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Full Length Article

Selection of Yield-Related Traits for Wheat Breeding in Semi-Arid Region

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Abstract

Wheat is an important cereal crop and one of the sources of nourishment and energy for humankind. But drought has affected wheat production seriously. This study has focused on wheat yield-related traits and tried to select suitable indexes for wheat breeding in semi-arid region. To this aim, a factorial experiment with two water regimes in field conditions was conducted. We found that the wheat line with higher grain yield also possessed higher spikelet number per spike (SN), 1000-kernel weight (TKW), and grain number per spike (GNPS) and the higher post-anthesis photosynthetic rate (Pn) than the others ($P<0.05$). The statistical analysis showed that under drought condition the higher grain yield was significantly associated with SN, TKW, GNPS and the higher post-anthesis Pn ($P<0.05$). Based on our findings, it is concluded that the post-anthesis Pn as physiological index and SN, TKW, and GNPS as agronomic trait are suitable in using selection indicators for wheat breeding in semi-arid region. © 2018 Friends Science Publishers

Keywords: Wheat; Drought; Grain yield; Selection indicators

Introduction

Wheat (*Triticum aestivum* L.) grain yield production is limited by water supply in about fifty percent of the wheat growing area in developing countries and almost 70% in developed countries, while it is a major crop for more than one third of the world population (Trethowan and Pfeiffer, 2000; Charkazi *et al*., 2010; Zhang *et al*., 2014). In China, especially the northwest China, available water is the most important factor limiting wheat yields. To adjust to the growing population, more grain should be produced in the future (Li *et al*., 2014). Thus, it is important to focus on breeding new wheat cultivars with more yield potential under drought conditions to help meet the increasing demands of population increase and food consumption, especially in Northwest China, which is a rainfed agricultural district with wheat as the main food crop (Foley *et al*., 2011; Qin *et al*., 2015).

After 1980s, a genetic improvement of wheat breeding ingrain yield production has been reported throughout the world (Austin, 1999; Maydup *et al*., 2014; Sun *et al*., 2014). A trend over time (1940s–2010s) towards a high photosynthetic rate of flag leaf and leaf area index at the heading stage was observed and both were significantly related to a yield increase (Sun *et al*., 2014). This showed that the photosynthetic rate plays an important role in the genetic improvement process of wheat. Water deficit decreases assimilation of CO_2 by forcing stomatal closure and when the stress becomes more severe, by alteration of thylakoid membranes (Lawlor and Cornic, 2002), which must be considered in wheat breeding in the future.

There are many factors which influence the wheat yield. Many studies found that in the wheat breeding process, there were no changes resulting from cultivar replacement in aboveground biomass, and the increased harvest index (*HI*) with decreased height resulted from increased grain weight (Brancourt-Hulmel *et al*., 2003; Zheng *et al*., 2011). Under water deficit status, leaf photosynthesis and grain yield were found to have positive correlation (Wada *et al*., 2008). This showed that an increase in the grain weight and leaf photosynthesis might be an effective way to improve wheat yield in semi-arid region.

As the aims of wheat production are grain yield improvement and grain production stability under drought stress conditions, development of drought tolerant varieties is the best strategy. The objective of our research is to detect which characters are important in maintaining high yield of wheat in semi-arid region. A set of recombinant inbred lines varying in plant height, photosynthetic rate and some other traits are used. A two-year field experiment was conducted.

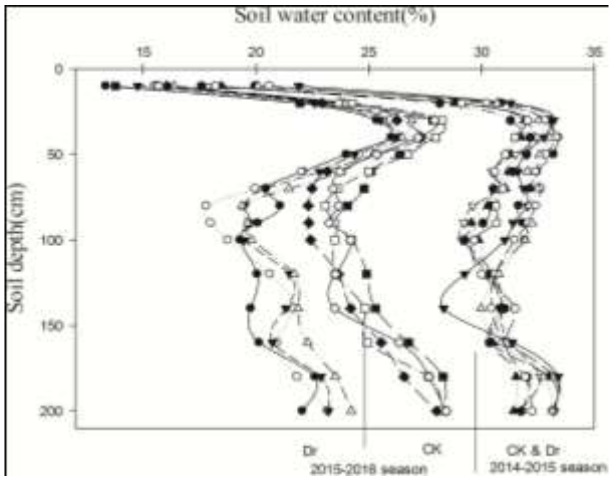

Fig. 1: Soil water content before sowing

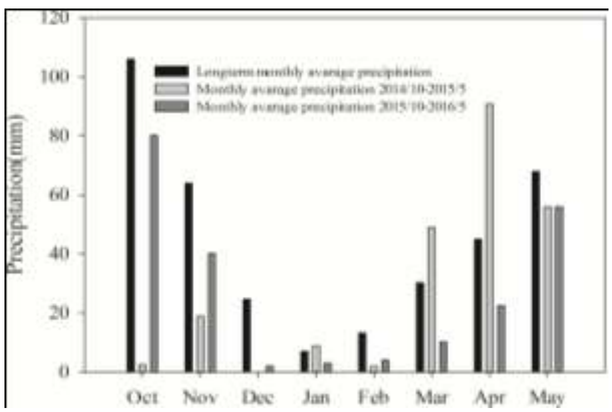

Fig. 2: Precipitation in these two growth seasons and the long-term mean at the experimental site

Materials and Methods

Plant Materials

Recombinant inbred lines developed from the hybridization of bread wheat variety 'Jinmai47' and the Magnif M1 were used in this study. The materials were developed by the College of Agronomy, Northwest A&F University, Yangling, Shaanxi Provence, P.R. China (Wang *et al.*, 2015). Lines (L34, L44, L33 and L16) used here were the F6 inbred population.

Field Experiment

The field experiments were conducted over two growing seasons-October 2014 to June 2015 and October 2015 to June 2016 in Yangling, Shaanxi Province, in Northwest China. The field management was the same as in our previous study (Sun *et al.*, 2014). A base fertilizer was applied [150 kg ha^{-1} urea (N) and 120 kg ha^{-1} calcium superphosphate (P_2O_5)] prior to planting, and no topdressing was applied before harvest. Among the two seasons, mung bean (*Phaseolus radiatus* L) was planted to make homogenization of the land fertilizer level. Two water treatments were implemented: one with normal rainfall and an irrigation event (CK) and another with no rainfall after the recovering stage (drought, Dr) in 2014–2015 season. In the first season, before sowing all plots were given a supplementary irrigation to make the same moisture (Fig. 1). In 2015–2016, in order to detect effect of more harsh environment on these wheat lines the precipitation was removed after germination (stage 9) (Zadoks *et al.*, 1974), and no supplementary irrigation was carried out before sowing. Thus in the second season, at the outset the soil water content of drought plots was lower than of CKs (Fig. 1). Rainfall during the two seasons is shown in Fig. 2. The precipitation of these two seasons was different. Precipitation of the first season was mainly concentrated in 2015/03–2015/04 and it was above long-term mean, while for the second season was mainly concentrated in 2015/10–1015/11 and below the long-term mean.

The irrigation event (70 mm) was provided for the CK treatment at the tillering stage (before the wintering stage) to ensure the achievement of a high yield potential. The cultivars were planted manually in plots (2.2×3.3 m^2 per plot; 11 rows, 20 cm apart; plant spacing of 2 cm).

The physiological index, photosynthetic rate (Pn) was determined using an Li-6400 portable photosynthesis system (LI-COR, Inc., Lincoln, Nebraska, USA) from 09:00 to 11:00 in 7–12 leaves at the jointing stage and at 10 days (10 d) and 17 days (17 d) after anthesis. At the jointing stage, the newest fully expanded leaves were used to detect the Pn, and for the last two measurements, the flag leaves were used.

At maturity stage, the grain number per spike (GNPS), spikelet number per spike (SN), and ear length (EL) were measured before sampling. Plant height and internodes length were also measured at maturity. Plant height was determined as the distance from the soil surface to the top of the spike excluding awns. After the investigation, plants within one square meter of each plot were harvested, divided and weighed to determine the total aboveground biomass dry weight, grain yield and harvest index (HI). Then, 1000-kernel weight (TKW) was determined. The HI was determined as the ratio of grain to total aboveground dry biomass.

Statistical Analysis

An analysis of variance was used to test for differences between the samples using the Least Significant Difference (LSD) method and Path coefficient analysis between grain and other agronomic traits were performed using SPSS 19.0 (SPSS Inc., Chicago, USA). Path coefficient analysis used the method of stepwise. The figures were drafted with SigmaPlot 12.5 (Systat Software Inc., San Jose, USA).

Results

Plant Height, Grain Yield and Harvest Index

The four lines exhibited different plant height (Table 1). The reduction in height of L33, L34 and L44 resulted from shortening of internodes length compared with the L16 line. The drought stress also reduced plant height, especially in 2015–2016 season due to the severe drought.

The L34 lines had the highest GY, followed by the L44, L33 and L16 lines under control condition. The statistical analysis showed no significant difference between the L34 and L44 lines (P>0.05), whose GY was significantly higher than the L33 and L16 lines in 2014–2015 season (Table 2). While in 2015–2016 season there was no difference among lines of L34, L44 and L16 under control condition. Under drought condition, in both growing seasons, L34 and L44 exhibited higher GY than L16 line (P<0.05), and there was also no difference between GY of L34 and L44 lines (P>0.05).Only the significant difference of aboveground biomass was found in lines of L33 and L44, L16 under control condition in 2015–2016 season. Due to this reason, L34 and L44 lines had higher HI than L16 lines in both season and two water conditions (P<0.05). These results indicate that the L34 lines had almost the same capacity with L44 lines to sustain the yield and HI.

Grain-associated Traits

The lines L34 and L44 showed an increased spikelet number per spike (SN), grain number per spike (GNPS) and 1000-kernel weight (TKW) under both water treatments in two growing seasons (P<0.05, Table 3). But L34 and L44 lines did not show an advantage in maintaining spike number per unit area (SNPA). Path coefficient analysis showed that the GY was effected by SN, TKW and GNPS in 2014–2015 season (P<0.05), and the effect of TKW on GY was mainly achieved by effecting the SN. But in 2015–2016 season, the GY was effected by SNPA, GNPS and TKW (P<0.05, Table 4).

Photosynthetic Rate

At the jointing stage, there was no significant difference among the lines under the same water treatment in both seasons, except for the L33 lines, which had a higher Pn than other lines under drought in 2014–2015 season and under control condition in 2015–2016 season (Table 5). By 10 d or 17 d after anthesis, drought significantly decreased the flag photosynthetic rate (Table 5). In 2014–2015 season, the L34 and L44 lines had a higher Pn than did the L16 lines under control conditions, especially the L34 lines. Under drought conditions, the L34 lines had the highest Pn, followed by the L44, L33 and L16 lines. In 2015–2016 season, due to a succession of cloudy days, we did not detect the Pn of 17 d after anthesis. But the advantage of the L34 lines was obvious, especially under drought conditions. The L34 lines had the highest Pn among the RILs under two conditions at 10 d after anthesis, while there was no significantly difference between L34 and L44 lines (P>0.05).

To test whether the Pn contributed to the higher grain yield, a correlation analysis between the Pn and GY was conducted (Fig. 3). The post-anthesis Pn was strongly correlated with the grain yield. Briefly, the grain yield was significantly positively correlated with Pn at 10 d ($R=0.80$, $p<0.05$) and 17 d ($R=0.72$, $p<0.05$) after anthesis in 2014–2015 season. In 2015–2016 season, the grain yield was significantly correlated with the Pn at 10 d after anthesis ($R=0.79$, $p<0.05$). In both seasons, we did not find a strong correlation between the grain yield and Pn at the jointing stage ($p>0.05$). We also find that the slop of trend line of 10d is higher than 17 and jointing stage in two seasons (Fig. 3). This highlighted the important role of Pn at 10 d after anthesis in maintaining wheat yield. However, considering all of the data, we can conclude that the higher post-anthesis Pn contributed to the higher grain yield.

Discussion

Breeders select for many traits in their efforts to improve adaptation to biotic and abiotic stress (Qin *et al*., 2013; Cao *et al*., 2017; Mahboob *et al*., 2017). An important consideration is agronomic type whereby initial selection is for an ideotype where plant height and grain yield are optimal for the target environment (Rebetzke *et al*., 2002; Rebetzke *et al*., 2012). Due to high plant height, the logging had effecting wheat yield seriously. In our experiment, under irrigation condition the plant height was higher than that in drought condition as observed for previous studies which showed that when the plant height was at 80 cm, the wheat would achieve the highest grain yield (Sun *et al*., 2014; Casebow *et al*., 2016; Yan and Zhang, 2017). In our experiment, L33 had the lowest height at the same water condition, which is closest to height of 80 cm. But its yield was not higher than that of others. We also found that spikes of L33 extended only partly beyond the flag leaf ligule and it came to maturity two weeks earlier than others, which would be negative effects on the grain yield. So the effect of plant height on yield is not obvious in our experiment.

A significant improvement in grain yield can be achieved by an increased grain number, TKW and *HI* with reduced plant height (Donmez *et al*., 2001). The yield was significantly positively correlated with GNPS, SN and TKW (Tab. 4). Furthermore, under drought stress, the L34 and L44 achieved relatively larger TKW and GNPS than other lines (Table 3). Breeders in America and France tend to concentrate on improving the grain number per unit area and the TKW, while Chinese breeders focus on three yield components (TKW, SNPA and GNPS) to improve the grain yield potential; the yield potential can be improved by increasing one or more of these components (Brancourt-Hulmel *et al*., 2003; Pedró *et al*., 2012; Wu *et al*., 2014; Qin *et al*., 2015). Further increases in the grain number per spike and TKW are considered the most likely way to improve the

Table 1: Performance and plant height traits of wheat lines under two water conditions

Year	Line	Spike length (cm)		Peduncle length (cm）		2nd internode From top (cm)		3rd internode From top (cm)		Plant Height (cm)	
		CK	Dr	CK	Dr	CK	Dr	CK	Dr	CK	Dr
2015	L33	8.59c	8.16c	25.76c	22.03c	24.39c	20.02c	18.94a	15.50ab	93.79c	76.19c
	L34	9.37b	8.70b	26.25bc	24.84bc	28.15b	25.41b	18.95a	17.13a	100.10b	96.27b
	L44	10.12a	9.82a	29.65b	27.13b	27.90b	25.65b	17.24b	16.33ab	96.08bc	92.41b
	L16	9.67ab	8.79b	40.79a	35.49a	32.05a	28.48a	19.63a	17.05a	107.79a	105.38a
2016	L33	9.11b	9.25ab	19.07c	13.44c	19.21c	15.85c	11.54b	12.75a	77.17c	64.91c
	L34	9.61b	9.73 a	24.56b	19.33b	25.54b	19.06b	17.70a	12.94a	97.63b	76.04b
	L44	9.73b	9.08b	24.86b	21.53b	25.26b	19.30b	17.69a	11.80a	98.16b	76.29b
	L16	10.43a	9.88 a	35.29a	26.69a	30.43a	22.31a	17.99a	12.19a	116.27a	85.60a

Note: Different letters indicate significant differences ($p<0.05$) under the same water condition

Table 2: Effects water condition on yield, biomass and harvest index of different wheat lines at field experiment

Year	Line	Grain yield (kg/m^2)		Aboveground biomass (kg/m^2)		Harvest index	
		CK	Dr	CK	Dr	CK	Dr
2015	L33	0.55b	0.37c	1.35a	1.10a	0.40ab	0.32b
	L34	0.66a	0.53a	1.47a	1.28a	0.45a	0.41a
	L44	0.65ab	0.57a	1.43a	1.27a	0.46a	0.45a
	L16	0.47c	0.43b	1.36a	1.32a	0.34b	0.33b
2016	L33	0.38b	0.26b	0.88b	0.55a	0.46ab	0.49b
	L34	0.47a	0.29a	0.95ab	0.56a	0.50a	0.52a
	L44	0.51a	0.29a	1.04a	0.57a	0.49a	0.51a
	L16	0.49a	0.23c	1.13a	0.53a	0.43b	0.44c

Note: Different letters indicate significant differences ($p<0.05$) under the same water condition

Table 3: Effects water condition on yield related traits at field experiment

Year	Line	Spike number per unit area (m^{-2})		Spikelet number per spike		Grain number per spike		1000-kernel weight (g)	
		CK	Dr	CK	Dr	CK	Dr	CK	Dr
2015	L33	582a	512a	17.3b	14.0c	35.5a	24.8c	41.18b	40.48ab
	L34	504a	464a	19.7a	17.8a	44.0a	41.0a	43.26a	39.92b
	L44	473a	503a	19.0a	17.0a	43.0a	42.9a	44.21a	42.28a
	L16	529a	531a	15.8c	16.0b	34.0b	29.3b	40.39b	36.45c
2016	L33	365ab	245a	15.6b	14.8c	36.6b	34.4b	45.86b	42.26b
	L34	268b	156b	18.4a	17.3a	50.0a	44.9a	49.90a	47.92a
	L44	285ab	191ab	18.8a	16.3b	52.3a	42.8a	51.07a	47.21a
	L16	387a	175ab	17.9a	15.3c	42.0b	37.9b	47.04b	42.72b

Note: Different letters indicate significant differences ($p<0.05$) under the same water condition

Table 4: Path coefficient analysis of yield traits into direct and indirect effects on grain yield at field experiment

2014-2015				2015-2016				
Independent	linear correlation coefficient	Path Coefficient		Independent	linear correlation coefficient	Path Coefficient		
	GY	SN	TKW		GY	SNPA	GNPS	TKW
SN	0.96**	**0.79**	0.18	SNPA	0.72**	0.79	-0.03	-0.04
TKW	0.77*	0.48	**0.29**	GNPS	0.67*	-0.03	0.92	-0.23
GNPS	0.95**			TKW	0.77*	0.14	0.86	-0.24
				SN	0.83**			

Note: Path coefficient and pearson correlation showing the effects of spikelet number per spike (SN), spike number per unit area (SNPA), grain number per spike (GNPS) and 1000-kernel weight (TKW) on grain yield (GY). Direct paths are shown in bold fonts. ∗ and ∗∗ indicate significance at $p< 0.05$ and $p < 0.01$ respectively

yield potential in the future on the Loess Plateau (Sun *et al*., 2014). Our results confirmed that these three indexes (SN, TKW, and GNPS) had directly positive effect on wheat grain yield. This showed that in dry-land farming, SN, TKW, and GNPS were suitable as selected index to breed high-yield wheat variety.

The photosynthetic rate, especially the flag leaf Pn, plays an important role in grain yield (Fischer *et al*., 1998; Shah and Paulsen, 2003). Many studies have confirmed that the rate of photosynthesis after flowering is positively correlated with the quantity of carbon assimilated for grain filling (Wardlaw, 1990; Masoni *et al*., 2007). However, Sun *et al*. (2014) found that the Pn of the flag leaf at the heading stage was positively associated with the grain yield and was also suggested that their result does not mean that the post-anthesis period was less important than the pre-anthesis

Table 5: Effects of water condition on photosynthetic rate at field experiment

Year	Photosynthetic rate (μmol CO_2 $m^{-2}s^{-1}$)						
	Line	Jointing stage		10 d after anthesis		17 d after anthesis	
		CK	Dr	CK	Dr	CK	Dr
2015	L33	22.16a	21.45a	17.32ab	11.40ab	15.91b	7.11a
	L34	21.20a	17.93b	19.82a	13.52a	18.75a	9.69a
	L44	21.24a	16.92b	20.64a	11.9ab	17.64ab	8.88a
	L16	19.72a	18.22b	15.92b	10.50b	16.49ab	7.73a
2016	L33	27.37a	20.25a	20.19b	18.75ab	--	--
	L34	25.60ab	20.96a	23.79a	20.21a	--	--
	L44	24.64ab	20.70a	22.01a	19.81a	--	--
	L16	21.02b	22.75a	20.25b	18.08b	--	--

Note: Different letters indicate significant differences ($p<0.05$) under the same water condition

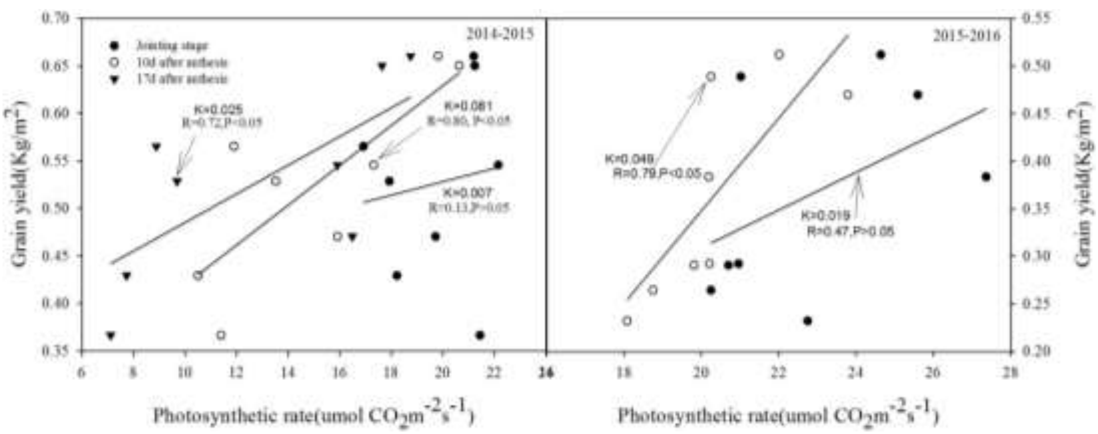

Fig. 3: Correlation between grain yield and photosynthetic rate at different growth stage.

period in determining the yields of dry-land wheat breeding. Sun *et al*. (2014) results came from research of wheat cultivar replacement. In this study, the post-anthesis Pn was strongly correlated with the grain yield, especially that at 10 d after anthesis (Fig. 3). Higher slop means more beneficial to grain yield (Qin *et al*., 2012). In our research, the slop of trend line between post-anthesis Pn and yield was higher than of jointing stage, which highlights the important role of post-anthesis Pn again. Our results suggest a vital function of post-anthesis Pn in improving wheat yield in semi-arid region.

Conclusion

Based on our findings, it is concluded that the post-anthesis Pn as physiological index and SN, TKW and GNPS as agronomic trait are suitable for wheat breeding in semi-arid region. On the other side, another index like root development need to be researched in the future too.

Acknowledgements

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