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SELECTION OF SALT-RESISTANT RICE GENOTYPES USING ANATOMICAL ROOT DATA OF SEVERAL CULTIVARS GROWN UNDER REAL, FULL-SEASON FIELD CONDITIONS

Mehmet AYBEKE

Trakya University, Faculty of Science, Department of Biology, Balkan Campus, 22030, Edirne
e-mail: mehmetaybeke@trakya.edu.tr

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Abstract: I examined anatomical characteristics data of roots of 29 rice cultivars grown under real field conditions (control and saline) during a full season (from germination to harvest) to establish whether the data based on these characteristics could be used to distinguish between resistant and sensitive cultivars. The roots were fixed and their microtome sections were stained using three different methods for each section. The sections were photographed and measurement data of 30 different parameters were obtained using computer-aided methods. All data were grouped in quantitative tables and evaluated. The results of the evaluations showed that xylem diameter, stellar diameter, root diameter and medullary cell wall thickness were the most important parameters in selection. The cultivars characterized with a high level of change in saline conditions compared to normal conditions were found to be the cultivars with the lowest yield values. The cultivars for which the number of variable parameters increased or decreased (including apoplastic barrier lignification) were found to be of the groups denoted as low-, moderate- and high-yield groups. These results indicated that extreme changes did not provide an advantage, while cultivars with moderate changes - the cultivars with more stable anatomical structures - were more resistant to stress and produced higher yields. Moreover, extreme apoplastic barrier lignifications were found to not to lead to an increase in yield, but to become and disadvantageous case for the plants. All present results are consistent with our previous studies and field observations. The potential use of new root anatomy parameters in selection and breeding of salt resistant rice cultivars were underlined.

Key words: *Oryza***,** salt stress, numerical anatomy, breeding, selection.

Tam Zamanlı ve Gerçek Tarla Koşullarında Yetiştirilen Çeltik Çeşitlerinin, Kök Anatomik Datalarına Göre Tuza Dayanıklı Genotiplerinin Seleksiyonu

Özet: Çalışmada gerçek tarla şartlarında (kontrol ve tuzlu) tam sezon yetiştirilen (çimlenmeden hasada kadar) 29 çeşit çeltikte kök anatomik datalarının, tuza dayanıklı olan genotiplerin seleksiyonunda bir kriter olarak kullanılıp kullanılmayacağının araştırılması amaçlanmıştır. Kök örnekleri, fikse edildikten sonra mikrotomla kesitleri alınmış ve ayrı ayrı 3 değişik boyama yöntemi ile boyanmıştır. Kesitlerden fotoğraflar çekilmiş ve 30 farklı parametre ölçümleri bilgisayar destekli yazılım ile kayıt edilmiştir. Tüm sayısal veriler tablolar halinde toplanıp değerlendirmeye alınmıştır. Sonuçlara göre; ksilem çapı, stele çapı, kök çapı ve medullar hücre çeperi kalınlığının, seleksiyon için en önemli ayırt edici parametreler olduğu tespit edilmiştir. Normal şartlara göre tuzlu ortamda yüksek düzeyde değişim gösteren çeşitlerin, en düşük verim gösteren çeşitler olduğu belirlenmiştir. Tuzlu koşullarda değişken parametre sayısının arttığı veya azaldığı (apoplastik bariyer lignifikasyon derecelerindeki değişimler de dahil olmak üzere) çeşitlerin özellikle "en düşük", "orta derece" ve "iyi" verimli" gruplara ait olduğu anlaşılmıştır. Ekstrem anatomik değişimlerin avantaj sağlamadığı, tersine orta derecede yani nispeten daha kararlı anatomik yapılı çeşitlerin, diğerlerine göre strese daha dayanıklı ve daha yüksek verimli oldukları tespit edilmiştir. Hatta apoplastik bariyerlerde ekstrem kalınlaşmaların, verimi arttırmadığı, tersine bir dezavantaja neden olduğu anlaşılmıştır. Tüm sayısal sonuçlar, az sayıdaki literatür kayıtları ve daha önceki çalışmalarım ve arazi gözlemlerim ile tutarlı çıkmıştır. Ayrıca tespit edilen yeni kök anatomik parametrelerin, tuza dayanıklı çeltik genotiplerinin seleksiyon ve ıslahında potansiyel kullanımı vurgulanmıştır.

Anahtar kelimeler: *Oryza***,** tuz stresi**,** nümerik anatomi, ıslah, seleksiyon.

Introduction

Salinity is one of the major environmental problems leading to decreases in the yields of agricultural products, particularly rice that is grown in submerged soil (Aybeke and Demiral 2012). Stress conditions related to salinity cause serious damages to cellular structures (Aybeke 2016, in press) and disturb physiological processes such as photosynthesis, water absorption and cellular metabolism (Pardo 2010). Furthermore, high levels of sodium ions (Na^+) cause an imbalance in ion homeostasis, resulting in ion toxicity (Assaha et al. 2013). Rice has complex resistance mechanisms, either morphological, biochemical and physiological, in response to salt stress (Henry et al. 2012). The anatomical aspects of these mechanisms were described in a recent study (Aybeke 2016, in press). These findings in this study demonstrated that moderate lignified wall thickening and sufficient protective modifications in apoplastic barriers can ensure adequate resistance against salt stress. In contrast, extreme changes in anatomical structures of roots cause a loss of energy and reduce plant yield. The present study examines, as a next step of the previous study of the author, the potential value of different numerical parameters of rice root anatomy for identification and selection of salt-resistant and -sensitive plants.

Materials and Methods

The experiments were coordinately conducted over a full growing season (from seed germination to harvest) in rice fields along the banks of the Meriç River (the control, non-saline water and soil) and in paddy fields which were irrigated with saline water of Ergene River. Cultural practices were implemented sowing seeds of 29 rice cultivars (see Table 1 for the cultivars used) in 2x3m parcels. The average temperature data of the experimental area and all water + soil analysis averages were obtained from the official meteorological state and regional agricultural research institute routine laboratory, respectively. Irrigation water and soil characteristic were obtained from the relevant governmental agencies and given as below. According to these corporations' reports, the day temperature ranged from 21°C to 31°C, while the night temperature fluctuated between 25°C and 32°C. The humidity ranged from 50% to 75% during the growing period. Chemical characteristics of the soil and water are as follows. In the Ergene basin, the soil pH was 7.47 (slightly alkaline); conductivity, 1591.00mmhos/cm; water pH was 7.96; EC×10^8, 3580micromhos/cm; SAR, 18.71. The irrigation water class was C4S3 (very high salt concentration, not suitable for irrigation). In the Meriç region, the soil pH was 7.05 (neutral); water pH was 7.49; EC×10^8, 630micromhos/cm; SAR, 5.64 and irrigation water class was C2S1 (good irrigation water which can be used for irrigation of almost all plants). In all trials, 85-day, 14-leafed, mature flowering plants were used (Sürek 2002). In the field, upper one third of adventitious roots were cut with lancets and fixed in formalin-acetic acid–alcohol mixture (Aybeke 2004). The cut samples were washed and stored with 96% and 70% alcohols, respectively. Paraffin sections of all root samples were made using a Leica RM2255 microtome and three different staining methods, Hematoxylin-Eosin, Alcian Blue-Safranin and Sartur staining for ergastic substances, were applied. The sections were incubated for 3-5 minutes in hematoxylin and washed with tap water before stained with eosin for 10-15 seconds. In Safranin-Alcian Blue method, paraffin sections were treated with 6 parts Safranin-4 parts Alcian Blue dye mixture for 3 minutes and washed with rising alcohol series. In Sartur staining (Çelebioğlu & Baytop 1949), sections were directly examined by using 1-3 drops of the dye under a light microscope (Olympus BH-2) for ergastic substance detection. The sections dyed with the former two staining methods were mounted on glass slides with Entellan after passing the xylene series. Microphotographs of the sections were taken with an Olympus BH-2 photomicroscope and measurements were performed using the Image J software. The rice cultivars that were investigated belonging to different yield classes, i.e., from the highest to lowest crop values under the same salty / normal field conditions, "Best", "Good", "Middle", "Low" respectively, as stated in our recent morphological and physiological study (Aybeke & Demiral 2012). The 30 numerical parameters are presented in Tables 1-4. All measurements are given "as comparative conversion tables" reflect the differences between the Meriç and Ergene conditions (anatomical plasticity), i.e. the normal and saline conditions. For the purpose of comparison of parameters' increased or decreased values in the saline-water group in comparison with the control group the parameters were defined as "improved" or "worsened" and the changed values of these parameters (extreme or non-extreme) were added. These results were the basis for the numerical anatomical distinction between the groups. A One-Way ANOVA test was applied to compare the mean measurements of the test groups and only distinguishing numerical data of the statistical analysis were presented because of their large metadata table properties. A P value <0.05 was used in statistically significant cases.

Results

Exodermis width

The lower and upper (↑↓) limits of exodermis width were 15.13µm (Altınyazı/Meriç) and 125.6µm (Meriç/Ergene), respectively. In the Best group, the exodermis in Kırkpınar cultivar was thicker than in Kral. The width of exodermis could not be used to distinguish between the groups. In Meriç samples, the limits were 15.13µm (Altınyazı) and 84.65µm (Veneria) in Meriç samples and were 20.47µm and 125.6µm in Ergene samples. The highest differences were seen in the Low group and in some cultivars of the Good group. Moreover, many positive changes were also found (Table 1).

Schleranchymatic hypodermis

Most cultivars in both experimental groups had one or two layers of hypodermis. In the Best group, the hypodermis in Kırkpınar cultivar remained unchanged and in Kral cultivar a partial change occured (Table 1).

Table 1. Parameters from exodermis up to pericycle.

Cultivars[1]	Exodermis width	Sch. hyp. row[2]	Sch. cell dim.[3]	Sch. hyp. wall th.[4]	Cortex width	Sch./lyz[5]	End. dia.[6]	End. wall th.[7]	Per. dia.[8]	Per.-xylem space[9]	Total exchange rates[10]
Kral	24.39 → 20.47	1.2 → 1	3.65 → 6.26 !	0.91 → 1.3	1851 → 1249 !	S.±/L → L	21.13 → 20.08	1.04 → 1.82	13.82 → 16.04	35.60 → 45.26 !	5 (2)▲, 4▼, 1#
Kırkpınar	63 → 86.21	1.2 → 1.2	16.56 → 19.04	3.78 → 2.6	1937 → 1524 !	S,L → S,±/ L	18 → 28.04 !	2.34 → 2.6	11.7 - 18.7 → 23.34	41.86 → 57.65 !	6 (2)▲, 2▼, 2#
7721	71.73 → 45 !	1 → 1.2	14.47 → 11.08	3.65 → 2.47	1079 → -	L → L	- → -	-→ 1.82 !	-→ 12 (partly deformed)	-→ 37.95 !	3(2)▲, 4 (1)▼, 4#
Sürek-95	53.86 → 21.13 !	2 → 1	19.82 → 3.26 !	4.69 → 0.78 !	1661 → 1556	L → L	25.43 → 31.69 !	3.65 → 4.69	0 → 15.26 !	-→ 47.60 !	4(3)▲, 5 (1)▼, 3#
Ece	63.52 → 53.86	2 → 1	18 → 15	4.17 → 2.47	1608 → 1281 !	L → L	22.82 → 20.6	1.69 → 2.08	9.52 → 16.04 !	31.30 → 35.21	3(1)▲. 6 (1)▼, 1#
Kros-424	51.39 → 78.52	1.2 → 1	13.82 → 20.47 !	2.21 → 1.82	2010 → 2424 !	L → L	12.39 → 16.43	1.17 → 4.95 !	7.82 → 16.69 !	19.56 → 28.04 !	7(5)▲, 1▼, 2#
Gala	58.04 → 66.91	1 → 1	12.39 → 18	2.47 → 4.3	1830 → 2294 !	S.±/L → L	18.13 → 27.13 !	1.69 → 2.34	18.26 → 18.26	45.65 → 39.78	6(2)▲, 2▼, 2#
Veneria	84.65 → 55.17 !	1 → 1	21.13 → 17.21	4.56 → 1.43 !	1873 → 1969	L → L	-→ 19.04 !	-→ 5.73 !	17.86 → 13.82	46.95 → 37.17 !	4(2)▲, 4(3)▼, 2#
Altınyazı	15.13 → 55.17 !	1 → 1	4.43 → 19.82 !	1.17 → 3.26	1048 → 984	S,± / L → L	27.39 → 18 !	2.86 → 3.26	15.91 → 18.26	36.52 → 37.17	6(2)▲, 3 (1)▼, 1#
Durağan	69 → 78.65	1 → 1	14.21 → 19.3	4.3 → 3.26	2462 → 1640 !	L → L	14.6 → 12.39	0.78 → 1.82	16.04 → 13.56	18.26 - 32.6 → 33.91	4▲, 4 (1)▼, 2#
Halilbey	58.04 → 48.26	2 → 1	15.91 → 10.3 !	3.62 → 1.69 !	1365 → 1291	S.± /L → S,±/ L	20.73 → 27.78 !	2.34 → 6 !	20.21 → 17.6	50.86 → 33.26 !	2(2)▲, 7(3)▼, 1#
Koral	49.69 → 49.69	2 → 1	14.73 → 11.73	3.78 → 2.34	1810 → 1269 !	S.± / L → L	26.86 → 24.39	1.56 → 6.39 !	18.91 → 18	19.56 → 44.34 !	2(2)▲, 6 (1)▼, 2#
N-41-T	56.60 → 42.78	1 → 1	12.91 → 15.13	1.95 → 1.04	1470 → 2094 !	S.± /L → L	21.13 → 18.52	2.73 → 2.6	18.39 → 12.39 !	41.73 → 32.6 !	2(1)▲, 7 (2)▼, 1#
Osmancık	51.78 → 56.60	1 → 1	15.91 → 15	3.65 → 1.82 !	1249 → 1587	L → L	26.21 → 23.34	1.95 → 7.34 !	14.3 - 18.9 → 19.56	11.73 - 27.39 → 41.08 !	5(2)▲, 2 (1)▼. 3#
Beşer	16.69 → 71.08 !	1 → 1.2	4.82 → 35.21 !	1.17 → 2.73	1523 → 1048 !	L → L	18.26 → 19.30	0.91 → 2.34 !	3.2 - 11.7 → 16.3 !	5.21 - 29.34 → 41.73 - 48.26 !	8(5)▲, 1(1)▼, 1#
Edirne	51 → 84.13 !	2 → 1	16.04 → 18.65	4.17 → 2.47 !	1492 → 1819	L → L	17.08 → 16.56	0.52 → 3.26 !	19.56 → 17.6	39.78 → 40.43	5(2)▲, 4 (1)▼, 1#
Gönen	76.04 → 73.17	2 → 2	38.6 → 16.3 !	4.3 → 4.17	2169 → 1259 !	L → L	15.65 → 23.73 !	1.82 → 7.17 !	25.69 → 18.91 !	60 → 39.78 !	2(2)▲, 5 (4)▼, 3#
İpsala	71.73 → 57.91	1.2 → 1	14.71 → 10.3	3.67 → 2.08	1450 → 2191 !	L → L	16.17 → 21.52 !	1.56 → 5.21 !	20.73 → 19.3	49.56 → 33.26 !	3(3)▲, 5 (1)▼, 2#
Karadeniz	56.60 → 32.21 !	1 → 1	14.73 → 10.17	2.34 → 1.69	1195 → 2028 !	L → L	18.13 → 13.04	1.95 → 1.82	17.6 → 18.91	44.34 → 28.69 !	2(1)▲, 6(2)▼, 2#
Kargı	44.21 → 63.52	1 → 1	15.39 → 15.52	2.73 → 2.08	1534 → 1185 !	L → L	17.21 → 27.13 !	1.95 → 6.39 !	19.43 → 24.13 !	33.91 - 41.08 → 44.34	5(3)▲, 2 (1)▼, 3#
Kızıltan	48.26 → 45.52	1 → 1	13.30 → 17.08	3.39 → 2.86	1386 → 1217	L → L	21.13 → 22.3	5.21 → 4.82	20.21 → 16.69 !	46.95 → 30 - 40.43	2▲, 5▼, 3#

Table 1. continued

Meriç	73.17 → 125.6 !	1 → 1	17.21 → 14.21	3.78 → 3	1492 → 963 !	L → L	21.39 → 23.37	1.56 → 4.17 !	8.73 → 23.08 !	3.91 → 41.73 !	5(4)▲, 3(1)▼, 2#
Neğiş	62.08 → 99.39 !	1.2 → 1	16.56 → 14.47	3.26 → 1.82	1238 → 1280	L → L	15.91 → 19.43	1.56 → 4.95 !	11.08 → 16.3 !	9.78 → 30 !	6(4)▲, 2▼, 2#
Ranbelli	44.21 → 0 !	1 → 1	13.04 → - !	3.91 → - !	1883 → 1386 !	L → L	22.56 → 28.56 !	3.13 → 5.73	19.56 → 18.91	30 - 43.69 → 50.86 !	3(2)▲, 4(4)▼, 3#
Rocca	82.17 → 66.26	1.2 → 2	24.39 → 10.56 !	3.91 → 1.43	1111 → 1492	L → L	13.69 → 18.78 !	1.56 → 4.43 !	9.7 - 15.6 → 14.47	25.95 - 32.6 → 43.04 !	5(3)▲, 3(1)▼, 2#
Şumnu	52.43 → 114.5 !	1 → 0	12.13 → 17.47	1.69 → 4.69 !	1470 → 1269	L → L	24.78 → 17.21 !	2.34 → 5.08 !	16.3 → 17.6	16.95 - 34.56 → 31.3	5(3)▲, 3(1)▼, 2#
Trakya	53.08 → 89.21 !	1 → 1	14.08 → 8.73 !	2.6 → 2.47	1408 → -	L → L	→ 27.65 !	→ 6 !	-→ 18.91 !	-→ 50.86 !	5(5)▲. 2(1)▼, 3#
Yavuz	66.26 → 60.78	2 → 1	16.56 → 13.82	3.31 → 2.86	1470 → 1344	L → S. rarely / L	24.52 → 20.73	3.91 → 3.26	13.04 → 16.3	32.6 → 37.82 !	3(1)▲, 7▼
Akçeltik	37.30 → 42.78	1 → 1	13.30 → 13.43	3 → 1.69	2020 → 973 !	L → L	18.39 → 21.26	1.82 → 2.73	6.13 - 8.86 → 20.6 !	4.56 - 10.43 → 33.91 - 39.78	5(1)▲, 2(1)▼, 3#

[1]The different colours in this column represent yield groups: Best (burgundy), Good (grey), Middle (yellow) and Low (blue); [2]schleranchymatic hypodermis row**;** [3]schleranchymatic cell dimension; [4]schleranchymatic hypodermis wall thickness; [5]aeraenchyma type, schizogenous (S), lysigenous (L), ± partially changed; [6]endodermal diameter; [7]endodermal wall thickness; [8]pericycle diameter; [9]distance between pericycle and xylem; [10]▲ = improved parameters, ▼ = worsened parameters, # = stable parameters. The numbers in parentheses indicate the number of over-changed parameters. Green, red or yellow backgrounds indicate that the parameter improved, worsened or remained unchanged (stable), respectively, in comparison with control. "→ ", towards saline conditions. "**!**", extreme changes.

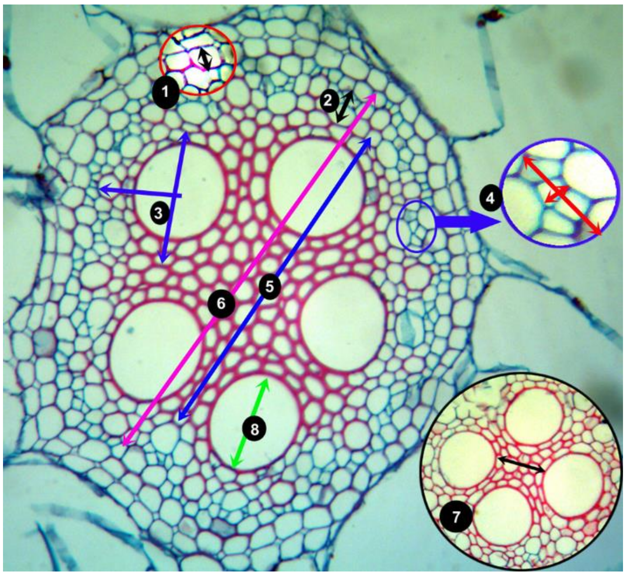

Figure 1. Schematic illustration of some measured parameters. **1)** diameter of endodermis, **2)** distance between pericycle and xylem (black arrows), **3)** xylem length and width (blue arrows), **4)** phloem length and width, (magnified in a circle and indicated by red arrows), **5)** xylem diameter (blue arrow), **6)** stelar diameter (pink arrow), **7)** medullary diameter (in a circle, in the lower right corner), **8)** vessel diameter (green arrow).

<u>*Schleranchymatic cell dimensions*</u>

The lower and upper limits (↑↓) were 19.82µm (Sürek in Ergene group) and 38.6µm (Gönen in Meriç group), respectively. There were no significant differences between the Best group and the other groups. The limits were 4.82µm (Beşer) and 38.6µm (Gönen) in Meriç samples and were 3.26µm (Sürek) and 35.21µm (Beşer) in Ergene samples. Kırkpınar appeared to be superior to Kral in both experimental groups. Cell dimensions increased in the Best group, while they partially increased or decreased in the other groups. Large differences were observed in almost all groups (Table 1).

<u>*The thickness of schleranchymatic hypodermis wall*</u>

The lower and upper limits (↑↓) were 0.78µm (Sürek/Ergene) and 4.69µm (Şumnu/Ergene), respectively. The limits were 0.91µm (Kral) and 4.69µm (Sürek) in Meriç samples. In the Best group, the hypodermis wall in the plants of Kırkpınar cultivar was thicker than those in Kral cultivar. The present data on the thickness of schleranchymatic hypodermis wall is not enough to show the differences between Meriç and Ergene samples. In all groups, there were some differences in wall thickness but extreme values were found in all except the Best group (Table 1).

<u>*Cortex width*</u>

The lower and upper limits (↑↓) were 1048µm (Altınyazı) and 2462µm (Durağan) in Meriç samples and were 984µm (Altınyazı) and 2424µm (Kros-424) in Ergene samples. A distinction of the groups based on the obtained data is not possible. Almost all groups showed extreme differences. Relative width reduction was greater than the relative increase in width. The conditions in Ergene Region led to a reduction in cortex width in many cultivars including the Best ones. Aerenchyma generally stayed lysigenous in samples of the Ergene group or transformed from schizogenous to lysigenous. Halilbey, Yavuz and Kıkrpınar (Best) maintained a relatively schizogenous structure (Table 1).

<u>*Endodermis diameter*</u>

The lower and upper limits (↑↓) were 12.39µm (Kros-424/Meriç) and 27.65µm (Trakya/Ergene). The Meriç limits were 12.39µm (Kros-424) and 27.39µm (Altınyazı) and the Ergene limits were 12.39µm (Durağan) and 31.69µm (Sürek-95). The endodermis diameter data did not allow to make a clear distinction between the two sample groups. The endodermis diameter in the Kırkpınar cultivar was significantly larger under Ergene (salty) conditions when compared to Meriç (control) conditions. In almost all groups, an extreme decreasing/increasing occurred. In the Low group, a relative increase in diameter was observed (Table 1, Fig. 1).

According to the data presented in Table 1, the values measured for the Best group increased under saline conditions in comparison with the control, but the increasing was not substantial.

In the Good group, measured values showed relatively higher increasing pattern and substantial increase rates were higher than in the Best group. On the other hand, the number of parameters that showed an increase in the Good group was lower than in the Best group. In the Middle and Low groups, the number of improved parameters increased in some cases but the changes were less obvious. There were more protective developments in the outermost layer of roots in the Best group. In some Good cultivars, the improvements shifted inwards. In the Middle and Low groups, the values of the outer and inner parameters decreased. Some Low cultivars such as Altınyazı, Beşer, Kros-424 and Akçeltik showed a substantial improvement in the parameter values (Table 1).

<u>*Endodermal wall thickness*</u>

The lower and upper limits (↑↓) were 0.52µm (Edirne/Meriç) and 7.34µm (Osmancık/Ergene), respectively. Meriç limits were 0.52µm (Edirne) and 1.56µm (Kızıltan) and the Ergene limits were 1.82µm (Kral, 7721) and 7.34µm (Osmancık). In Both Meriç and Ergene Regions endodermal walls of the plants of Kırkpınar cultivar were much thicker than Kral cultivar. The present data on endodermal wall thickness did not allow to show differences between the groups. In almost all cultivars, wall thickness increased under the saline conditions. However, substantial increases were found more often in the Low group than in the others. There were no stable data and wall thinning was rarely seen. (Table 1).

Table 2. Changes in vascular cylinder parameters in response to salt stress.

Cultivars[1]	Xylem length	Xylem width	Phloem length	Phloem width	Xylem lignification[2]	Xylem diameter	Stelar diameter	Xyl./stele ratio	Root diameter	Xyl./root dia.ratio[3]	Total exchange rates[4]
Kral	20.21 → 39.13 !	177.65 → 190.95	40.43 → 15.91 !	193.3 → 45.13 !	1 → 1	443.34 → 346.17 !	466.30 → 375.91 !	0.95 → 0.92	5472 → 3994 !	0.13 → 0.12	2(1)▲, 5(5)▼, 3#
Kırkpınar	36.39 → 27.65 !	273.78 →186.78 !	12.65 → 21.26 !	272.34 → 49.43 !	1 → 1	403.04 → 554.86 !	446.34 → 588.78 !	0.9 → 0.94	3836 → 5672 !	0.17 → 0.16	4(4)▲, 3(3)▼, 3#
7721	-→ 20.73 !	-→ 44.86 !	-→ 40.69 !	-→ 34.43 !	-→ 1	-→ 344.6 !	-→ 395.47 !	-→ 0.87	→3694 !	-→ 0.17	10(7)▲
Sürek-95	-→ 34.82 !	160.04 → 132.52	-→ 25.95 !	-→ 64.17 !	2 → 2	-→ 343.95 !	-→ 377.86 !	-→ 0.91	4510 → 3338 !	-→ 0.14	7(4)▲, 2(1)▼, 1#
Ece	35.6 → 37.04	87 → 140.86 !	28.95 → 17.6 !	47.21 → 38.34 !	2 → 2	588.65 → 331.69 !	417.65 → 370.04 !	0.91 → 0.83	5451 → 3597 !	0.13 → 0.15	3(1)▲, 6(5)▼, 1#
Kros-424	13.82 → 44.86 !	186.13 → 157.95	11.73 → 20.73 !	185.6 → 37.95 !	2 → 2	280.56 → 326.86	640.69 → 398.08 !	0.98 → 0.87	2486 → 3731 !	0.19 → 0.15	4(3)▲, 5(2)▼, 1#
Gala	38.6 → 30.52 !	143.21 → 177.39	55.17 → 16.95 !	76.56 → 37.3 !	1 → 2	344.86 → 292.43 !	461.60 → 397.17 !	0.77 → 0.83	3526 → 4110 !	0.17 → 0.14	4(1)▲, 6(5)▼,
Veneria	-→ 27.26 !	230.08 → 210.13	-→ 12.78 !	-→ 41.21 !	2 → 2	369 → 320.08 !	443.08 → 351.52 !	0.88 → 0.86	4684 → 4033 !	0.21 → 0.16	3(3)▲, 6(3)▼,1#
Altınyazı	41.34 → 28.3 !	115.69 → 119.86	18.78 → 17.34	33.39 → 24.65 !	2 → 2	345.26 → 289.82 !	379.95 → 354.26	0.9 → 0.81	3263 → 2998	0.17 → 0.17	1▲,7(3)▼, 2#
Durağan	31.3 → 28.82	47.86 → 129.78 !	12 → 18.26 !	55.17 → 24.39 !	2 → 2	442.82 → 337.04 !	474.26 → 383.60 !	0.93 → 0.87	5076 → 2878 !	0.15 → 0.19	3(2)▲, 6(4)▼,1#
Halilbey	43.43 → 17.6 !	200.73 → 176.08	28.95 → 19.17 !	66.91 → 44.08 !	1 → 3	502.69 → 332.34 !	522.26 → 390.78 !	0.96 → 0.85	4560 → 3160 !	0.18 → 0.17	1▲, 8(6)▼, 1#
Koral	20.73 → 39.91 !	124.3 → 128.47	23.86 → 24.91	198.39 → 65.47 !	1 → 1	384.26 → 416.73	417.91 → 476.86 !	0.91 → 0.87	3464 → 4684 !	0.19 → 0.12	5(2)▲, 4(2)▼,1#
N-41-T	15.91 → 24.13 !	129.26 → 121.82	37.17 → 13.17 !	123.91 → 33.39 !	1 → 1	370.3 → 313.69 !	416.73 → 344.73 !	0.88 → 0.9	3380→ 3994 !	0.18 → 0.21	3(2)▲, 5(4)▼,2#
Osmancık	20.73 → 24.13	49.44 → 121.69 !	27.13 → 21.26 !	267.39 → 39.78 !	1 → 2	-→ 271.3 !	-→ 340.82 !	-→ 0.79	- → 2754 !	-→0.18	8(4)▲,2(2)▼
Beşer	40.43 → 24.13 !	44.21 → 153.78 !	42.39 → 30.39 !	56.08 → 111.72 !	1 → 1	471.65 → 349.04 !	483.39 → 408.78 !	0.97 → 0.85	4545 → 4084 !	0.18 → 0.15	2(2)▲, 7(5)▼,1#
Edirne	26.21 → 40.04 !	91.04 → 131.08 !	15.13 → 18.65	51.78 → 36.52 !	1 → 2	430.69 → 332.73 !	417.65 → 370.04 !	0.93 → 0.83	5389 → 3328 !	0.12 → 0.15	5(2)▲,5(3)▼
Gönen	44.21 → 39.78	185.86 → 89.73 !	44.21 → 20.6 !	92.08 → 26.08 !	2 → 2	476.73 → 418.95 !	573 → 498.78 !	0.83 → 0.83	4078 → 4780 !	0.19 → 0.17	1(1)▲, 8(5)▼,1#
İpsala	57 → 25.3 !	256.82 → 100.95 !	18.39 → 16.56	87.39 → 10.95 !	3 →4	506.86 → 290.34 !	554.6 → 316.69 !	0.91 → 0.91	5740 → 2515 !	0.14 → 0.19	1▲,8(6)▼, 1#
Karadeniz	28.95 → 40.82 !	182.08 → 127.04 !	14.34 → 15.91	101.47 → 31.95 !	1 → 1	352.95 → 298.82 !	420.91 → 335.86 !	0.83 → 0.88	4108 → 3347 !	0.14 → 0.15	3(1)▲. 5(5)▼,2#
Kargı	46.04 → 37.3 !	204.65 → 122.73 !	28.56 → 18.26 !	134.34 → 45.52 !	1 → 2	340.69 → 366.26	372.91 → 430.04 !	0.91 → 0.85	3886 → 3681	0.15 → 0.16	2(1)▲, 7(4)▼,1#
Kızıltan	49.82 → 23.47 !	139.56 → 199.56 !	24.91 → 19.56	215.86 → 39.13 !	3 → 1	361.3 → 451.30 !	412.69 → 542.08 !	0.87 → 0.83	3823 → 4259 !	0.16 → 0.19	5(4)▲,5(2)▼

Table 2. continued

Meriç	40.43 → 25.3 !	53.73 → 147.65 !	18.13 → 22.69	76.69 → 30.52 !	1 → 1	354.26 → 480.52 !	331.17 → 518.60 !	1.06 → 0.92	3410 → 3995 !	0.18 → 0.21	6(4)▲. 3(2)▼,1#
Neğiş	24.13 → 24.91	104.34 → 112.04	31.04 → 30.39	189.78 → 37.69 !	1 → 2	330.65 → 311.73	313.43 → 340.69	1.05 → 0.91	4429 → 3054 !	0.13 → 0.15	4(4)▲, 5(2)▼,1#
Ranbelli	33.13 → 19.95 !	103.43 → 148.43 !	13.95 → 46.3 !	95.86 → 41.34 !	1 → 2	360.78 → 489.13 !	377.47 → 551.73 !	0.95 → 0.88	3995 → 3622	0.14 → 0.2	6(4)▲, 4(2)▼
Rocca	37.17 → 31.69 !	-→ 205.69 !	24.52 → 32.73 !	67.69 → 139.44 !	1 → 1	404.60 → 338.47 !	408 → 368.73 !	0.99 → 0.91	→ 3790 !	0.18 → 0.13	4(4)▲, 5(3)▼,1#
Şumnu	16.95 → 30 !	-→ 264.91 !	20.86 → 19.56	214.69 → 63.78 !	1 → 2	478.30 → 353.08 !	474.91 → 420.78 !	1 → 0.83	→ 3355 !	0.18 → 0.18	4(3)▲, 5(3)▼,1#
Trakya	- → 26.86 !	37.95 → 179.08 !	→ 18 !	-→ 36.52 !	-→ 2	-→ 324.65 !	-→ 377.47 !	→ 0.86	3347 →- !	-→ 0.18	10(7)▲
Yavuz	19.3 → 22.56	35.86 → 214.04 !	14.47 → 8.73	107.6 → 47.73 !	1 → 2	345.26 → 282.13 !	355.69 → 317.86 !	0.97 → 0.88	2573 → 3612 !	0.18 →-	4(2)▲,6(3)▼
Akçeltik	24.91→ 23.47	35.86 → 65.47 !	13.82 → 17.6	16.56 → 30.78 !	2 → 2	406.04 → 305.73 !	412.95 → 372.91 !	0.98 → 0.81	3586 → 4486 !	0.19 → 0.11	5(3)▲, 4(2)▼,1#

[1] different colors in this column represent groups as burgundy (Best), gray (Good), yellow (Middle), blue (Low); 2: xylem lignification degrees; 1: less lignified, 2: lignification a little more, 3: very lignified, 4: lignification significantly too; [3]: xylem / root diameter ratio; [4]▲ = improved parameters, ▼ = worsened parameters, # = stable parameters. The number in parentheses indicates the number of over-changed parameters. Green, red or yellow background indicates that the parameter improved, worsened or remained unchanged (stable), respectively, in comparison with control. "→ ", towards saline conditions. "**!**", extreme changes.

Table 3. Changes in vascular cylinder parameters in response to salt stress.

Cultivars[1]	Medul. dia[2]	Medul. cell wall th.[3]	Xyl. par. Length[4]	Xyl. par. width[5]	Xyl. par. prop.[6]	Proto. lign.[7]	Proto. lign. prop.[8]	Proto. wall th.[9]	Total exchange rates[10]
Kral	153.26 → 70.43 !	5.47 → 4.04	20.86 - 54.78 → 36.52	26.47 - 142.17 → 54.13 !	large, regular, sometimes single-celled → sparse, regular	+ → +	regular, on all walls → regular, on all walls	1,56 → 1,95	4(2)▼,4#
Kırkpınar	117 → 165.91 !	5.73 → 4.43	32.60 → 44.34	31.3 → 93.91 !	very small, single-celled → sparse, regular / rarely damaged	+ → +	on all walls → only on the corner of walls	2.6 → -	3(2)▲,1▼,4#
7721	-→ 75.13 !	-→ 3.39 !	-→ -	-→ -	damaged →damaged	poor → +	poor → walls and corners	→ 1.43	6(2)▲,2#
Sürek-95	0 → 88.69 !	0 → 6.26 !	-→ 27.13 !	-→ 30,65 !	→ single / 2-celled. lignified	+ → +	-→ walls and corners	-→ 3	5(4)▲,3#
Ece	192.91 → 96.78 !	6.13 → 2.86 !	-→ 27.39 - 34.43	-→ 66.65 - 89.6	irregular, damaged, crushed → sparse, sometimes wide / lost	+ → +	walls and corners → walls and corners	-→ 1.56	2▲,2(2)▼,4#
Kros-424	78.13 → 72.13	2.86 → 3.13	16.95 → 20.86 - 36.52 !	30 - 46.95 → 48.26 - 129.13 !	single-celled, sometimes no → sparse, sometimes wide, / unicellular	+ → +	thin on walls and corners → very thin on walls and corners	1.56 → 1.17	3(2)▲,1▼,4#
Gala	84.13 → 75.65	2.08 → 5.47 !	34.56 - 48.9 → 29.34	111.65 - 205.43 → 43.43 - 53.86 !	multicellular large, intact cells → single / 2-celled, rarely. regularly	+ → +	walls and corners → on corners, but thick on some walls	1.04 → 1.95	1(1)▲,4(1)▼, 3#
Veneria	-→ 58.69 !	1.69 → 5.6 !	23.47 - 37.82 → 22.17 - 26.47	53.73 - 98.08 → 30 - 44.34	two / three-cell, partially large → single / two-cell, regular	+ → +	walls and corners → very thin on walls and corners	1.56 → 1.17	2(2)▲,2▼,4#
Altınyazı	139.69 → 109.55	3.26 → 4.69	26.73 → 24.13	30.13 → 26.21	very uniform, single-cell → very rare, single / two cells	+ → +	corners and little on walls → corners and little on walls	0.91 → 1.82	1▲, 4▼,3#
Durağan	118.69 → 76.82 !	3.39 → 3.91	30.26 → 16.82 - 22.1	30.3 → 29.73 - 47.73	wide, on the protoksilem and just under of arches → single-celled, sometimes no	+ → +	thin on walls and corners → thin on walls and corners	1.56 → 1.3	2▲,3(1)▼,3#
Halilbey	166.3 → 88.04 !	6 → 8.34 !	22.04 - 26.86 → 29.47	62.47 - 116.34 → 20.6 !	2-3-celled, locally large, robust → 2-3-celled, lignified on cell corners	+ → +	walls and corners → walls and corners	1.43 → 2.08	2(1)▲,2(2)▼, 4#
Koral	122.73 → 112.56	3.91 → 4.04	18.26 - 22.95 → 18.26 - 36.5	43.04 - 74.34 → 36.52 - 93.52 !	single / two-3 cell → sometimes single-celled, sometimes locally large	+ → +	walls and corners → walls and corners	1.17 → 1.82	4(1)▲,1▼,3#

Table 3. continued

N-41-T	123.26 → 41.73 !	4.56 → - !	24.78 → 22.17	35.21 - 49.56 → 43.04	regular, single / two-cell → usually single-celled	+ → +	thin on walls and corners → thin on walls and corners	-→	4(2)▼,4#
Osmancık	166.95 → 73.04 !	2.08 → 3.91 !	22.17 → 24.78	62.6 - 86.08 → 26.08 !	Place to place damaged → only single-celled, regular	+ → +	walls and corners → corners and some walls	1.56 → 1.82	3(1)▲,2(2)▼, 3#
Beşer	166.95 → 123.91 !	3 → 3.13	24 - 36.7 → 36.13	46.17 - 65.73 → 347.21 !	multicellular, cell shape broken → VERY LARGE!!	+ → +	walls and corners → walls and corners	1.43 → 1.69	3(1)▲,1(1)▼, 3#
Edirne	159.13 → 81 !	4.95 → 5.47	26.6 - 54.65 → 23.60 - 34.17	53.73 - 61.82 → 30 - 46.95 !	2-3-celled, locally damaged → single / 2-celled, rare	+ → +	corners, very little on walls → corners, very little on walls	0.91 → 1.3	1▲,3(2)▼,4#
Gönen	165.65 → 157.17	4.3 → 4.3	29.86 - 32.6 → 36.26 - 38.21	64.56 - 73.3 → 35.86 - 132.78 !	single / 2, multicellular and large, locally cells intact → 2-3-celled, lignified on cell corners	+ → +	walls and corners → walls and corners	2.73 → 1.3	3(1)▲,1▼,4#
İpsala	163.82 → 65.60 !	4.3 → 4.3	35.47 → 25.43	53.21 → 36.13	single / 2-3-celled, regular, firm → 2-3-celled, damaged	+ → +	walls and corners, sometimes thick → walls and corners	3 → 1.43	4(1)▼,4#
Karadeniz	99.13 → 57.39 !	3.39 → 5.08	24.78 - 37.82 → 22.95 - 27.39	19.56 - 53.47 → 43.04 - 123.91 !	single / 2-3-celled, firm → 2-3 / partially multicellular, and locally wide	+ → +	walls and corners → walls and corners	1.56 → 1.95	3(1)▲,2(1)▼, 3#
Kargı	67.69 → 80.86	2.73 → 8.47 !	26.86 - 28.17 → 26.21 - 45.65	30.26 - 62.47 → 28.56 - 54.47	one / rarely two cells, regularly → one / rarely two cells, regularly	+ → +	walls and corners → quite thick on all walls	1.56 → 2.34	3(1)▲,1▼,4#
Kızıltan	116.08 → 112.17	4.69 → 4.43	22.30 - 26.60 → 48.26 - 63.91 !	31.3 - 44.3 → 60 - 170.86 !	Single/two-celled → 2-3-celled/ locally too extended	+ → +	walls and corners → walls and corners	1.3 → 2.21	3(2)▲,2▼,3#
Meriç	124.56 → 124.43	2.47 → 4.56	22.17 → 32.6	30 → 58.69	corrupted, damaged → 2-3-celled, regular	+ → +	all walls → walls and corners	3 → 1.82	4▲,4#
Neğiş	Non-lign..thin → 47.60 !	1.95 → 2.86	27 → 24.78 - 26.08	42.39 → 24.78	2-3 cell, regular, firm → Single / 2-cell, regular	+ → +	walls and corners → walls and corners	1.69 → 1.43	3▲,1▼,4#
Ranbelli	116.08 → 189.78 !	4.17 → 6.26 !	27.13 - 37.82 → 31.3 - 52.3 !	62.6 -135.65 → 33.91 - 159.13 !	multicellular, robust, regular → 2-3 cell / locally very wide	+ → +	walls and corners → corners and some walls	1.17 → 1.69	5(1)▲,3#
Rocca	120.39 → 45.65 !	3.91 → 3.91	19.56 - 31.3 → 23.47 - 40.17	61.3 - 80.86 → 70.43 - 94.56	several celled, 2-3 cell → 2-3-celled, regular	+ → +	walls and corners → corners and some walls	1.82 → 1.95	2▲,1(1)▼,5#

Table 3. continued

Şumnu	132.39 → 73.04 !	3.13 → 3.39	36.52 - 50.86 → 23.47	86.08 - 93.9 → 24.78 !	multicellular, place to place corrupt → single / 2 cell	+ → +	corners and some walls → all walls	1.56 → 1.3	2▲,3(2)▼,3#
Trakya	-→ 70.43 !	-→ 5.73 !	-→ 15.65 - 27.26	-→ 30 !	damaged→ single / 2-cell. local large	+ → +	poor → thick	1.04 → 2.47	6(3)▲,2#
Yavuz	78.65 → 26.08 !	3.26 → 3.91	24.78 - 37.82 → 24.78 - 31.30	46.95 - 114.78 → 32.6 - 75.65 !	Narrow / wide → single / two-cell, regular	+ → +	corners and walls → corners and walls	-→ 2.34	2▲, 3(2)▼,3#
Akçeltik	120 → 96.52 !	2.6 → 8.6 !	16.17 → 20.86 - 42.13	72.91 → 41.73 - 53.6 !	damaged, crushed → regular, 2-3-celled	+ → +	corners, very little on wall → sometimes thick, sometimes not	1.17 → 2.34	3(1)▲,2(2)▼, 3#

[1] different colors in this column represent groups as burgundy (Best), gray (Good), yellow (Middle), blue (Low); [2] Medullary diameter; [3] Medullary cell wall thickness; [4] Xylem parenchyma length; [5] xylem parenchyma width; [6] xylem parenchyma properties; [7] protoxylem lignification status (+: lignified); [8] protoxylem lignification properties; [9] protoxylem wall thickness; xylem lignification degrees; 1: less lignified, 2: lignification a little more, 3: very lignified, 4: lignification significantly too; [10] xylem / root diameter ratio; [4]▲ = improved parameters, ▼ = worsened parameters, # = stable parameters. The number in parentheses indicates the number of over-changed parameters. Green, red or yellow background indicates that the parameter improved, worsened or remained unchanged (stable), respectively, in comparison with control. "→ ", towards saline conditions. "!", extreme changes.

Pericycle diameter

The lower and upper (↑↓) limits were 7.82µm (Kros-424/Meriç) and 19.56µm (Osmancık/Meriç) in Meriç samples and 12.39µm (N-41T) and 24.13µm (Kargı) in Ergene samples. The pericycle diameter of the Best group in both sampling sites was larger in the roots of Kırkpınar cultivar than in Kral cultivar. In general, the pericycle diameter increased in the Best, Good and Low groups, while in the Middle group, there was a comparative decrease. In general, there was an increasing change in dimension of pericycle, while an extreme increasing appeared in “Low” (Table 1).

The distance between the pericycle and xylem

The lower and upper Meriç sample limits (↑↓) were 3.2µm (Beşer) and 60µm (Gönen) while the limits in Ergene samples were 18.91µm (Karadeniz) and 23.34µm (Kırkpınar). For both regions, the distance between the pericycle and xylem was wider in Kırkpınar in comparison with Kral. The Best and other groups could not be distinguished on the basis of these data. In almost all groups, there were some extreme differences between the Meriç and Ergene region samples. There were more increases than decreases in the value of this parameter, with only one cultivar retaining the same value. Overall, there was a substantial increase in the distance between the pericycle and xylem (Table 1, Fig. 1).

Xylem length and width:

The Meriç limits of xylem length were 13.82µm (Kros-424) and 57µm (İpsala), and the Ergene limits were 17.6µm (Halilbey) and 44.86µm (Kros-424). The xylem width limits were 35.86µm (Yavuz, Akçeltik/Meriç) and 273.78µm (Kırkpınar/Meriç) in Meriç and were 44.86µm (cultivar 7721) and 264.91µm (Şumnu) in Ergene. A group classification was not possible based on these present data. There were extreme changes in xylem lengths (increase and decrease), with no cases of unchanged length. Xylem length is highly affected by salinity. The response of xylem width to salinity was seen as an increase or a decrease, but the differences in groups could be negligible. The large increases were more often observed in the Low group (Table 2, Figure).

Phloem length

The limits (↑↓) were 18µm (Trakya/Ergene) and 55.17µm (Gala/Meriç). Meriç limits were 11.73µm (Kros-424) and 55.17µm (Gala) and Ergene limits were 18µm (Trakya) and 46.3µm (Ranbelli). No distinction could be made using the present data on phloem length (Table 2, Fig. 1).

Phloem width

The limits (↑↓) were 10.95µm (İpsala/Ergene) and 272.34µm (Kırkpınar/Meriç). Meriç limits were 16.56µm (Akçeltik) and 272.34µm (Kırkpınar) and Ergene limits were 10.95µm (İpsala) and 41.34µm (Ranbelli). Generally, the phloem width substantially decreased; increased and stable values were rare or absent. Phloem length changed in the same manner, increased or decreased accordingly (Table 2, Fig. 1).

The degree of xylem lignification

Kral and Kırkpınar (Best) cultivars showed a similar response, i.e. generally, the lignification in xylem and protoxylem decreased. The Good group gave results similar to the Best group, but the lignification in Kros-424 increased slightly. There was an increase in the lignification in Gala cultivar in Ergene Region and a decrease in Veneria (Ergene). In some cultivars of the Middle group, the lignification increased; this was clearly seen in Durağan, Osmacık and Halilbey and slightly in N-41-T cultivars. The Low group generally showed a significant increase in lignification in the Ergene Region in comparison with the Meriç.

Xylem diameter

The limits (↑↓) were 271µm (Osmancık/Ergene) and 588.65µm (Ece/Meriç). Meriç limits were 330.65µm (Neğiş) and 588.65µm (Ece) and Ergene limits were 271µm (Osmancık) and 554.89µm (Kırkpınar). Kırkpınar cultivars from Ergene samples had greater xylem diameter than Kral cultivars from Meriç samples. Generally, extreme decreases in diameter occurred more often than increases. Moreover, the xylem diameters in the Best and Good groups were significantly larger than in other groups (Table 2, 6, Figure).

Stelar diameter

The limits (↑↓) were 313.49µm (Neğiş/Meriç) and 640.69µm (Kros-424/Meriç). Ergene limits were 317.86µm (Yavuz) and 588.78µm (Kırkpınar). In general, there were significant reductions in the "Best" and "Good" groups in comparison with others. Stele appeared to be larger in “Middle and Low” groups (Table 2, 6, Fig. 1).

Xylem/stele ratio:

There were no significant differences between the xylem/stele ratios in the “Best” and the other groups. Xylem and stele diameters decreased or increased at the same time.

Root diameter (width)

The limits (↑↓) were 3054µm (Neğiş/Ergene) and 5672µm (Kırkpınar/Ergene). Meriç limits were 2486µm (Kros-424) and 5740µm (İpsala). The roots in Kırkpınar cultivar were wider than in the Kral (Best). Extreme diameter changes were found in nearly all cultivars. The roots in the Meriç were wider than in Ergene Region, particularly in the Low group. However, in the Ergene Region, the Best and some Good and Low cultivars showed a substantial increase in the root width. The largest root diameter was found in the Kırkpınar cultivar (Table 2).

Table 4. Changes in vascular cylinder parameters in response to salt stress.

Cultivars[1]	Ves. dia.[2]	Ves. wall th.[3]	Total exchange rates[4]
Kral	83.60 - 96.78 → 80.86 - 93.91	5.08 → 3.91	1▼,1#
Kırkpınar	93.39 - 105.26 → 95.34 - 124.17 !	4.95 → 4.04	1(1)▲,1▼
7721	→ 64.43 - 81.65 !	→ 2.73 !	2(2)▲
Sürek-95	→ 68.47 - 84.65 !	→ 3.52 !	2(2)▲
Ece	84.65 – 120 → 73.3 - 81.39 !	4.69 → 2.47	2(1)▼
Kros-424	73.43 - 78.65 → 79.95 - 84.39	2.86 → 3.52	2▲
Gala	72.13 - 99.52 → 81 – 89.6	1.43 → 3.39 !	1(1)▲.1▼
Veneria	→ 77.6 - 96.91 !	0 → 4.82 !	2(2)▲
Altınyazı	56.08 - 82.04 → 65.86 - 78.91	3.39 → 3.39	1▼,1#
Durağan	82.3 - 102.78 → 79.43 - 89.86	2.86 → 3.26	1▲,1▼
Halilbey	92.73 - 113.34 → 64.95 - 84.52	4.82 → 3.26	2(2)▼
Koral	81.78 - 95.47 → 49.3 - 89.6	3.78 → 2.47	2(2)▼
N-41-T	89.73 - 108.78 → 58.82 - 87.91 !	3.26 → 2.6	2(2)▼
Osmancık	52.43 - 98.47 → 71.6 - 86.86	1.82 → 3.65 !	1(1)▲,1▼
Beşer	67.82 - 85.56 → 77.6 - 94.82	3.65 →2.73	1▲,1▼
Edirne	56.08 - 106.04 → 77.47 - 90.65 !	3.78 → 3	2(1)▼
Gönen	99.13 - 122.86 → 89.08 - 105.13	3.52 → 5.21	1▲,1▼
İpsala	84.13 - 100.56 → 68.08 - 84.26	4.3 → 3	2▼
Karadeniz	88.17 - 115.43 → 90.39 - 95.47	4.04 → 2.21 !	2(1)▼
Kargı	91.69 - 100.3 → 60.52 - 77.21	1.95 → 2.21	1▲.1▼
Kızıltan	93.91 - 104.47 → 87.65 - 107.08	3.78 → 3.91	2▲
Meriç	50.73 - 65.08 → 95.21 - 121.69	3.26 → 2.47	1▲,1▼
Neğiş	95.47 - 118.56 → 81 - 91.3	0 → 2.08 !	2(1)▲
Ranbelli	97.04 - 113.08 → 81 - 108.65	2.86 → 4.95	1▲,1▼
Rocca	93.39 - 107.6 → 97.82 - 121.04 !	3.65 → 2.73	1(1)▲,1▼
Şumnu	120.26 - 130.43 → 65.21 !	6.39 → 2.73 !	2(2)▼
Trakya	71.08 - 92.86 → 79.17 - 96.39	0 → 3.65 !	2(1)▲
Yavuz	93.39 - 107.6 → 74.34 - 96.39	3.52 → 2.73	2▼
Akçeltik	50.86 - 106.95 → 69.13 - 83.6 !	1.82 → 2.86	1▲,1(1)▼

[1] Different colors in this column represent groups as burgundy (Best), gray (Good), yellow (Middle), blue (Low); [2] Vessel diameter; [3] Vessel wall thickness; [4]▲ = improved parameters, ▼ = worsened parameters, # = stable parameters. The number in parentheses indicates the number of over-changed parameters. Green, red or yellow background indicates that the parameter improved, worsened or remained unchanged (stable), respectively, in comparison with control. "→ ", towards saline conditions. "!", extreme changes.

Xylem/root diameter ratio

This parameter could not be used for specific group classification. In the Best group in Meriç and Ergene Regions, the xylem/stele and xylem/root diameter ratios were the same. In other groups, there were some increases or decreases in ratio values and there was no change in some cases.

In the Best group, the Kırkpınar cultivar showed some conservative modifications (green cells) in contrast to Kral; for instance, the diameters of xylem, root and stele increased. However, in the phloem of the Kırkpınar cultivar, the changes tended to be in the opposite direction (negative, red cells). There were 4–5 extreme changes in the Good group. Cultivar 7721 performed very poorly (small diameters) under the Meriç conditions (control). There were extreme differences (without any gaps in the structure) under the saline conditions of Ergene in comparison with the control. In the Best group, the parameter values increased. There were no extreme changes. Both xylem and stele diameters decreased. The changes in the xylem and phloem diameters were seen more often in opposition to each other in comparison with the Best group.

In the Middle group, the improvements were less obvious. The degree of extreme changes was comparable in the “Best” and “Good” groups. However, the xylem and stelar diameters significantly decreased in these groups. In the Low and Middle groups, there was a decrease in xylem and phloem sizes, while the protective modification rates were low in both groups. Some extreme changes were found in Low cultivars (cv. Trakya) (Table 2).

In the Best group, the medullary diameter and wall thickness decreased in the Kral cultivar and increased in Kırkpınar. The xylem parenchyma and protoxylem lignification features remained the same, and the xylem parenchyma properties improved (Kırkpınar). Kırkpınar showed more positive changes than Kral, but no striking differences were observed. In Kral cultivar, the medullary diameter and xylem parenchyma sizes were severely reduced with some deterioration in xylem properties. In the Good group, there were some changes in the medullary diameter and the xylem parenchyma size. Sürek-95 and 7721 cultivars showed some moderate changes, but higher increases could also be seen. Xylem parenchyma features and protoxylem characteristics remained unchanged. The thickness of the medullary wall increased in nearly all Middle cultivars (unlike in other groups), and there were some inversely proportional changes in the medullary diameter and xylem parenchyma size. No extreme changes occurred. Xylem parenchyma and protoxylem characteristics remained the same. In the Low group, the medullary diameter decreased. In contrast, the thickness of the medullary wall increased in most of the Low group cultivars. However, there were both increases and decreases in the size of xylem parenchyma. In the Meriç Ranbelli cultivars, the xylem parenchyma was larger in Trakya, this difference was very large (Table 3).

Medullary diameter

The limits (↑↓) were 70.43µm (Trakya/Ergene) and 192.91µm (Ece/Meriç). Meriç limits were 67.69µm (Kargı) and 192.91µm (Ece) and Ergene limits were 70.43µm (Trakya) and 189.78µm (Ranbelli). There were no specific limitations in any groups. There were some extreme reductions in the medullary diameter. In contrast, in the Best group, there was an increase in the diameter in the Kırkpınar cultivar (Table 3, Figure).

Medullary cell wall thickness

The limits (↑↓) were 1.69µm (Veneria/Meriç) and 8.6µm (Akçeltik/Ergene). Meriç limits were 1.69µm (Veneria) and 6.13µm (Ece) and Ergene limits were 2.86µm (Ece) and 8.6µm (Akçeltik). Ece cultivar (Good group) had the thickest medullary cell wall in Meriç samples but the thinnest in Ergene. Similarly, while the Akçeltik cultivar had thin walls in Meriç samples, under Ergene conditions its walls were the thickest. The changes were in descending order in the Best cultivars, while in other yield groups they generally occurred in ascending order. The Best group was significantly different from others (Table 6).

Length of xylem parenchyma

The limits (↑↓) were 15.65µm (Trakya/Meriç) and 63.91µm (Kızıltan/Ergene). The largest values were found in Edirne and Kral cultivars under Meriç conditions. The Ergene limits were 22.7µm (N41T) and 63.91µm (Kızıltan). Groups could not be classified with regard to the present data. The differences between Meriç and Ergene Regions were both positive and negative; large increases in the length of xylem parenchyma were found only in some of the cultivars.

Width of xylem parenchyma

The limits (↑↓) were 20.06µm (Halilbey/Ergene) and 347.21µm (Beşer/Ergene); Meriç limits were 19.56µm (Karadeniz) and 205.43µm (Gala). Both increases and decreases in width were observed (no stable values); the structure of xylem parenchyma was volatile. There are no specific limitations in a particular group.

Xylem parenchyma properties

Under Ergene conditions, there was a reduction in cell numbers in Kral and Kırkpınar cultivars (Best). However, the tissue was always solid and with the same structure. In the Good group, three different types of features were observed in the xylem parenchyma. The tissue was either malformed in both environments, damaged in Meriç but stayed in a regular form in Ergene, or intacted in both regions. In the Middle group, several different responses were seen: the parenchyma was shrunken (Altınyazı, Durağan), contracted and lignified (Halilbey) or expanded (Koral). In the case of the Osmancık cultivar,

Table 5. Summary of changes.

Cultivars	Exodermis to pericycle	Xylem, root diameter	Xylem par., proto., medulla[1]	Vessel	Total change rates
Kral	5 (2)▲, 4▼, 1#	2(1)▲, 5(5)▼, 3#	4(2)▼,4#	1▼,1#	7 (3)▲, 14(7)▼, 9#
Kırkpınar	6 (2)▲, 3 (1)▼, 1#	4(4)▲, 3(3)▼, 3#	3(2)▲,1▼,4#	1(1)▲,1▼	14 (9)▲, 8(4)▼, 8#
7721	3(2)▲, 4 (1)▼, 4#	10(7)▲	6(2)▲,2#	2(2)▲	21 (13)▲, 4(1)▼, 6#
Sürek-95	4(3)▲, 5 (1)▼, 3#	7(4)▲, 2(1)▼, 1#	5(4)▲,3#	2(2)▲	18 (13)▲, 7(2)▼, 7#
Ece	3(1)▲, 6 (1)▼, 1#	3(1)▲, 6(5)▼, 1#	2▲,2(2)▼,4#	2(1)▼	8 (2)▲, 16(9)▼, 6#
Kros-424	7(5)▲, 1▼, 2#	4(3)▲, 5(2)▼, 1#	3(2)▲,1▼,4#	2▲	16(10)▲, 7(2)▼, 7#
Gala	6(2)▲, 2▼, 2#	4(1)▲, 6(5)▼,	1(1)▲,4(1)▼, 3#	1(1)▲,1▼	12(5)▲, 13(6)▼, 5#
Veneria	4(2)▲, 4(3)▼, 2#	3(3)▲, 6(3)▼,1#	2(2)▲,2▼,4#	2(2)▲	11(9)▲, 12(6)▼, 7#
Altınyazı	6(2)▲, 3 (1)▼, 1#	1▲,7(3)▼, 2#	1▲, 4▼,3#	1▼,1#	8(2)▲, 15(4)▼, 7#
Durağan	4▲, 4 (1)▼, 2#	3(2)▲, 6(4)▼,1#	2▲,3(1)▼,3#	1▲,1▼	10(2)▲, 14(6)▼, 6#
Halilbey	2(2)▲, 7(3)▼, 1#	1▲, 8(6)▼, 1#	2(1)▲,2(2)▼, 4#	2(2)▼	5(3)▲, 19(13)▼, 6#
Koral	2(2)▲, 6 (1)▼, 2#	5(2)▲, 4(2)▼,1#	4(1)▲,1▼,3#	2(2)▼	11(5)▲, 13(5)▼, 6#
N-41-T	2(1)▲, 7 (2)▼, 1#	3(2)▲, 5(4)▼,2#	4(2)▼,4#	2(2)▼	5(3)▲, 18(10)▼, 7#
Osmancık	5(2)▲, 2 (1)▼, 3#	8(4)▲,2(2)▼	3(1)▲,2(2)▼, 3#	1(1)▲,1▼	17(8)▲, 7(5)▼, 6#
Beşer	8(5)▲, 1(1)▼, 1#	2(2)▲, 7(5)▼,1#	3(1)▲,1(1)▼, 3#	1▲,1▼	14(8)▲, 10(7)▼, 5#
Edirne	5(2)▲, 4 (1)▼, 1#	5(2)▲,5(3)▼	1▲,3(2)▼,4#	2(1)▼	11(4)▲, 14(7)▼, 5#
Gönen	2(2)▲, 5 (4)▼, 3#	1(1)▲, 8(5)▼,1#	3(1)▲,1▼,4#	1▲,1▼	7(4)▲, 15(9)▼, 8#
İpsala	3(3)▲, 5 (1)▼, 2#	1▲,8(6)▼, 1#	4(1)▼,4#	2▼	4(3)▲, 19(8)▼, 7#
Karadeniz	2(1)▲, 6(2)▼, 2#	3(1)▲, 5(5)▼,2#	3(1)▲,2(1)▼, 3#	2(1)▼	8(3)▲, 15(9)▼, 7#
Kargı	5(3)▲, 2 (1)▼, 3#	2(1)▲, 7(4)▼,1#	3(1)▲,1▼,4#	1▲,1▼	11(5)▲, 11(5)▼, 8#
Kızıltan	2▲, 5▼, 3#	5(4)▲,5(2)▼	3(2)▲,2▼,3#	2▲	12(6)▲, 12(2)▼, 6#
Meriç	5(4)▲, 3(1)▼, 2#	6(4)▲, 3(2)▼,1#	4▲,4#	1▲,1▼	16(8)▲, 7(3)▼, 7#
Neğiş	6(4)▲, 2▼, 2#	4(4)▲, 5(2)▼,1#	3▲,1▼,4#	2(1)▲	15(9)▲, 8(2)▼, 7#
Ranbelli	3(2)▲, 4(4)▼, 3#	6(4)▲, 4(2)▼	5(1)▲,3#	1▲,1▼	15(7)▲, 9(7)▼, 6#
Rocca	5(3)▲, 3(1)▼, 2#	4(4)▲, 5(3)▼,1#	2▲,1(1)▼,5#	1(1)▲,1▼	12(8)▲, 10(5)▼, 8#
Şumnu	5(3)▲, 3(1)▼, 2#	4(3)▲, 5(3)▼,1#	2▲,3(2)▼,3#	2(2)▼	11(6)▲, 13(8)▼, 6#
Trakya	5(5)▲, 2(1)▼, 3#	10(7)▲	6(3)▲,2#	2(1)▲	23(16)▲, 2(1)▼, 5#
Yavuz	3(1)▲, 7▼	4(2)▲,6(3)▼	2▲, 3(2)▼,3#	2▼	9(3)▲, 18(5)▼, 3#
Akçeltik	5(1)▲, 2(1)▼, 3#	5(3)▲, 4(2)▼,1#	3(1)▲,2(2)▼, 3#	1▲,1(1)▼	14(5)▲, 9(6)▼, 7#

[1] all xylem parenchyma, protoxylem and medullary properties. ▲ = improved parameters, ▼ = worsened parameters, # = stable parameters. The number in parentheses indicates the number of over-changed parameters.

Table 6. Statistical analysis results of only distinguishing numerical anatomical characters between salt-resistant and salt-susceptible rice cultivars*

Cultivars[1]	Xylem diameter	Stellar diameter	Root diameter	Medullary cell wall thickness
Kral	-7.5 / 1.5 / 0.000**	-6.1 / 3.9 / 0.000**	-12 / 2.5 / 0.005	-9.5/ 3.5 / .24
Kırkpınar	-8 / 2.5 / 0.000**	5.8 / 2.5 / 0.000**	-10 / 2.5 / 0.000**	-10/ 3 / .012**
7721	-7 / 2.1 / 0.353	-6.2 / 2.5 / 0.000**	10 / 3.5 / 0.421	-8.5 / 3.5/ 0.15
Sürek-95	7.5 / 1.1 / 0.32	6.5 / 2 / 0.229	-11 / 2.5 / 0.000**	-9.5/ 2.8 / 0.32
Ece	-6.5 / 2.5 / 0.003	-8.5 / 2.9 / 0.000**	-10 / 1.8 / 0.52	-10/ 1.9 / 0.25**
Kros-424	-6 / 1.5 / 0.000**	-6.8 / 3 / 0.048	-15 / 2.5 / 0.000**	-10.5 / 3 / 0.05
Gala	-9.5 / 3.5 / 0.000**	7 / 3 / 0.000**	-13 / 3.5 / 0.000**	-11/ 2.5 / 0.04
Veneria	-5 / 2 / 0.02	-7 / 2 / 0.4	-11 / 2.4 / 0.156	-8.2 / 3.5 / 0.02
Altınyazı	-8 / 1.4 / 0.05	-7.8 / 3 / 0.405	-14.5 / 2.1 / 0.52	-9.5 / 3 / 0.25
Durağan	-3.5 / 1.2 / 0.003	7 / 2.7 / 0.033	-10.5 / 1.8 / 7.8	-10 / 2.5 / 0.31
Halilbey	-6 / 3 / 0.025	-8.1 / 3.1 / 0.014	-9 / 2.6 / 0.216	-8.5 / 2.3 / 0.51
Koral	5.5 / 3.5 / 0.045	-7 / 3.5 / 0.014	-10 / 1.9 / 0.56	-11 / 1.2 / 0.004
N-41-T	7.5 / 1 / 0.003	-7.5 / 3 / 0.351	-11.5 / 1.8 / 0.355	-13 / 1 / 0.04
Osmancık	-7 / 2 / 0.042	-6 / 2 / 0.225	-10 / 2.9 / 0.17	-11 / 2.3 / 0.1
Beşer	-8.5 / 1.8 / 0.031	-6 / 2.9 / 0.024	-11 / 2.5 / 0.55	-11 / 3.1 / 0.12
Edirne	-7.2 / 2 / 0.025	-5.5 / 2.5 / 0.025	-10.5 / 3.5 / 0.65	-11.5 / 6.2 / 0.35
Gönen	7 / 1.2 / 0.004	-4.1 / 2.1 / 0.217	-10.5 / 3.2 / 0.52	-10 / 2.5 / 0.3
İpsala	7.5 / 3.5 / 0.25	-7.5 / 3 / 0.313	-6 / 3.5 / 0.4	-10 / 2.5 / 0.41
Karadeniz	-6 / 0.5 / 0.25	-8 / 3.5 / 0.55	-10 / 3.5 / 0.55	-10 / 2.9 / 0.35
Kargı	7.5 / 1 / 0.044	-5.5 / 2.8 / 0.23	-8.5 / 1.9 / 0.45	-10.5 / 3 / 0.23
Kızıltan	-9 / 2.5 / 0.023	5.5 / 1.7 / 0.025	-14.5 / 2.2 / 0.000**	-12 / 3.2 / 0.35
Meriç	-3.5 / 1 / 0.03	-6.5 / 2.5 / 0.4	-11 / 2.4 / 0.55	4 / 3.2 /0.52
Neğiş	-7.5 / 3.1 / 0.0253	-6.1 / 3.9 / 0.049	-12 / 2.5 / 0.56	-9.5 / 3.2 / 0.32
Ranbelli	-8 / 2.5 / 0.353	-5.8 / 2.5 / 0.013	-10 / 2.5 / 0.47	-10 / 2 / 0.12
Rocca	7 / 4.1 / 0.023	-6.2 / 2.5 / 0.055	-10 / 3.5 / 0.41	-8.5 / 2.5 / 0.24
Şumnu	-7.5 / 2.5 / 0.355	-6.5 / 2 / 0.292	-11 / 2.5 / 0.715	-9.5 / 2.5 / 0.05
Trakya	6.5 / 3.2 / 0.24	-8.5 / 2.9 / 3	-10 / 1.8 / 0.562	-10 / 4.5 / 0.001
Yavuz	-6 / 1.5 / 0.023	-6.8 / 3 / 4.8	-15 / 2.5 / 0.585	-10.5 / 2.5 / 0.009
Akçeltik	-9.5 / 1.5 / 0.053	-7 / 3 / 5.1	-13 / 3.5 / 0.000**	-11 / 1.5 / 0.12

* For each row, mean difference / std. error / significance values were given** represents that the mean difference is significant at the 0.05 level.[1] The different colors in this column represent groups as burgundy (Best), gray (Good), yellow (Middle) and blue (Low).

the tissue was mostly undamaged. In the Low group, more different features were seen in the Meriç than in the Ergene Region: regular shape, reduced and increased values, the same cell number but with increased lignification, unchanged, increased cell number anddimension, significantly enlarged on stele. In some cases, reduced cell numbers were observed, the tissue partially contracted or partly improved and lignified.

Protoxylem lignification status

Protoxylem lignification existed in all cultivars, but a clear difference between the extent of lignification under normal and salty conditions was found only in cultivar 7721.

Comparisons based on protoxylem status: In the Best group, the Kral cultivar displayed a regular, all wall surface lignification but in Kırkpınar the lignification shifted towards the corners of the cell wall. In the Good, Middle and Low groups, there was less lignification or it was thicker in the corners and in other parts of the protoxylem cell wall.

Protoxylem wall thickness: The wall thickness dramatically decreased in the Kırkpınar cultivar (the Best group), but remained the same in Kral. In the Middle and Low groups, the wall thickness changed very little. Both protoxylem lignification and wall thickness were stable under both experimental conditions and could not be used for a specific group classification.

Vessel diameter

The vessel diameter parameter values were highly variable in all groups, but the range of variation was not extreme. While it had the same value in Kral (Best), it increased slightly in Kırkpınar. In the Good group, it either increased or decreased. A reduction in the vessel diameter was observed throughout the Middle group. In the Low group, it either increased or decreased. This parameter could not be used for classification purposes (Table 4, Figure).

Vessel wall thickness

The Best group showed a partial reduction in wall thickness. The thickness increased in nearly all cultivars of the Good group. In the Middle and Low groups, it (thickness) increased slightly or remained the same. Extreme changes were found in very few cultivars. No specific characteristics could be applied to any single group.

In the Best group, Kırkpınar cultivar showed more improvements than Kral. Kırkpınar had the same rate of decrease and stability for the various parameter values, which should be resulted in well-balanced protection. The Good group could effectively be divided into three sub-groups: Group 1, with many increases and some very large increases (cultivars 7721, Sürek and Kros-424); Group 2, with 11–12 constituent varieties with a positive (an increase in parameter value) modification (Gala, Venaria) but none excessive; Group 3, which had the lowest number of positive modifications (Ece). In Group 1, there were very few negative (decreased parameter values) modifications. Group 2 had almost the same negative modification rate as Group 1. Group 3 had more negative modifications and extreme negative rates than the other groups. The numbers of conserved (stable) values were nearly the same in all groups. In contrast, large increases and decreases in the measured values were apparent in this group. The Middle group could be divided into two sub-groups: cultivars with greatly increased parameter values (Osmancık) or with greatly reduced values (others).

The Best Group's balance which was derived from similarity of positive and negative modifications rates and stable data completely lost in the Middle Group. In other words higher rates of negative and extremely negative modifications were seen in the Middle Group.

The Low group could be divided into four sub-groups. In Group 1, the positive and extremely positive modification rates were higher than other modification rates. Group 2 had higher rates of the negative and extremely negative modifications than other modification types. Group 3 had similar numbers of negative and positive modifications, and Group 4 had similar numbers of all modification types (Beşer).

Discussion

In the present study, I attempted to determine whether the selection of resistant and susceptible rice specimens could be achieved using various anatomical parameters of the root. It was not possible to distinguish between the Best and the other groups using parameters such as exodermis width, cell dimensions and wall thickness of schleranchymatic hypodermis, cortex width, endodermal diameter and wall thickness, pericycle diameter, the distance between pericycle and xylem, phloem length and width, xylem lignification degree and medullary diameter. However, xylem diameter, stelar diameter, root diameter and medullary cell wall thickness could be used as numerical parameters to distinguish between the Best group and other groups. One would expect that roots with narrow cortex and increased xylem and stelar diameter, would increase the flow of water and decrease exposure of salt stress. The increased diameters of the xylem and stele found in the Best group (Kırkpınar) provide good support for this idea. The present data also showed that the moderate improving or worsening modifications (shown in green or red, respectively, in Table 2) supplied a relatively good balance. However, the extreme modifications (positive or negative) did not protect from the salt stress. Furthermore, the extreme modification rates were found in low-yield cultivars, as noted in previous studies (Aybeke & Demiral 2012). For example, excessive wall thickness and lignification in apoplastic barriers and medullary wall thickness negatively affected the yield (Aybeke 2016, in press). When the xylem lignification increased the stelar diameters decreased meaning that these two parameters were inversely related. The stelar diameter and xylem diameter were good parameters for the selection of salt-resistant rice specimens despite the variations in their values. As an example of this idea, I investigated the wall thickness in the Low group. It appeared to be important for the efficiency of moderate lignified wall thickening, but in a balanced way. The present data also showed that the values of important selective parameters related to the xylem were preserved in the Best group (especially Kırkpınar) but showed reversible changes in the Good group. In the Middle and Low group, negative changes were observed (Table 2). Moreover, the changes in xylem diameter and stelar diameter were directly related to each other. A point of further interest was the extreme decrease in the cortical width in Meriç Region (control) in comparison with Ergene Region (salty conditions). The cortex is an aeranchymatic buffer zone by which water reaches the stele through apoplastic barriers. By lowering the total water volume in the intermediate zone and enlarging the xylem vessels, a rapid transition of water to the organs above the ground could be achieved. The cortical spaces were small in almost all cultivars, but the xylem and stelar diameters increased, particularly in the Best group. Similarly, there was a general decrease in phloem and xylem parenchyma cells. Other non-distinguishing (but important) parameters were increased endodermal wall thickness, pericycle diameter and the general amount of space between the pericycle and xylem relative to the root diameter. The increased size of the pericycle cells was possibly related to the increase in the lateral root formation. Indeed, during the field observations, the decay of the submerged parts of the plant stem and the development of denser lateral roots were observed in several cultivars, such as Kızıltan. The outer zones of the roots were found to be very important in stress resistance (Aybeke 2016, in press). Similarly, as shown in Table 1 (in green and red), the protective modifications particularly concentrated in the outer region. When these protective modifications were not sufficiently developed, other modifications near to the root centre could be seen.

The data obtained by measuring the anatomical parameters of the root led to make conclusions similar to those suggested in a recent study (Aybeke 2016, in press). The present data showed that the salt-stress resistance could be provided by a partial increase in the cell size, increase in the thickness of apoplastic barriers, and stelar diameter and balanced improvements in the xylem structure. The salt-stress resistance could be provided by a partial increase in the cell size, increase in the thickness of apoplastic barriers and stelar diameter and balanced improvements in the xylem structure.

These parameters could be effectively used in the selection of salt-resistant plants. To the best of our knowledge, such a broad anatomical selection study has not yet been published; only limited efforts have been made. It was reported that in tolerant rice varieties, large xylem vessels with reduced aerenchyma and high starch content are required for the maintenance of water potential and energy storage (Singh et al. 2013). Another study suggested that high salinity might result in narrow vessels and increased vessel density, thereby maximising water uptake under high-salt conditions (Sobrado 2007). This idea is partly supported by the present data. Even though vessel diameter is not a distinguishing parameter for the Best group and other group selections, the xylem and stelar diameters are very useful for this selection. In summary, the results presented here comprise the most comprehensive information on the anatomical selection of salt-resistant rice specimens, thus filling an important gap in knowledge. Future full-season experiments will direct detailed physiological investigation about salt tolerance in rice.

Conclusion

With the help of detailed anatomical works of the present study, it was tested whether root anatomical data of rice could safely be used for salt-resistant / -susceptible rice selection or not. From the present data, xylem diameter, stelar diameter, root diameter and medullary cell wall thickness are the important distinguishing numerical parameters between these salt resistant and susceptible rice cultivars. Additionally, balanced apoplastic barrier changes are beneficial for plant resistance and provide high yield. Consequently; these findings filled the big gap in selection of salt resistant rice based on root anatomical data and in the future, these obtained new results could be economically and confidently under real field conditions.

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