Tolerance of Wheat mutant (*Triticum aestivum* L.) genotypes in lowland against limited water availability

M Farid, Nasaruddin, R M Amin, and I Ridwan

Department of Agronomy, Faculty of Agriculture, Hasanuddin University, Jalan Perintis Kemerdekaan KM 10 Makassar 90245, Indonesia.

E-mail: farid_deni@yahoo.co.id

Abstract. A study was carried out from October to December 2017 as part of a development program for wheat plants tolerant to drought in Indonesian lowlands. Three conditions of water availability used were 81-100%, 61-80% and 41-60% of the field capacity tested on 13 wheat genotypes resulted from a wheat plant breeding program. As a comparison, 2 varieties of wheat were used namely Dewata and Munal. The experiment was carried out in the Greenhouse of the Faculty of Agriculture, Hasanuddin University using a Split Plot Design with water conditions as the main plot and genotype as the subplots. The results showed that the wheat mutant genotypes with production higher than the comparison varieties in lower water availability conditions of 61-80% and 41-60% of field capacity (fc) were Nias 250 4.6.2 and Nias 350 3.8.9. Both genotypes yielded 1.95 g.plant⁻¹ and 1.10 g.plant⁻¹, respectively in the 61-80% fc and only produced 0.40 g.plant⁻¹ in 41-60% fc water level. In addition, the genotypes were categorized as tolerant based on the stress tolerance index.

1. Introduction

Currently, the problem of environmental stress as an effect of global warming was faced worldwide especially in developing countries. The two main types of stresses are drought and high temperature. Wheat production decreased significantly in high temperature environment in 15 million ha of wheat crop land in developing countries. More than 7 million ha of wheat are grown in high-temperature stressed environments, which averages a daily temperature of more than 17.5 °C in the coldest month [1]. Needs of developing countries such as Indonesia with import activities. Wheat imports to Indonesia during the period of January 2015 to January 2016 increased significantly 3.8% or 8.20 million tons from the previous period of 7.49 million tons. Domestic wheat production needs to be supported by technology in accordance with agro-climate in Indonesia. To be involved in wheat imports, Indonesia needs to make efforts to produce wheat in the country. For this reason, it is necessary to examine wheat lines from the crossing so that wheat is suitable for the place temperature [2].

To increase the competitiveness and production of wheat as a food source and diversification, an effort on extensification of the plant in lower altitude is necessary to develop wheat varieties adaptable to higher temperatures in the lowland (400 - 600 m above sea level). One of the limiting factors for the extensification of wheat in the lowlands is temperature stress [3].

Water requirements for wheat plants to produce optimally are between 450 - 650 mm, depending on climate and length of plant growth [4]. The accuracy of water availability in the growth stage has an effect on wheat production. Based on the results of the study of Nasaruddin et al. [5], the wheat mutant...
genotype that produced the highest growth and production was N.300 4.3.6 (1.92 t.ha⁻¹) and was different from all other mutants and comparison varieties. Mutant genotypes that provide higher growth and production than all comparison varieties are N.350 3.1.4 (1.86 t.ha⁻¹), N.200 2.3.3 (1.67 t.ha⁻¹), N.250 4.2.1 (1.48 t.ha⁻¹), N.200 2.4.B.6 (1.36 t. ha⁻¹), N.250 4.5.2 (1.26 t. ha⁻¹), N.350 3.2.2 (1.26 t. ha⁻¹), and N.350 3.1.3 (1.22 t. ha⁻¹). Mutants that produce higher yields than the three comparative variants (Dewata, Selayar and Munal) with results > 1 t. ha⁻¹, but lower than Nias varieties (1.15 t.ha⁻¹) are N.200 2.5.2 (1.11 t.ha⁻¹), N.250 4.6.2 (1.14 t.ha⁻¹), and N.350 3.6.2 (1.07 t.ha⁻¹). Thus, there are 11 potential mutant genotypes for further selection in the effort to develop adaptive wheat in the lowlands.

2. Research Methodology
The research was carried out at the Experimental Garden of the Faculty of Agriculture, Hasanuddin University, located in the Tamalanrea District of Makassar City at an altitude of < 40 m above sea level (asl) with an average temperature of 24 °C in the morning and 32 °C during the day. The research was carried out from November 2017 to January 2018 and set in the form of experiments using Split Plot design with the main plot of water availability (K) consisting of three levels, namely 81-100% of field capacity (fc) (k0), 61-80% fc (k1), and 41-60% fc (k2), while subplot was the wheat genotypes consisting of 13 mutants, namely: g1 (M 1.7.1), g2 (N.350 3.6.2), g3 (N.350 4.2.1), g4 (N.350 3.1.3), g5 (N.350 3.2.2), g6 (N.250 4.5.2), g7 (N.350 3.1.4), g8 (N.200 2.5.1), g9 (M.200 1.7.1), g10 (N.250 4.6.2), g11 (N.350 3.8.9), g12 (S.300 8.3.1), g13 (N.200 2.5.2) and 2 comparison varieties g14 (Dewata) and g15 (Munal). Seeds were planted in polybags containing mixtures of 2:1 soil and cow manure. Fertilization was carried out using Urea 300 kg.ha⁻¹, SP36 200 kg.ha⁻¹, KC1 100 kg ha⁻¹. Fertilization was applied twice at 10 days after planting (DAP) and 30 DAP. Fertilizer was applied to all experimental units with a dose of Urea 0.15 g, SP36 0.0795 g, and NPK 0.4995 g. The parameters observed were the number of productive tillers, number of seeds per panicle, seed weight per panicle and productivity. Data analysis was carried out using analysis of variance (table 1) followed by Least Significant Difference (LSD) test at 0.05 level whereas heritability is in a broad sense was calculated using Syukur et al. [6]:

\[ H = \frac{\sigma^2_g}{\sigma^2_e + \sigma^2_p} \]

Heritability values are grouped according to Bahar and Zen [7], value of < 0.2 categorized as low, 0.2 - 0.5 as moderate and > 0.5 as high.

| Source of Variation | Degree of Freedom (df) | Mean Square (MS) | Expectation of Mean Square (EMS) |
|---------------------|------------------------|-----------------|---------------------------------|
| Replication         | r-1                    | M6              | \( \sigma^2_e + g \sigma^2_f + pg \sigma^2_r \) |
| Main Plot (P)       | p-1                    | M5              | \( \sigma^2_e + g \sigma^2_f + r \sigma^2_P + rg \sigma^2_P \) |
| Error (p)           | (r-1)(p-1)             | M4              | \( \sigma^2_e + g \sigma^2_f \) |
| Genotype (G)        | g-1                    | M3              | \( \sigma^2_e + r \sigma^2_P + rpg \sigma^2_G \) |
| P x G               | (p-1)(g-1)             | M2              | \( \sigma^2_e + r \sigma^2_P \) |
| Error (g)           | p(r-1) (g-1)           | M1              | \( \sigma^2_e \) |
| Total               | rg-1                   |                 |                                 |

\( r = \) replication; \( g = \) genotype, \( \sigma^2_e = \) environment variation, \( \sigma^2_G = \) genotypic variation, \( \sigma^2_P = \) interaction variation, \( \sigma^2_f = \) drought stress variation. \( \sigma^2_p = M1, r \sigma^2_P = M2 - M1, \sigma^2_G = (M3 - (M2+M1)) / (r x p), \sigma^2_P = \sigma^2_G + \sigma^2_e \).

The stress tolerant index (STI), based on seed production, was calculated using the formula proposed by Fischer and Maurer in Fernandez [8]:

2
STI = (Ypi \times Ysi)/Yp^2

where:

\[ Ysi = \text{Mean of a drought stressed genotype} \]

\[ Ypi = \text{Mean of a unstressed genotype} \]

\[ YP = \text{Mean of all unstressed genotypes} \]

The criteria for determining the tolerance level for drought stress is if the value of ITC is ≤0.5, the genotype is sensitive, if 0.5 < ITC ≤1.0 then the genotype is medium tolerant, and if ITC > 1.0 then the genotype is tolerant.

3. Results and Discussion
Table 2 shows that genotype N.350 3.8.9 (g11) gave the highest number of productive tillers in water availability of 81-100% fc (k0) (3.73 tillers), 61-80% fc (k1) (3.19 tillers) and 41-60% fc (k2) (2.27 tillers). These values were significantly different from all comparison varieties at k0 and k1, whereas in k2 condition only differed significantly from comparable varieties of the Dewata. The character of the number of productive tillers is a generative component that greatly affects the amount of production that will be produced in each clump. The formation of the number of productive tillers is strongly influenced by the condition of the surrounding environment, the high temperature of the environment will result in cell death in plants so that the process of development and growth of vegetative and generative organs is inhibited. This is in accordance with the opinion of Schoffl et al. [9] that very high temperatures can damage or cause cell death within minutes after the plant is exposed to high temperatures. In line with Nur's [10] opinion on the development of the number of tillers, and the number of productive tillers determined by environmental factors, especially air temperature, the higher the air temperature tends to slow the development of the number of productive tillers.

Table 2. The number of productive tillers of several wheat genotypes in various water availability.

| Genotypes   | Water availability |
|-------------|--------------------|
|              | 81-100% fc (k0)    | 61-80% fc (k1)   | 41-60% fc (k2)   |
| g1 (M 1.7.1) | 2.67               | 2.26             | 1.33             |
| g2 (N.350 3.6.2) | 2.17               | 1.50             | 1.27             |
| g3 (N.250 4.2.1) | 1.83               | 1.57             | 1.17             |
| g4 (N.350 3.1.3) | 2.83               | 2.17             | 1.49             |
| g5 (N.350 3.2.2) | 1.62               | 1.39             | 1.17             |
| g6 (N.250 4.5.2) | 1.80               | 1.66             | 1.50             |
| g7 (N.350 3.1.4) | 1.57               | 1.44             | 1.17             |
| g8 (N.250 2.5.1) | 1.50               | 1.24             | 1.10             |
| g9 (M.200 1.7.1) | 2.67               | 1.73             | 1.17             |
| g10 (N.250 4.6.2) | 3.33 ab             | 2.63 a           | 2.00             |
| g11 (N.350 3.8.9) | 3.73 ab             | 3.19 ab          | 2.27 a           |
| g12 (S.300 8.3.1) | 1.73               | 1.66             | 1.10             |
| g13 (N.2.5.2) | 2.00               | 1.63             | 1.17             |
| g14 (Dewata) (a) | 2.17               | 1.91             | 0.34             |
| g15 (Munal) (b) | 2.40               | 2.09             | 1.10             |
| LSD 0.05    | 0.61               |

Numbers followed by the same letter in column (a, b) means significantly different from comparison varieties of Dewata (a) and Munal (b) in LSD test α = 0.05. fc = field capacity.
Table 3 shows that the genotype N.350 3.1.4 (g7) produced the highest number of seeds (12.00 seeds) in normal water availability (81-100% fc) and was significantly different from all comparable varieties, while genotype N.350 3.8.9 (g11) showed the highest number of seeds (9.43 seeds) on water availability 61-80% (k1) and was significantly different from all comparable varieties. When water availability dropped to 41-60% fc (k2) the highest number of seeds (7.85 seeds) obtained by genotype N.250 4.6.2.

Among all growth phases of the wheat plant, high temperature stress has the greatest effect on seed yield because it affects the process of pollination and seed filling. This is in accordance with the opinion of Nasaruddin et al. [5], high temperature stress causes the seeds to fail to form so that it will affect the number of seeds produced in the panicle and also affect the seed weight per panicle.

Table 3. Number of seeds per panicle of several wheat genotypes in various water availability.

| Genotypes       | Water availability |            |            |            |
|-----------------|--------------------|------------|------------|------------|
|                 | 81-100% fc (k0)    | 61-80% fc (k1) | 41-60% fc (k2) |
| g1 (M 1.7.1)    | 10.42 ab           | 6.43       | 4.00       |
| g2 (N.350 3.6.2)| 9.54               | 6.77       | 3.33       |
| g3 (N.250 4.2.1)| 8.88               | 6.77       | 3.93       |
| g4 (N.350 3.1.3)| 9.54               | 5.10       | 2.73       |
| g5 (N.350 3.2.2)| 6.54               | 5.77       | 3.00       |
| g6 (N.250 4.5.2)| 11.38 ab           | 8.77 ab    | 5.33 ab    |
| g7 (N.350 3.1.4)| 12.00 ab           | 7.40       | 3.67       |
| g8 (N.250 2.5.1)| 8.63               | 6.10       | 4.33       |
| g9 (M.200 1.7.1)| 5.88               | 7.10       | 3.67       |
| g10 (N.250 4.6.2)| 10.88 ab          | 8.27 b     | 7.85 ab    |
| g11 (N.350 3.8.9)| 11.65 ab         | 9.43 ab    | 7.67 ab    |
| g12 (S.300 8.3.1)| 6.54               | 5.43       | 2.33       |
| g13 (N.2.5.2)   | 10.67 ab           | 8.00       | 3.67       |
| g14 (Dewata) (a)| 8.03               | 6.43       | 3.33       |
| g15 (Munal) (b) | 8.36               | 6.10       | 3.13       |

LSD (0.05) 1.940

Numbers followed by the same letter in column (a, b) means significantly different from comparison varieties of Dewata (a) and Munal (b) in LSD test α = 0.05. fc: field capacity.

Genotype N.250 4.6.2 (g10) showed the heaviest seed weight of all treatments of water availability with an average value of 0.48 g, 0.37 g and 0.24 g and is significantly different from all comparison varieties (table 4). Wheat plants that are experiencing water shortages and high temperatures in the generative phase will affect the size of seeds to be produced. This is in accordance with the opinion of Asana and Williams [11] in his research on controlled rooms with temperatures of 25-35 °C to get the weight of wheat seeds decreased by 16% for each increase in temperature of 5 °C. This means that if there is an increase in temperature of 10 °C, there will be a decrease in seed yield to 8%, an increase in empty grain 5-6%, and a smaller size of seeds 3-4%. High environmental temperatures inhibit the physiological and biochemical processes of plants, including the disruption of the supply of assimilated ingredients to seeds, which results in a decrease in the accumulation of dry weight of wheat plants. Among the phases of wheat plant growth, high temperature stress in the anthesis phase has the greatest effect on seed yield because it affects the pollination and filling process.
### Table 4. Seed weight per panicle of several wheat genotypes in various water availability.

| Genotypes | Water availability | 81-100% fc (k0) | 61-80% fc (k1) | 41-60% fc (k2) |
|------------|--------------------|-----------------|----------------|----------------|
| g1 (M 1.7.1) | 0.38 | 0.23 | 0.09 |
| g2 (N.350 3.6.2) | 0.35 | 0.25 | 0.08 |
| g3 (N.250 4.2.1) | 0.31 | 0.23 | 0.08 |
| g4 (N.350 3.1.3) | 0.33 | 0.18 | 0.06 |
| g5 (N.350 3.2.2) | 0.25 | 0.22 | 0.08 |
| g6 (N.250 4.5.2) | 0.47 ab | 0.36 ab | 0.14 |
| g7 (N.350 3.1.4) | 0.47 ab | 0.30 b | 0.10 |
| g8 (N.250 2.5.1) | 0.38 | 0.27 | 0.13 ab |
| g9 (M.200 1.7.1) | 0.22 | 0.27 | 0.09 |
| g10 (N.250 4.6.2) | 0.48 ab | 0.37 ab | 0.24 ab |
| g11 (N.350 3.8.9) | 0.42 ab | 0.35 ab | 0.17 ab |
| g12 (S.300 8.3.1) | 0.22 | 0.18 | 0.04 |
| g13 (N.2.5.2) | 0.48 ab | 0.36 ab | 0.12 |
| g14 (Dewata) (a) | 0.34 | 0.26 | 0.08 |
| g15 (Munal) (b) | 0.31 | 0.23 | 0.08 |
| LSD 0.05 | 0.06 |

Numbers followed by the same letter in column (a, b) means significantly different from comparison varieties of Dewata (a) and Munal (b) in LSD test α = 0.05. fc: field capacity.

### Table 5. Production of several wheat genotypes in various water availability.

| Genotypes | Water availability | 81-100% fc (k0) | 61-80% fc (k1) | STI | 41-60% fc (k2) |
|------------|--------------------|-----------------|----------------|-----|----------------|
| g1 (M 1.7.1) | 1.01 ab | 0.51 | MT | 0.12 | S |
| g2 (N.350 3.6.2) | 0.76 | 0.38 | S | 0.10 | S |
| g3 (N.250 4.2.1) | 0.56 | 0.36 | S | 0.09 | S |
| g4 (N.350 3.1.3) | 0.95 | 0.37 | MT | 0.09 | S |
| g5 (N.350 3.2.2) | 0.40 | 0.30 | S | 0.09 | S |
| g6 (N.250 4.5.2) | 0.85 | 0.59 | MT | 0.21 | S |
| g7 (N.350 3.1.4) | 0.78 | 0.46 | MT | 0.12 | S |
| g8 (N.250 2.5.1) | 0.54 | 0.33 | S | 0.15 | S |
| g9 (M.200 1.7.1) | 0.59 | 0.47 | S | 0.11 | S |
| g10 (N.250 4.6.2) | 1.62 ab | 0.95 ab | T | 0.48 ab | T |
| g11 (N.350 3.8.9) | 1.58 ab | 1.10 ab | T | 0.40 ab | MT |
| g12 (S.300 8.3.1) | 0.39 | 0.30 | S | 0.05 | S |
| g13 (N.2.5.2) | 0.96 | 0.60 | MT | 0.13 | S |
| g14 (Dewata) (a) | 0.74 | 0.49 | MT | 0.14 | S |
| g15 (Munal) (b) | 0.75 | 0.47 | MT | 0.14 | S |
| NP BNT | 0.23 |

Numbers followed by the same letter in column (a, b) means significantly different from comparison varieties of Dewata (a) and Munal (b) in LSD test α = 0.05. fc: field capacity. STI = Stress Tolerance Index, S = Sensitive, MT = Medium Tolerant, T = Tolerant.
Table 5 shows that genotype N.250 4.6.2 (g10) genotypes produce the highest production in water availability 81-100% (k0) (1.62 g.plant$^{-1}$) and 41-60% (k2) (0.48 g.plant$^{-1}$) and significantly different with all comparable varieties, while the highest production of 61-80% (k1) water availability (1.10 g.plant$^{-1}$) was produced by genotype N.350 3.8.9 (g10) with significantly different from all varieties comparison. The stress tolerance index (STI) in the treatment of water availability 61-80% (k1) produced 2 genotypes which showed tolerant (T) properties to the treatment given, namely genotype N.250 4.6.2 (g10) and genotype N.350 3.8.9 (g10), while the treatment of water availability 41-60% (k2) produces 1 tolerant genotype (T) for the given treatment, namely genotype N.250 4.6.2 (g10). The amount of production produced is influenced by the appearance of vegetative morphology and generative components. This is in line with the opinion of Taiz and Zeiger [12], that drought stress affects plant morphology and decreases crop yields. The amount of yield produced on plants is strongly influenced by plant metabolic activity. According to Levitt [13] drought stress is caused by a lack of water supply from root areas and excessive water demand by leaves where the rate of evapotranspiration exceeds the rate of absorption of water by plant roots. This will result in a decrease in photosynthetic activity, so that the amount of assimilate produced decreases and causes panicle formation and the filling of seeds will decrease.

Table 6 shows that characters that have a broad coefficient of genetic diversity and high heritability values were the number of productive tillers, number of seeds per panicle, weight of seeds per panicle, and production indicating potential characters to be improved and developed in the next generation. High heritability values indicate a more significant genetic influence compared to the environment. Heritability analysis determines the phenotypic differences of a character caused by genetic or environmental factors, high heritability values can give an idea that the characters observed are more influenced by genetic factors than the environment [5].

| No | Parameter                        | Heritability | Category |
|----|----------------------------------|--------------|----------|
| 1  | Number of Productive Tiller      | 61.62        | High     |
| 2  | Number of Seeds per Panicle      | 54.24        | High     |
| 3  | Seed Weight per Panicle          | 69.40        | High     |
| 4  | Production                       | 69.50        | High     |

4. Conclusion

Genotypes that have adaptive potential grow and have high productivity on water availability of 81-100% of field capacity (fc) (k0), namely N.250 4.6.2 (1.62 g.plant$^{-1}$) and N.350 3.8.9 (1.58 g.plant$^{-1}$), on water availability 61-80% fc (k1), which was N.350 3.8.9 (1.10 g.plant$^{-1}$) and on water availability 41-60% fc (k2), namely N.250 4.6.2 (0.48 g.plant$^{-1}$). Characters that have a broad coefficient of genetic diversity and high heritability, namely the number of productive tillers, number of seed per panicle, weight of seeds per panicle and production.

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