Effect of Terminal Drought Stress on Morpho-Physiological and Yield Potential Traits of Bread Wheat Genotypes

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Abstract – The field experiment was conducted with 50 bread genotypes at the research farm of Agriculture and Forestry University, Rampur from December 2014 to April 2015 to identify the morpho-physiological traits, yield and yield potential traits in advanced lines and commercial varieties of bread wheat associated with drought tolerance and to screen drought tolerant wheat genotypes. The experiment was carried out in alpha lattice design with two replications under irrigated and drought conditions. The results of combined analysis of variance and mean comparisons showed significant differences for all the genotypes in both conditions. Mean values of all the morpho-physiological, yield and yield potential traits showed decrease in drought stress condition in comparison to the irrigated condition because of the response to drought stress. In drought stress condition, the genotype WK 2507 produced the highest yield with 2.4 ton/ha while the genotype WK 2513 produced the lowest yield with 0.095 ton/ha. In irrigated condition, the genotype WK 2437 produced the highest yield with 2.94 ton/ha while the genotype WK 2523 produced the least yield with 0.272 ton/ha. However, genotypes WK 2525, WK 2507, Munali#1, WK 2437 were superior for grain yield in both drought and irrigated conditions. The genotypes WK 2507, WK 2503, WK 2524 were promising lines for drought condition. Correlation studies showed the significant positive correlation between grain yield with thousand grain weight under drought condition while it days to heading, and flag leaf senescence in drought and irrigated conditions.

Keywords – Drought, Genotypes, Wheat, Yield.

I. INTRODUCTION

Wheat is a temperate cereal with an optimum temperature regime of 15-18°C during the grain filling stage. With an average 0.06°C/year, a rise in temperature from 1975 to 2006 by 1.8°C has been recorded in the country [1]. Change in climate due to greenhouse effect have made the earth warmer and have changed the precipitation pattern resulting the incidence of floods or drought globally [2]. Moreover, the drought problem under wheat growing season is more pronounced in Nepal and severe dry periods are increasing, concomitantly irrigation is one of the production constraints of Nepalese agriculture especially during rain off seasons.

Drought stress is characterized by reduction of water content, diminished leaf water potential and turgor loss, closure of stomata and decrease in cell enlargement and growth. Severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of plant [3]. Water stress inhibits cell enlargement more than cell division. It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism and growth promoters (Jaleel et al., 2008). In wheat, there are several genes which are responsible for drought stress tolerance and produce different types of enzymes and proteins for instance, late embryogenesis abundant (lea), responsive to abscisic acid (Rab), rubisco, helicase, proline, glutathione-S-transferase (GST), and carbohydrates during drought stress.

It is the need of time to develop the varieties, which have drought tolerant potential to increase area under cultivation and yield of wheat crop in Nepal. The present study will be aimed to screen out drought tolerant varieties of wheat with high yield potential, through understanding of physiomorphological traits in response to drought stress. Ultimately, it helps in the mitigation process of climate change effects, water scarcity, and food security which improves the livelihood of the farmer, living in poor marginal rainfed land of Nepal.

II. MATERIALS AND METHODS

The research was conducted at Agronomy research farm under Agriculture and Forestry University, Rampur, Chitwan. Geographically, Rampur is in the Terai belt at 27º 37’ N Latitude and 84º 25’ E Longitude at an altitude of 256 m asl. This place has a humid sub-tropical climate where summers are hot and winters are cold with total annual rainfall reported as 1582.6 mm. All the meteorological information like temperature, rainfall, relative humidity was recorded in National Maize Research program, Rampur, Chitwan. The rice- wheat cropping system of the field is selected as research field. There was be wheat crop during December 2014 to June 2015 and rice is planted until the next season, i.e. Nov. 2015.

Composite soil samples were taken from the field at different depth (0-30) cm for soil analysis. A set of 50 wheat genotypes were taken from Agriculture Botany Division, Nepal Agriculture Research Council (NARC), Khumaltar, Nepal. They consist of forty-five Wheat Khumal (WK) lines, one Nepal line (NL), one commercial variety and three promising wheat genotypes developed for rain fed conditions of Nepal hills. WK 1204 was used as the standard check variety. The experiment was conducted in Alpha Lattice design, at moisture stress environments and with irrigations as normal condition. Each set of experiment
was replicated two times in both environments. Irrigated plots were supplied with irrigation as per recommended and needed dose in critical stages. Drought experiment will be conducted within the plastic tunnel. To avoid the drought plot from moisture (rain as well as dews), the drought plot was covered with a removable plastic sheet which was removed in the morning and put on the evening. The size of the plot will be 3 m² (3 m x 1 m). The sowing was done in December, 2014 at the seed rate of 150 kg/ha. Every genotype was sown in a 25 cm row space consisting of 3 rows per treatment. Genotypes with the replicates will be randomized. The manure was used at the rate of 15 ton/ha and the individual plots will be fertilized with recommended dose of 120:60:60 kg NPK/ha. All the phosphorus, potash and half dose of nitrogen were applied before sowing. The remaining dose of nitrogen was applied in two split doses. The field was made weed-free whenever seen. The traits taken for data observations were days to booting, days to heading, days to anthesis, days to flag leaf senescence, days to maturity, flag leaf area, plant height, canopy temperature, SPAD reading, relative water content, thousand grain weight, number of grains per spike, grain weight per spike, biomass yield and grain yield.

Data entry and processing was carried out using Microsoft Office Excel 2007. Analysis of variance of all parameters and calculation of means was done by using R.3.2.1 software package for alpha lattice design. Correlation coefficient between various morphophysiological, secondary and yield attributing traits was done by SPSS 16 software package. Multivariate analysis (UPGMA clustering and PCA) was done by using MINITAB 15 software package. Graphs and tables were constructed by using MS Office Excel program.

**Table I. List of the genotypes used for the experiment**

<table>
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<tr>
<th>Entry No.</th>
<th>Genotypes</th>
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<td>WK 2519</td>
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<td>25</td>
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</table>

**Table III.**

**A. Phenological Traits**

**A.1. Days to Heading and Flag Leaf Senescence**

There was highly significant (P<0.001) difference in days to heading for the genotypes and blocks in drought and irrigated environments respectively as shown by the ANOVA in Table III. The mean number of days to heading to heading for drought and irrigated condition was almost similar 74.56 days and 75.33 days respectively. In drought condition WK 2355 heading was earliest with the mean of 63 days and WK 2513 heading was the last in 115 days. Similarly, in irrigated condition WK 2495 heading was the earliest with the mean of 65 days and WK 2513 heading was last in 110 days. In drought condition, WK 1204 headed with the mean of 73 days while it was headed almost similar with mean of 73 days in irrigated condition.

There was highly significant difference (P<0.001) for the genotypes and at (P<0.05) for the environment in days to flag leaf senescence as shown by the ANOVA in Table III. Mean number for days to flag leaf senescence for drought and irrigated condition were 112 days and 113 days respectively. In drought condition, WK 2353 senesced earliest in 101 days where as WK 2513 was senesced last in 138 days. Similarly, in irrigated condition the genotype WK 2505 senesced the earliest in 100 days and WK 2513 senesced last in 136 days. WK 1204 senesced with the mean of 109 days in drought condition while it senescence with the mean of 114 days in irrigated condition. Mean days to heading and flag leaf senescence is under drought and irrigated conditions is shown in Table IV and V.

**Fig. 1.** The monthly average maximum and minimum temperature, relative humidity and rainfall over the experimental period in Rampur, Chitwan, 2014/2015
B. Secondary Traits

B.1. Area Under SPAD Retrieve Curve (AUSRC)

There was highly significant difference at (P≤0.001) for the genotypes and environment in area under SPAD retrieve curve (AUSRC) as shown by the ANOVA in Table 3. Mean area under SPAD retrieve curve in drought and irrigated condition was 451.4 and 499 respectively as presented in Table IV and V. In drought condition, WK 2513 had the lowest area under SPAD curve with 261.03 and WK 2480 had the highest area under SPAD curve with 617.4. Similarly, in irrigated condition WK 2513 had the lowest AUSRC with value 207.46 and WK had the highest AUSRC with value 704WK 1204 had mean AUSRC with 435 in drought condition while it was 501 in irrigated condition.

B.2. Flag Leaf Relative Water Content (RWC)

There was highly significant (P≤0.001) difference in flag leaf relative water content for the genotypes and environment in both the conditions as shown by the ANOVA in Table III. The mean relative water content of wheat genotypes in drought condition was 0.86 and for irrigated condition it was 0.97 as shown in Table 4 and 5. WK 2566 had the highest RWC with 1.24 and WK 2516 had the lowest RWC with 0.63 in drought condition. Similarly, highest RWC of WK 2514 with 1.42 and lowest RWC of WK 2512 with 0.57 in irrigated condition. Mean flag leaf relative water content of WK 1204 in drought condition was 0.85 in drought condition while it was 0.89 in irrigated condition. Genotypes WK 2514, WK 2566, WK 2381 showed higher mean relative water content while WK 2218, WK 2495, WK 2513, WK 2512 showed lower relative water in comparison to WK 1204 in both the conditions. Mean flag leaf relative water content of all the genotypes under drought and irrigated treatments is shown in Table IV and V.

C. Yield and Yield Potential Traits

C.1. Plant Height

There was highly significant (P≤0.001) difference for the genotypes and environment in plant height as shown by the ANOVA in Table 3. The mean plant height of wheat genotypes in drought and irrigated condition were 98.5 cm and 103.8 cm respectively as shown in the Appendix 9 and 10. In drought condition, WK 1481 had the highest plant height with 126 cm and whereas WK 2540 had the lowest plant height with 77.25 cm. Similarly, in irrigated condition WK 1481 had the highest plant 140.5 cm and WK 2513 had the lowest plant height 77.15cm respectively. In drought condition, WK 1204 had mean plant height of 86.45cm while it was 94.7cm in irrigated condition. Genotypes WK 1481, WK 2546 showed greater plant height whereas WK 2540, WK 2508, WK 2438 showed lower plant height in both the condition. The mean plant height of all genotypes under and drought irrigated conditions is presented in Table IV and V.

C.2. Thousand Grain Weight and Grain Yield

There was highly significant (P≤0.001) difference in thousand grain weight for the different wheat genotypes as shown by the ANOVA in Table III. Genotype by interaction showed that thousand grain weight was also highly significant (P<0.01) in drought and irrigated environments. The mean thousand grain weight of wheat genotypes under irrigated and drought conditions were 40 gm. For irrigated condition, WK 2513 the least thousand grain weight of 12.8 gm and the highest was for WK 2515, WK 2414 and WK 1481 with thousand grain weight of 60.3 gm, 59.2 gm and 55 gm respectively. Similarly, in drought condition, WK 2546 had the lowest thousand grain weight of 12.2 gm and WK 2510 had the highest thousand grain weight with 49.5 gm. WK 1204 had thousand grain weights of 40 gm in drought condition while it had 34.73 gm in irrigated condition.

There was highly significant difference at (P≤0.001) in grain yield for the genotypes and significant (P≤0.01) difference in grain yield at environment and replication respectively as shown by the ANOVA in Table III. There is also significant difference at (P≤0.05) for the interaction between the genotypes and environment for grain yield. Mean grain yield of wheat genotypes for irrigated and drought conditions were 1.38 ton/ha and 1.57 ton/ha respectively as presented in the Table IV and V. In drought condition, highest grain yield was found in WK 2507 with 2.40 ton/ha which is followed by WK 2502 with 2.11 ton/ha respectively and the lowest grain yield was obtained from WK 2513 with 0.95 ton/ha. Similarly, in irrigated condition the grain yield was highest for WK 2437 with 2.94 ton/ha and the lowest yield was for WK 2513 with 0.272 ton/ha respectively. WK 1204 had grain yield of 1.87 ton/ha in drought condition while it had 2.19 ton/ha in irrigated condition.

Genotypes WK 2507, WK 2503, WK 2352, Munal#1, WK 2525, WK 2486, WK 2558 were superior for grain yield whereas the other six genotypes (WK 2513, WK 2505, WK 2546, WK 2562, WK 2521, WK 2414, WK 2248) were inferior for grain yield in drought condition. WK 2437, WK 2525, WK 2506, WK 2381, WK 2515, Munal#1 were superior genotypes for grain yield whereas WK 2513, WK 2388, WK 2257, WK 2485, WK 2546, WK 2494, WK 2278, WK 2564, WK 2480 were inferior genotypes for grain yield in irrigated condition. The mean grain yield of genotypes in both the conditions is presented in the Figure 2. The mean thousand grain weight and grain yield under drought and irrigated conditions is shown in Table IV and V.
Fig. 2. Comparison between wheat genotypes for grain yield under drought and irrigated conditions at AFU, Rampur (2014/15)

Table III. Combined mean square analysis of variance of different morpho-physiological traits of 50 bread wheat genotypes under drought and irrigated conditions at AFU, Rampur (2014/2015)

<table>
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<th>Traits</th>
<th>Mean Sum Square Genotype</th>
<th>Mean Sum Square Envt</th>
<th>Mean Sum Square G×E</th>
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<td>a. Phenological traits</td>
<td></td>
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</tr>
<tr>
<td>• Days to heading</td>
<td>185.37**</td>
<td>29.64</td>
<td>12.71</td>
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<tr>
<td>• Days to flag leaf senescence</td>
<td>131.36***</td>
<td>48.02*</td>
<td>11.91</td>
</tr>
<tr>
<td>• Days to maturity</td>
<td>135.08***</td>
<td>6.48</td>
<td>14.23</td>
</tr>
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<td>b. Secondary traits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Area under SPAD retrieve curve</td>
<td>19032**</td>
<td>69544**</td>
<td>10033</td>
</tr>
<tr>
<td>• Relative water content</td>
<td>0.0585***</td>
<td>0.5875***</td>
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</tr>
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<td>c. Yield and yield potential traits</td>
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<tr>
<td>• Plant height</td>
<td>262.274***</td>
<td>1421.2***</td>
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<td>• Leaf area</td>
<td>707***</td>
<td>3658***</td>
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<tr>
<td>• Thousand kernel weight</td>
<td>147.16***</td>
<td>9.03</td>
<td>60.29***</td>
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<td>• Grain yield</td>
<td>0.7814***</td>
<td>1.916***</td>
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Table IV. Average values for different morpho-physiological, yield and yield potential traits in drought condition at AFU, Rampur Chitwan (2014/2015).

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<th>PH</th>
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### Table V. Average values for different morpho-physiological, yield and yield potential traits in irrigated condition at AFU, Rampur Chitwan (2014/2015)

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<td>0.8106254</td>
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<td>2.091379</td>
</tr>
<tr>
<td>WK 2241</td>
<td>68.4838</td>
<td>113.766</td>
<td>556.1759</td>
<td>98.61554</td>
<td>1.0414971</td>
<td>59.22447</td>
<td>1.940409</td>
</tr>
<tr>
<td>WK 2372</td>
<td>78.02429</td>
<td>116.0819</td>
<td>483.3159</td>
<td>121.70687</td>
<td>0.8986053</td>
<td>50.05846</td>
<td>1.4806174</td>
</tr>
<tr>
<td>WK 2353</td>
<td>68</td>
<td>102.8799</td>
<td>497.9567</td>
<td>106.73336</td>
<td>0.8824</td>
<td>38.53035</td>
<td>1.4762878</td>
</tr>
<tr>
<td>WK 2104</td>
<td>72.52429</td>
<td>113.6637</td>
<td>477.1167</td>
<td>95.46434</td>
<td>0.878389</td>
<td>34.7298</td>
<td>2.187697</td>
</tr>
<tr>
<td>WK 2355</td>
<td>70.92712</td>
<td>113.4297</td>
<td>362.5383</td>
<td>88.51678</td>
<td>1.0139498</td>
<td>33.67548</td>
<td>1.8242964</td>
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<tr>
<td>WK 2359</td>
<td>68.94332</td>
<td>111.5178</td>
<td>465.8083</td>
<td>108.52532</td>
<td>0.9568279</td>
<td>39.73344</td>
<td>1.5822829</td>
</tr>
</tbody>
</table>

**Notes:**
- **DTH:** Days to heading, **DTA:** Days to anthesis, **DFLS:** Days to flag leaf senescence, **DM:** Days to maturity, **PHT:** Plant height, **LA:** Leaf Area, **GY:** Grain yield, **RWC:** Relative water content, **AUSRC:** Area under SPAD retrieval curve, **TGW:** Thousand grain weight.
Correlation studies of the different morpho-physiological, secondary and yield and yield potential traits in drought condition are presented in Table VI. Days to heading showed highly significant positive correlation with days to flag leaf senescence (0.81***) and days to maturity (0.81***) while it showed highly significant negative correlation with grain yield (-0.441**) and thousand grain weight (-0.45**). Days to flag leaf senescence showed highly significant and positive correlation with days to maturity (0.99**). However, it showed negative correlation with...
with grain yield (-0.30*). Days to maturity was negatively correlated with number of thousand kernel weight (0.45*). Grain yield showed highly significant positive correlation thousand grain weight (0.38**).

Table VI. Pearson correlation of different morpho-physiological traits under drought condition at AFU, Rampur, Chitwan Nepal, 2014/15

<table>
<thead>
<tr>
<th>DTH</th>
<th>DFLS</th>
<th>DM</th>
<th>GY</th>
<th>AUSRC</th>
<th>TGW</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTH</td>
<td>1</td>
<td>.810**</td>
<td>.809**</td>
<td>-.444**</td>
<td>-.072</td>
</tr>
<tr>
<td>DFLS</td>
<td>1</td>
<td>.989**</td>
<td>-.296*</td>
<td>0.151</td>
<td>-.325*</td>
</tr>
<tr>
<td>GY</td>
<td>1</td>
<td>.0444</td>
<td>.379**</td>
<td>1</td>
<td>.128</td>
</tr>
<tr>
<td>AUSRC</td>
<td>1</td>
<td>.128</td>
<td>.379**</td>
<td>1</td>
<td>.128</td>
</tr>
</tbody>
</table>

DTH = Days to heading, DFLS= Days to flag leaf senescence, DM = Days to maturity, GY= Grain yield, AUSRC = Area under SPAD retrieve curve, TGW= Thousand grain weight

Table VII. Pearson correlation of different morpho-physiological traits under irrigated condition at AFU, Rampur, Chitwan Nepal, 2014/15

<table>
<thead>
<tr>
<th>DTH</th>
<th>DFLS</th>
<th>DM</th>
<th>GY</th>
<th>AUSRC</th>
<th>TGW</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTH</td>
<td>1</td>
<td>.705**</td>
<td>.730**</td>
<td>-.439**</td>
<td>-.21</td>
</tr>
<tr>
<td>DTA</td>
<td>.694*</td>
<td>.718**</td>
<td>-.456**</td>
<td>-.222</td>
<td>-.358*</td>
</tr>
<tr>
<td>DFLS</td>
<td>1</td>
<td>.998**</td>
<td>-.365**</td>
<td>.022</td>
<td>-.123</td>
</tr>
<tr>
<td>DM</td>
<td>1</td>
<td>-.375**</td>
<td>0.01</td>
<td>.0166</td>
<td>.228</td>
</tr>
<tr>
<td>PHT</td>
<td>-0.304*</td>
<td>.179</td>
<td>.234</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GY</td>
<td>1</td>
<td>.166</td>
<td>.228</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUSRC</td>
<td>1</td>
<td>.333*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TKW</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DTH= Days to heading, DFLS= Days to flag leaf senescence, DM= Days to maturity, GY= Grain yield, AUSRC= Area under SPAD retrieve curve, TGW= Thousand grain weight

E. Multivariate Analysis
E.1. UPGMA Clustering

E.1.1. Cluster Analysis under Drought Condition

The dendrogram of flag leaf senescence, leaf area, plant height, biomass yield, grain yield, relative water content, AUSRC under drought condition are presented in figure 15. Distance among different cluster centroids are presented in the Table 8. The dendrogram is classified into two major groups and six clusters. Group A consists of five clusters and Group B has only one cluster. Cluster was obtained based on similarity percentage and related characters. The Group A consists of five clusters and 49 genotypes. Cluster I was found to be the largest cluster and divided into three quadrants. Right quadrant consists of 10 genotypes i.e. WK 2208, WK 2272, WK 2564, WK 2507, WK 2257, Chyakura#1, WK 2408, WK 2508, NL1223, Mid quadrant consists of 8 genotypes i.e. WK 2278, WK 2551, WK 2509, WK 2546, WK 2480, WK 2505, WK 2511. Left quadrant consists of 4 genotypes i.e. WK 2353, WK 1204, WK 2515, WK 1481. It has been observed that the genotypes in this cluster have early flag leaf senescence, small leaf area, plant height, low in biomass yield and grain yield, low in relative water content, AUSRC, and thousand grain weight. Cluster II was the second largest cluster and consists of 30% of the genotypes. Left quadrant consist of 5 genotypes viz. WK 2248, WK 2550, WK 2566, WK 2506, WK 2514. Middle quadrant consists of 7 genotypes i.e. WK 2414, WK 2519, WK 2562, WK 2381, Danphe, Munal#1, WK 2438. Genotypes WK 2558, WK 2510, WK 2512 were grouped into the right quadrant of second cluster. It has been found that the genotypes with higher value of traits like days to flag leaf senescence, flag leaf area, biomass yield, grain yield, relative water content, AUSRC, and thousand grain weight grouped into this cluster. Similarly, cluster III consists of 10 genotypes (WK 2352, WK 2355, WK 2540, WK 2218, WK 2359, WK 2494, WK 2495, WK 2503, WK 2525, WK 2485) which represents 20% of the total genotypes. The genotypes with highest value of grain yield and thousand grain weight were grouped into this cluster. Cluster IV consists of two genotypes (WK 2388, WK 2555), which contributes 4% of the total genotypes. The genotypes in this cluster have lowest values of leaf area, grain yield and thousand grain weight. Cluster V consists of WK 2513. In this group, the genotype showed lowest values for plant height, grain yield, relative water content, AUSRC, thousand grain weight with late in flag leaf senescence.

D.2. Correlation Studies under Irrigated Condition

Correlation studies of the different morpho-physiological traits, secondary traits, yield and yield potential traits under irrigated condition are presented in Table VII. Days to heading showed highly significant positive correlation with days to flag leaf senescence (0.71***) and days to maturity (0.730***) while it showed highly significant negative correlation with grain yield (-0.44***) and significant negative correlation with thousand grain weight (-0.33*). Days to flag leaf senescence showed highly significant positive correlation with days to maturity (0.998**), spike length (0.36**) but it was negatively correlated with grain yield (-0.37**). Days to maturity showed highly significant negative correlation with grain yield (-0.38*). Plant height was found to be significant and negatively correlated with grain yield (-0.304*). Similarly, AUSRC was significant and positively correlated with thousand grain weight (0.333*).
The increased in the flag leaf senescence in stressed condition in comparison to non-stressed have been found in the literature. It has been reported that the “stayed green” or delayed senescence plays an important role in grain development during stress conditions which allow the plants to retain their green leaves for a prolonged grain filling period. Terminal drought stress stimulates the senescence of the wheat plant which may increase nutrient remobilization from the stem to developing grains and this may compensate for senesce induced losses in grain yield [4]. Stay green genotypes might contribute to higher yield and enhance drought tolerance if normal photosynthesis duration is prolonged and there high intrinsic chlorophyll concentration so the delayed senescence is considered to desirable trait in cereal breeding.

A.2. Days to Maturity

The highly significant (P<0.001) difference for days to maturity in genotypes suggested the genotypes were fall into different maturity group. It had been confirmed with the findings of others [5]-[6]. The interaction between genotype and environment was non-significant and it showed no variability across environment. The decrease in maturity days under stressed is controlled by the lower of nutrients in the plants with decreased chlorophyll in leaves due to the lack of nitrogen needed for the assimilation. The loss of the chloroplast integrity in the leaf causes the early senescence in drought that ultimately leads plant to mature early.

A.3. Area Under SPAD Retrieve Curve (AUSRC)

[7] found the similar reports of decrease in chlorophyll content in drought stress conditions. AUSRC is decreased in the drought stress treatment because the drought stress decrease the total the total chlorophyll content is found to reduce under water stress conditions. Drought stress inhibits the photosynthesis of plants by causing changes in chlorophyll content, by affecting chlorophyll pigments and by damaging the photosynthetic apparatus. The chlorophyll content in flag leaves reflects the photosynthetic activity and yield potential of wheat genotypes. It has been found that decrease in chlorophyll content faster in drought sensitive than in drought tolerant genotypes. It has been reported that high chlorophyll capacity of wheat genotypes under drought condition could be identified by selecting the genotypes with high chlorophyll capacity. SPAD meter reading measures the total chlorophyll content in the leaves that could be used as a screening tool for selecting the genotypes under drought condition. The results also agree with the explanation given by [8].

A.4. Plant Height

Highly significant (P<0.01) differences among the genotypes for plant height showing variation in plant height agreed with the findings of [9]-[10]. [10] reported the similar findings of significant difference in environment and non-significant difference of genotype and interaction in plant height for wheat genotypes. The decrease in plant height of all genotypes in drought condition in comparison to irrigated condition may be due to decrease in relative turgidity and dehydration of protoplasm which is associated with a loss of and reduced expansion of cell and cell division. The reduction in plant height under water stress condition could be attributed to decline in cell enlargement and more leaf senescence [11]. These results are similar with findings of [12] who had observed significant reduction in plant height under drought stress condition.

A.5. Thousand Grain Weight (TGW)

Highly significant difference (P<0.001) in thousand grain weight for genotypes indicates the variability among the literature.

### Table VIII. Distances between cluster centroids under drought condition at AFU, Rampur, Chitwan (2014/2015)

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster1</td>
<td>0.000</td>
<td>95.719</td>
<td>93.968</td>
<td>180.593</td>
<td>212.274</td>
</tr>
<tr>
<td>Cluster2</td>
<td>0.000</td>
<td>191.489</td>
<td>87.233</td>
<td>306.790</td>
<td></td>
</tr>
<tr>
<td>Cluster3</td>
<td>0.000</td>
<td>275.978</td>
<td>120.408</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster4</td>
<td>0.000</td>
<td>388.923</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster5</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**IV. DISCUSSION**

A. Major Drought Responsive Traits

A.1. Days to Flag Leaf Senescence

The highly significant (P<0.001) differences for days to maturity in genotypes suggested the genotypes were fall into different maturity group. It had been confirmed with the findings of others [5]-[6]. The interaction between genotype and environment was non-significant and it showed no variability across environment. The decrease in maturity days under stressed is controlled by the lower of nutrients in the plants with decreased chlorophyll in leaves due to the lack of nitrogen needed for the assimilation. The loss of the chloroplast integrity in the leaf causes the early senescence in drought that ultimately leads plant to mature early.

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A.5. Thousand Grain Weight (TGW)

Highly significant difference (P<0.001) in thousand grain weight for genotypes indicates the variability among
genotypes revealed with findings of [13]. Decrease in thousand grain weight under drought stress condition was reported by [14]. The decrease in thousand grain weight may be due distributed nutrient uptake efficiency and photosynthetic translocation within the plant that produced shriveled grains due to hastened maturity [15]. This is possible due to the shortage of moisture which forces plant to complete its grain formation in relatively lesser time. Grain weight is a function of grain length and width. [16], [17] reported the critical period of grain weight determination which starts shortly before anthesis and continues throughout the grain filling duration determines the final grain size in wheat. Thus, drought stress during grain-filling period reduces grain weight significantly.

A.6. Grain Yield

[18] reported highly significant (P≤0.001) differences in genotypes showing variation for grain yield that confirms with our findings. [19] reported the similar findings. Genotype by environment interaction was significant (P≤0.05) for grain yield showing variation among genotypes across different moisture regime confirmed with the reports of [20]-[21]. Decrease in grain yield under drought condition was reported by many researches [22]-[23]-[24]. Grain yield was greater in irrigated condition than in drought environment as a consequence of more spikes per square meter, heavier grains, and a longer plant cycle. The as significant reduction in grain yield due to post anthesis water stress may result from a reduction of production of photo-assimilates (source limitation), power of the sink to absorb photo-assimilates and the grain filling duration. [9] reported the severe reduction in grain yield with 40% reduction at three irrigation stage to 98% in the post anthesis indicates that the sensitivity of grain yield to drought stress depends upon the severity of the stress and the stage in which the drought condition was imposed.

B. Correlations Studies

The negative and significant correlation between days to heading and grain yield in drought condition were similar with the reports [14]. These were also in the agreement with findings of several workers [25]-[26]. Negative association between days to maturity with grain yield also confirmed with the findings of [26]-[27]. Likewise, significant positive correlation of grain yield with thousand grain weight in drought treatment were in support with the findings of [10] and other researchers such as [28]. In drought stress condition, some of the genotypes compensate grain yield loss through transfer of photo-assimilates to the developing grains which may cause increase in number of grains per spike along with the increased grain weight per spike and thousand grain weight which finally results in increment of grain yield. Significant negative correlation of plant height with grain yield in irrigated condition agreed with the findings of [19]. The reason is that the increase in plant height would result in reduction of grain yield because of mobilization of carbohydrates towards the reproductive organ for seed formation rather to vegetative organ. Highly significant positive correlation of thousand grains weight and grain weight per spike in irrigated treatment agreed with the findings of [10], [29] reported that the chlorophyll content was positively correlated with biomass yield in drought condition.

V. CONCLUSION

Wheat (Triticum aestivum) is the third most important cereal crop of Nepal after rice and maize. Drought stress is the major problem in wheat production in many parts of the world including Nepal. It is one of the most common environmental stresses which affect the plant production through the alteration in plant metabolism and gene expression. It is the major challenge to agriculture scientists and plant breeder’s despite in the present scenario for the wheat production despite of many decades of research. It is the major constraint to the wheat production in many developing countries of the world and occasional causes of loss of agricultural production in many developed ones. Drought stress may occur at any time during the wheat growing season i.e. early or late however severe yield reduction occurs after anthesis. The amount and distribution of rainfall during the wheat growing season influence the variability in yield from year to year and from location to location. It is necessary to improve productivity of wheat under rainfed and dry conditions in Nepal through breeding of drought tolerant cultivars with high yield to solve the problems of food security.

The mean values of all phenological traits, secondary traits, yield and yield potential traits in drought condition were less than in irrigated condition. Genotypes were significantly different for all phenological traits in irrigated and drought treatments. Days to flag leaf senescence showed significant difference for environment and genotypes. Mean number of days to flag leaf senescence was 112.2 days and 113.8 days in drought and irrigated environment respectively. Similarly, the mean days to maturity were 116.97 days and 117.33 days in drought and irrigated treatment respectively. Secondary traits area under SPAD retrieve curve, relative water content and canopy temperature showed significant difference for environment and genotypes. It was observed mean AUSR of 459 and 493 in drought and irrigated condition respectively. It was observed significant difference in genotypes and environments for yield and yield potential traits. Genotype by environment interaction showed significant difference for grain yield and thousand grains weight. The mean thousand grains weight was 40.03gm in drought condition while it was 40.45 gm in irrigated. Similarly, the mean grain yield was 1.38 ton/ha in drought condition whereas it was 1.57 ton/ha in irrigated condition. In drought stress condition, the genotype WK 2507 produced the higher yield (2.4 ton/ha) followed by the genotypes WK 2507 (2.40 ton/ha), WK 2503 (2.11 ton/ha), WK 2514 (2.10 ton/ha), WK 2532 (2.04 ton/ha) and Munial#1 (2.03 ton/ha). In irrigated condition, the genotype WK 2437 produced the higher yield (2.94 ton/ha) followed by WK 2506 (2.35 ton/ha), WK 2381 (2.31 ton/ha) and WK 2515 (2.30 ton/ha).

Correlation studies were performed among different morpho-physiological traits in drought and irrigated conditions. Days to heading also showed highly significant and positive correlation with days to flag leaf senescence in
drought and irrigated environments. It was observed highly significant and negative correlation of days to heading with grain yield and thousand grains weight in both the environments. Days to flag leaf senescence showed highly significant and positive correlation with days to maturity while it was significant and negative correlated with grain yield in drought and irrigated conditions. There was significant and negative correlation of plant height with grain yield under irrigated condition. Grain yield showed highly significant positive correlation with thousand grains weight and significant positive correlation with number of grains per spike in drought condition whereas it showed highly showed highly significant and positive correlation with thousand grains weight in irrigated condition. UPGMA clustering of genotypes were done to identify the genotypes with similar traits which can be useful for selecting parents in breeding programs. The greater the distance between parents for individual components of yield, the greater the progeny variance. The genotypes belonged to respective cluster could be used in crop improvement program for respective character. This study can help plant breeders to increase the genetic diversity by selecting materials from divergent parentage for crosses, which can reduce the vulnerability to diseases and climate changes.

VI. RECOMMENDATIONS FOR FURTHER RESEARCH

Genotypes WK 2507, WK 2503, WK 2352, Munal#1, WK 2525, WK 2486, WK 2558 were identified as drought tolerant and high yielding genotypes under our drought stress condition. It is recommended for further wheat breeding research in rainfed and drought conditions of Terai and inner-Terai of Nepal. WK 2513, WK 2505, WK 2546, WK 2562, WK 2511, WK 2414, WK 2248 were drought sensitive genotypes and they are not recommended for cultivation under drought and rainfed conditions. WK 2437 and WK 2525 were identified as high yielding genotypes for grain yield under irrigated condition and it can be recommended for further wheat breeding research in irrigated conditions of Terai and inner Terai. However, genotypes WK 2525, WK 2507, Munal#1 and WK 2437 were superior genotypes for grain yield in both drought and irrigated conditions. Genotypes WK 2353, WK 2218, WK 2355, WK 2495, WK 2505 were early for phenological traits like days to booting, heading, flag leaf senescence and maturity. Hence it can be recommended for terminal drought stress condition in Terai and inner-Terai as early varieties.

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REFERENCES


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