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Differential Responses of Grain Yield and Quality to Salinity between Contrasting Winter Wheat Cultivars

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ABSTRACT

An experiment was carried out to study the grain yields and quality criteria of contrasting wheat (*Triticum aestivum* L.) cultivars, DK961 (salt-tolerant) and JN17 (salt-sensitive) in response to a series of salinity levels (0, 50, 100, 150 mM). Salinity led to a reduction in grain yields of both cvs, however, DK961 was less affected than JN17. For grain quality, the 1000-seed weight of JN17 was rapidly reduced in saline conditions compared to the control, while it declined slightly in DK961. Grain protein content of DK961 increased by 0.2, 0.7 and 3.5%, respectively in 50, 100, 150 mM NaCl treatments compared to control. Those figures of JN17 reached 1.5, 5.3 and 9.9%. Flour yield of DK961 declined by 2.6, 3.7 and 3.9%, respectively in the above-mentioned salt treatments than control. The extent of reduction in flour yield was larger in JN17 than in DK961. Salinity induced positive effects on ash content and sedimentation volumes. The pasta quality parameters, *e.g.* wet gluten content, water absorbance, dough development time and dough stability time of DK961 displayed non-significant (P >0.05) changes under 50 and 100 mM NaCl concentrations against the control, while they declined considerably in the 150 mM NaCl treatment. However, pasta quality of JN17 declined significantly along with a reduction in grain yield under all levels of salt concentration. Our results suggested that wheat grain quality was closely associated with its growth under salinity stresses. Therefore, to obtain high grain yield and better quality of wheat in saline farmlands, only salt-tolerant wheat cultivars should be considered.

Keywords: contrasting salt tolerance, grain yield, pasta quality, protein and ash contents, sodium chloride, *Triticum aestivum* L.
Abbreviations: cv(s), cultivar(s); **DDT**, dough development time; **DST**, dough stability time; **SDS**, sedimentation volumes; **WA**, water absorbance; **WGC**, wet gluten content

INTRODUCTION

Salinity, considered to be one of the most serious stresses worldwide, significantly inhibits the growth and productivity of most high plants, including wheat (Lawlor 1995; Able *et al.* 2003). Some reports note that salinity reduces the growth of wheat by leading to specific ion toxicity and enhancing the generation of reactive oxygen species (ROS), resulting in a decrease of photosynthetic capacity (Able *et al.* 2003; Zheng *et al.* 2008a). Differential responses to salinity stress have been noted in wheat cultivars differing in salt tolerance (Munns 2002; Ma *et al.* 2006). The yield of wheat depends on its capacity to adjust to cell osmoregulation, stomatal function, activation of enzymes, protein synthesis, oxidants metabolism and photosynthesis (Cherel 2004; Zheng *et al.* 2008b). For instance, salt-tolerant wheat could obtain higher grain yield than salt-sensitive genotypes (Sairam *et al.* 2002; Stepien and Klobus 2005; Zheng *et al.* 2009).

Winter wheat (*Triticum aestivum* L.) is one of the main crops which contribute protein and calories for the daily diet of people, especially in North China (FAO 1985; Zhang *et al.* 2007). Although significant achievements have been obtained in wheat yield over the past several decades, requirement for high quality has also increased as life-styles improve (Park *et al.* 2006, 2008).

Two main factors determining wheat quality are variety and plant growth environment (Quail 1996). Salinity is a common stress which affects grain yield (Zheng *et al.* 2008b). In China, for instance, about 10% of arable land is exposed to salinity stress, which is still expanding due to irrational irrigation (Zhu *et al.* 2001). New wheat varieties developed by breeders possess improved salt tolerance and yield potential. However, general concerns have risen that new wheat varieties are inferior in quality characteristics compared to old varieties (Ohm and Chung 1999; Curic *et al.* 2008). For maximum grain security and improved nutrition, wheat varieties with both high yield and quality are required (Torbica *et al.* 2007). Nevertheless, little information exists on the relationships between salt tolerance and wheat grain quality. Therefore a careful study on the yield and quality of contrasting wheat cultivars responding to salinity stress is urgently needed.

An experiment was carried out to study the responses of contrasting wheat cultivars (salt-tolerant DK961 and salt-sensitive JN17) to salinity in a greenhouse of Dezhou Academy of Agricultural Science, China. The grain quality and yield of these two cultivars under salt stress was analyzed.

MATERIALS AND METHODS

Plant culture and experimental set-up

On 10 Oct. 2006, 60 seeds of salt-tolerant DK961 and 60 seeds of salt-sensitive JN17 were separately sown in each of 12 plastic containers (length × width × height = 0.6 m × 0.5 m × 0.5 m). Two rows were sown in each container, with DK961 on the left and JN17 on the right. The row spacing was 25 cm. Containers were filled with field soil, which was classified as light loam. Organic C, available N, P, and K were 0.86%, 121.86, 175.71 and 80.51 mg kg^{-1}, respectively. Seedlings were thinned to 55 per row in each container on 10 d after planting. 15 g compound fertilizer (N: P_2O_5: K_2O = 46: 35: 19) was applied twice for each container at the wheat jointing and filling stage, respectively.

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Control plants were irrigated with distilled deionized water. Experimental seeds were exposed to increased levels of NaCl concentration (50, 100 and 150 mM) solution. Water lost by evapotranspiration was replenished each day. The average day/night temperature was kept at 16-32 and 10-16°C, respectively. The relative humidity (RH) was 75-86% during the experiment. The plants were illuminated by natural day light supplemented with fluorescence light. The maximal photosynthetically active radiation (PAR) was approximately 1800 μmol m^{-2} s^{-1} at canopy height during a 14 h photoperiod.

Grain yield and quality criteria analysis

Grain yield was obtained after harvest and sampled twice from each block. Grain quality was analyzed according to the methods described in AACC (2000). For each grain quality criteria, the value of each experimental treatment was the mean of 6 measurements (2 grain samples × 3 blocks). Nine grain quality criteria were considered in this study:

1000-seed weight: 1000-seed weight was considered relevant to semolina yield. The weight of 500 seeds was obtained after removing broken kernels and foreign materials. There were three replicates. The mean (n = 3) was multiplied by 2 to obtain the 1000-seed weight.

Flour yield: Flour yield is defined as the semolina extraction of the grain. It was determined on a 500 g grain sample. Flour was milled according to the AACC (26-10) method using Brabender senior mill (Quadrumat Junio, Brabender, Germany). The flour was weighed to obtain flour weight. The flour yield was expressed as percentage of flour in grain.

Water absorption (WA): It is defined as the amount of water used to allow the maximum density of dough to reached 500 ± 20 Brabender Unit (B.U.) line. It was expressed in percentage and determined by a grain quality analysis instrument (JFZD-300, Zhengzhou, China).

Protein content: The nitrogen content (N) was determined following the Kjeldahl Nitrogen Determination method (AACC approved method 46-13). The protein content (PC) was calculated by using the following formula: PC (mg g^{-1} dm) = N×5.7

Ash content: A low value of ash content is important in the assessment of semolina quality. Ash content was determined in duplicate on a 5 g flour sample by dry combustion for 16 h at 580°C in a Muffle furnace (AACC approved method 08-01).

Wet gluten content: Wet gluten content was determined on a 10 g flour sample by automatically washing with a 2% NaCl solution buffered at pH 6.8 (AACC approved method 30-10). The extracted wet gluten was weighed and the result was expressed as a percentage.

Sedimentation test (SDS): SDS was considered as a comprehensive index to estimate the wheat gluten quality and quantity. It was based on the hydration capacity and flocculation of flour in a low acidity media. The volume of the sedimentation in a set time was defined as SDS.

Dough development time (DDT): It was defined as the kneading time from start adding water to reach maximum denseness of dough. Its unit is min.

Dough stability time (DST): The dough stability time was defined as the time from the curve reaching 500 B.U. line to leaving 500 B.U. line. It was determined by a 50 g E-type farinograph (Brabender, Germany).

Statistical analysis

The experiment was arranged in a completely randomized design with four levels of NaCl concentrations (0, 50, 100, 150 mM) and two wheat cultivars. Data of six replicates (2 containers × 3 replicates per container) for each treatment were analyzed. Statistical analysis was processed using analysis of variance (ANOVA) in the General Linear Model procedure of SPSS (Ver. 11.5, SPSS, Chicago, IL, USA). The effects of salt stress on grain yield and quality were verified using a *t*-test for multiple comparisons. Significant effects were determined at 0.05, 0.01 and 0.001, respectively.

RESULTS AND DISCUSSION

Grain yield and quality criteria

Tables 1 and **2** show the grain yields and quality criteria, respectively for DK961 and JN17 under a series of NaCl concentrations. Under non-saline condition, the grain yield of DK961 was lower than that of JN17. This might be explained firstly DK961 that is a small spike type, in which yield is dependent on high density. JN17 is a big spike type whose yield is determined by the number of seeds per spike. In this case, the same density of DK961 and JN17 used in this study might be not appropriate; secondly, fast-growth may be one of the forms for DK961 to avoid excessive Na^+ accumulation in plant tissues under salt condition. DK961 grew too quickly and was too tall at the vegetative stage in non-saline conditions, which led to about 10% of the plants lodging. In contrast, JN17 was a semi-dwarf wheat variety. It grew much stronger than DK961 under control conditions. The 1000-seed weight and ash content of DK961 were lower, but its protein content was 4.9% higher than that of JN17. The wet gluten content was 14.9% lower, but SDS was 15.4% higher in DK961 than in JN17. Both dough development time (DDT) and dough stability time (DST) expressed longer in DK961 than in JN17. In salinity treatments, the reduction in DK961 grain yield was not significant (P >0.05) at 50 and 100 mM NaCl compared to the control. However, the yield of DK961 decreased rapidly at 150 mM NaCl. The variation of 1000-seed weight was similar to that of grain yield. The ash and protein contents of DK961 increased, but did not reached significant levels (P

Table 1 Responses of grain yields and quality criterions of the salt-tolerant DK961 to a series of salinity concentrations (0, 50, 100, 150 mM NaCl). Non-saline (0 mM NaCl) treatment was used as control. Data are mean ± SE (n = 6). Different letters within a column indicate significant differences ($P \leq 0.05$, *t*-test).

DK961	NaCl concentrations (mM)			
	0 (Control)	50	100	150
Yield (g m^{-2})	656.5 ± 29.9 a	643.2 ± 20.3 a	611.4 ± 39.8 a	393.6 ± 32.7 b
1000-seed weight (g)	41.1 ± 3.1 a	40.6 ± 2.7 a	40.9 ± 2.6 a	36.2 ± 3.3 b
Flour yield (%)	76.0 ± 5.6 a	74.0 ± 4.9 a	73.2 ± 4.7 b	73.0 ± 5.3 b
Water absorbance (%)	58.3 ± 4.9 b	60.2 ± 3.2 ab	62.7 ± 4.1 a	58.1 ± 3.4 b
Protein content (mg g^{-1})	132.9 ± 12.1 b	133.2 ± 12.9 b	133.8 ± 11.8 b	137.5 ± 14.7 a
Ash content (%)	1.5 ± 0.3 a	1.4 ± 0.4 a	1.4 ± 0.6 a	1.3 ± 0.4 b
Sedimentation test (ml)	33.2 ± 1.8 a	30.3 ± 2.9 b	30.5 ± 2.3 b	31.4 ± 3.4 b
Wet gluten content (%)	34.7 ± 2.7 a	34.3 ± 2.9 a	33.6 ± 2.2 a	32.9 ± 3.7 b
Dough development time (min)	5.3 ± 0.2 a	4.8 ± 0.3 a	4.2 ± 0.3 a	3.3 ± 0.5 b
Dough stability time (min)	5.6 ± 0.3 a	5.1 ± 0.2 a	4.8 ± 0.3 a	4.1 ± 0.6 a

Table 2 Responses of grain yields and quality criterions of the salt-sensitive JN17 to a series of salinity concentrations (0, 50, 100, 150 mM NaCl). Non-saline (0 mM NaCl) treatment was used as control. Data are mean ± SE (n = 6). Different letters within a column indicate significant differences ($P \leq 0.05$, *t*-test).

JN17	NaCl concentrations (mM)			
	0 (Control)	50	100	150
Yield (g m^{-2})	692.3 ± 37.8 a	530.9 ± 21.1 b	313.6 ± 23.2 c	140.8 ± 19.7 d
1000-seed weight (g)	42.3 ± 3.3 a	41.4 ± 3.1 a	32.6 ± 4.2 b	30.3 ± 4.3 b
Flour yield (%)	75.0 ± 5.3 a	72.1 ± 4.7 a	68.2 ± 3.9 b	64.3 ± 4.1 c
Water absorbance (%)	57.7 ± 4.7 a	53.5 ± 3.9 a	47.1 ± 3.7 b	41.4 ± 4.3 c
Protein content (mg g^{-1})	126.7 ± 9.6 a	128.6 ± 10.3 a	133.5 ± 13.1 a	139.3 ± 15.2 a
Ash content (%)	1.7 ± 0.2 a	1.6 ± 0.3 b	1.6 ± 0.3 b	1.5 ± 0.2 c
Sedimentation test (ml)	39.3 ± 2.1 a	39.7 ± 3.1 a	38.2 ± 4.3 a	41.3 ± 4.8 a
Wet gluten content (%)	30.2 ± 1.3 c	32.3 ± 1.5 b	31.0 ± 2.1 b	34.3 ± 2.3 a
Dough development time (min)	5.1 ± 0.3 a	4.2 ± 0.4 b	3.5 ± 0.2 b	2.4 ± 0.2 c
Dough stability time (min)	5.2 ± 0.3 a	4.6 ± 0.3 a	3.3 ± 0.4 b	2.9 ± 0.3 b

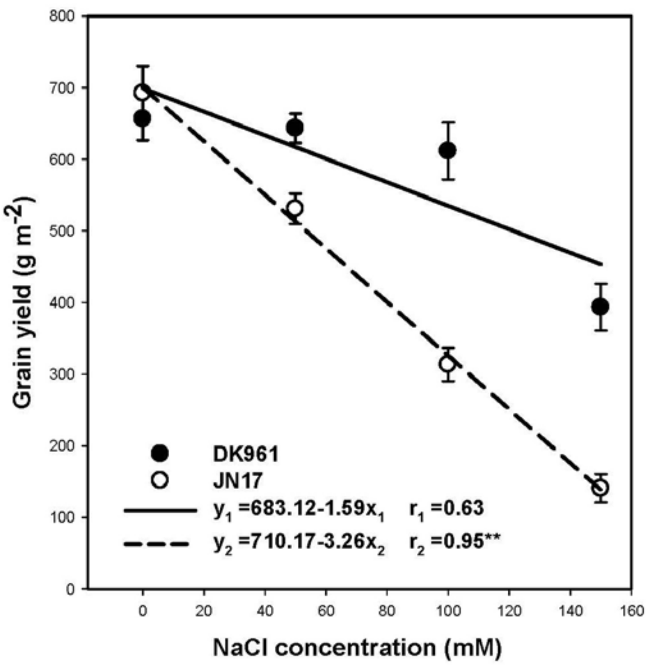

Fig. 1 Changes in grain yield of salt-tolerant DK961 and salt-sensitive JN17 under a series of salinity concentrations (0, 50, 100, 150 mM NaCl), and the regression curves between grain yield and NaCl concentration. Regression equations and coefficients were processed by "Fit Curves" of SigmaPlot10.0 (SPSS Inc. Chicago, Illinois, USA). *, **, *** express significance at $P = 0.05, 0.01, 0.001$, respectively.

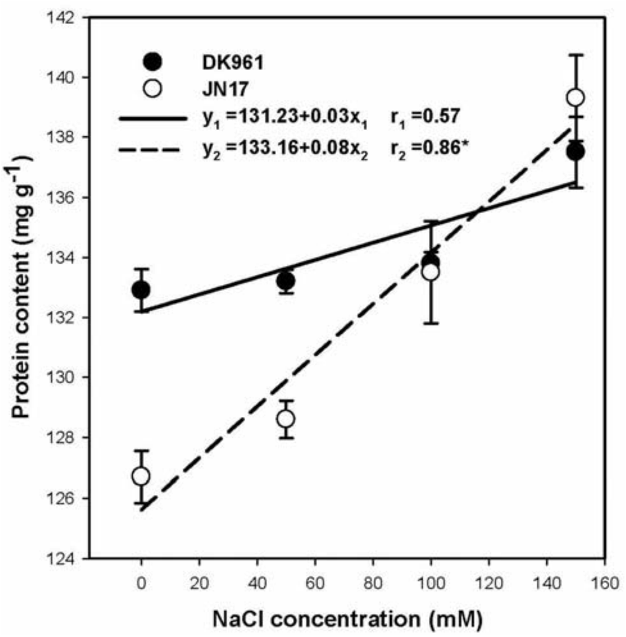

Fig. 2 Changes in protein content of salt-tolerant DK961 and salt-sensitive JN17 under a series of salinity concentrations (0, 50, 100, 150 mM NaCl), and the regression curves between protein content and NaCl concentration. Regression equations and coefficients were processed by "Fit Curves" of SigmaPlot10.0 (SPSS Inc. Chicago, Illinois, USA). *, **, *** express significance at $P = 0.05, 0.01, 0.001$, respectively.

>0.05) at 50 and 100 mM NaCl. In contrast, the 1000-seed weight and grain yield of JN17 decreased significantly in each salinity treatment more than in the control. The ash and protein contents increased continuously as salt concentration increased. The wet gluten content and SDS, main parameters for pasta quality, were also considerably affected by salt stresses.

The salt-tolerant wheat could maintain higher photosynthetic capacity than salt-sensitive wheat under salinity stress (Minhas 1996; Zheng *et al.* 2009). Therefore, the grain quality criteria of salt-tolerant wheat expressed non-significant differences between salinity treatments and control. But those parameters of salt-sensitive wheat are drastically affected (Fustier *et al.* 2009) by salinity. The present study suggested that breeding and the use of salt-tolerant wheat cultivars might be the most promising strategies for harvesting higher grain yield and quality under saline conditions.

Regression analysis

Fig. 1 presents the correlations between grain yield and salt concentrations in DK961 and JN17. Grain yields of both cultivars were negatively affected by salinity. However, the reduction in grain yield was much lower in DK961 than in JN17 at each salt concentration. The correlation between grain yield of DK961 and salt concentration was non-significant ($p = 0.14$, $r_1 = 0.63$), but it was significant ($p = 0.0015$, $r_2 = 0.95$) in JN17.

High protein content is associated with good pasta and flour making values (Pareyt *et al.* 2008). As shown in **Fig. 2**, the protein content of both cultivars increased as salt concentration increased. Nevertheless, a non-significant correlation ($p = 0.12$, $r_1 = 0.57$) was noted in DK961, while a considerable correlation ($p = 0.02$, $r_2 = 0.86$) was observed in JN17 (**Fig. 3**). This might be caused by the salinity-induced reduction of photosynthetic capacity leading to less starch synthesis and accumulation in grain (Park *et al.* 2008). In contrast, nitrogen metabolism was relatively stable (Keutgen *et al.* 2005); as a result the content of protein in grain increased somewhat.

Generally, plant grain yield is negatively related with its protein content (Park *et al.* 2006). Stress conditions caused a reduction in grain yield and an increase in protein content. Balancing grain yield and quality is considered to be essential but complicated. In this study, the correlations between both parameters were found to be highly significant ($p = 0.0003$, $r_1 = 0.9997$) in DK961 and considerable ($p = 0.0176$, $r_2 = 0.9824$) in JN17. This might be explained by

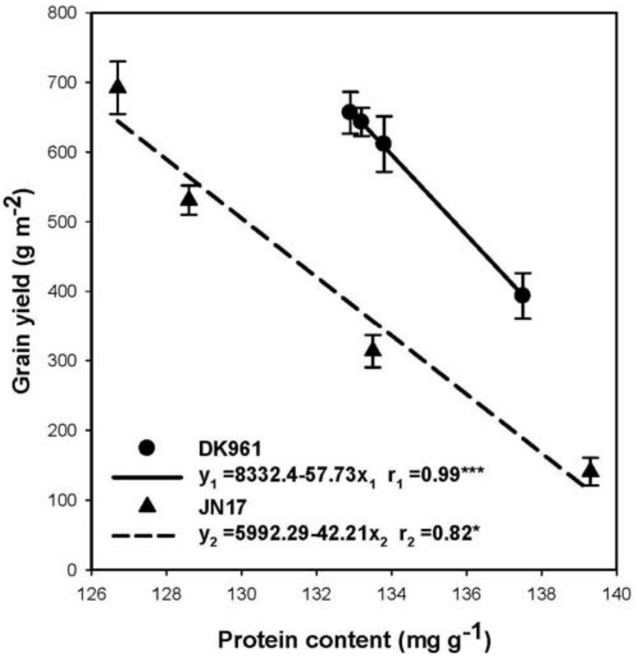

Fig. 3 Correlations between grain yield and protein content in salt-tolerant DK961 and salt-sensitive JN17. Regression equations and coefficients were processed by "Fit Curves" of SigmaPlot10.0 (SPSS Inc. Chicago, Illinois, USA). *, **, *** express significance at $P = 0.05$, 0.01, 0.001, respectively.

the fact that salt-tolerant wheat can effectively impair salinity-induced injury and maintain normal physiological and biological metabolism (Muranaka *et al.* 2002; Zheng *et al.* 2008a). Therefore, little reduction of grain yield and a high increase in protein content took place in salt-tolerant wheat under lower (50 mM) and intermediate (100 mM) salt concentrations. This finding might be useful for selecting varieties with high grain yield and quality under saline conditions.

CONCLUSIONS

In this study, salinity-induced variations in grain yield and quality were smaller in the salt-tolerant wheat than in the salt-sensitive one. The salt-tolerant wheat could simultaneously maintain high grain yield and quality under lower (50 mM) and intermediate (100 mM) salt concentrations. Excessive NaCl (150 mM) also considerably increased the ash and protein contents, but it drastically decreased grain yield. Since pasta quality is essential in the agro-industry, breeders should pay attention to this aspect, and not only to grain yield.

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