Screening of shade tolerant hybrid maize based on stress tolerance index

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Abstract. The development of adaptive and high-yielding maize varieties tolerant to shade stress is the right strategy to increase productivity and national maize production by utilizing the land in shaded conditions or under annual stands with 40% shade intensity. This study aimed to assess the best genetic material before releasing new shade tolerant maize varieties. This experiment was conducted in shaded and unshaded conditions in the Indonesian Cereal Research Institute, Maros, from July-October 2018 in KP. Pandu, North Sulawesi under coconut trees from March-August 2019. The design is using a randomized block design with three replications. The genetic material used consisted of 10 three-lane cross-hybrid maize, SHD01, SHD02, SHD03, SHD04, SHD05, SHD06, SHD07, SHD08, SHD09, and SHD10, and two comparison varieties of three-lane cross-hybrid maize, Bima-19, and P-35. Shade causes a reduction in light intensity, impacting changes in the microclimate under the shade. This is indicated by the dynamics of changes in light intensity which are quite high between maize crops in shaded and unshaded conditions. Tolerance to shade stress was assessed by measuring the difference in yield between unshaded environmental conditions and shaded environmental conditions to assess average productivity under normal and shaded conditions using the stress tolerance index (STI). The adaptive level in shade conditions of the candidate varieties SHD02 and SHD10 was significantly better than that of the Bima 19 and P 35 varieties, with the STI values of these candidates being 0.87 and 0.80, while the two comparison varieties Bima 19 and P 35, were respectively only 0.62.

1. Introduction
Maize is one of the strategic commodities and has high economic value because apart from being the main food source of carbohydrates and protein after rice, maize is also used as industrial raw material for animal and household feed. The need for maize continues to increase along with the increasing rate of population growth and the increasing need for food and feed. The demand for maize continues to increase but is not matched by an increase in production. Efforts to increase production are carried out by producing hybrid varieties of maize, one of which is a three-way cross hybrid. In addition, the increase in maize production can also be done by adjusting the cropping pattern, namely the insertion cropping pattern system. Inserted plants will affect the appearance and production of these plants, especially in the efficiency of using light intensity (shade).

The effect of shade on plant growth can be seen very clearly in plants growing under shade. The growth of plants under the shade is increasingly inhibited when the level of shade is higher. Meanwhile, as the main source of light for plants, solar radiation is one of the main requirements for the continuity of the photosynthesis process. This difference can occur because the light in...
agroforestry systems is more complex [1], among others, light irradiation under trees is not constant while under artificial shade is always constant. In addition, there is competition for water and nutrients in the agroforestry system between intercrops and trees [2].

Low light intensity due to shade is a limiting factor in optimizing production on plantation land. Shade stress has the potential to cause maize plants to become tall and thin, the number of leaves is reduced, and the cobs are smaller [3]. In addition, shading can also result in changes to the solar radiation received by plants both in intensity and quality so that it affects plant photosynthesis, plant growth, and production.

The assembly of adaptive and high-yielding maize varieties that are tolerant to shade stress is the right strategy to increase productivity and national maize production by utilizing the land in shaded conditions or under annual stands with 40% shade intensity. The development of shade-tolerant three-way cross hybrid maize is one alternative in supporting the development of new production sources in plantation areas. The advantages of three-way cross hybrid maize varieties include: (1) The production of seeds produced is higher than that of single crosses so that the price of seeds is cheaper and affordable for farmers.

The study aimed to obtain the best genetic material before releasing new varieties that were adaptive to shade conditions and had high yields in both shaded and shaded conditions <40%. This candidate variety will be a good choice in the components of maize cultivation in shaded and unshaded conditions to increase farming and maize production in Indonesia.

2. Materials and Methods
This research was carried out in two conditions, namely shaded and unshaded conditions in the experimental garden of the Cereal Crops Research Institute, Maros. In the shading conditions, it was carried out in the Screen House using 35% black paranet and in the unshaded condition, it was carried out in an open field. The research was conducted from July to October 2018. The research location is located at an altitude of 5 m above sea level (asl), inceptisol soil type with rainfall type C3 according to the Oldeman climate type classification [4].

The research was carried out under a coconut tree in KP. Pandu, North Sulawesi on March-August 2019. The design used was a randomized block design (RBD) with three replications. The genetic material used consisted of 10 three-lane cross-hybrid maize, namely: SHD01, SHD02, SHD03, SHD04, SHD05, SHD06, SHD07, SHD08, SHD09, and SHD10, and two comparison varieties of three-lane cross-hybrid maize, namely Bima-19 and P-35.

This research was conducted using a Randomized Completed Block Design, 3 replications. If there is a difference in the mean value of the variety in the F test, it is continued with the Least significant difference (LSD) test at the 5% significance level by comparing the candidate varieties with the comparison varieties. Analysis of the stability of the results using Finlay and Wilkinson’s method [5].

2.1 Maize planting
Soil tillage was carried out with perfect tillage, then plots were made measuring 3 meters x 5 meters and planting holes with a distance of 70 cm x 20 cm. Seeds are planted two seeds per hole. When the plants were 10 days after planting (DAP), thinning was done to 1 plant per clump. Dosage and timing of fertilization follow the habits of local farmers, but for farmers who are not used to growing maize with optimal management, you can follow the dosage and timing of fertilization as follows: first fertilization, apply NPK Phonska fertilizer (15:15:15:15) at the age of 7 - 10 days after planting (DAP) with a dose of 350 kg/ha and 100 kg urea/ha, second fertilization, given when the plants are 30-35 DAP with Urea at a dose of 200 kg/ha.

2.2 Climatic conditions and light intensity
Measurement of weather/climate data is carried out every two weeks according to the age of plant growth. There is a tendency to increase temperature along with plant growth where the temperature at the initial growth (average 27.1°C) is lower than the physiological ripe phase (28.1°C). The intensity of
solar radiation also continued to increase from 380.8% in the initial phase to 499.6% in the mature physiological phase. Although there is a tendency to increase rainfall in October, the average temperature and intensity of radiation remain high. Meanwhile, the results of temperature measurements in shade treatment decreased with increasing plant age. Shade causes a reduction in light intensity, impacting changes in the microclimate under the shade. The air temperature under the shade is lower at 24.57°C with a higher humidity at 68.38% than without the shade. Li [6], reported that the accumulated effective temperature of the maize canopy in the shade treatment decreased with increasing shade intensity.

Shade causes a reduction in light intensity, impacting changes in the microclimate under the shade. This is indicated by the dynamics of changes in light intensity which are quite high between maize crops in shaded and unshaded conditions. The average light intensity at 09.00 am in shaded conditions is 305 lux. Meanwhile, in conditions without shade, the range of sunlight intensity is higher, namely 528 lux. The same phenomenon was obtained at 12 o'clock observation where the condition without shade was higher than 63% shade. This condition causes the environment under the shade to be shadier, which is indicated by lower temperature and light intensity. Observations between time also showed a higher light intensity at the observation at 12.00 than the observations at 09.00 and 15.00.

Measurements of light intensity in the treatment without shade and shade treatment in the morning, afternoon, and evening. In the treatment without shade, the intensity of light received was 54866.7 lux (100% light), shade treatment at 09.00 am the intensity of light received was 35166.7 lux. (64% light), at 12.00 the light intensity received was 36233.3 lux (66% light) and at 15.00 the light intensity received was 28066.6 lux (51% light).

The collected data was maize production with 4 rows of harvest in the middle and then converting the yield of wet shelled cobs in the middle four rows of plants per plot (kg) to t/ha using the formula:

\[
\text{Yield (t/ha)} = \frac{10000}{100-15} \times \frac{100-KA}{L.P} \times \frac{BTkP}{1000} \times SP
\]

where:
- \(K.A\) = Water content of seeds at harvest
- \(L.P\) = Harvested area (m²).
- \(BTkP\) = Harvested Peeled Cob Weight (kg)
- \(SP/R\) = the average of ‘shelling percentage’ (rendemen)

Tolerance index and criteria for tolerance level to shade stress are calculated based on formula: \(STI = \frac{Y_{pi} \times Y_{si}}{Y_{p}}\) by Fernandez [7], where:
- \(Y_{si}\) = Seed yield of a genotype under stress conditions
- \(Y_{pi}\) = Seed yield of a genotype at optimum conditions
- \(Y_s\) = Average seed yield of all genotypes under stress conditions
- \(Y\) = Average seed yield of all genotypes at optimum conditions

3. Results and Discussion

3.1. Stress tolerance index (STI)
Tolerance to shade stress was assessed by measuring the difference in yield between open or unshaded environmental conditions and shaded environmental conditions, to assess average productivity under normal and shaded conditions using the stress tolerance index (STI).

The stress tolerance index (STI) value indicates that the higher the STI value, the more adaptive it is to the target stress conditions [7]. The adaptive level in shade conditions of the SHD02 and SHD10 varieties was significantly better than the Bima 19 and P 35 varieties with the STI values of these candidates being 0.87 and 0.80, respectively, while the two comparison varieties Bima 19 and P 35 were respectively only 0.62 (Table 2).
The average seed yield of the SHD02 and SHD10 candidate varieties in open conditions (without shade) was not significantly different from the best comparison variety, namely P 35, but under shade conditions, the seed production of SHD02 and SHD10 was significantly higher than the Bima 19 and P 35 varieties. The seed production of the SHD02 and SHD10 varieties, respectively, was 7.3 t/ha and 7.0 t/ha, significantly higher than the Bima 19 and P 35 varieties with only 5.4 t/ha and 6.2 t/ha respectively (Table 1).

| Hybrid | Pandu | Maros | Average | STI |
|--------|-------|-------|---------|-----|
|        | Open  | Shade | Open    | Shade | Open | Shade |  |
| SHD 01 | 9.6 a | 6.4   | 9.2     | 5.6   | 9.4  | 6.0   | 0.65 |
| SHD 02 | **10.1 a** | **7.6 b** | **10.4** | **6.9 b** | **10.3 a** | **7.3 ab** | **0.87 ab** |
| SHD 03 | 9.4   | 5.9   | 9.4     | 5.3   | 9.4  | 5.6   | 0.61 |
| SHD 04 | 8.1   | 6.0   | 9.2     | 4.8   | 8.7  | 5.4   | 0.54 |
| SHD 05 | 7.9   | 5.8   | 8.6     | 5.3   | 8.3  | 5.5   | 0.54 |
| SHD 06 | 8.5   | 5.5   | 9.2     | 4.9   | 8.9  | 5.2   | 0.54 |
| SHD 07 | 9.8 a | 6.2   | 9.9     | 4.3   | 9.8 a| 5.2   | 0.60 |
| SHD 08 | 9.1   | 6.1   | 8.9     | 5.9   | 9.0  | 6.0   | 0.62 |
| SHD 09 | 9.2   | 6.2   | 9.7     | 6.1   | 9.5  | 6.1   | 0.67 |
| SHD 10 | **9.6 a** | **7.3 b** | **10.1** | **6.8** | **9.9 a** | **7.0 b** | **0.80 ab** |
| Bima 19| 8.5   | 6.1   | 8.7     | 6.3   | 8.6  | 6.2   | 0.62 |
| P 35  | 9.6   | 5.6   | 10.1    | 5.2   | 9.9  | 5.4   | 0.62 |
| Average| 9.1   | 6.2   | 9.5     | 5.6   | 9.3  | 5.9   | 0.64 |
| SE    | 0.3   | 0.5   | 0.7     | 0.6   | 0.4  | 0.3   | 0.05 |
| LSD   | 1.0   | 1.5   | 2.0     | 1.7   | 1.1  | 0.9   | 0.14 |
| KK    | 6.5   | 14.1  | 12.5    | 14.7  | 7.0  | 9.5   | 13.1 |

Description: a = Significantly better than Bima 19 on the 5% LSD test; b = Significantly better than P 35 on the 5% LSD test

Fernandez [7] stated that the stress tolerance index (STI) could identify genotypes with high yields, both under stress and under stress conditions. Several researchers have selected several tolerant genotypes based on stress selection parameters both under stress conditions and under optimum conditions [8], [9], [10], [11].

Generally, under conditions of lack of light, the plant will grow taller due to stem elongation and thinness and at the expense of leaf development, which reduces yield. However, it is different with certain varieties that were produced specifically to survive in shade conditions. Shade-tolerant varieties are more efficient in utilizing sunlight for photosynthesis so that it affects yields compared to varieties that are not shade-tolerant [12].

The level of shade affects the growth and development of maize plants. Maize plants are C4 plants with characteristics that are very sensitive to shade. During the development phase, shade on these plants can reduce seed weight and affect internode length [13]. The study results [14], showed that the amount of solar radiation absorbed by maize plants under coconut plants aged 5 years and 50 years was more than coconuts aged 20 years, so that maize cultivation was not recommended between coconuts aged 20-30 years. Because it will lead to reduced production. The selection of maize varieties which tolerant to low light is the right way to develop these crops in standing areas. The study results [15], showed that Pioneer 11 maize varieties were able to produce up to 3.9 t/ha at a
shading level of up to 60%. Furthermore, Syafrudin [3] reported that 9 maize genotypes were tolerant to low light intensity.

4. Conclusion
The results indicated that the SHD02 and SHD10 hybrids had a better adaptation rate than the comparison varieties Bima 19 and P35 with ITC values of 0.87 and 0.80, respectively. The higher the STI value, the more adaptive it is to shade stress conditions.

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