



**Full Length Article**

## Genetic Correlation Analysis of Photosynthetic Characteristics, Yield and Drought Resistance in Spring Wheat (*Triticum aestivum*)

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### Abstract

Twenty eight strains of spring wheat (*Triticum aestivum* L.) from CIMMYT were used as materials to measure stomatal conductance (Gs), photosynthetic rate (Pn) and transpiration rate (Tr) of flag leaf at early and middle filling stages under rainfed and irrigated conditions as well as yield related traits in spring wheat. Heritability of these traits, genetic correlations and correlative heritability between these traits and drought resistance were analyzed. The result showed that under two water regimes, genetic correlations between most of the traits and the drought resistance index (DI) were significant. The heritability of Tr, Gs at early filling stage, days to anthesis, height of plant, thousand grain weight and grain yield per plot were higher (50.71% to 68.28%), and the correlative heritability of Gs at early filling stage to drought resistance index was also higher (0.47) under irrigated condition. But the heritability of days to anthesis, grain number per spike and grain yield per plot was higher (50.23% to 82.15%) under rainfed condition. The correlative heritability of Pn, Tr at middle filling stage and Gs at early and middle filling stage, grain number per spike and grain yield per plot to drought resistance index were higher (0.41 to 0.77). Based on the conjoint analysis of genetic correlation and heritability of trait, the selection efficiencies of the traits on the drought resistance under irrigated condition for Gs at the early filling stage, and under rainfed condition, Pn, Tr at middle filling stage, Gs at early and middle filling stages, grain number per spike and yield per plot, were higher than rest of traits. This suggests that we should emphasize choice of these traits in practice of drought resistant breeding in spring wheat. © 2017 Friends Science Publishers

**Keywords:** Spring wheat; Photosynthetic characteristics; Drought resistance; Yield; Genetic correlation; Heritability

### Introduction

In recent years, the drought is getting worse with global warming, and had already become a direct threat to world food production (Hou *et al.*, 2013). Wheat (*Triticum aestivum* L.) is the largest food crop in the world, and drought is a major factor limiting the yield of wheat (He *et al.*, 2011). It has shown that photosynthesis in wheat leaves during heading, flowering and filling stages was an important factor to determine the yield of wheat (Bai *et al.*, 2008; Feras *et al.*, 2011). Therefore, the study on relation of photosynthesis-related traits, yield and drought resistance under water stress will help to reveal the mechanism of photosynthetic characteristics, and provide a reference for drought resistant breeding in wheat.

The loss of crop yield under water stress is mainly due to reduced luminous energy use efficiency (Bai *et al.*, 2006). In addition, Wang *et al.* (2006) reported that photosynthetic parameters of wheat flag leaf decreased greatly during the whole grain filling stage under drought stress. It had been reported that leaf photosynthetic parameters of dryland wheat were less effected than of irrigated one under water

deficit after anthesis, showing high capacity of water use (Nie *et al.*, 2010; Wu *et al.*, 2015); Bai *et al.* (2006) believed that the decrease in net photosynthetic rate under water stress was mainly due to stomatal factors; Liu and Chen (1990) showed that decrease of photosynthetic ability of wheat mesophyll cells caused the decline of wheat photosynthesis under drought stress. On the other hand, Zhao *et al.* (2007) showed that Pn, chlorophyll content and proline content could be considered as physiological index for evaluating the drought resistance of wheat varieties. The soluble sugar and protective enzyme activities were highly correlated with drought resistance index, and can be also regarded as the index for evaluating the drought resistance of wheat varieties (Wang *et al.*, 2011; Luo *et al.*, 2015). Yasmeeen *et al.* (2013) reported that drought resistance in wheat could be improving by exogenous application of growth enhancers. However, all these reports were based on the phenotypic correlation between traits, and had not considered the effects of environment on phenotypic expression. Therefore, all results of the above reports were not better reflection of the relationship between physiological or agronomic traits and drought resistance.

In present study, we found heritability of traits related to photosynthetic characteristics and yield, genetic correlations and correlative heritability between these traits and drought resistance were analyzed under rainfed and irrigated conditions, these traits as index of drought resistance breeding were evaluated. The purpose was to provide the reference for drought resistance breeding in wheat.

## Materials and Methods

### Plant Material

A total of 28 strains of spring wheat from CIMMYT were numbered 9607, 9625, 9628, 9692, 9738, 9746, 9611, 9614, 9633, 9637, 9643, 9646, 9649, 9655, 9656, 9658, 9662, 9669, 9681, 9696, 9698, 9700, 9725, 9728, 9742, 9610, 9693, and 9654.

Experiments were carried out from March to July 2014 and 2015 in wheat field of Shanxi Agricultural University (37°25' N, 112°25' E). The experimental soil was sandy with, soil organic matter of 15.6 g kg<sup>-1</sup>, total nitrogen of 2.8 g kg<sup>-1</sup>, available phosphorus of 10.4 mg kg<sup>-1</sup>, available potassium of 126.7 mg kg<sup>-1</sup>.

### Field Designs

The field design was consisted of randomized complete blocks with three replications. Each plot consisted of four rows of 2 m long, with 25 cm between rows. Forty seeds were sown in each row. One water regime was rainfed and used as the drought stress environment with a total of 109 mm rainfall during the growing season of the year 2014, and a total of 141 mm rainfall during the growing season of the year 2015. The other was well watered with 650 mm of water applied at the sowing, jointing, flowering and mid-grain filling stages, respectively. Weeds were controlled by chemical herbicides.

### Measurement of Photosynthetic Traits

Ten flowering plants in each line were tagged. At 10 and 20 days after anthesis, stomatal conductance (Gs, mmol m<sup>-2</sup> s<sup>-1</sup>), photosynthetic rate (Pn, μmol, m<sup>-2</sup> s<sup>-1</sup>), and transpiration rate (Tr, mmol, m<sup>-2</sup> s<sup>-1</sup>) of flag leaves were measured with a portable photosynthetic apparatus of CI-340 from 9:00 to 11:00 in the morning on some a sunny day when air temperature was relatively stable, and three plants of each lines were measured with three replication. Before measuring, a gas buffer system was connected with the apparatus to ensure that CO<sub>2</sub> concentration of the leaf chamber was stabilized at about 350±10 μmol mol<sup>-1</sup>. When measuring, the relative humidity of the apparatus was set to about 40%, quantum flux density (photosynthetically active radiation) was stabilized at about 1200±20 μmol m<sup>-2</sup> s<sup>-1</sup> by setting control parameters.

### Plant Harvesting

At maturation period, height of plant (Ht) was measured. After harvest, spikelet per main spike (SMS, the 10 main panicle average the value), grain number per spike (GrNo/S, the average value of the random 10 ears), sterile spikelet number (SSNo, the average value of the random 10 ears), thousand grain weight (TGW, 1000 grain weight), harvest index (HI) and grain yield per plot (GY/P) were investigated.

### Data Analysis

The data for both the years were averaged. The heritability and correlations of all traits were analyzed using Excel 2013 and SPSS v.17.0 software.

Drought resistance coefficient (DRC), comprehensive drought resistance coefficient (CDRC) and drought resistance index (DI) (Du *et al.*, 2011) were calculated according to the following formula:

DRC= Numerical value of index characters under rainfed condition/Numerical value of index characters under irrigation condition× 100%

$$CDRC = \frac{1}{n} \sum_{i=1}^n DRC$$

DI = CDRC × yield under rainfed condition/mean yield of all the tested cultivars rainfed condition.

Correlation coefficient, heritability, and correlative heritability were calculated as follows:

$$r_p = \frac{COV_p}{S_{p_x} S_{p_y}} \quad r_g = \frac{COV_g}{S_{g_x} S_{g_y}} \quad r_e = \frac{COV_e}{S_{e_x} S_{e_y}}$$

$$H_{xy} = \frac{COV_g}{S_{p_x} S_{p_y}} \quad H^2 = \frac{V_g}{V_g + V_e} \times 100\%$$

In the form  $r_p$  for the phenotypic correlation coefficient of x and y;  $r_g$  for the genetic correlation coefficient;  $r_e$  for the environmental correlation coefficient;  $H_{xy}$  for the correlative heritability of trait x and y;  $H^2$  for the heritability. The relative efficiency of indirect selection (CRy/Ry) (Zhao *et al.*, 2005) is calculated by the following formula:

$$CRy/Ry = (i_x/i_y) \cdot r_g \cdot (H_x/H_y)$$

$i_x$  and  $i_y$  for selection intensity of trait x and y,  $r_g$  for genetic correlation coefficient of trait x and y;  $H_x$  and  $H_y$  for evolution of heritability of trait x and y.

## Results

### Drought Resistance in Spring Wheat Varieties

The drought resistance coefficients (DRC) of all given traits for one strain were different, and the drought resistance coefficients of the same one trait from different strains were also different (Table 1 and 2).

**Table 1:** The drought resistance coefficients of yield traits in spring wheat

| Item | Flw    | Ht     | SMS    | GrNo/S | SSNo   | TGW    | HI    | GY/P  |
|------|--------|--------|--------|--------|--------|--------|-------|-------|
| 9607 | 115.01 | 87.02  | 107.01 | 110.13 | 159.49 | 73.81  | 96.73 | 92.46 |
| 9625 | 123.33 | 89.14  | 105.56 | 102.65 | 79.86  | 71.06  | 97.10 | 65.59 |
| 9628 | 240    | 90.09  | 101.85 | 113.43 | 128.47 | 66.18  | 95.95 | 63.56 |
| 9692 | 111.11 | 91.33  | 103.25 | 96.42  | 127.88 | 79.09  | 93.26 | 89.83 |
| 9738 | 200    | 93.21  | 104.92 | 131.06 | 91.27  | 72.06  | 97.12 | 86.07 |
| 9746 | 175    | 85.97  | 101.75 | 100.19 | 207.64 | 75.59  | 96.63 | 59.72 |
| 9611 | 144.44 | 82.24  | 101.67 | 89.68  | 216.87 | 58.93  | 95.07 | 34.56 |
| 9614 | 200    | 91.06  | 107.31 | 108.6  | 115.56 | 95.1   | 94.43 | 71.46 |
| 9633 | 133.33 | 89.96  | 101.67 | 121.89 | 175.46 | 73.72  | 96.51 | 49.97 |
| 9637 | 88.89  | 88.96  | 100.37 | 121.5  | 132.82 | 60.24  | 96.45 | 90.51 |
| 9643 | 52.78  | 91.39  | 98.48  | 94.09  | 157.5  | 74.72  | 97.09 | 65.79 |
| 9646 | 150    | 93.27  | 102.44 | 105.24 | 132.14 | 74.48  | 93.13 | 49.14 |
| 9649 | 108.33 | 89.58  | 103.51 | 121.95 | 115.49 | 73.03  | 94.97 | 73.24 |
| 9655 | 136.11 | 84.77  | 95     | 87.12  | 164.86 | 63.9   | 96.67 | 43.26 |
| 9656 | 102.78 | 89.14  | 98.04  | 111.78 | 76.48  | 77.37  | 97.56 | 58.46 |
| 9658 | 115    | 88.67  | 103.92 | 131.99 | 260    | 82     | 97.27 | 94.39 |
| 9662 | 83.33  | 94.14  | 94.64  | 104.87 | 100.37 | 79.29  | 96.43 | 45.13 |
| 9669 | 30.56  | 89.37  | 117.43 | 138.84 | 101.35 | 73.29  | 95.46 | 49.62 |
| 9681 | 108.33 | 91.44  | 103.42 | 102.21 | 267.41 | 74.17  | 95.83 | 74.43 |
| 9696 | 184.44 | 89.86  | 96.49  | 90.61  | 126.97 | 77.33  | 95.07 | 68.84 |
| 9698 | 116.67 | 96.95  | 98.42  | 111.18 | 135    | 84.47  | 95.79 | 80.16 |
| 9700 | 122.22 | 100.39 | 95.09  | 117.84 | 53.49  | 102.84 | 96.73 | 68.1  |
| 9725 | 133.33 | 86.55  | 114.81 | 120.17 | 199.63 | 76.54  | 96.91 | 82.03 |
| 9728 | 200    | 94     | 110.82 | 125.39 | 190.17 | 69.11  | 97.77 | 64.41 |
| 9742 | 166.67 | 90.31  | 107.02 | 117.77 | 236.35 | 86.41  | 98.64 | 91.89 |
| 9610 | 127.78 | 85.36  | 101.68 | 101.98 | 180.37 | 77.85  | 97.37 | 59.89 |
| 9693 | 100    | 95.74  | 107.67 | 94.61  | 100.12 | 78.99  | 96.23 | 56.26 |
| 9654 | 93.33  | 87.75  | 103.51 | 112.68 | 127.18 | 83.67  | 93.51 | 79.08 |

Note: Flw- the flowering period, Ht-plant height, SMS- spikelet number, GrNo/S- grain number per spike, SSNo- sterile spikelets, TGW- 1000 grain weight, HI- harvest index, GY/P- grain yield per plot. the same below

The differences of comprehensive drought resistance coefficients (CDRC) among strains were not significant (78.61 to 114.63). This suggested that the DRC of someone trait and the CDRC of a line or variety cannot reflect the difference of the drought resistance among strains. However, the difference of the drought resistance index (DI) among strains was significant (Table 2), and therefore, it is better to use DI to evaluate the drought resistance among strains. Drought resistance indices of strain 9692, 9738, 9746, 9681, 9742 and 9654 were larger (127 to 167), and had stronger drought resistance, while the drought resistance indices of strain 9611, 9614, 9646, 9655, 9662 and 9669 were smaller (47 to 60), and had weaker drought resistance (Table 2).

**Heritability of the Traits Related to Photosynthetic Characteristics and Yield in Spring Wheat**

Under irrigated condition, the heritability of Tr and Gs at early filling stage, flowering period, plant height, thousand grain weight and grain yield per plot were higher (50.71 to 68.28%), while under rainfed condition, heritability of flowering period, grain number per spike and grain yield per plot were higher (50.23 to 82.15%) (Table 3). Obviously, there were significant differences of heritability of Tr and Gs at early filling stage, plant height and thousand grain

**Table 2:** The drought resistance coefficients and drought resistance indices of photosynthetic characteristics in spring wheat

| Item | Pn (10) | Pn (20) | Tr (10) | Tr (20) | Gs (10) | Gs (20) | CDRC   | DI     |
|------|---------|---------|---------|---------|---------|---------|--------|--------|
| 9607 | 86.09   | 81.05   | 93.25   | 84.19   | 93.97   | 86.46   | 97.62  | 119.29 |
| 9625 | 95.33   | 98.67   | 82.22   | 48.07   | 85.03   | 92.65   | 89.59  | 78.83  |
| 9628 | 68.30   | 79.79   | 73.76   | 72.65   | 85.73   | 86.00   | 97.56  | 98.11  |
| 9692 | 99.21   | 87.85   | 92.46   | 67.94   | 92.17   | 86.70   | 94.18  | 157.56 |
| 9738 | 90.36   | 80.01   | 86.50   | 70.82   | 85.49   | 87.00   | 98.28  | 151.11 |
| 9746 | 85.38   | 76.98   | 70.24   | 74.45   | 92.17   | 88.49   | 99.30  | 127.00 |
| 9611 | 61.20   | 59.82   | 62.02   | 45.40   | 78.98   | 61.20   | 85.15  | 50.32  |
| 9614 | 82.19   | 64.04   | 84.52   | 59.47   | 96.66   | 75.06   | 96.10  | 52.93  |
| 9633 | 77.63   | 47.47   | 74.36   | 76.08   | 87.93   | 64.64   | 90.76  | 111.62 |
| 9637 | 98.51   | 61.62   | 98.30   | 95.38   | 97.62   | 113.26  | 97.82  | 80.49  |
| 9643 | 99.56   | 53.85   | 78.18   | 81.93   | 90.88   | 83.57   | 87.13  | 107.51 |
| 9646 | 80.09   | 62.35   | 80.79   | 84.06   | 79.69   | 76.56   | 90.24  | 60.06  |
| 9649 | 102.55  | 50.96   | 88.04   | 80.11   | 89.64   | 90.00   | 91.53  | 75.55  |
| 9655 | 84.06   | 70.73   | 88.63   | 44.59   | 87.65   | 77.53   | 87.49  | 55.25  |
| 9656 | 78.46   | 83.19   | 92.16   | 72.36   | 82.05   | 72.88   | 85.19  | 78.99  |
| 9658 | 99.18   | 99.10   | 94.26   | 90.79   | 96.08   | 67.56   | 113.00 | 116.14 |
| 9662 | 81.57   | 33.33   | 68.30   | 65.22   | 74.39   | 79.57   | 78.61  | 56.83  |
| 9669 | 76.50   | 48.72   | 100.12  | 72.23   | 99.98   | 63.12   | 82.61  | 47.43  |
| 9681 | 74.17   | 63.77   | 97.50   | 90.99   | 90.60   | 81.23   | 101.75 | 136.63 |
| 9696 | 93.06   | 82.26   | 95.41   | 82.39   | 90.30   | 79.51   | 96.61  | 94.12  |
| 9698 | 72.12   | 74.67   | 98.71   | 69.91   | 79.69   | 81.21   | 94.64  | 73.54  |
| 9700 | 45.83   | 60.21   | 95.67   | 122.07  | 80.27   | 61.48   | 87.29  | 70.24  |
| 9725 | 68.06   | 86.26   | 93.15   | 75.43   | 92.08   | 98.77   | 103.69 | 112.51 |
| 9728 | 54.19   | 98.84   | 98.57   | 114.97  | 87.80   | 63.60   | 108.19 | 121.24 |
| 9742 | 98.32   | 97.38   | 95.93   | 103.01  | 85.49   | 99.02   | 114.23 | 167.10 |
| 9610 | 70.59   | 38.41   | 83.52   | 110.21  | 88.83   | 80.02   | 93.13  | 82.42  |
| 9693 | 72.41   | 40.48   | 98.22   | 85.85   | 80.40   | 88.21   | 87.79  | 71.91  |
| 9654 | 99.31   | 32.37   | 98.76   | 97.74   | 90.36   | 80.18   | 96.96  | 129.37 |

Note: Pn (10) - Pn at the early filling stage , Pn (20) - Pn at the middle filling stage; Tr (10) - Tr at the early filling stage , Tr (20) - Tr at the middle filling stage, Gs (10) - Gs at the early filling stage, Gs (20)- Gs at the middle filling stage; CDRC- comprehensive drought resistance coefficient, DI -drought resistance index. the same below

weight under the two water conditions. It indicated that these traits were greatly influenced by drought. But the differences of heritability of the flowering period and grain yield per plot were less under the two water conditions, suggesting least effect of drought.

**Correlations between Photosynthetic Characteristics and Yield Traits and Drought Resistance in Spring Wheat**

Under irrigated condition, significantly positive correlations of phenotypic and genetics exist between Gs at early filling and middle stages and drought resistance index (Table 4), but the environmental correlations between them were not significant, showing that the correlation variations were mainly from genes. The phenotypic, genetic and environmental correlations between grain yield and drought resistance index were very marked, indicating that the correlation variation was influenced by genes and environment. On the other hand, there was greatly genetic positive correlation between Tr at the middle filling stage and drought resistance index, but the phenotypic correlation was small. There was a larger phenotypic negative correlation between the sterile spikelets and drought resistance index, and the genetic correlation between

**Table 3:** Heritability of photosynthetic characteristics and yield traits in spring wheat (%)

| Trait   | Water condition |         |
|---------|-----------------|---------|
|         | Irrigated       | Rainfed |
| Pn (10) | 41.18           | 35.46   |
| Pn (20) | 33.62           | 26.69   |
| Tr (10) | 50.71           | 35.63   |
| Tr (20) | 49.18           | 27.03   |
| Gs (10) | 52.4            | 33.28   |
| Gs (20) | 39.02           | 26.22   |
| Flw     | 58.45           | 82.15   |
| Ht      | 82.23           | 32.72   |
| SMS     | 48.26           | 42.79   |
| GrNo/S  | 46.67           | 50.23   |
| SSNo    | 9.99            | 32.82   |
| TGW     | 73.42           | 44.71   |
| HI      | 30.79           | 20.56   |
| GY/P    | 68.28           | 78.87   |

**Table 4:** The correlation coefficients between the photosynthetic characteristics and yield traits and drought resistance index of spring wheat under two different water conditions

| Trait   | Irrigated |           |          | Rainfed  |          |          |
|---------|-----------|-----------|----------|----------|----------|----------|
|         | $r_p$     | $r_g$     | $r_c$    | $r_p$    | $r_g$    | $r_c$    |
| Pn (10) | 0.2877    | 0.3450    | 0.0990   | 0.3089   | 0.5518** | -0.2405  |
| Pn (20) | 0.2249    | 0.3315    | -0.1158  | 0.6000** | 0.9284** | -0.2076  |
| Tr (10) | 0.3625    | 0.4207*   | 0.0907   | 0.5446** | 0.7720** | -0.2104  |
| Tr (20) | 0.3831    | 0.4749**  | -0.2546  | 0.7462** | 0.8961** | -0.0275  |
| Gs (10) | 0.6143**  | 0.7357**  | -0.0099  | 0.6989** | 0.9620** | -0.0672  |
| Gs (20) | 0.5165**  | 0.6829**  | -0.0717  | 0.6720** | 0.9782** | -0.0008  |
| Flw     | -0.0053   | 0.0334    | -0.2628  | 0.1588   | 0.1642   | 0.0951   |
| Ht      | 0.1705    | 0.1825    | 0.0265   | 0.2087   | 0.2412   | 0.1624   |
| SMS     | 0.3524    | 0.4427*   | -0.0698  | 0.5008** | 0.5980** | 0.1562   |
| GrNo/S  | 0.2529    | 0.2577    | 0.2803   | 0.5254** | 0.6579** | -0.1324  |
| SSNo    | -0.4799** | -0.8140** | -0.3560  | 0.1388   | -0.0366  | 0.1981   |
| TGW     | 0.0070    | -0.0208   | 0.2656   | 0.0103   | 0.2052   | -0.1615  |
| HI      | 0.2548    | 0.3075    | 0.1358   | 0.2652   | 0.4482*  | -0.0940  |
| GY/P    | 0.5055**  | 0.4876**  | 0.6660** | 0.9714** | 0.9835** | 0.8411** |

Note: “\*” and “\*\*”, Significance at 0.05 and 0.01 probability levels, respectively; ns, not significant

them was more significant, with larger environmental correlation. This showed that the correlation variations were greatly affected by environment (Table 4).

Under rainfed condition, significantly phenotypic and genetic positive correlations existed between the Pn at the middle filling stage; Tr, Gs at the early and middle filling stages, spikelet number, grain number per spike and drought resistance index, and the environmental correlations were small, it showed that the correlation variations were mainly caused by genes. The phenotypic, genetic and environmental correlations between grain yield per plot and drought resistance index were very stronger, showing that the correlation variation was restricted by genetic and environment. Although the genetic correlation between Pn at early filling stage and drought resistance index was significant, phenotype correlation was small it showed that the correlation variation was easy to be influenced by environment (Table 4).

### The Relative Efficiency of the Selection of Drought Resistance in Spring Wheat

The relative efficiency of selection for drought resistance in breeding work can be understood by the combined analysis of genetic correlation coefficient and heritability. Under rainfed condition, the selection efficiencies of drought resistance were higher, (relative efficiency 0.52 to 0.99) based on Pn at middle filling stage, Tr, Gs at early and middle filling stages, grain number per spike, grain yield per plot. Under irrigated condition, only that of Gs at early filling stage was higher (relative efficiency 0.63). But under two water condition, the selection efficiencies were lower (relative efficiency 0.44 to -0.02) based on Pn at early filling stage, the flowering period, plant height, spikelet number, sterile spikelets, 1000 grain weight, harvest index and grain yield per plot (Table 5).

### Correlative Heritability between the Main Photosynthetic Characteristics and Yield Traits and Drought Resistance in Spring Wheat

Under irrigation condition, the correlative heritability between Gs at early filling stage and drought resistance index was larger (0.47) (Table 6), but under rainfed condition, the correlative heritability between Pn, Tr at middle filling stage, Gs at early and middle filling stages, grain number per spike, yield per plot and drought resistance index were larger (0.41 to 0.77). In the selection of the drought resistance in spring wheat, the selection of these traits can gave better results.

### Discussion

Drought resistance refers to the survival and production capacity of plant under the atmospheric or soil condition (Zhang and Deng, 2000). It had been reported in large numbers that the drought resistance in wheat was evaluated according to growth, morphological characteristics, physiological and biochemical indexes (Ei *et al.*, 1998; Jing, 1999; Liu *et al.*, 2003; Ma *et al.*, 2005; Wang *et al.*, 2008). However, drought resistance is a very complex biological trait, and no single index can exactly evaluate the level of drought resistance in plant (Clarke and Mc, 1982). Drought resistance coefficient proposed by Chionoy was not a good index for drought resistance, because it cannot explain the plasticity of cultivars with high yield or high yield potential (Lan, 1994). However, drought resistance index (DI) should be a more intuitive and easy operability index (Ji *et al.*, 2007; Zhang *et al.*, 2007; Xu *et al.*, 2014). In present study, DIs were higher (127 to 167) in spring wheat strains of 9692, 9738, 9746, 9681, 9742 and 9654 with stronger drought resistance, but DIs in spring wheat strains of 9611, 9614, 9646, 9655, 9662 and 9669 were smaller (47 to 60) with poor drought resistance.

**Table 5:** The relative efficiency of photosynthetic characteristics and yield traits on the selection of drought resistance in spring wheat

| Trait   | Condition | Genetic correlation h <sup>2</sup> (%) | h     | Relative efficiency |         |
|---------|-----------|--|-------|---------------------|---------|
| Pn (10) | Irrigated | 0.3450                                 | 41.18 | 6.417               | 0.2512  |
|         | Rainfed   | 0.5518                                 | 35.46 | 5.955               | 0.3728  |
| Pn (20) | Irrigated | 0.3315                                 | 33.6  | 5.796               | 0.2180  |
|         | Rainfed   | 0.9284                                 | 26.69 | 5.166               | 0.5442  |
| Tr (10) | Irrigated | 0.4207                                 | 50.71 | 7.121               | 0.3399  |
|         | Rainfed   | 0.7720                                 | 35.63 | 5.969               | 0.5228  |
| Tr (20) | Irrigated | 0.4749                                 | 49.18 | 7.013               | 0.3779  |
|         | Rainfed   | 1.0000                                 | 27.03 | 5.199               | 0.5899  |
| Gs (10) | Irrigated | 0.7357                                 | 52.4  | 7.239               | 0.6043  |
|         | Rainfed   | 0.9620                                 | 33.28 | 5.769               | 0.6297  |
| Gs (20) | Irrigated | 0.6829                                 | 39.02 | 6.246               | 0.4839  |
|         | Rainfed   | 0.9782                                 | 26.22 | 5.121               | 0.5684  |
| Flw     | Irrigated | 0.0334                                 | 58.45 | 7.645               | 0.0289  |
|         | Rainfed   | 0.1642                                 | 82.15 | 7.094               | 0.1321  |
| Ht      | Irrigated | 0.1825                                 | 82.23 | 9.068               | 0.1877  |
|         | Rainfed   | 0.2412                                 | 32.72 | 5.72                | 0.1565  |
| SMS     | Irrigated | 0.4427                                 | 48.26 | 6.947               | 0.3489  |
|         | Rainfed   | 0.5980                                 | 42.79 | 6.541               | 0.4438  |
| GrNo/S  | Irrigated | 0.2577                                 | 46.67 | 6.832               | 0.1997  |
|         | Rainfed   | 0.6579                                 | 50.23 | 7.087               | 0.5290  |
| SSNo    | Irrigated | -0.8140                                | 9.99  | 3.161               | -0.2919 |
|         | Rainfed   | -0.0366                                | 32.82 | 5.729               | -0.0237 |
| TGW     | Irrigated | -0.0208                                | 73.42 | 8.569               | -0.0202 |
|         | Rainfed   | 0.2052                                 | 44.71 | 6.687               | 0.1556  |
| HI      | Irrigated | 0.3075                                 | 30.79 | 5.549               | 0.1936  |
|         | Rainfed   | 0.4482                                 | 20.56 | 4.534               | 0.2305  |
| GY/P    | Irrigated | 0.4876                                 | 68.28 | 8.263               | 0.4571  |
|         | Rainfed   | 0.9835                                 | 78.87 | 8.881               | 0.9910  |

**Table 6:** The correlative heritability between the photosynthetic characteristics and yield traits and drought resistance of spring wheat

| Trait   | Water condition |         |
|---------|-----------------|---------|
|         | Irrigated       | Rainfed |
| Pn (10) | 0.1949          | 0.2902  |
| Pn (20) | 0.1741          | 0.4259  |
| Tr (10) | 0.2883          | 0.3870  |
| Tr (20) | 0.2941          | 0.4907  |
| Gs (10) | 0.4707          | 0.4894  |
| Gs (20) | 0.3776          | 0.4436  |
| Flw     | 0.0226          | 0.1315  |
| Ht      | 0.1463          | 0.1229  |
| SMS     | 0.2716          | 0.3455  |
| GrNo/S  | 0.1551          | 0.4119  |
| SSNo    | -0.2278         | -0.0185 |
| TGW     | 0.0158          | 0.1217  |
| HI      | 0.1569          | 0.1744  |
| GY/P    | 0.3558          | 0.7714  |

In wheat drought resistance breeding, selection of multiple traits were usually based on phenotypic correlations between traits, but these coefficients are often effected by environmental factors, thus it is necessary to divide the phenotype correlation into genetic and environmental correlations. Genetic correlation coefficient is not influenced by environmental factors, it truly reflects the heritable relationship between quantitative traits, therefore, it is better in the breeding selection than

phenotypic correlation coefficient (Wang *et al.*, 2007). Nevertheless, There is no simple and poor relations among phenotypic, genetic and environmental correlation coefficient, so the ideal selection effect cannot be obtained only base on genetic correlation relationship selection in the breeding (Jin *et al.*, 2003). Heritability is a genetic ability in which parental traits are passed from parents to the next generation; it can be used as the index of evaluating hereditary strength of a trait (Zhang *et al.*, 2009). If one trait is of high heritability and significant genetic correlation with other traits, it can be regarded as an index of selection in the breeding (Jing, 1999). If one trait is only of high heritability or higher genetic correlation with other traits, it will not be a good index of selection in the breeding. In the study, relative efficiency of selection of drought resistance in spring wheat was calculated, based on heritability and genetic correlation between traits. It can be seen that under irrigated condition the selection efficiencies of Gs at the early filling stage, under rainfed condition, Pn at middle filling stage, Gs, Tr at early and middle filling stages, grain number per spike, grain yield per plot were higher than rest of traits in drought resistance breeding of spring wheat.

In addition, Dai *et al.* (2003) proposed a genetic parameter related to genetic variation, the correlative heritability. It is the relevant part of the genetic causes of the phenotypic correlation between traits. The analysis of the process can be simplified by using the correlative heritability instead of the genetic correlation coefficient, and results are more convincing. In this study, under irrigated condition, Gs at the early filling stage, and Pn, Tr at middle filling stage, Gs at early and middle filling stages, grain number per spike, yield per plot under rainfed conditions had larger (0.41 to 0.77) correlative heritability with drought resistance and had higher selection efficiencies in these traits. This indicated that the selection of these traits will get better results in drought resistance breeding of spring wheat.

## Conclusion

The drought resistance in spring wheat was influenced by many photosynthetic characteristics and yield factors. The union analysis of genetic correlation and heritability of traits related to photosynthetic characteristics and yield found that the selection efficiencies of Gs at the early filling stage under irrigated condition and Pn, Tr at middle filling stage, Gs at early and middle filling stages, grain number per panicle, yield per plot under rainfed condition, were higher. And the correlative heritability between these traits and drought resistance were also larger in spring wheat. Therefore attention should be to the investigation and selection of these traits in spring wheat breeding for drought resistance.

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