Salt tolerance of barley (*Hordeum vulgare* L.) cultivars at the germination stage: Analysis of the response functions

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Abstract

Two models, initially proposed by Van Genuchten (1983) for evaluating salinity-yield response curves at the adult stage, were applied to study the salinity response of 24 barley cultivars at the germination stage.

According to the calculated salinity threshold, EC_t (the solution electrical conductivity, EC, at which germination starts to decrease), and EC_{50} (the solution EC at which germination is reduced by 50%) parameters, both models give similar results, although model 2, a sigmoid-form curve, fits the observed data slightly better than model 1, a piecewise response function.

Also, the results suggest that, for model 1, EC_t seems to be the most reliable parameter for screening barley germplasm because it clearly discriminates the relative salt-tolerance of the studied cultivars and, furthermore, it basically determines their salinity response for the 100 to 50% germination interval.

On the other hand, the model 1 s parameter — percent germination decrease per unit salinity increase above EC_t — is less relevant because of its smaller variation interval and lack of correlation with EC_{50}, indicating that the salinity response of the studied cultivars for the 50% germination value is independent of this parameter.

Key words

barley, germination, response functions, salt tolerance, screening, threshold salinity

Introduction

The increasing food demands of the world population have often led to the use of marginal salt-affected soils and/or low quality waters. Thus, salinity of arable land is an increasing problem in many irrigated areas of the world and is a significant factor in reducing crop productivity (Srivastava and Jana, 1984; Szabolcs, 1979).

Several solutions have been proposed in an attempt to solve this increasing problem. One of them is the search for plant germplasm with a high relative salt tolerance (Shannon, 1984). Barley is known to be one of the most salt-tolerant crops (Maas and Hoffman, 1977; Shannon, 1984), having a high level of variability in tolerance among cultivars (Ayers, 1953; Donovan and Day, 1969; Schaller et al., 1981; Srivastava and Jana, 1984).

However, the search for reliable sources, present or potential, of salt-tolerant germplasm requires not only suitable, quick, and accurate methods of screening (Shannon, 1984), but also a correct evaluation of its salt-tolerance. Several models have been suggested to fit the genotypes salinity response of any particular species (Maas and Hoffman, 1977; Van Genuchten, 1983). Salinity tolerance at the germination stage, the period until the first leaf emerges from the coleoptile, might be a suitable and quick test for screening a great number of genotypes (Schaller et al., 1981) if it can be standardized through such models which until now have been used only on mature plants.

Therefore, the objectives of this work are: 1) to evaluate the reliability of two models, initially proposed by Van Genuchten for studying salinity yield response curves at the adult stage, with the aid of the salinity response of 24 barley cultivars at the germination stage; and 2) to determine the most adequate parameter in both models to describe the salt tolerance of these cultivars at this stage.

Materials and methods

Twenty-four barley cultivars from the germplasm collection of the S.I.A. (Agricultural Research Service, Zaragoza, Spain) were used. Treatments were the control, with an electrical conductivity (EC) of 0.8 dS m^{-1} at 25°C, and 9 saline solutions made up of equal weights of NaCl and $CaCl_2$ with ECs ranging from 4 to 36 dS m^{-1} at 25°C, increasing with steps of 4 dS m^{-1}.

Synthetic sponge-texture cloths, previously equilibrated with these saline solutions, were placed in plastic trays. Three filter papers plus a folded one were put on the cloths and 40 seeds of each cultivar were placed on the folded paper. 400 ml of the treatment solutions were added to each tray, and they were covered with aluminium sheets to avoid water losses. The trays were placed in a dark climatic room at 23°C.

After 20 days, the number of germinated seeds (those with the first coleoptile leaf emerged) was recorded and the relative germination percentage (RGP) of each cultivar was calculated, taking the control treatment as 100.

Two models, initially proposed by Van Genuchten (1983) to study the salinity-yield response curves at the adult stage, were used to establish the salinity response functions of these cultivars at the germination stage.

Model 1, a piecewise response function similar to the one proposed by Maas and Hoffman (1977) is given by:

$$Y = \begin{cases} Y_m & 0 \le EC \le EC_t \\ Y_m - Y_m \; s\left(EC - EC_t\right) & EC_t < EC \le EC_0 \\ 0 & EC > EC_0 \end{cases}$$

where: Y = absolute yield;

Y_m = absolute yield in non-saline conditions;

s = absolute value of the slope of the response function between EC_t and EC_0.

EC = electrical conductivity of root medium solutions;

EC_t = threshold EC or salinity at which yield starts to decrease;

EC_0 = EC at which yield equals zero.

Model 2, a sigmoid-form function, is given by (Van Genuchten, 1983):

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

where: EC_{50} = EC at which yield decreases by 50 %;

p = an empirical constant.

The above equations were used in the sense that Y_m was replaced by the maximum germination, G_m, of the control, and Y by the respective RGPs of the treatments.

The computer "SALT" programme (Van Genuchten, 1983) was used to carry out these computations. This programme, applied to the germination stage, calculates the number of germinated seeds in non-saline conditions, G, the values of EC_t and s (model 1), and EC_{50} and p (model 2), as well as the fitted RGP, by taking G_m as 100.

Results and discussion

Table 1 presents the calculated values of EC_t, s, EC_{50} and p for each cultivar.

From these parameters, EC_{50} for model 1 and $EC_t^{'}$ for model 2 were calculated according to the following equations:

$$EC_{50} = \frac{1}{2s} + EC_t; \quad EC_t^{'} = \frac{EC_{50}}{\sqrt[p]{99}}$$

where: $EC_t^{'}$ = EC at which germination decreases by 1% (that is, G = 0.99 G_m). This value can be taken as an "approximate" salinity threshold (for this model, EC_t = 0), for comparison purposes with EC_t of model 1.

Table 1 shows that the variability in tolerance of barley cultivars is high. If the threshold salinity EC_t is taken as the reference parameter, some cultivars, such as 'Mari', 'Viva' or 'Kim', are about three times as tolerant as 'Barbarrosa', 'Koru' or 'Igri'. Previous studies have also noted this fact (Ayers, 1953; Donovan, 1979; Schaller et al., 1981; Srivastava and Jana, 1984), although the variability range of our cultivars seems to be slightly higher.

When linear regressions between the parameters of both models are fitted (Table 2), it can be demonstrated that they differ very little in their results. Thus, the threshold salinities, EC_t (model 1) and $EC_t^{'}$ (model 2), are significantly correlated (r = 0.82) at the 0.05 significance level, the regression coefficient being equal to one, although the negative intercept means that, in general, the $EC_t^{'}$ values are somewhat lower than the respectives EC_t.

The same results are obtained if the regression EC_{50} (model 1) – EC_{50} (model 2) is fitted, but in this case the correlation coefficient is higher (r = 0.99). As the Spearman's correlation, ρ, which compares the salt-tolerance order of the studied cultivars, is also high (Table 2), it may be concluded that both models give similar results for the germination percentage interval between 100 and 50.

It should be noted, however, that, from a statistical point of view, model 2 fits the observed data slightly better than model 1, as shown by the sums of the squared deviations (SSQ), which are generally lower for model 2 (Table 1). Model 2 is also biologically more acceptable as it fits a sigmoid response curve to salinity (Van Genuchten, 1983; 1984). This is illustrated in Figure 1, which gives the response functions “Relative Germination—EC” of both models for three barley cultivars.

Finally, the linear regression between the calculated parameters for model 1 (Table 2), which is the most widely used for establishing salt tolerance at the adult stage (Maas, 1984; Maas and Hoffman, 1977; Shannon, 1984), suggests that EC_t is the most appropriate parameter for determining the salt tolerance of the studied cultivars. Thus, the high and significant correlation ($\alpha = 0.05$) between EC_t and EC_{50} ($r = 0.91$; $\rho = 0.89$) suggests that EC_t basically determines the response of the barley cultivars to salinity for the 100 to 50% germination interval, the one with the greatest economic interest. In other words, the cultivars with the greatest EC_t will generally have the greatest RGP in that interval. In addition, the wide variation interval of the EC_t parameter (Table 1) helps to differentiate the relative salt tolerance of the studied cultivars more clearly, which is important for screening germplasm in breeding programmes (Maas and Hoffman, 1977; Noble, 1983; Shannon, 1984).

On the other hand, 80% of the model 1 s parameter of the studied cultivars have a variation interval ranging only from 4 to 7%. Furthermore, the correlation between s and EC_{50} is not significant ($r = 0.28$; $\rho = 0.26$) at the 0.05 significance level, which means that this parameter is less relevant for determining the salt-tolerance of the tested barley cultivars.

Also, the implicit assumption made in the Maas and Hoffman’s crop salt tolerance classification (Maas, 1984; Maas and Hoffman, 1977) that EC_t and s are negatively correlated cannot be applied to the barley varieties evaluated in this work, as shown by the positive correlation between EC_t and s presented in Table 2.

Although this fact means that the established differences between cultivars in EC_t will be reduced for salinity values above this threshold, the small slope of the linear regression between EC_t and s is such that, as mentioned above, s and EC_{50} are not correlated (that is, the 50% germination value is independent of s), whereas EC_t and EC_{50} are still highly correlated, although the slope of the line is below one.

If this different behaviour between crop species and crop cultivars is corroborated by other studies, EC_t might no longer be the only parameter for evaluating the salinity response of crop varieties, a fact that would complicate these studies because EC_t is more easily defined that the s parameter.

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Table 1. Calculated values of EC_t, s (model 1), EC_{50} and p (model 2), as well as the sums of the squared deviations, SSQ (both models) for 24 barley cultivars at the germination stage.

Cultivar	EC_t dS m^{-1} at 25 °C	s %	EC_{50} dS m^{-1} at 25 °C	p	SSQ model 1	SSQ model 2
Ager	24.1	8.1	30.2	11.8	36.1	66.2
Alpha	14.3	4.3	27.4	7.2	157.6	198.7
Aurora II	21.3	4.5	32.1	6.6	11.4	20.4
Barbarrosa	8.6	3.8	20.3	3.7	185.5	226.0
Begofia	21.7	6.4	29.7	9.7	32.4	37.4
CBC-22	23.1	4.9	32.9	6.2	32.4	34.5
Criter	22.2	6.2	30.7	23.0	167.0	100.6
Dobla	22.0	4.2	33.7	5.8	11.8	5.0
Georgie	15.6	5.2	26.0	8.9	85.4	51.7
Gerbel	19.2	4.3	32.6	39.5	356.0	147.5
Hassan	19.2	5.5	28.0	8.4	28.8	11.6
HJAa	21.4	5.1	31.2	7.0	58.4	71.7
Igri	10.1	4.0	20.4	4.1	313.0	291.5
Kim	27.0	10.1	32.6	35.5	96.2	71.7
Koru	9.4	4.1	20.4	4.8	51.2	22.3
Logra	11.3	6.8	18.4	7.8	54.8	31.6
Marib	27.2	10.3	32.1	17.2	9.4	18.9
Monlon	14.1	4.2	24.8	5.0	135.1	114.9
Osa	19.5	6.0	28.5	17.1	140.6	55.8
Patty	25.6	8.7	31.7	13.7	116.4	142.5
Pen	20.1	5.2	29.7	6.9	290.0	318.0
Regia	18.4	5.4	27.2	11.9	160.4	72.4
Viva	27.1	5.2	36.3	11.4	17.4	6.5
Warboys	19.6	5.4	28.3	7.6	13.1	12.8

[a] HJA.A33-M 66.85.

[b] Mari-Coho/847 x Ptr-Emir.

Table 2. Linear regression analysis (y = a + bx) for parameters EC_t, EC_{50}, s and $EC_t^{'}$ determined with two salinity response models for 24 barley cultivars at the germination stage. r is the correlation coefficient, and ρ is the Spearman's correlation coefficient.

y	$EC_t^{'}$ mod. 2 dS m^{-1} at 25°C	EC_{50} mod. 2 dS m^{-1} at 25°C	EC_{50} mod. 1 dS m^{-1} at 25°C	s mod. 1	s mod. 1
x	$EC_t^{'}$ mod. 1 dS m^{-1} at 25°C	EC_{50} mod. 1 dS m^{-1} at 25°C	EC_t mod. 1 dS m^{-1} at 25°C	EC_t mod. 1 dS m^{-1} at 25°C	EC_{50} mod. 1 dS m^{-1} at 25°C
a	-1.1	-2.2	15.0	1.8	2.4
b	1.0	1.1	0.7	0.2	0.1
r	0.82^{s}	0.99^{s}	0.91^{s}	0.63^{s}	0.28^{NS}
p	0.74^{s}	0.98^{s}	0.89^{s}	0.62^{s}	0.26^{NS}

s: Significant at α = 0.05.

NS: non significant at α = 0.05

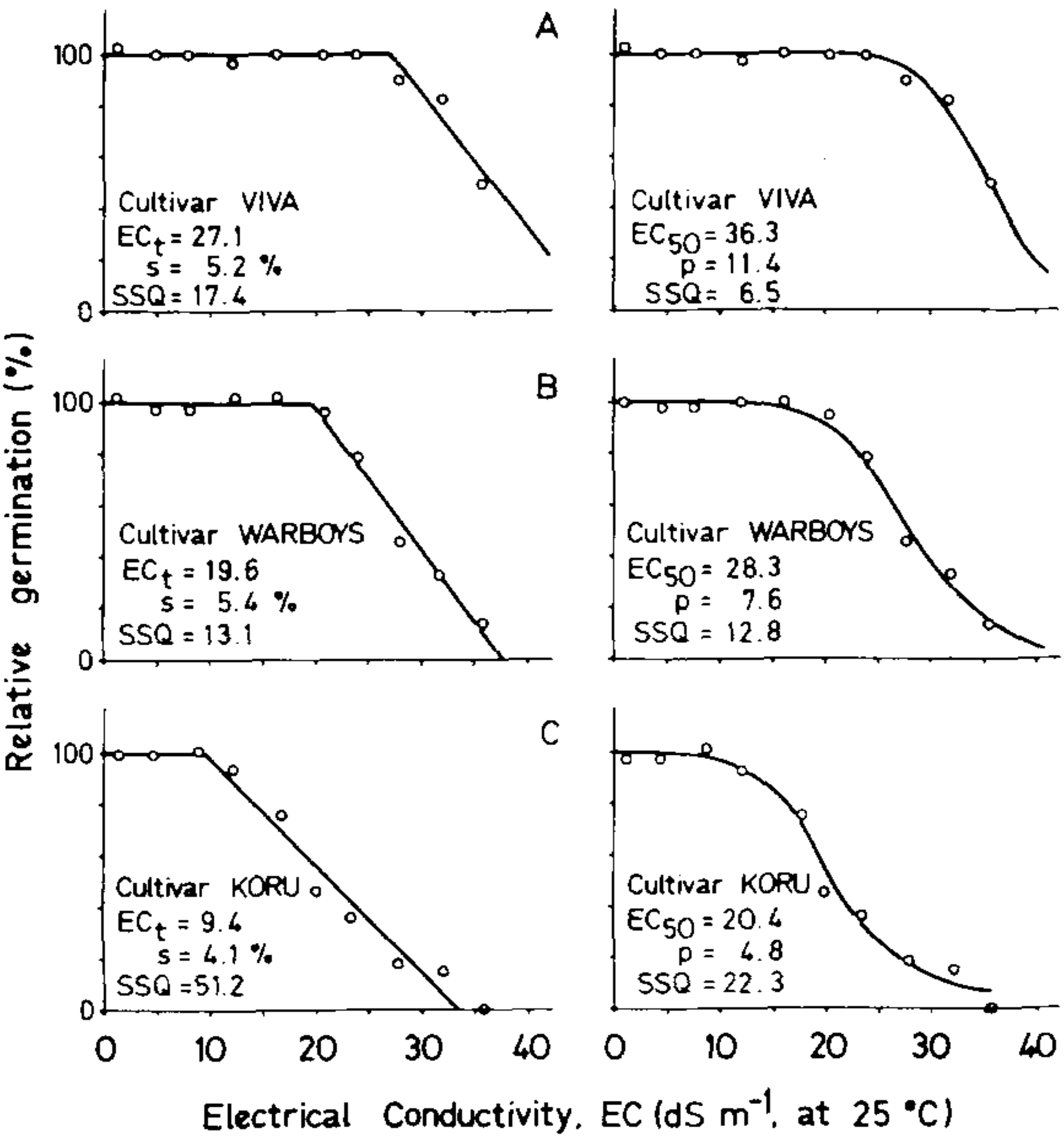

Fig. 1. Relationship between relative germination (%) and solution electrical conductivity (dS m^{-1} at 25 °C). Left: Model 1. Right: Model 2. SSQ = sums of squared deviations.