlation analysis between leaf rolling at the age of 45-80 dap with seed yields showed that the significantly negative impact of leaf rolling on the yield was apparent at 50 daps (flowering phase) to 80 dap (seed hardening phase) with correlation coefficient ( $r$ ) in the range of -0.25 to -0.54 (Table 3). The highest correlation coefficient value ( $r = 0.54$ ) was at 75 daps when all hybrid maize genotype shade experienced leaf rolling with score 2-5, where almost 50% of hybrid maize genotype test (44,2%) scored 2 and 50% other hybrid maize genotypes scored 3 (Figure 4). In contrast, the correlation coefficient between leaf rolling and yield is low ( $r < 0.45$ ) if all genotypes of test hybrid maize have not experienced leaf rolling (45-70 dap) or whole genotype of the test hybrids experienced leaf rolling (80 daps) with >70% genotype hybrid scored 3 and 30% scored 4-5. This suggests that the effective score assessment time of leaf rolling of the hybrid genotypes was when the whole hybrid genotypes had leaf rolling with  $\pm 50\%$  genotype had leaf rolling scored 2 and  $\pm 50\%$  of other genotypes scored 3.

### 3.4. Correlation of Leaf Rolling with Relative Moisture Content and Leaf Temperature

**Table 3.** The correlation coefficient between grain yield, leaf temperature, relative moisture content and leaf rolling score under drought conditions

| Vari<br>able | Yield    | RWC      | Leaf temperature correlation<br>coefficient |       |       |       |           | Leaf rolling correlation coefficient |           |       |       |       |       |       |
|--------------|----------|----------|---------------------------------------------|-------|-------|-------|-----------|--------------------------------------|-----------|-------|-------|-------|-------|-------|
|              |          |          |                                             |       |       |       |           |                                      |           |       |       |       |       |       |
|              |          |          | 50d<br>ap                                   | 55dap | 60dap | 65dap | 70d<br>ap | 75da<br>p                            | 45da<br>p | 50dap | 55dap | 60dap | 65dap | 70dap |
| RW           | 0.4      |          |                                             |       |       |       |           |                                      |           |       |       |       |       |       |
| C            | 0        | **       |                                             |       |       |       |           |                                      |           |       |       |       |       |       |
| TD_50        | 0.0<br>9 | 0.0<br>5 |                                             |       |       |       |           |                                      |           |       |       |       |       |       |
|              | -        | -        |                                             |       |       |       |           |                                      |           |       |       |       |       |       |
| TD_55        | 0.1<br>3 | 0.0<br>8 | 0.0<br>8                                    |       |       |       |           |                                      |           |       |       |       |       |       |

4. \*, \*\* significant at 1% and 5 % level, n = 70, dap= day after planting, RWC= Relative moisture content, LT= leaf temperature, SPD = leaf rolling score

Leaf temperatures in drought stress conditions were significantly correlated with relative leaf water content ( $r = -0.37$ ) (Table 2). The correlation shows that the higher the relative water content of the leaves the lower the leaf temperature. Keeping the leaf relative water content high in drought stress conditions indicates the ability of maize plants to absorb enough soil water through deep roots and suppress water loss through transpiration [1, 30].

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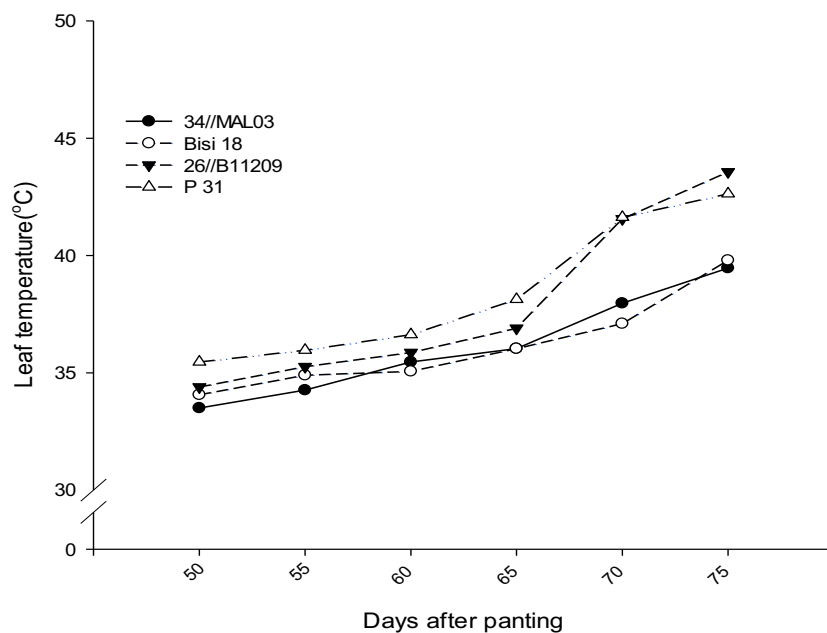


**Figure 5.** Leaf temperature of four inbreeds under drought stress at 50-75 dap and soil moisture content of 16,9-21%

The correlation analysis showed that high leaf relative water content significantly positively correlated with the yield ( $r = 0.40$ ) (Table 2). The correlation indicates that the higher the leaf relative water content, the higher the yield obtained in drought stress conditions. The high leaf relative water content allows the synthesis process to be processed well so that the results obtained are relatively high in drought stress conditions [11]. High yields were also shown in hybrid 34/Mal 03 and Bisi 18 which had high leaf relative water content and low leaf temperatures in drought stress conditions with yields of 4.3 t/ha and 3.9 t/ha compared to hybrid maize with relatively low leaf water content and high leaf temperatures such as hybrid 26/B11209 and P 31 with yields only 1.3 t/ha and 1.2 t/ha (Table 1).

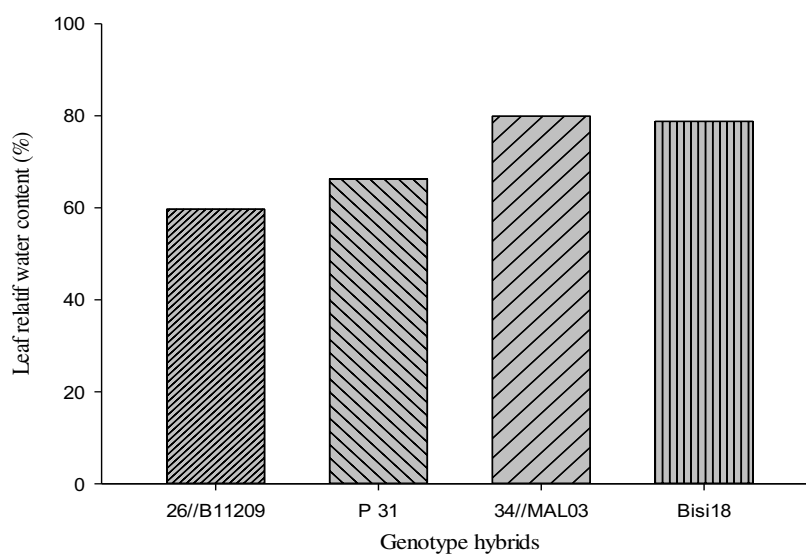


**Figure 6.** Leaf relative moisture content of four genotypes under drought stress at 75 dap and soil moisture content of 16,9%

#### 4. Conclusions

Early leaf rolling of studied hybrids genotypes during the drought stress period indicated a higher susceptibility to drought condition and produced lower grain yield as compared to the late leaf rolling genotypes. The hybrid 26/B11209 and P 31 that experienced early leaf rolling and a higher leaf rolling score ranged from 4.3 and 3.9 had yield of only 1.3 t/ha and 1.2 t/ha respectively, lower compared to the hybrid 34/Mal 03 and Bisi 18 that experienced a delayed leaf rolling and lower leaf rolling score (<2.5) with grain yields reached 4.3 t/ha and 3.9 t/ha respectively. The hybrids 34/Mal 03 and Bisi 18 had mechanisms to reduce the area of leaves affected by radiation and maintain relatively higher leaf moisture content compared to hybrids 26/B11209 and P 31. Leaf relative moisture content of hybrid maize 34/Mal 03 and Bisi 18 was higher viz., 79.9% and 78.7% respectively and lower leaf temperatures (39.4-39.8°C) as compared to hybrids 26/ B11209 and P 31. The effective score assessment time of leaf rolling of the hybrid genotypes was when the whole hybrid genotypes experienced leaf rolling with  $\pm 50\%$  genotype had leaf rolling scored 2 and  $\pm 50\%$  of other genotypes scored 3.

#### References

- [1] Végh K 2013 Root and leaf traits, water use and drought tolerance of maize genotypes *Biologia* **68**.
- [2] Daryanto S, Wang L and Jacinthe PA 2016 Global synthesis of drought effects on maize and wheat production. *PLoS One* **11** 78-80
- [3] Efendi R, Takdir AM and Azrai M 2017 Combining ability of maize inbreds under drought and low N stresses in hybrid development *Indonesian J. of Food Crops* **1** 83
- [4] Avramova V, Elgawad HA, Zhang Z, Fotschki B, Casadevall R, Vergauwen L, Knapen D, Taleisnik E, Guisez Y, Asard H and Beemster GTS 2015 Drought induces distinct growth response, protection, and recovery mechanisms in the maize leaf growth zone *Plant Physiology* **169** 1382
- [5] Nemali KS, Bonin C, Dohleman FG, Stephens M, Reeves WR, Nelson DE, Castiglioni P, Whitsel JE, Sammons B, Silady RA, Anstrom D, Sharp RE, Patharkar OR, Clay D, Coffin M, Nemeth MA, Leibman ME, Luethy M and Lawson M 2015 Physiological responses related to increased grain yield under drought in the first biotechnology-derived drought-tolerant maize *Plant, Cell & Enviro.* **38** 18-66
- [6] Liu Y, Subhash C, Yan J, Song C, Zhao J and Li J 2011 Maize leaf temperature responses to drought: thermal imaging and quantitative trait loci (QTL) mapping. *Enviro. and Exp. Bot.* **71** 158
- [7] Kadioglu A and Terzi R 2007 A dehydration avoidance mechanism: leaf rolling. *The Bot. Rev.* **73** 1
- [8] Efendi R and Azrai M 2010 Response of maize genotypes to drought stress: role of root. *Indonesian J. of Food Crops* **29** 1
- [9] Kadioglu A, Terzi R, Saruhan N and Saglam A 2012 Current advances in the investigation of leaf rolling caused by biotic and abiotic stress factors *Plant Sci.* **182** 42
- [10] Saglam A, Kadioglu A, Demiralay M and Terzi R 2014 Leaf rolling reduces photosynthetic loss in maize under severe drought *Acta Botanica Croatica* **73** 315
- [11] Riboldi LB, Oliveira RF and Angelocci LR 2016 Leaf turgor pressure in maize plants under water stress *Australian J. of Crop Sci.* **10** 878
- [12] Sirault XRR, Condon AG, Wood JT, Farquhar GD and Rebetzke GJ 2015 "Rolled-upness": phenotyping leaf rolling in cereals using computer vision and functional data analysis approaches. *Plant Methods* **11** 52
- [13] Puglielli G, Gratani L and Varone L 2017 Leaf rolling as indicator of water stress in *cistus incanus* from different provenances. *BioRxiv* **31** 1
- [14] Song Y, Birch CJ and Hanan J 2010 Maize canopy production under contrasted water regimes. *Annals of App. Biol.* **157** 111

- [15] Lu Y, Hao Z, Xie C, Crossa J, Araus J-L, Gao S, Vivek BS, Magorokosho C, Mugo S, Makumbi D, Taba S, Pan G, Li X, Rong T, Zhang S and Xu Y 2011 Large-scale screening for maize drought resistance using multiple selection criteria evaluated under water-stressed and well-watered environments. *Field Crops Res.* **124** 37
- [16] Song K, Kim K-H, Kim HC, Moon J-C, Kim JY, Baek S-B, Kwon Y-U and B-M Lee 2015 Evaluation of drought tolerance in maize seedling using leaf rolling *The Korean J. of Crop Sci.* **60** 8.
- [17] Araus JL, Slafer GA, Royo C and Serret MD 2008 Breeding for yield potential and stress adaptation in cereals *Critical Rev. in Plant Sci.* **27** 377
- [18] Zia S, Sophrer K, Wenyong D, Spreer W, Romano G, and Xiongkui H 2011 Monitoring physiological responses to water stress in two maize varieties by infrared thermography *Int J. Agric. & Biol. Eng.* **4** 7
- [19] Hasanuzzaman M, Nahar K, Alam MM, Roychowdhury R and Fujita M 2013 Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. *Int. J. of Mol. Sci.* **14** 9643
- [20] Gao Y and Lynch JP 2016 Reduced crown root number improves water acquisition under water deficit stress in maize (*Zea mays* L.) *J. of Exp. Bot.* **67** 4545
- [21] Monneveux P, Sanchez C and Tiessen A 2008 Future progress in drought tolerance in maize needs new secondary traits and cross combinations *The J. of Agric. Sci.* **146** 287.
- [22] Weber VS, Melchinger AE, Magorokosho C, Makumbi D, Bänziger M and Atlin GN 2012 Efficiency of managed-stress screening of elite maize hybrids under drought and low nitrogen for yield under rainfed conditions in Southern Africa *Crop Sci.* **52** 1011.
- [23] Efeoglu B, Ekmekçi Y and Çiçek N 2009 Physiological responses of three maize cultivars to drought stress and recovery *South African J. of Bot.* **75** 34
- [24] Bänziger M, Edmeades GO, Beck D and Bellon M 2000 Breeding for drought and nitrogen stress tolerance in maize: from theory to practice. CIMMYT., Mexico, D.F. p 5 8
- [25] Çakir R 2004 Effect of water stress at different development stages on vegetative and reproductive growth of corn *Field Crops Res.* **89**
- [26] Anwar S, Iqbal M, Akram HM, Niaz M and Rasheed R 2016 Influence of drought applied at different growth stages on kernel yield and quality in maize (*Zea mays* L.) *Com. in Soil Sci. and Plant Analysis* **47** 22-25
- [27] Maazou SR, Tu J, Qiu J and Liu Z 2016 Breeding for drought tolerance in maize (*Zea mays* L.). *American J. of Plant Sci.* **07** 18-58
- [28] Kulathunga MRDL 2013 Traits associated for adaptation to water limited environment of cereal crops a review of literature *Int. J. of Scientific & Tech. Res.* **2**
- [29] Bolafios J and Edmeades GO 1996 The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize *Field Crops Res.* **48** 65
- [30] Sebastian S and Peter W 2014 Root characteristics associated with drought tolerance in maize *Online*
- [31] Romano G, Zia S, Spreer W, Sanchez C, Cairns J, Araus JL and Müller J 2011 Use of thermography for high throughput phenotyping of tropical maize adaptation in water stress *Comp. and Electro. in Agric.* **79** 67
- [32] Chen J, Xu W, Velten J, Xin Z and Stout J 2012 Characterization of maize inbred lines for drought and heat tolerance *J. of Soil and Water Cons.* **67** 354