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Salt tolerance in durum wheat cultivars

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Abstract

This work presents the response of 17 durum wheat (*Triticum turgidum* L. var. *durum*) genotypes to a salinity gradient established with 7 saline treatments using a drip-injection irrigation system. According to the results, grain yield was the most sensitive parameter. Vitron was the most tolerant cultivar (EC_{e50} = 16.6 dS m^{-1}) and Bolenga the most sensitive (EC_{e50} = 7.5 dS m^{-1}). The average value of EC_{e50} was 11.3 dS m^{-1}, markedly lower than that usually mentioned in the literature. The spike length, the number of spikelets and of grains per spike, and the harvest index were the most tolerant characters. Salinity significantly increased the concentration of chloride and sodium in the leaves, although potassium content did not vary with increasing salinity. No consistent relationship was found between EC_{e50} and the leaf Cl, Na and K concentrations, which could not, therefore, be used in screening for salinity tolerance. Vitron was the most interesting cultivar due to the tolerance of its yield, thousand kernel weight, grain size and plant height.

Key words: *Triticum turgidum*, grain yield, yield components, leaf ion concentration.

Resumen

Tolerancia a la salinidad en cultivares de trigo duro

Se presenta en este trabajo la respuesta de 17 genotipos de trigo duro (*Triticum turgidum* L. var. durum) a un gradiente de salinidad obtenido mediante la aplicación de 7 tratamientos de agua de distinta conductividad eléctrica, utilizando una doble fuente de goteo. Los resultados indican que el rendimiento fue el carácter más afectado por la salinidad. El cultivar más tolerante fue Vitrón (CE_{e50}= 16,6 dS m^{-1}), siendo Bolenga el más sensible (CE_{e50}= 7,5 dS m^{-1}). El valor medio de CE_{e50} fue de 11,3 dS m^{-1}, sensiblemente inferior al que habitualmente se cita en la literatura científica. La longitud de la espiga, el número de espiguillas y el de granos por espiga y el índice de cosecha fueron los caracteres menos afectados por la salinidad. La salinidad incrementó de forma significativa la concentración de cloruro y de sodio en las hojas, aunque el contenido en potasio no experimentó variación al cambiar la salinidad a la que estaban sometidas las plantas. Esta relación de la salinidad con los contenidos de cloruro y de sodio en hoja no permitió establecer ningún tipo de relación entre los iones y el índice de tolerancia CE_{50} de los cultivares estudiados. Vitrón fue el cultivar más interesante por su tolerancia en el rendimiento, peso de mil granos, calibre y altura de planta.

Palabras clave: *Triticum turgidum,* rendimiento en grano, componentes de producción, concentración iónica foliar.

Introduction

Durum wheat is a typical mediterranean species: 60% of its production is concentrated in southern Europe, Northern Africa and the Middle East. In the mediterranean climate, rainfall mainly concentrates in autumn and winter and wheat crops often suffer water deficit. Water stress can be controlled by irrigation in areas with adequate water supplies. More than 33% of world agriculture production is grown on irrigated lands, representing 18% of the total cultivated soils (Hoffman *et al.*, 1990). However, intensification of the irrigation is restricted both by limited water resources in arid and semiarid regions that require irrigation, and because of environmental degradation that can result from intensive or inadequate use of water that can lead to salinization of the soils and deterioration in water quality of irrigation return flows.

Durum wheat is an economically important crop and can be considered as moderately tolerant to salinity. The EC_{e50} (electrical conductivity of the saturation extract that reduces yield to half that obtained in non-saline conditions) is 15 dS m^{-1}, lower than the 18 dS m^{-1}

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of barley that, together with cotton, are the most tolerant crops (Maas, 1986). According to Ayers and Westcot (1985), there is no yield reduction of durum wheat with an irrigation of up to 5.7 dS m^{-1}; yield reductions of 25% occur with 10 dS m^{-1} and of 50% with a salinity of the-irrigation water of 15 dS m^{-1}. Studies of salt tolerance of durum wheat genotypes carried out in natural saline environments did not give good results owing to the spatial variability of salinity and its temporal variation (Shannon, 1984), being necessary to carry out a large number of measurements of salinity and water status that increase considerably the costs of selection. Alternatively, the plot can be salinized and the level of salinity maintained by irrigating with saline water. The Department of Soils and Irrigation of the Servicio de Investigación Agroalimentaria de Aragón developed an irrigation system called Drip-Injection System (DIS), to create salinity gradients in the soil. Aragüés *et al*. (1999) carried out the experimental validation of the system, determining its advantages and limitations, and Royo *et al.* (2000) verified the system by analyzing the precision obtained when functions of response to salinity were established for 10 barley cultivars.

In this work, the DIS was used with the following objectives: 1) to study the response to salinity of 17 durum wheat (*Triticum turgidum* L. var. *durum* Desf) cultivars, evaluating the yield and other characters that can be used in future breeding programs; 2) to establish response functions to the salinity of the characters studied, indicating their tolerance parameters.

Material and methods

The experiment was carried out in the experimental farm of the Servicio de Investigación Agroalimentaria (Montañana, Zaragoza, Spain) in the season 1998/1999. A total of 17 durum wheat genotypes were studied: 7 (Altar-aos, Bolenga, Bolido, Bolo, Borli, ID-1053 and Valira) from the breeding program of Lerida University, 6 (Aw12/Bit, Korifla, Lagost-3, Ombrabi-3, Sebah and Waha) from the international institutions CIMMYT (International Maize and Wheat Breeding Centre) and ICARDA (International Centre for Agricultural Research in the Dry Areas) and 4 (Anton, Jabato, Mexa, and Vitron) commercial cultivars.

We used the irrigation system DIS (Aragüés *et al.* 1999), based on the combination of two pumps in parallel: a centrifugal pump for supplying fresh water and an injection pump for injecting saline water into fresh water flow. Fresh and saline waters are mixed in the irrigation line to produce an irrigation water whose salinity (EC_{iw}) depends on the total number of emitters installed in that sector. Seven irrigation water salinity treatments of EC_{iw} = 2, 5, 8, 11, 17, 20 and 23 dS m^{-1} were imposed. The saline solution in the tank (made up of NaCl and $CaCl_2$ in a 2 :1 weight ratio) had EC = 60 dS m^{-1}. The irrigation time of each sector was programmed so that the applied volume of irrigation water was the same in all treatments: 8.4 mm during winter and 12.6 mm in the spring. We applied 46 irrigations from the 15 February to 2 June, 1999. After each irrigation, the volume and the salinity of the water was measured for each sector.

Figure 1 shows the schematic layout of the DIS irrigation network. A total of 14 irrigation sectors controlled by solenoid valves were installed. The division of the saline treatments into one, two, or three irrigation sectors was required to satisfy both the target EC_{iw} and the proper irrigation uniformity within each 1.5 m^2 subplots. In each treatment, each variety was sown in a 1.2 × 1.5 m^2 subplot, comprising six rows of whe-

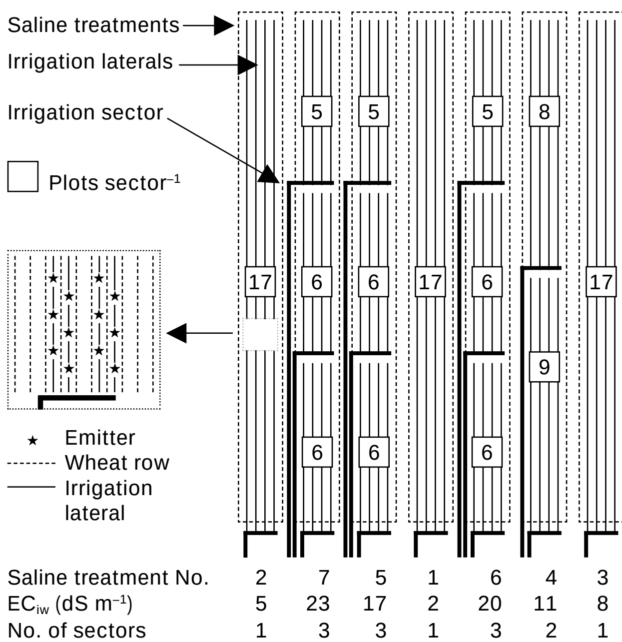

Figure 1. Schematic layout of the DIS (Drip-Injection Irrigation System) irrigation network. Each of the saline treatments (1 a 7) is characterized by its target EC_{iw} (irrigation water EC) value, and divided into 1 to 3 irrigation sectors. Each irrigation sector has 4 laterals with the appropriate number of emitters to deliver its target EC_{iw} (see example in left dashed rectangle). The number of subplots in each sector is indicated within the small rectangles.

at, 0.2 m apart, and four irrigation laterals interspersed between the rows. Two additional rows of wheat were sown at each side of the subplots in order to control potential seepage between plots.

Before starting the irrigation season, soil samples were taken at two different depths 0-25 and 25-50 cm, in 42 plots (6 per treatment), to study the initial salinity levels. The apparent salinity of the 119 plots was measured with a Geonics EM 38 electromagnetic sensor (EMS), on three dates: 21st April, 18th May and 4th June, 1999. On the last day, another soil sampling session was practiced at 32 points: four points per treatment (six in treatments 20 and 23 dS m^{-1}), in order to calibrate the apparent salinity measurements and to transform them into saturation extract. The linear regression equation was:

$$EC_{1:5} = 1.22\ EC_{sem} + 0.04\ (R^2 = 0.82)$$

Values of $EC_{1:5}$ were transformed to EC of the saturation extract (EC_e) by the equation:

$$EC_e = 12.86\ EC_{1:5}\ (R^2 = 0.99)$$

obtained in the same plot where the experiment was carried out.

In addition to yield, other characters were also measured: plant height up to the base of the spike, leaf ion contents, number of spikes per meter and harvest index. In 20 spikes from each plot the following characters were determined: spike length, number of spikelets per spike and number of grains per spike. In the harvested grain, both the weight of one thousand kernels and grain size were measured. Measurements of leaf ion contents were made at heading stage taking the first leaf below the flag leaf in 10 plants from the plots irrigated with 2, 8, 17 and 23 dS m^{-1}. The leaves were introduced into plastic syringes and frozen. After thawing, the leaf sap was extracted by applying pressure to the plunger of the syringe (Royo and Aragüés, 1999). The chloride contents of the liquid obtained was measured with a Buchler chlorometer according to Cotlove's methodology (1963) and the Na^+, Ca^{2+} and K^+ cations by atomic absorption spectrophotometry with a Perkin-Elmer model 3030 spectrophotometer. The grain size value was the weight of grains larger than 2.5 mm expressed as percentage of the sample weight (40 g).

The ratios between the characteristics studied and salinity were established for each wheat genotype by a sigmoidal response model [option 12 of the SALT program described by van Genuchten (1983)]:

$$Y = \frac{Y_m}{1 + \left(EC / EC_{50} \right)^p}$$

where: Y and Y_m are the values of the parameter studied for a given EC and for non-saline conditions, respectively. EC_{50} is the EC that reduces the value of the character by 50% and p is a parameter that determines the steepness of the curve and that, like Ym and EC_{50}, is calculated by the program. The goodness of fit of the response functions was assessed by the correlation coefficient between the observed and the estimated Y values. EC values used to calculate the response functions were those of the saturation extract, obtained from the mean values of EC_{sem} using the previously described calibration equations. For characters that did not follow a curvilinear model, a simple linear regression line was tried. Finally, for characters without a significant salinity response, the ST/CT ratio was calculated as an estimate of tolerance (Royo and Aragüés, 1995), where ST is the mean value of the character for the three most saline treatments and CT the value in the control treatment. Analysis of variance was carried out for this parameter and for ion contents, taking the cultivars as replications within each character. Separation of the means was done with Duncan's multiple comparisons. In addition to the previously mentioned SALT program, the SAS statistical package was used (SAS Inc., 1988).

Results and Discussion

Soil salinity

The salinity gradient of the irrigation water produced by the system was very similar to the target salinity gradient (Table 1). No treatment was more than 0.5 dS m^{-1} away from the objective value, except for treatment 8 dS m^{-1}, which had a mean value of 6.5 dS m^{-1}. On the other hand, the coefficients of variation of the different irrigation treatments were similar and not high and in no case exceeded 15%.

Soil samples were taken in February, before the start of saline irrigation, indicating the residual salinity in the plot from previous experiments. Table 1 shows the mean values of saturation extract EC for each treatment. Some of them, such as treatment 2, had a high mean salinity. This treatment was excluded from the analysis because of the poor emergence obtained in its plots that can be explained by its high initial salinity.

Table 1. Mean ± standard deviation of the salinity of the water applied (EC_{iw}, dS m^{-1}) in the 46 irrigations, and of the saturation extract (Ec_e, dS m^{-1}) in soil samples taken at 0-50 cm depth at the beginning (15 February 1999) and at the end (4 June 1999) of the irrigation sessions. The number of observations used to calculate each mean are given in brackets

Treatment	EC_{iw} (dS m^{-1})	EC_e (dS m^{-1})	
		Initial	Final
T-1 (2 dS m^{-1})	2.4 ± 0.3	3.2 ± 0.8 (6)	2.9 ± 0.0 (4)
T-2 (5 dS m^{-1})	5.2 ± 0.5	8.6 ± 2.3 (6)	8.5 ± 3.5 (4)
T-3 (8 dS m^{-1})	6.5 ± 0.9	2.6 ± 0.1 (6)	8.7 ± 0.8 (4)
T-4 (11 dS m^{-1})	11.0 ± 1.6	2.9 ± 0.6 (6)	8.4 ± 1.9 (4)
T-5 (17 dS m^{-1})	17.1 ± 2.4	5.7 ± 1.5 (6)	13.6 ± 3.5 (4)
T-6 (20 dS m^{-1})	19.9 ± 2.7	2.6 ± 0.5 (6)	11.5 ± 3.0 (6)
T-7 (23 dS m^{-1})	22.2 ± 3.1	6.6 ± 1.5 (6)	16.2 ± 4.8 (6)

Although there was a salinity gradient at the end of the experiment (Table 1), some treatments had a higher salinity than that corresponding to the irrigation water used. Therefore, the response functions were calculated using the salinity of the saturation extract of soil (EC_e) and not that of the irrigation water (EC_{iw}).

Effect of salinity on development

Salinity produced an earlier heading date: a mean of 6 days earlier for the different varieties in the most saline treatment. A clear effect of salinity was to shorten the stem length. The mean height in the control treatment was 72.3 cm, and only reached 50.6 cm in the treatment irrigated with water of 23 dS m^{-1}. In general, there was a negative association between height and salinity, and only Vitron and Altar-aos did not show any significant correlation (Table 2). For the remaining cultivars, Valira, Korifla, and Mexa presented the steepest slope and were, therefore, those most sensitive to salinity, while Bolido and Jabato were the least affected. This decrease in plant height was most evident in the tallest varieties and there was a positive correlation (r = 0.53, P<0.05) between height in the control treatment and the regression slope for decreased height/salinity.

Ion contents

The chloride and sodium contents in leaf sap clearly increased with increasing salinity of the irrigation water (Table 3).

Table 2. Height measurements for the 17 genotypes in the control treatment (Y_0), parameters a and b and correlation coefficient of the regressions: Y = a + bX, of height (Y, cm) *versus* salinity (X, EC_e)

Variety	Y_0 (cm)	a (cm)	b (cm dS^{-1} m)	R
Antón	77.5	76.7	–1.47	0.87*
Jabato	71.0	75.8	–1.18	0.81*
Mexa	81.5	82.3	–1.80	0.86*
Vitron	74.5			0.70^{ns}
Aw12/BIT	77.5	77.9	–1.35	0.89*
Korifla	84.5	90.1	–1.98	0.98**
Lagost-3	75.5	83.8	–1.59	0.88*
Omrabi-3	76.5	78.3	–1.46	0.93**
Sebah	77.0	77.1	–1.29	0.88*
Waha	67.5	74.9	–1.44	0.87*
Altar-Aos	66.5			0.76^{ns}
Bolenga	73.0	78.9	–1.64	0.99**
Bolido	62.0	64.4	–1.00	0.85*
Bolo	74.5	74.4	–1.26	0.85*
Borli	57.5	61.2	–1.32	0.98**
Id-1053	76.0	83.0	–1.23	0.96**
Valira	74.0	74.8	–2.07	0.87*

Significance: ** P < 0.01, * P < 0.05, ^{ns} P > 0.05.

The mean chloride contents of the treatments were significantly different (P<0.05). The results obtained for Na^+ were quite similar, since only treatments using irrigation water of 8 and 17 dS m^{-1} produced similar concentrations. Lagost was the genotype with the lowest chloride and sodium contents in the leaves of the plant subjected to the control treatment (88 and 44 mmol L^{-1}, respectively), while Valira was the one that accumulated the most chloride (220 mmol L^{-1}) and Anton the one with the most sodium (150 mmol L^{-1}) in the sap of leaves in the control. In the maximum salinity treatment the minimum values were 223 mmol L^{-1} of Cl^- and 230 mmol L^{-1} of Na^+ in Bolo and the ma-

Table 3. Mean values for the 17 genotypes and, in brackets, coefficient of variation of the Cl^-, Na^+ and K^+ contents measured in leaf sap in the saline treatments studied

Treatment	Cl (mmol L^{-1})	Na (mmol L^{-1})	K (mmol L^{-1})
2 dS m^{-1}	150 (23) a	102 (30) a	383 (14) a
8 dS m^{-1}	256 (24) b	386 (26) b	399 (14) a
17 dS m^{-1}	358 (19) c	355 (31) b	415 (28) a
23 dS m^{-1}	513 (23) d	519 (39) c	413 (24) a

For each ion, mean values followed by a different letter are different at P < 0.05, according to the Duncan test.

ximum values were 945 and 1013 mmol L^{-1} of Cl^- and Na^+, respectively, in Bolenga.

The behaviour was different for K^+, since the mean values of the leaf contents for the treatments studied (Table 3) were not significantly different (P>0.05).

In an experiment with 18 barley cultivars and three salinity levels of the irrigation water: EC_{ar} = 2, 10 and 17 dS m^{-1}, Isla *et al.* (1997) found that mean values of chloride and sodium in the leaves were 1.3 and 1.5 times higher, respectively, than those of the control treatment. According to values of Table 3, durum wheat accumulates much more chloride and especially sodium than barley when submitted to salt stress. In contrast, the data obtained for potassium contents show a similar behaviour for both species since there is hardly any change in this ion with increasing salinity of the irrigation water. For most of the genotypes, the chloride contents of the sap was linearly related to the electrical conductivity of the soil (Table 4). Anton was the genotype that accumulated the least chloride in the leaves as the salinity increased, less than 15 mmol L^{-1} for each dS m^{-1} increase in salinity. At the other extreme, Bolenga accumulated 56 mmol L^{-1} of Cl^- for each dS m^{-1} increase in salinity.

Although there was no association between the chloride and sodium contents in the control treatment, significant correlations were found between these ions in the saline treatments, especially in the most saline one (r = 0.89, P<0.01).

Table 4. Measurement of the chloride contents in leaves of the genotypes in the control treatment (Y_0), parameters a and b and correlation coefficient of the regressions: Y = a + bX, of the concentration (Y, mmol L^{-1}) *versus* soil salinity (X, dS m^{-1})

Variety	Y_0 (mmol L^{-1})	a (mmol L^{-1})	b (mmol L^{-1} dS^{-1} m)	R
Antón	150	102	14.8	0.96*
Jabato	154	111	19.1	0.98*
Mexa	145	81	23.1	0.93*
Vitron	130	107	15.9	0.93*
Aw12/BIT	124	67	20.2	0.93*
Korifla	157			0.55^{ns}
Lagost-3	88	15	29.9	0.93*
Omrabi-3	157	–3	35.9	0.97*
Sebah	128			0.83^{ns}
Waha	152			0.80^{ns}
Altar-Aos	132	–109	44.1	0.92*
Bolenga	199	155	56.5	0.93*
Bolido	214	116	27.8	0.94*
Bolo	116			0.69^{ns}
Borli	132	–1	35.6	0.98*
Id-1053	154	23	32.7	0.92*
Valira	220	160	17.8	0.96*

Significance: * P < 0.05, ^{ns} P > 0.05.

On the other hand, it is generally accepted that salinity reduces the K^+ content producing deficiency of this ion (Grattan and Grieve, 1994) because of a competitive process between Na^+ and K^+ absorption. In our experiment, there was a weak but significant negative correlation (r = -0.66, P<0.05) between the Na^+ and K^+ contents in the control treatment that was not observed in the most saline treatment. The negative effects of salinity in plants by reducing potassium absorption can be minimized with Ca^{2+} addition, as Cramer *et al.* (1991) and Huang and Redmann (1995) reported. In our experiments, the saline solution used contained $CaCl_2$, as well as NaCl, to prevent the nutritional disorders associated with high Na^+ contents. This can explain the response obtained in potassium content in saline treatments.

Yield

Salinity clearly affected grain yield in the genotypes studied, and the mean yield, that was 4520 kg ha^{-1} in the control treatment, decreased to 849 kg ha^{-1} in the most saline treatment. Figure 2 shows the response functions of yield to salinity (kg ha^{-1}) for each genotype, with the parameter EC_{e50} and the correlation coefficient between the yields obtained and those estimated by the model. Adjustments of response to the model were all significant (P<0.05), except for Anton and Borli.

The mean value of the parameter EC_{e50} of tolerance of grain yield to salinity was 11.3 dS m^{-1}, and Bolenga and Vitron were the least and most tolerant genotypes, respectively. Using a 95% confidence interval for the EC_{e50} given by the program, one can conclude that Vitron is more tolerant than Mexa, Bolenga, Bolo and Valira. The mean value obtained for the parameter EC_{50} indicates a lower tolerance than that reported by Ayers and Westcot (1985), who proposed a EC_{e50} value of 15 dS m^{-1}. Francois *et al.* (1986), with only two durum wheat cultivars, obtained a conductivity threshold of 5.9 dS m^{-1} and a reduction in yield of 3.8% per unit of increased salinity over the threshold value, equivalent to an EC_{e50} of 19 dS m^{-1}, 68% higher than that obtained in our work with 17 genotypes. The differences with other works can be attributed to the different experimental conditions: climate, genotypes,

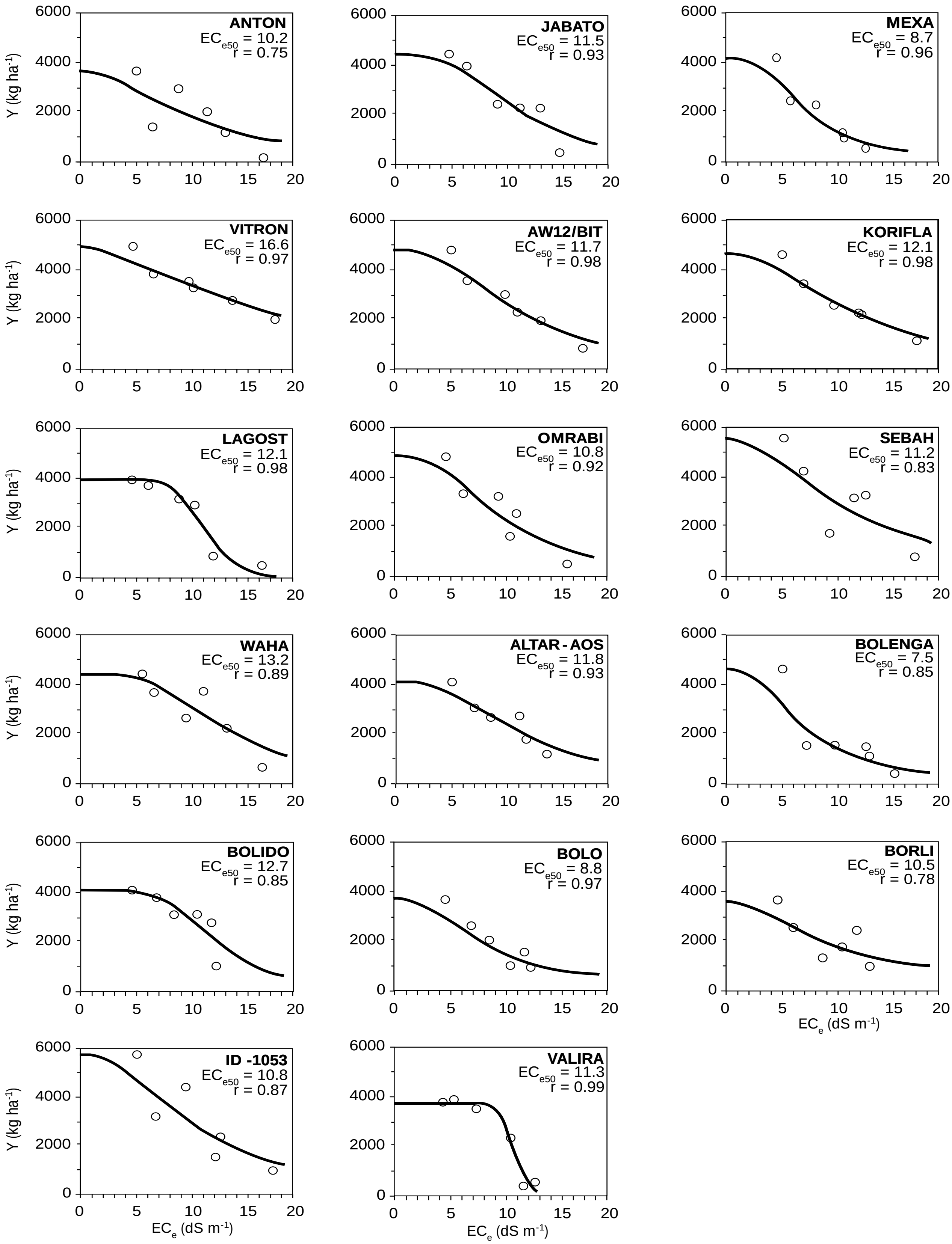

Figure 2. Soil salinity (EC_e)-Grain yield response functions of 17 durum wheat genotypes.

salinity levels, periods of salt water application, etc. Works carried out on barley with the same DIS system (Royo *et al.*, 2000), indicated that the tolerance obtained (EC_{e50} = 13.1 dS m^{-1}) was notably lower than that recorded by Ayers and Westcot (1985) for barley.

As observed previously, there was a rise in the sodium and chloride ion contents in the leaf sap as salinity increased. There was a significant negative correlation in six of the genotypes between the chloride content of the leaves and yield. In contrast, for sodium, although correlations were high they were not significant in any genotype. This lack of significance could be due to the high Ca^{2+} levels used in the experiment, coinciding with works by Aloy (1995) and Isla (1996), and seems to indicate that the Cl^- ion is the main cause of crop toxicity when the Ca^{2+} is in excess in saline media. However, in spite of the association found between chloride contents and yield, no association could be established with the tolerance parameter EC_{e50} of grain yield, which permits tolerance of the genotypes to be determined before the harvest, facilitating selection tasks. This lack of an association between ion contents and tolerance could indicate that a greater accumulation of ions in the leaf would not imply less salt tolerance, although the leaf analysis we carried out, did not distinguish partitioning of the ions in the vacuole.

Other characters

Thousand kernel weight (TKW) was not so affected by salinity as yield. The response was linear and significant fits were obtained in 14 of the 17 genotypes. Lagost-3 was the most sensitive variety, since its TKW decreased by 1.82 g for each dS m^{-1} increase in salinity, and Vitron was the least affected with a relative decrease of only 0.32 g (Table 5).

If EC_{e50} is taken as the value of EC_e that reduces the TKW to half the value of the intercept of the regression line, a mean value of EC_{e50} = 22.7 dS m^{-1} is obtained, much higher than the mean EC_{e50} of the yield that was 11 dS m^{-1}. Royo and Aragüés (1995), in several experiments on barley using the triple sprinkler system to create a saline gradient, also found that TKW was less affected by salinity than yield.

Grain size was another character less affected by salinity than yield, since the mean value of EC_{e50} was 16.2 dS m^{-1}. Jabato was the most sensitive genotype given its EC_{e50} of only 12.2 dS m^{-1}, and Vitron the most tolerant with an EC_{e50} = 29.7 dS m^{-1} (Table 5). Royo and Aragüés (1995) found that grain size in barley was more sensitive to salinity than yield. This discrepancy can be explained because, besides being different species, they used saline sprinklers and the toxic effect produced by ionic absorption via the leaves wet with the saline water accelerated senescence, thus resulting in a worse maturation and smaller grain size. In contrast, in this work with drip irrigation, ions were not absorbed by the leaves that remained green for a longer time producing better grain.

Table 5. Parameters of linear regression of thousand kernel weight (TKW) and grain size curvilinear model in 17 genotypes *versus* soil salinity

Cultivar	TKW		Grain size	
	a (g)	b (g dS^{-1} m)	EC_{e50} (dS m^{-1})	Maximum size (%)
Antón	33.3	–0.71	15.3	69.1
Jabato			12.2	79.3
Mexa	42.0	–1.20	14.6	82.3
Vitron	31.1	–0.32	29.7	84.8
Aw12/BIT	39.2	–0.87	23.4	79.4
Korifla	41.2	–1.06	22.8	81.2
Lagost-3	52.8	–1.82	15.8	83.8
Omrabi-3			15.4	82.4
Sebah	36.9	–0.77		
Waha	38.3	–1.01	15.6	75.1
Altar-Aos	38.0	–0.87	15.5	82.9
Bolenga	35.7	–0.99	12.4	73.6
Bolido	32.4	–0.45	14.6	73.4
Bolo	38.5	–1.30	21.9	80.0
Borli	36.2	–0.88	14.8	73.0
Id-1053	44.3	–1.25	20.2	88.9
Valira			14.8	86.4

Other characters were also studied whose response did not fit either the curvilinear or the linear regression model, indicating little or no sensitivity to salinity. In order to compare the tolerance of these characters that did not fit any model, for each of them the mean value (n = 17 genotypes) of the ST/CT ratio was calculated. Concerning the yield, a high correlation was found with the tolerance parameter EC_{e50} ($r = 0.79$, $P<0.01$). The order of tolerance for the remaining characters relative to their mean value of ST/CT is presented in Table 6. This classification was quite similar to that obtained in barley by Royo and Aragüés (1995). Neither the length nor the number of spikelets of the spike were affected by salinity. Yield reduction with salinity can be attributed to lower weight per individual seed and to a reduction in spike number whi-

Table 6. Tolerance to salinity of agronomic characters of durum wheat: mean values of the ratio saline treatment/control treatment (ST/CT) (n = 17 genotypes)

Character	ST/CT
Spike length	0.99 a
No. spikelets per spike	0.95 ab
No. grains per spike	0.89 abc
Harvest index	0.83 bcd
Spikes m^{-1}	0.79 bcde
Height	0.77 cde
Thousand kernel weight	0.71 def
Grain size	0.61 ef
Yield	0.38 g

Characters with different letters indicate significantly different tolerances at $P < 0.05$, according to Duncan's test.

le the number of grains per spike was not affected. The results of other works both for durum wheat and for other cereals are not conclusive and only a small number of genotypes have been studied. Maas and Poss (1989) found different responses for wheat depending on the stage of crop development when salt stress was applied. Grieve *et al.* (2001) observed that salinity applied early had a greater effect on yield than salt stress applied later, and the number of spikes was the most affected character.

In the present experiment with DIS, plants were submitted to stress during the whole cycle. The value of ST/CT = 0.83 for the harvest index suggests that this parameter only decreases slightly as salinity increases, i.e. straw yield would almost have the same salt tolerance as grain yield, which would be more sensitive. Francois *et al.* (1986), on the basis of EC_{50}, reported grain yield was more sensitive than straw, but later, Francois *et al.* (1988) found that the grain yield of triticale presents a higher tolerance than the straw.

None of the tolerance parameters (EC_{e50}, regression line slope or ST/CT) of the characters studied were related to the EC_{e50} of the yield. It is, therefore, not possible to estimate the tolerance of this character using that of other characters measured before the harvest.

Although the data refer to only one year, it can be concluded that durum wheat is moderately tolerant to salinity, but less than barley. The tolerance found, however, was less than 30% of values commonly accepted in the literature, which could be overestimated. Studies on the behavior of the different genotypes for the characters considered here revealed that Vitron was the most interesting cultivar due to the tolerance of its yield, TKW, grain size and plant height.

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