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Full Length Research Paper

Responses of morphological traits of spring wheat to drought stress in Qinghai Province of China

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Spring wheat is a widely planted crop in Qinghai Province of Northwestern China, where drought acts as a major bottleneck for stable production. However, responses of wheat to moisture deficit remain unclear in this region. Experiments of 60 spring wheat cultivars in randomized complete bock design with three replications were carried out to determine effects of moisture deficit on 11 morphological traits under normal irrigation and drought stress at Ping'an Ecological Agriculture Station, Qinghai province, China. The results showed that all the morphological traits except plant height (PH) were significantly influenced by water condition. Internode length under spike (IL), tillers per plant (T/P), spikelets per spike (S/S), fertile spikelets per spike (FS/S), and grain weight per spike (GW/S) were mainly affected by water condition and could be used as indexes of moisture deficit. Spike length (SL), distance of spike to flag leaf (DSL), kernels per spikelet (K/S), grains per spike (G/S), and 1000 grain weight (GW) were influenced by genotypes and their interaction with environments. Drought stress changed correlations among the morphological traits. The results of non-metric multidimensional scaling (NMDS) on morphological traits revealed that the 60 cultivars responded to moisture deficit similarly. The distance of cultivars in the same decade between normal irrigation and drought stress became larger with time, indicating that the current breeding program has enlarged the difference of cultivars to water-limited environment and it might reduce yield stability under high extreme drought frequency in the future.

Key words: Yield-related characteristic, general linear model, non-metric multidimensional scaling, drought stress, spring wheat.

INTRODUCTION

Climate change has resulted in a high frequency of extreme drought events (IPCC, 2007), and thus greatly influenced agriculture worldwide, particularly in arid and semi-arid areas (Lal, 2004). Drought is the most important environmental stress for yield improvement in agriculture region under water-limiting conditions (Cattivelli et al., 2008). Identification and understanding of responses and mechanism of drought tolerance in wheat has long been stumbling block for wheat breeders (Moustafa et al., 1996). Many studies have used statistical methodologies to assess moisture stress on wheat morphological performance (Fischer and Wood, 1979; Roozeboom et al., 2008; Zhe et al., 2010; Ahmadizadeh et al., 2011) and their general conclusion was that genotypes, water conditions and their interaction significantly affected the yield and end-use quality. Moreover, effect of water condition or genotype was much more than their interaction (Dencic et al., 2000; Rizza et al., 2004; Chang et al., 2010). Yield reduction induced by moisture deficit was due primarily to reduction in kernel weight and kernels per spike (Guttieri et al., 2001; Golabadi et al., 2006). To some extent, end-use quality like flour protein and flour extraction was

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promoted under proper water-limited environment (Blum, 2005). Morphological traits, such as plant height, spike length, kernels per spike, grain weight per spike and so on, have been used for drought evaluation (Ayed et al., 2010).

Qinghai province is part of the Qinghai-Tibetan Plateau, belonging to an arid or semi-arid ecosystem. Spring wheat is the most important crop with a history of cultivation for several thousand years (Deng et al., 2006). However, water resource in the region is a limiting factor for the crop production. The precipitation in most of wheat growing areas in Qinghai province is less than 500 mm annually, but the yield of spring wheat is the highest in all the crops under rainfed farming condition. For example, spring wheat cultivar Gaoyuan 602 once achieved 589 kg/667 m^2 in the dry mountain land where the precipitation was about 400 mm. Under irrigation condition, spring wheat cultivar Gaoyuan 338 reached 1013.5 kg/667 m^2, which is still the high yield record of wheat in China. Spring wheat cultivars in Qinghai province had many special agronomic characteristics which could enable them to produce stable and high yield both in the irrigation and rainfed farming areas (Chen, 1994). Therefore, studying responses of morphological traits of spring wheat to drought stress in Qinghai is of importance. It could help to understand the mechanism of drought resistance of spring wheat and thus to breed drought-resistant varieties in the future. Liu et al. (2010) reported the association of morphological traits with drought stress in Qinghai-Tibetan Plateau wheat. Nevertheless, a comprehensive study with enough cultivars and agronomic characteristics is still lacking (Chang et al., 2010).

The primary aim of this research is to compare responses of morphological traits of 60 spring wheat cultivars released in Qinghai province under normal irrigation and drought stress conditions. Those 60 cultivars were released from 1960s to 2000s. Differences of morphological traits among the 5 decennium were evaluated and some discussions were made according to our results related to the future climate scenario.

MATERIALS AND METHODS

Site description

The normal irrigation experiment was carried out at Ping'an Station of Ecological Agriculture (N36°30′, E101°59′; 2100 m), Northwest Institute of Plateau Biology, the Chinese Academy of Sciences. The station is located in Ping'an county, Qinghai province. Its annual mean of air temperature was 7.6°C. The average monthly maximum and minimum temperatures occurred in July (19.2°C) and January (-5.6°C), respectively. The annual precipitation was 310.1 mm. The wheat was irrigated three times in the growing period. The drought stress experiment was carried out at Shuwan village (N36°28′, E101°55′; 2500 m), not far away from the normal irrigation field, so it was assumed that this site had the same rainfall as Ping'an station did. It is typical dry mountain land area with no irrigation throughout the year.

Plant materials, experiment design and measurements

Sixty wheat cultivars with three replications were planted at the two sites for evaluating their responses to drought stress. They could be divided to 5 groups according to their certificated years in Qinhai province: (1) group 1960 including Abbondanza (1957, registered year, the same below) and Gaoyuan 182 (1969); (2) group 1970 including Xiangnong 3 (1970), Mobo (1976), Gaoyuan 506 (1978), and Huzhuhong (1979); (3) group 1980 including 10 cultivars namely: Qingnong 524 (1984), Qingnong 469 (1984), Hanhai 304 (1986), Gaoyuan 602 (1987), Chaichun 018 (1988), Chaichun 044 (1988), Chaichun 236 (1988), Humai1 1 (1988), Qingchun 533 (1988), and Xinzhe 9 (1988); (4) group 1990 including 20 cultivars: Gaoyuan 465 (1990), Gaoyuan 466 (1990), Qingchun 415 (1993), Chaichun 901 (1994), Dongchun 1 (1994), Gaoyuan1 58 (1994), Gaoyuan 356 (1994), Qingchun 891 (1994), Zhangchun 811 (1994), Qingchun 570 (1996), Gaoyuan V028 (1997), Gaoyuan 175 (1998), Gaoyuan 205 (1998), Gaoyuan 913 (1998), Lemai 5 (1998), Minhe 853 (1998), Gaoyuan 448 (1999), Gaoyuan 584 (1999), Gaoyuan 932 (1999), and Minhe 588 (1999); and (5) group 2000 including 24 cultivars: Gaoyuan 671 (2000), Humai 13 (2000), Qingchun 587 (2000), Gaoyuan 115 (2001), Lantian 3 (2001), Minhe 665 (2001), Qingchun 952 (2001), Gaoyuan 142 (2002), Lemai 6 (2003), Moyin 1 (2003), Moyin 2 (2003), Ningchun 26 (2003), Qingchun 144 (2003), Ganchun 20 (2004), Humai 14 (2004), Humai 15 (2005), Qingchun 37 (2005), Qingchun 38 (2005), Qingchun 39 (2005), Shanhan 901 (2005), Tongmai 1 (2005), Caoxuan 5 (2007), Gaoyuan 437 (2008), and Gaoyuan 412 (2009).

These 60 cultivars were planted on March 25 in 2010 by randomized complete block method. Eleven morphological traits namely plant height (PH), spike length (SL), distance of spike to flag leaf (DSL), internode length under spike (IL), tillers per plant (T/P), spikelets per spike (S/S), fertile spikelets per spike (FS/S), kernels per spikelet (K/S), grains per spike (G/S), grain weight per spike (GW/S) and 1000 grain weight (GW), were measured at the mature period in August.

Statistical method

Independent-Sample T test and bivariate correlation were used for evaluating difference and relationship between morphological traits under normal irrigation and drought stress. General lineal model was adopted for distinguishing differences among genotypes, environments and their interactions. The data were analyzed in SPSS17.0 (SPSS Inc, USA). In order to distinguish those differences much more comprehensively, non-metric multi-dimensional scaling (NMDS), the most powerful ordination method (Clarke, 1993), was applied in PCORD5.0 (MjM Software, USA).

RESULTS AND ANALYSIS

Effect of drought stress on morphological traits

The morphological traits observed at Ping'an station were compared with those at Shuwan village utilizing independent-sample T test (Table 1). All the morphological traits (except of PH) varied significantly between the two sites. SL, T/P, S/S, FS/S, K/S, G/S, GW/S and GW decreased (P <0.01), while DSL and IL increased (P<0.05) when the wheat cultivars were planted at drought site (Shuwan village). T/P, G/S and GW/S decreased by 58.55, 24.75 and 35.71%, respectively and the other indices' decreases fluctuated from -17.39% to

Table 1. Statistics analysis for 11 morphological traits of 60 spring wheat cultivars under normal irrigation and drought stress.

Trait	Treatment	Mean*	C.V. (%)	Main effect variability		Interaction variability
				Genotype (G)	Treatment (T)	G×T
Plant height (PH, cm)	Normal irrigation	92.96	14.71	42.95%	0.15%	29.28%
	Drought stress	91.93	14.18	P < 0.001	P = 0.25	P < 0.001
Spike length (SL, cm)	Normal irrigation	10.91^A	16.05	23.91%	7.87%	31.72%
	Drought stress	9.86^B	18.43	P < 0.001	P < 0.001	P < 0.001
Distance of spike to flag leaf (DSL, cm)	Normal irrigation	18.23^B	28.97	32.97%	8.82%	21.97%
	Drought stress	21.40^A	23.15	P < 0.001	P < 0.001	P < 0.001
Internode length under spike (IL, cm)	Normal irrigation	38.97^b	17.74	3.46%	83.72%	4.01%
	Drought stress	40.40^a	14.47	P = 0.008	P < 0.001	P = 0.001
Tillers per plant (T/P, no)	Normal irrigation	7.19^A	22.66	1.27%	96.72%	1.29%
	Drought stress	2.98^B	22.95	P < 0.001	P = 0.25	P < 0.001
Spikelets per spike (S/S, no)	Normal irrigation	20.52^A	10.32	4.32%	83.26%	3.33%
	Drought stress	19.08^B	17.88	P < 0.001	P < 0.001	P = 0.02
Fertile spikelets per spike (FS/ S, no)	Normal irrigation	19.67^A	9.54	8.16%	78.64%	6.53%
	Drought stress	18.19^B	18.37	P < 0.001	P < 0.001	P < 0.001
Kernels per spikelet (K/S, no)	Normal irrigation	4.35^A	11.01	18.47%	39.02%	16.09%
	Drought stress	3.71^B	16.10	P < 0.001	P < 0.001	P < 0.001
Grains per spike (G/S, no)	Normal irrigation	62.39^A	14.98	17.23%	26.17%	19.92%
	Drought stress	46.95^B	21.31	P < 0.001	P < 0.001	P < 0.001
Grain weight per spike (GW/S, g)	Normal irrigation	2.80^A	19.44	15.75%	50.80%	16.20%
	Drought stress	1.80^B	24.67	P < 0.001	P < 0.001	P < 0.001
1000 grain weight (GW, g)	Normal irrigation	45.70^A	14.19	28.61%	25.59%	23.60%
	Drought stress	38.43^B	15.41	P < 0.001	P < 0.001	P < 0.001

*Represents the analysis of variance based on independent-sample T test. Superscripted lower and upper case letter indicate significance at P<0.05 and P<0.01 level.

15.90%. PH, SL and DSL were primarily determined by genotypes and their interaction with environments. IL, T/P, S/S, FS/S and GW/S were mainly controlled by environments, while interaction effect between genotypes and environments as well as genotypic effect for those traits was significant but much less than that of environments. Genotypic and interaction effects contributed approximately equally to the variation of K/S, G/S and GW from normal irrigation to water deficit. Effects of environments, genotypes and their interactions ranged from 0.15 to 96.72%, 1.27 to 42.95%, and 1.29 to 31.72%, resulting in the averages of 45.52, 17.92 and 15.81%, respectively. In conclusion, environment was dominating factor for variability to drought stress.

Effect of drought stress on correlation among morphological traits

The correlation coefficients of PH with G/S and GW/S were much larger and more significant under drought stress than those under normal irrigation (Table 2). Under drought stress, the remarkable correlations of SL with DSL and K/S were eliminated while the positive correlations of SL with PH and IL were enhanced. The relations of DSL with G/S and GW/S were also changed significantly. For those traits which were significantly correlated with IL, especially for GW/S and GW, the correlation coefficients under water deficit condition increased compared with those under normal irrigation.

Table 2. Correlation coefficients among morphological traits of 60 spring wheat cultivars under normal irrigation and drought stress.

Drought Irrigation	PH	SL	DSL	IL	T/P	S/S	FS/S	K/S	G/S	GW/S	GW
PH		0.48**	0.53**	0.79**	0.06	0.25**	0.26**	0.01	0.24**	0.46**	0.07
SL	0.26**		0.11	0.37**	-0.07	0.22**	0.23**	-0.06	0.28**	0.43**	0.11
DSL	0.73**	0.19*		0.88**	0.08	0.01	0.02	0.09	0.08	0.23**	0.27**
IL	0.71**	0.23**	0.79**		0.03	0.11	0.13	0.04	0.17*	0.41**	0.25**
T/P	0.04	0.02	0.08	0.05		-0.03	-0.03	0.02	-0.02	-0.19**	-0.03
S/S	0.41**	0.46**	0.07	0.15	-0.12		0.98**	0.71**	0.82**	0.35	0.03
FS/S	0.36**	0.43**	0.03	0.11	-0.08	0.96**		0.73**	0.85**	0.42**	0.05
K/S	-0.13	0.25**	-0.24**	-0.15*	0.02	0.26**	0.31**		0.85**	0.38**	0.22**
G/S	0.14	0.44**	-0.09	0.03	0.03	0.58**	0.61**	0.76**		0.59	0.15
GW/S	-0.07	0.37**	-0.12	0.01	-0.06	0.22**	0.30**	0.68**	0.62**		0.38
GW	-0.09	0.04	0.00	0.06	0.01	-0.31**	-0.27**	0.08	-0.12	0.46**	

"*" and "**" represent significance at $P<0.05$ and $P<0.01$ level, respectively.

However, the significant negative correlation between IL and K/S turned to be a little positively correlated. No traits, except GW/S under water deficit, were significantly correlated to T/P, indicating that T/P was relatively independent and insusceptible to drought stress. It could be further deduced that those yield-related traits responded complicatedly to drought stress. Compared with normal irrigation, the evidently positive correlation between G/S and GW/S was faded away while those relations of G/S with S/S, FS/S and KS were enhanced and all the correlation coefficients were above 0.80. Similarly, drought stress weakened the correlation between GW and GW/S, and strengthened the relationship of GW with other agronomic characteristics, such as DSL and IL. Summarily, drought stress could obviously change the relationship among those agronomic characteristics.

Effect of drought stress on overall 60 cultivars

The final stress solution and final instability for 2-dimensional were 7.68 and 0, suggesting that the results were the good ordination with no risk of drawing the false inferences (Clarke, 1993). Two axis's cumulative variability was up to 97.1% and its orthogonality was 99.5%. The first axis's variability was 83.9% and the more variability of axis 1 indicated that a clear discrimination among the cultivars could be made on the basis of those morphological traits. IL, FS, S/S and T/P imposed the main influence on axis 1, with positive effect of the former two traits and negative effect of the latter two (Figure 1). G/S, GW/S, GW and K/S influenced axis 1 positively, but relatively less. Axis 2 combined positive force of PH and DSL. SL showed approximately equal influence to the two axes, and its correlation coefficients with axis 1 and 2 were 0.40 and 0.42, respectively. Two groups were easily identified on the basis of environments and the result was similar to that from high environmental variability (Table 1), which also suggested that those morphological traits of 60 spring cultivars might be indistinctive to drought stress.

DISCUSSION

Morphological traits' response

Agronomic traits PH, SL, and DSL were mainly determined by genotypes and their interaction with environments (Table 1), which suggested that they would be genotype indexes of spring wheat in Qinghai. This might be a reflection of favorable weather conditions (long sunlight, conformable diurnal temperature amplitude, synchronous heat and moisture) for spring wheat growth in the experiment area. Especially consistent PH between environments reflected the favorable growing conditions (Jaradat, 1991). Plant height was mainly affected by genotypes rather than environments. This result was coincided with previous works from Italy, Mexico and Turkey (Naghavi et al., 2002).

IL, T/P, S/S, FS/S and GW/S were more determined by environment factors (Table 1), which were coherent with morphological performance of 37 durum wheat landraces under drought stress (Ahmadizadeh et al., 2011). The sensible reason was that these agronomic characteristics reflected cultivar capacity to adjust to environment and to compensate when stand establishment was poor (Jaradat, 1991). IL/PH was 0.44 under drought stress, and significantly more than 0.42 under normal irrigation ($P<0.001$), which was supported by higher ratio of IL/PH in dry areas (Jaradat, 1991). However, those morphological traits were mutually correlated and strongly related to drought resistance. Hence, identifying which

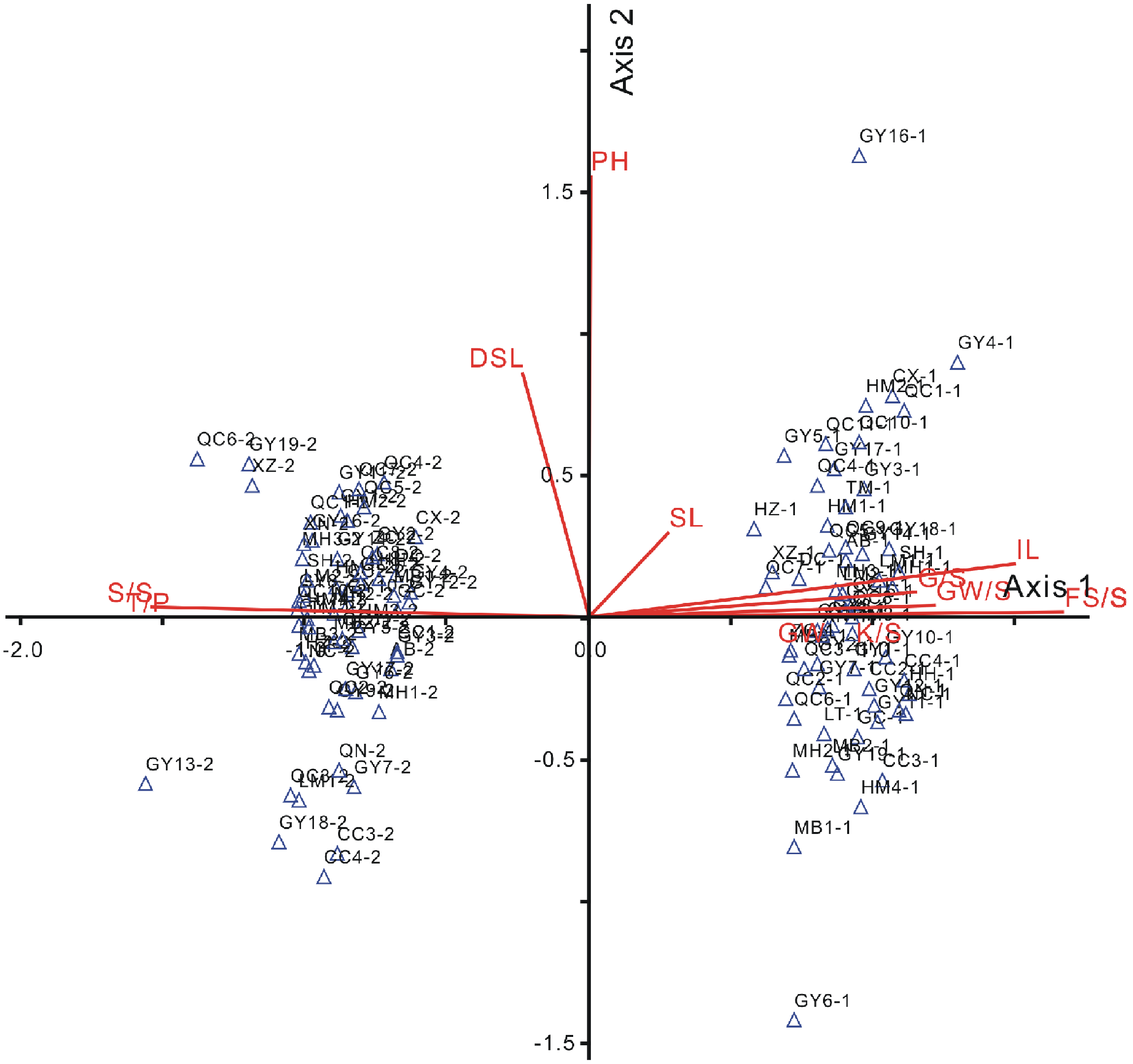

Figure 1. Results of non-metric multidimensional scaling analysis of 60 spring wheat cultivars (letters before "-" are abbreviations of cultivars' names; "-1" and "-2" represent normal irrigation and drought stress, respectively).

plant growth trait for assessing water stress was only a labor intensive procedure (Fischer and Wood, 1979; Clarke et al., 1983).

Genotype, environment and its interaction influenced three yield components (S/S, K/S and GW) differently. S/S increased to 7.55% under normal irrigation, and the variation was mainly controlled by environment. Mean environment variability of three yield components' variation (S/S, K/S and GW) was 49.29%, ranging from 25.59 to 83.26%. This result coincided with the report on yield of spring wheat under water stress in northwestern China (Liu et al., 2010) and similar to previous conclusion that spring wheat yield was mainly determined by environment (Duggan et al., 2000; Roozeboom et al., 2008; Chang et al., 2010). The genotype and its interaction with environment were 17.14 and 14.34%, indicating that wheat breeding had some certain contribution on yield promotion. Considering that GW/S has been proved to have significantly positive and most direct effect on grain yield (Simane et al., 1993; Dencic et al., 2000; Guttieri et al., 2001), so it was classified to the yield-traits. Those S/S, K/S, GW and GW/S yield-traits averagely declined by 24.94% under water-limited conditions in our study, which also meant that wheat grain yield was unstable and sensitive to drought stress in northwestern China (Pan et al., 2003; Deng et al., 2006).

Overall, for the 11 morphological traits from 60 spring wheat cultivars, the effects of genotype, environment and their interaction were 17.92, 45.52 and 15.81%, respectively (Table 1). Moreover, NMDS analysis showed that environment, not genotype factor, distinguished the different response of 60 spring cultivars, which was partly consistent with the view that genotypic divergence was the result of altitude and long-term average rainfall

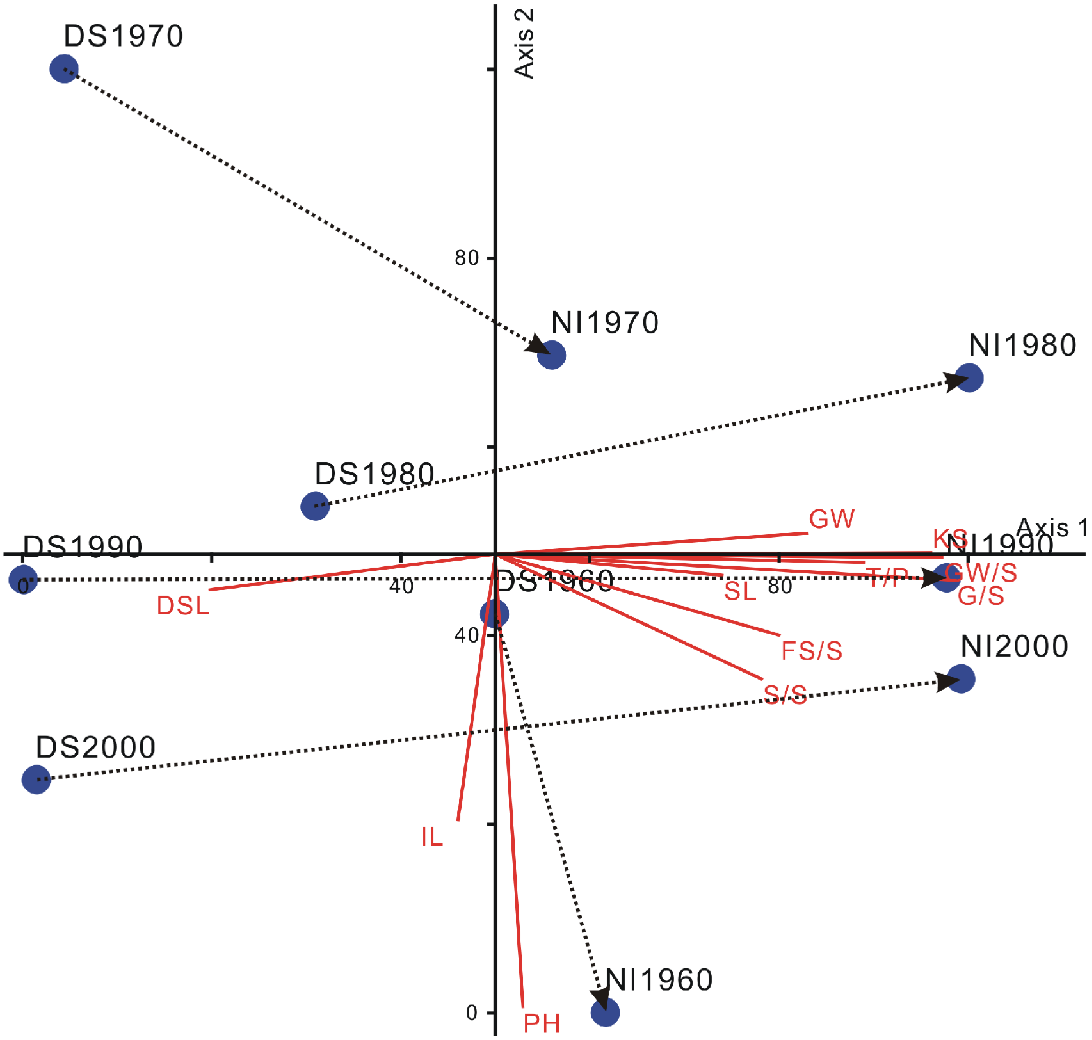

Figure 2. Results of non-metric multidimensional scaling (NMDS) analysis on 5 decade group of 60 spring cultivars in Qinghai ("DS" and "NI" stand for "drought stress" and "normal irrigation", respectively, while the 4 digit numbers represent the registered decade of cultivars).

according to analysis 132 landrace all over Jordan (Jaradat, 1991). Therefore, it was coherent with the result that environment effect was more important than that of genotype (Duggan et al., 2000; Chang et al., 2010; Zhe et al., 2010).

Modern breeding for drought stress

The final stress for 2-dimensional solution and final instability were 2.47 and 0, which suggested that the result was excellent with no prospect of misinterpretation (Clarke, 1993). Two axis's cumulative variability was up to 97.3% and its orthogonality was 98.0%, with the first axis's 71.5%. SL, T/P, S/S, FS/S, KS, G/S, GW/S and GW imposed the main positive influence while DSL enforced the negative effect on axis 1. Axis 2 combined the negative effect of PH and IL (Figure 2). The distance of decadal cultivars between normal irrigation and drought stress became much more farther with time, which partly indicated that modern breeding program enlarged the difference of cultivar response to water stress, mainly due to chasing high yield goal (Fischer and Wood, 1979; Cattivelli et al., 2008) and high yield potential might not be compatible with superior drought resistance under most dryland area (Blum, 2005). The phenomenon was consistent with that direct selection for increased yield in the absence of drought stress increased drought susceptibility and decreased yield under drought (Fischer and Wood, 1979).

Moreover, results from segregating family analysis indicated that it would improve yield from the selection under moisture stress environment better than selection from non-moisture stress environment (Golabadi et al., 2006). The current yield stability of the spring wheat was relatively not high in Qinghai (Figure 2), therefore the strategy with not only high yield but strong stability should be taken in the future breeding progress (Cattivelli et al., 2008). The extreme rainfall and drought would be highly frequent and available rainfall might decrease (IPCC, 2007). Consequently, seeking high yield only might weaken the crop buffer capacity to moisture deficit in Qinghai.

Conclusion

On the responses of those 60 spring wheat cultivars to drought stress in Qinghai province of northwestern China, the field experimental results showed that all of the morphological traits except PH were significantly influenced. IL, T/P, S/S, FS/S and GW/S could be indexes of moisture deficit and primarily controlled by drought stress. SL, DSL, K/S, G/S and GW were comprehensively influenced by genotypes and their interaction with environments. Drought stress weakened the relationship among yield-traits and changed the correlations among morphological traits. The results of NMDS on 11 morphological traits of 60 cultivars revealed that spring wheat cultivars responded specifically to moisture deficit environment and did not specifically to genotypes. Mainly due to only chasing high crop yield, the distance of cultivars in the same decade from the normal irrigation to drought stress indicated that modern wheat breeding has enlarged the difference of spring wheat cultivars to water deficit and might weaken the buffer capacity under high frequency of extreme drought in the future scenario. The further long-term multi-site experiments on morphological traits of spring wheat should be studied to comprehensively evaluate inter-annual and site variations, and stability responses to drought stress in Qinghai.

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