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YIELD STABILITY AND DROUGHT RESISTANCE IN WHEAT

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There is little information on interaction between productivity, stability and drought resistance of crop. This problem is very important in Kazakhstan, where the most of the agricultural area is located in arid and semiarid regions. In this context the genotype × environment interaction (GEI) is of major importance to the plant breeders in developing improved drought resistant cultivars. In this study GEI and stability parameters of recombinant inbred lines (RILs) has been determined by field testing at three contrasting environments. The comparison of the performance and stability of the lines L3, L10, L5, L1 indicated that this breeding material tended to display better performance for main of productivity traits and stability for plant grain yield as compared with other RILs and parental forms. There was positive association between high leaf Relative Water Content (RWC), low leaf Relative Water Loss (RWL) and yield stability. Both physiological parameters (RWC and RWL) are good indicators of drought adaptation by wheat genotypes. A comparison of glume pubescent and unpubescent lines has shown close negative correlation for spike RWL and spike RWC of all pubescent RILs ($R^2 = -0.845$). So the glume pubescence can be used as a morphological marker and indirect criterion for selection of drought resistant genotypes. As a result several promising lines combining high yield stability and drought resistance has been selected and used in breeding program.

Key words: drought resistance, genotype × environment interaction, stability, RWC, RWL, wheat

Abbreviations: GEI = genotype × environment interaction, RIL = recombinant inbred lines, RWC = relative water content, RWL = relative water loss, FLA = flag leaf area, NKS = number of kernel per spike, WKS = weight of kernel per spike, WKP = weight of kernel per plant, W1000k = weight of 1,000 kernels

INTRODUCTION

It is known that a high level of productivity and stability of yield are controlled by different genetic systems. That makes possible to successfully combine these two valuable characters in new cultivars. However, studies on interaction between productivity, stability and drought resistance are not sufficient. This problem is very important in Kazakhstan, where most of the agricultural area is located in arid and semiarid regions. In this context the genotype × environment interaction (GEI) is of major importance to the plant breeders in developing improved drought resistant cultivars. GEI may be defined as the failure of genotypes to have the same relative performance from one environment to another (Baker 1988). Understanding of the causes of GEI can help to identify traits that contribute to better cultivar performance and environments that facilitate cultivar evaluation (Yan and Hunt 2001). Although the importance of GEI has long been realized by geneticist and breeders, its study could not make a headway because the mechanism of GEI has not been sufficiently studied. In this connection there appears to exist the necessity studies of this problem on special genetic objects as recombinant inbred lines (RILs) since they are more convenient model objects. Such an approach makes it possible to reveal the contribution of concrete genetic background on resistance to unfavourable environmental factors.

In order to study stability in terms of plant response to drought stress it is necessary to look for the physiological parameters related to plant adaptation (Nagy *et al.* 1995). Plant growth and plant water status in response to soil water deficit play an important role in tolerance to drought and in yield stability. Relative water content has been proposed from many studies as a selection criterion for drought tolerance in crops (Martin *et al.* 1989, Schonfeld *et al.* 1988). High RWC as the tendency for greater leaf hydration seems to be a consequence of osmotic adjustment connected to drought resistance (Morgan 1984). Another parameter – Relative Water Loss (RWL) – is a direct measurement of plant water deficit and also a good criterion for the selection of drought tolerant plants (Clarke and McCaig 1982, Jamaux *et al.* 1997). As a rule a study of crop drought resistance is based either on using of physiological traits or productivity components. Knowledge of the relationship stability parameters and drought resistance would potentially help guide effective selection efforts. Therefore, the objective of this study was to assess the associations between yield stability, drought resistance and physiological parameters in wheat.

MATERIAL AND METHODS

The experimental material has been grown at three locations in Southeast Kazakhstan: KazNIIZ, Karaoi, and Shimkent. Favourable conditions include fertilizing – N (60) and P (30) – and include over 400 mm overall rainfall. Water shortage conditions include low rainfall (200–300 mm). Fertilizer treatments corresponded to those normally recommended for the site and management practice. Nitrogen fertilizer was applied at a rate 60 kg ha^{-1} and phosphate fertilizer in a rate 30 kg ha^{-1}. The irrigated foothill zone (KazNIIZ) is a relatively well-watered location, the wheat plants were irrigated 3 times during their development at a rate 600 m^3/ha. Karaoi is situated in the desert-steppe zone therefore its climate is extremely dry with great variation, the whole vegetation period, especially during wax-ripeness, is characterised by drought and dry winds. Karaoi is a non-irrigated location. The hill-steppe zone of the Shimkent region has a relatively mild climate, while drought and dry winds during the period of wax-ripeness considerably reduce the wheat yield. The plants here were irrigated 2 times at a rate 600 m^3/ha. The soils in all three locations are light, ranging from sandy loess to brown semidesert soils to light silty loams and other alluvial soils. Experiments were made in 3 randomised blocks. Each plot was 1.25-m long, each single row with a 0.3 m spacing between rows, 25 seeds were sown in each row. A population of 16 recombinant inbred lines (RILs) of winter wheat (*T. aestivum* L.) cultivars where used. Recombinant inbred lines (RILs) F_8 were derived from F_5 bulks, produced from the cross 'Bogarnaya 56'/'Spartanka'. Based on field performance, 'Bogarnaya 56' (var. *pyrotrix*) is more drought resistant than 'Spartanka' (var. *lutescence*). RILs were randomly derived from the F_5 bulks, with F_6 head rows grown in field conditions. The RILs were sown in the 2000/2001 growing season. Tests were sown at the normal sowing dates for the various locations during 20–30 September. Available weather data for this location is shown in Table 1.

The parent cultivars are differed in morphological traits: ♀ 'Bogarnaja 56' is var. *pyrotrix* (with red glume, glume pubescent, awnless; ♂ 'Spartanka' used as a male parent relate to the var. *lutescence* (white glume, glume unpubescent, awnless). RILs differed in spike morphological traits: glume colour and glume pubescence. The physiological traits evaluated are relative water content (RWC), relative water loss (RWL). Both RWC and RWL were measured by the standard method in top fully-expanded leaves at midday, at pre-anthesis and anthesis stages once a week during stress development. RWC (%) was calculated according to Barrs and Weatherley (1962) using RWC = 100 × (Wf–Wd)/(Wt–Wd). Fresh weight (Wf) was determined from one flag leaf, turgescent weight (Wt) from the same leaf incubated for 20 h at 4 °C in a water bath in a darkness, dry weight (Wd) was measured after dehydration of the leaves for 48 h at 70 °C. RWL was determined using RWL = 100 × (Wf–W4h)/(Wt–Wd). The weight of leaf after 4 h (W4h) was measured after slight dehydration of

Table 1

Monthly rainfall (R) and monthly average of mean temperature (T) during 2000/2001 growing season at KazNIIZ

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.
R (mm)	22.6	17.8	42.3	38.8	46.3	31.6	89.2	92.6	17	22.7	4.5	20.8
T (°C)	9.2	5.7	–2.0	–5.9	–6.0	2.0	8.1	14.9	19.5	23.2	22.6	17.7

flag leaf during 4 h at room temperature according to Jamaux *et al.* (1997). Individual flag leaf area (cm^2) was measured using a LI-Cor 3000 Area Meter (LiCOR Instruments, Lincoln, NE, USA). The productivity traits evaluated here are number of kernels (NKS) and weight of kernels per spike (WKS), weight of kernels per plant (WKP) and weight of 1,000 kernels (W1000k).

To analyse the Genotype × Environment Interactions (GEI) the method of Eberhart and Russel (1966) was used. They described a stable variety as one with a regression coefficient, $b = 1$ and minimum deviation from the regression, $s^2d = 0$.

RESULTS AND DISCUSSION

Analysis of variance was done for each test and for traits of productivity. The genotype (factor A), environment (factor B) and genotype × environment interactions (factor AB) mean squares were all highly significant ($p = 0.01$) for all traits. Evaluation of genotypic performance at a number of environments provides useful information to determine their stability.

Based on the regression coefficient *b*, the genotypes tested could be ranged as those having more than average stability and below average stability for kernel weight per plant as an important traits of productivity correlated with total grain yield. Many genotypes belonged to the average stability group. L11, L12 had an average yield and average stability as their *b* values were not different from 1 (Table 2). Genotype L8 had regression coefficient which is significantly less than unit which show its lack of response to changes in environment. Genotypes 4, 5, 16, 13, 'Spartanka' had a regression coefficient which is significantly greater than 1 which indicates its good response to changes in environmental conditions and specific adaptation to favourable conditions. These materials can be considered as sensitive and having below average stability. Genotypes 6, 7, 14, 'Bogarnaya 56' had *b* significantly less than 1 indicating their constant expression of the trait under the variety of environments and better adaptation to poor environments. Genotypes 5, 3, 10, 2, 1 displayed similar patterns of adaptation and stability. These can be considered as stable genotypes as genotypes exhibiting low deviations mean square (S^2d). Thus, the most stable genotypes in kernel weight per plant were the lines L5, L3, L10, L2 and L1.

The parameters of water status and productivity components in KazNIIZ were studied among experimental material under moderate drought conditions only (Table 3). Variance analysis (ANOVA) was used to determine whether differences existed between lines and parents. These differences were significant at 5% level. For parental lines, there were no significant differences for RWC, whereas for flag leaf area, relative water loss and productivity traits significant differences were found. The most of RILs exceeded the parents in RWC, among them L3, L5 and L10 had positive significant differences. As to RWL, significant differences were observed in lines L10, L11 and L12 in comparison with parental forms (Table 3). The considerable decrease in flag leaf RWL during stress developing was observed by these lines L10, L11 and L12. According to Jamaux *et al.* (1997) lower level of leaf water loss under drought might be related to higher capacity plants for osmotic adjustment. The highest flag leaf area compare to parent 'Bogarnaya 56' had only lines L4–L6. The higher number of kernel per spike compared to parent cultivars had the line L10 only. A little improving effect in kernel weight per spike (KWS) and more considerable in kernel weight per plant (KWP) was shown also by line L10. As to weight of 1,000 kernels several lines exceeded considerable parental forms, namely L2–L7, L12, L14–L16.

We also studied the associations between water status parameters and productivity components for the group of high yielding RILs. The RWC of flag leaf was positively correlated with all of yield components (Table 4). Strong correlations of these traits ($R^2 = 0.66; 0.94; 0.60$) were noted for NKS, WKS and

Table 2

Mean values and stability parameters for kernel weight per plant of RILs and their parents evaluated under 3 environments

Entry	Mean KWP (g)	b_i	S^2d
♀ 'Bogarnaya 56'	3.90	0.81	0.16
♂ 'Spartanka'	3.65	1.42	0.78
L1	4.86	0.95	0.07
L2	4.33	0.95	0.30
L3	4.82	1.09	0.44
L4	4.67	1.51	1.73
L5	3.81	1.03	0.28
L6	4.61	0.70	0.55
L7	4.05	0.83	0.25
L8	3.78	0.42	0.01
L9	3.71	0.87	0.81
L10	4.38	1.14	0.25
L11	3.85	0.88	0.42
L12	3.83	0.88	0.06
L13	5.47	1.59	0.09
L14	3.47	0.77	0.01
L15	4.49	1.31	1.28
L16	4.27	1.27	1.11

Table 3

Parameters of water status and yield components of 16 RILs and their parents

Entry	Genotype	RWC (%)	RWL (%)	FLA (cm^2)	NKS	KWS (g)	KWP (g)	W1000k (g)
'Bogarnaja 56'	RgRgHgHg	77±2.0	53±3.5	18.73±1.71*	50.6±2.0	2.19±0.09	4.93±0.4	38.3±0.7
'Spartanka'	rgrghghg	75±1.7	59±2.3*	14.56±0.17*	43.1±1.7*	1.63±0.05*	4.26±0.18	36.7±0.7*
L1	rgrgHgHg	81±1.5	53±2.0	20.55±1.21	38.6±1.5*	1.7±0.07*	4.57±0.18	42.7±1.1*
L2	rgrgHgHg	80±1.5	51±3.0	21.17±1.29	43.6±1.5*	1.95±0.06*	5.3±0.20	44.4±0.6*
L3	rgrghghg	84±1.0*	50±3.0	20.92±1.16	38.7±1.1*	1.74±0.06*	4.99±0.20	5.0±1.1*
L4	rgrghghg	77±2.0	55±2.5	20.59±0.38*	42.0±1.6*	1.68±0.09*	5.18±0.30	40.0±0.9
L5	rgrghghg	82±2.0*	55±3.8	21.51±1.13*	43.1±1.6*	2.01±0.09	5.0±0.20	45.5±1.1*
L6	RgRghghg	79±2.0	60±2.2	20.65±1.22*	41.2±1.8*	1.92±0.09*	5.1±0.30	47.0±0.9*
L7	rgrghghg	79±1.6	55±1.6	18.43±0.25	41.0±1.5*	1.8±0.07*	4.9±0.20	43.0±1.0*
L8	RgRgHgHg	79±2.0	55±3.0	16.11±1.12	43.3±2.1*	1.8±0.06*	4.5±0.20	41.1±1.0
L9	rgrghghg	79±2.3	54±1.9	18.46±1.23	42.9±2.5*	1.75±0.08*	5.1±0.30	41.0±1.0
L10	rgrgHgHg	83±1.6*	43±2.9*	20.56±0.78	55.0±2.3*	2.3±0.09	6.0±0.20*	41.0±1.0
L11	rgrgHgHg	79±1.0	48±1.8*	13.02±0.18	54.0±1.7	1.88±0.07*	4.7±0.30	35.0±1.0*
L12	rgrghghg	79±1.5	46±3.3*	17.46±0.14	42.1±1.9*	1.81±0.08*	4.7±0.20	43.0±0.8*
L13	RgRghghg	78±1.7	58±1.7	13.71±0.58	44.8±1.9*	1.79±0.09*	5.0±0.20	40.0±0.9
L14	RgRghghg	79±2.0	55±2.3	14.71±1.53	37.0±1.3*	1.7±0.05*	4.9±0.20	47.4±0.7*
L15	rgrgHgHg	76±1.7	53±2.0	16.66±1.11	34.0±1.4*	1.7±0.07*	4.6±0.20	50.5±1.0*
L16	RgRgHgHg	79±1.8	56±1.6	15.02±1.05	40.0±2.1*	1.9±0.07*	4.9±0.21	48.9±1.1*

♀ 'Bogarnaja 56', ♂ 'Spartanka', * = significant at 5% level of probability, compared to drought resistant parent 'Bogarnaya 56'

Table 4
Relationship between water status and quantitative traits in the most productive recombinant inbred lines of winter wheat

Parameters	NKS	WKS	WKP	W 1000 k	FLA
RWC (flag leaf)	0.66**	0.94**	0.60*	0.13	0.43
RWL (spike)	–0.38	–0.06	–0.26	–0.45*	–0.31
RWL (flag leaf)	–0.86**	–0.78**	–0.91**	–0.34	–0.36
FLA	0.18	0.32	0.42*	0.0	1.0

* = significant at 5% level of probability, ** = significant at 1% level of probability

WKP. RWL of spike and weight of 1,000 kernels were significantly negatively correlated (R = –0.45* $P < 0.05$). It seems, the trait W1000k can be a good indicator for drought resistance. The RWL of flag leaf was found to be negatively correlated with all of productivity components. Highly significant of these correlations were with number of kernel per spike (–0.86** $P < 0.01$), weight kernel per spike (–0.78** $P < 0.01$) and weight kernel per plant (–0.91** $P < 0.01$). Flag leaf area tended to be positively related to yield components, but no significant correlation was found between these traits.

Association between two traits of water status RWC and RWL of spike was estimated for two groups with contrasting morphological traits: 1. with glume pubescence, genotype HgHg, and 2. without glume pubescence, genotype hghg (Fig. 1). RWL was negatively correlated with RWC in each group tested. In the group of pubescent spike the strongest correlation ($R^2 = -0.845^{**}$) was noted. The plants in the unpubescent group displayed non-significant correlation between the above traits ($R^2 = -0.279$). It is well-known that RWC is positively correlated with drought resistance, while RWL is negatively related to this trait (Schonfeld *et al.* 1988). The negative correlation between RWC and RWL suggests that the smaller degree of water loss is connected to the ability of spike to better reservation of moisture under conditions of water shortage. Earlier Blum (1988) observed that such morphological traits as leaf colour, glaucousness and pubescence contribute to the stress avoidance, by reducing radiation absorbed by the plant and increasing crop albedo. Our data also allow us to suggest that glume pubescence, perhaps, reflects in the infrared spectrum and promote a defence from the overheating and therefore can be used as an indirect criterion for selection of the higher drought resistant genotypes.

Based on the greater level of leaf RWC of RILs, evaluated under moderate relatively well-watered conditions in case of KazNIIZ, we concluded that the lines L3, L10, L5, appeared more drought resistant in comparison with parental forms (Table 3). It is suggested that there is a positive association between flag leaf RWC measured at midday at anthesis stage and yield stability. This

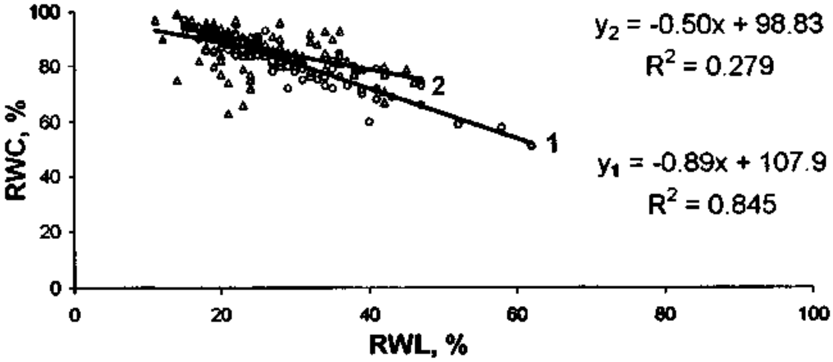

Fig. 1. Relationship between spike relative water content (RWC) and spike relative water loss (RWL) among pubescent and unpubescent RILs in grain filling stage. Association between two traits of water status RWC and RWL of spike was estimated for two groups with contrasting morphological traits: 1. with glume pubescence, genotype HgHg, and 2. without glume pubescence, genotype hghg

conclusion is in agreement with results of some authors, who reported close correlation in crops between RWC and yield stability (Clarke and McCaig 1982, Schonfeld *et al.* 1988). In this paper we do not present data from study on physiological parameters in the two contrasting zones. Therefore we believe that further research is required to elucidate influence of RWC on wheat yield stability under severe dry conditions and to determine its physiological causes.

The classification of the 18 entries resulted in three entry groups with lower, middle and higher level of RWL, respectively (Fig. 2). As a rule the RILs with high and middle level of stability grouped closely together in both sets of RWL (A and B). Moreover, all RILs from A and B groups are characterised by higher flag leaf area, as well as by higher weight of 1,000 kernels. Thus, the lower level of RWL coupled with higher RWC (see Table 3) indicates on better adaptation of wheat genotypes to unfavourable conditions, that is confirmed

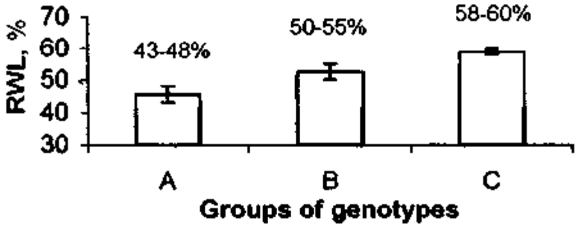

Fig. 2. The classification of RILs based on their level of flag leaf RWL. The group A includes L3, L10–L12; group B includes L1–L2, L4–L5, L7–L9, L14–L15 and parent 'Bogarnaya 56'; group C includes L6, L13, L16 and parent 'Spartanka'

by close correlations between low RWL and all productivity traits of most stable wheat genotypes (Table 4).

CONCLUSION

Thus, the comparison of the performance and stability of the lines L1, L3, L5, L10 indicated that this breeding material tended to display better performance and stability for grain yield. There is positive association between high leaf RWC, low leaf RWL and yield stability. These two physiological parameters are good indicators of drought adaptation by wheat genotypes. The glume pubescence can be used as a morphological marker and indirect criterion for selection of drought resistant genotypes.

As a result several promising lines combining high yield stability and drought resistance has been selected and used in breeding program.

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