Effect of Soil Salinity and Alkalinity on Grain Quality of Tolerant, Semi-Tolerant and Sensitive Rice Genotypes

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Abstract: Soil salinity and alkalinity adversely affects the productivity and grain quality of rice. The grain quality of 19 rice genotypes characterized as salt tolerant (T), semi-tolerant (ST) and sensitive (S) was assessed in lysimeters containing saline and highly alkaline soils. Head rice recovery was reduced by salinity stress whereas it was not affected by alkalinity stress. The ratios of length/width (grain dimension) were significantly reduced in T genotypes even at low electrical conductivity (EC, 4 mS/cm) and alkalinity (pH 9.5), whereas in ST genotypes, it was significantly reduced at high salinity (EC 8 mS/cm). There was no significant effect of any levels of salinity or alkalinity on grain dimensions in S genotypes. Amylose content was significantly reduced in T and ST groups even at low EC (4 mS/cm) and alkalinity (pH 9.5) and the effect in S genotypes was only at high salinity. Starch content showed significant reduction at high salinity and alkalinity (EC 8 mS/cm and pH 9.8) in T and ST genotypes and no significant effect was observed in S genotypes. The effect of both levels of salinity (EC 4 and 8 mS/cm) and high alkalinity (pH 9.8) on gel consistency was observed only in S genotypes. The tolerant genotypes IR36 under high salinity, and CSR10 and CSR11 under alkali stress showed lesser reduction in amylose content. The tolerant genotypes BR4-10, and semi-tolerant CSR30, CSR29 and CSR13 showed better gel consistency under saline and alkali stress. Amylose content was affected even at low salinity stress and thus important to consider in breeding rice for salt tolerance. Overall, the grain quality of tolerant and semi-tolerant genotypes was less affected by saline and alkali stress compared to sensitive ones.

Key words: alkalinity; amylose content; electrical conductivity; rice; pH; salinity; starch content; gel consistency

Rice plays an important role in world economy, being the staple food for two-thirds of its population. Although since the mid 1960S, plant type based high yielding varieties have been developed and released, which brought a quantum jump in production and productivity, yet for the acceptance and spread of varieties, grain quality has become an important criteria after yield (Shobha Rani et al, 2006). Soil degradation due to salinity and alkalinity is a serious environmental problem of global significance, affecting the livelihood and nutritional security in nearly 100 million hectare in south and southeast Asia, including about 8.4 million hectare in India (Tyagi and Minhas, 1998). Rice (Oryza sativa L.) is the staple food of this region and major efforts are underway for improving the rice based farming systems (Hossain and Fischer, 1995; van Nguyen and Ferrero, 2006) to meet the challenges posed by various biotic and abiotic stress.

Selection/breeding of salt tolerant genotypes has been carried out for over three decades (Flowers, 2004). Rice is considered to be sensitive to salinity and tolerant to alkalinity and some traditional salt tolerant varieties can withstand high pH of up to 10.0 under irrigated conditions (Mishra and Bhattacharya, 1980). Although salinity affects all stages of growth and development of rice, but salinity at the reproductive stage depresses grain yield much more than salinity at the vegetative stage (Akbar and Pomnamperuma, 1982; Surekha Rao et al, 2008).

A better understanding of the factors that contribute to the overall grain quality of rice will lay the foundation for developing new breeding and selection strategies for combining high quality with high yield. This is necessary to meet the growing global demand for high quality rice while offering producing countries...
additional opportunities for generating higher export revenues (Fitzgerald et al, 2009).

The growth and yield of rice plants growing in salt affected soils besides being adversely affected by the direct osmotic effect of salts, is also affected due to nutritional imbalance caused by reduced availability of nutrients, which in turn affects the nutrition value and quality as a whole of rice grain. The appearance of milled rice is important to the consumer. Quality in rice encompasses storage, milling and market quality, cooking and eating quality and nutrition quality of the grain. Amylose content (AC) determines the texture of cooked rice and is considered as the single most important character for predicting rice cooking and processing behaviour (Juliano, 1979; Webb, 1985). However, the cohesiveness, tenderness, colour and gloss differ greatly based on gel consistency. The extent of variation in grain quality among landraces, salt tolerant selections and bred varieties is an area which has received very little attention. There is very little work on the effect of salinity on rice grain quality (Tauranova, 1978; Siscar-Lee et al, 1990). Grains of rice grown in saline soils had higher brown rice protein (higher nutritional value), less translucent grain, lower starch and amylose content than their control samples. However, alkali spreading value and gel consistency were not affected by culture in saline soils (Siscar-Lee et al, 1990). The effects of alkalinity stress on rice grain quality have not been well studied. Some of the indigenous traditionally cultivated salt tolerant rice varieties have potential for consumer’s preferences and it could be used for breeding programme for the improvement of valuable grain quality traits such as amylose content, gelatinization temperature and grain shape which influence the physicochemical properties like texture (Bhonsle and Krishnan, 2011).

In the previous studies, with a few exceptions, most of the studies on screening of crops for salinity tolerance or quality have used single salt only, usually NaCl. However in nature, the soil solution is a complex mixture of different ionic species. Secondly, very few genotypes have been analyzed for stress responses to quality. Also, evaluation of tolerance to salinity and alkalinity has been conducted separately by different workers using different sets of genotypes for the two types of stress. There have been no studies involving the simultaneous screening of a large number of genotypes of varying stress tolerance for salinity as well as alkalinity tolerance at the same time and to compute the genotype by environment interaction effect on rice grain quality so as to identify varieties that have good tolerance to salinity and/or alkalinity while preserving grain quality.

In the present study, we screened eight tolerant, eight semi-tolerant and three sensitive rice genotypes for salinity as well as alkalinity tolerance in saline and alkali soils in lysimeters installed adjacent to rice fields in North India and analyzed the plants for various tolerance attributes and grain quality parameters.

**MATERIALS AND METHODS**

Nineteen rice genotypes representing a range of tolerance to salt response were selected for this study conducted at the Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana in northern India. The study area is typical of semi-arid sub-tropical India with climatic conditions of hot and dry summers and cold winters. The rice genotypes evaluated in the study ranged from traditional, tall landraces to bred dwarfs and are cultivated in different agro-ecological regions of the Indian sub-continent. The origin and parentage of the genotypes and other plant characteristics are the same as those described by Surekha Rao et al (2008) given in Supplemental Table1.

Selected rice genotypes were grown during summer and monsoon season (June to November) in the five lysimeters (6.0 m long × 3.0 m wide × 1.5 m deep) filled up with alluvial soil for two consecutive growing seasons. The details of salinization and alkalinization are described by Surekha Rao et al (2008). Achieved final levels of salinity and alkalinity as measured by the electrical conductivity (EC) of soil saturation extract and pH of soil-water suspension in 1:2 ratio, were 4 and 8 mS/cm and pH 9.5 and 9.8, respectively (pH of saturation paste was 8.5 and 8.8, respectively). Normal soil (pH 7.3, EC 1.2 mS/cm) was used as control. For rice, pH levels that produce 50% reduction in yield are pH 9.8–10.2 for tolerant varieties, 9.4–9.8 for semi-tolerant varieties and < 9.4 for sensitive varieties (Mishra, 1994). A pH level of 9.5 was thus considered a critical limit for screening rice varieties and compared with a higher level of 9.8. All the methods used for soil analysis are described by Hesse (1971). The soils were sandy loam in texture, low in available N, medium to high in available P and high in available K. The salient physico-chemical and fertility properties of the soils are listed in Table 1.

**Physical attributes**

*Head rice recovery (HRR)*
The head rice recovery is the quantity of unbroken rice recovered after shelling of rough rice and milling expressed as percentage of rough rice. A sample of clean rough rice was passed through a shelling machine (Satake Rice Dehulling Machine, Satake Co., Hiroshima, Japan) to remove the husk from the grains. The dehulled or brown rice was then milled in a McGill miller no 2 for 2 min to remove the bran and the embryos. The milled rice was separated into broken and unbroken grains with a manual sieving device. The proportion of whole grains thus recovered was weighed. All the methods used for determining rice grain quality were as described by Juliano (1979).

**Grain dimensions (size and shape)**

Length and width of 10 unbroken grain of each genotype was measured with a dial caliper (Ogawa Seiki Co. Ltd; Tokyo, Japan). The rice grains were categorized into various classes as given below.

<table>
<thead>
<tr>
<th>Grain size</th>
<th>Scale</th>
<th>Size category</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>Extra Long</td>
<td>≥ 7.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Long</td>
<td>6.1–7.0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Medium</td>
<td>5.5–6.0</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Short</td>
<td>≤ 5.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grain shape</th>
<th>Scale</th>
<th>Shape</th>
<th>Length/width ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>Slender</td>
<td>≥ 3.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Medium</td>
<td>2.1–3.0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Bold</td>
<td>1.1–2.0</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Round</td>
<td>≤ 1.0</td>
</tr>
</tbody>
</table>

**Chemical attributes**

**Amylose content**

The amylose content is analyzed in the whole rice flour by the means of a colorimetric iodine method (Juliano, 1971), 20 mg of rice grain powder was boiled in 10 mL of 1 mol/L KOH for 10 min in a water bath and volume was made up to 100 ml. To 10 mL of this extract, 0.5 mL of 1 mol/L HCl, 0.2 mL of I-KI reagent (0.2% Iodine-2% KI aqueous solution) were added and volume made up to 50 mL. The intensity of the color was read at 590 nm after 30 min. A standard curve was prepared by dissolving 40 mg of potato amylose in 9 mL of 1 mol/L NaOH and 1 mL of ethanol and boiling for 10–15 min. After cooling, the volume was made up to 100 mL. The aliquots of the above extract (1–5 mL) were taken in 50 mL volumetric flasks, 0.5 mL glacial acetic acid and 0.2 mL I-KI reagent were added and volume made to 50 mL.

Based on amylose content, milled rice is classified in ‘amylose groups’ as follows: waxy (0.0%–2.0% amylose content), very low (2.1%–10.0%), low (10.1%–20.0%), intermediate (20.1%–25.0%), and high (25.1–33.0%) (Juliano, 1979).

**Grain starch content**

Starch content was estimated by the iodine blue test. Seventy-five milligrams of rice grain powder were boiled in 50 mL of distilled water for 20 min in a water bath and filtered after cooling. To 3 mL of the filtrate, 40 mL of distilled water, 1.0 mL of iodine reagent (0.1% iodine-1% of KI in 15% HCl solution) and 1.0 mL concentrated HCl were added and volume made up to 50 mL. The transmission was read at 600 nm using a Spectronic-21, spectrophotometer (Shimadzu, Japan). The blanks consisted of 1.0 mL iodine reagent, 1.0 mL HCl and 48 mL distilled water mixture. Starch content was directly read off from transmission rate. Starch content of rice grains was categorized as low (<40%, medium (41%–60%) and high (>61%).

**Gel consistency**

It is based on the consistency of a cold 4.4% milled rice paste in 0.2 mol/L KOH (Cagampang et al, 1973). To triplicate portions of 100 mg of rice powder in a test tube (13 mm × 100 mm), 0.2 mL of 95% ethanol containing 0.025% thymol blue was added (alcohol prevents clumping of the powder during alkali gelatinization whereas, thymol blue gives color to the alkali paste to make the front easier to read) followed by 2 mL of 0.2 mol/L KOH and vortexed. The tubes were covered with glass marbles and heated in a

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**Table 1. Salient physico-chemical and fertility properties of the experimental soils.**

<table>
<thead>
<tr>
<th>Property</th>
<th>Normal</th>
<th>Saline-1</th>
<th>Saline-2</th>
<th>Alkali-1</th>
<th>Alkali-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (1 : 2) (soil : water)</td>
<td>7.3</td>
<td>8.2</td>
<td>8.7</td>
<td>9.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Electrical conductivity (mS/cm)</td>
<td>1.5</td>
<td>4.2</td>
<td>8.2</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Cation exchange capacity (cmol/kg)</td>
<td>10.1</td>
<td>11.6</td>
<td>12.4</td>
<td>12.0</td>
<td>13.1</td>
</tr>
<tr>
<td>Organic carbon (g/kg)</td>
<td>4.6</td>
<td>4.8</td>
<td>5.0</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Total N (g/kg)</td>
<td>0.56</td>
<td>0.42</td>
<td>0.43</td>
<td>0.48</td>
<td>0.50</td>
</tr>
<tr>
<td>Available P (kg/hm²)</td>
<td>12.0</td>
<td>9.0</td>
<td>17.0</td>
<td>12.0</td>
<td>19.4</td>
</tr>
<tr>
<td>Available K (kg/hm²)</td>
<td>241.0</td>
<td>179.0</td>
<td>202.0</td>
<td>200.0</td>
<td>225.0</td>
</tr>
</tbody>
</table>
vigorously boiling water bath for 8 min to ensure that the tube contents reach two-thirds of the height of the test tube. The tubes were then removed and allowed to stand for 5 min before cooling them in an ice water bath for 20 min. After this, the tubes were placed horizontally on a table and left undisturbed for 1 h. The total length of the gel (mm) from the bottom of the tube to the gel front was measured with the aid of a graph paper. This test separated the genotypes into three categories: 1) Very flaky rice with hard gel consistency (26–40 mm); 2) Flaky rice with medium gel consistency (41–60 mm); and 3) Soft rice with soft gel consistency (61–100 mm).

**Statistical analysis**

Based on the grain yield performance in both saline and alkali soils, 19 of the 25 genotypes were categorized into tolerant (< 25% grain yield reduction from the normal soil), semi-tolerant (30%–50% reduction) and sensitive (> 50% reduction), whereas six did overlap these groups (Surekha Rao et al, 2008). The grain quality data of the 19 genotypes were subjected to analysis of variance (ANOVA) using SPSS package to compute genotypic (G) and environmental effects (E) and G × E interactions across all the five environments.

**RESULTS**

The rice genotypes used in this study belonged to traditional landraces (tall) as well as the medium and dwarf ones bred for high yield and tolerance to salinity and alkalinity (Surekha et al, 2008). As a general trend, HRR was reduced by salinity stress whereas it was not affected by alkalinity stress. The HRR found to vary between 57.8%–60.3%, 52.0%–63.1% and 54.4%–59.0% for salt tolerant (T), semi-tolerant (ST) and sensitive (S) genotypes at EC 8 mS/cm and pH 9.8, respectively (Fig. 1). The tolerant (CSR21 and BR4-10) and semi-tolerant (Panvel-1) genotypes showed higher HRR with minimum reduction under higher salinity and alkalinity levels (Table 2).

As a general observation, grain dimensions (ratio of length/width, L/W) were significantly reduced in T genotypes even at low EC (4 mS/cm) and alkalinity (pH 9.5), whereas in ST genotypes, they were significantly reduced only at high salinity (EC 8 mS/cm). There was no effect of any level of salinity and alkalinity on grain dimensions in the S genotypes. The average L/W of T, ST and S genotypes varied between 2.2–2.3, 2.6–2.5 and 3.0–3.1 at EC 8 mS/cm and pH 9.8, respectively (Fig. 1). Among the T genotypes, CSR21 had high L/W of 2.7 with an increase of 0.5% and 2.2% at EC 8 mS/cm and pH 9.8, respectively. Semi-tolerant genotype CSR30 had high L/W of 3.1 and with least reduction of 17.0% and 18.8%, whereas the sensitive P.Bas-1 had a higher L/W of 3.4 and 3.6 with the least reduction of 11.5% and 5.7% at EC 8 mS/cm and pH 9.8, respectively (Fig. 1).

The amylose content of T, ST, and S genotypes ranged between 19%–36%, 20%–30% and 15%–25%, respectively. The T and ST genotypes showed slightly higher amylose of 26.1% and 25.6% than the S genotypes, which had intermediate amylose content (21.2%) in normal soil. In saline (EC 8 mS/cm) and alkali (pH 9.8) soil, the T genotypes had low amylose content of 16.5% and 16.9%, the ST genotypes had 16.4 and 17.2%, and the S genotypes had 15.1% and 17.4% respectively.

The amylose content of T and ST genotypes reduced at both levels of salinity and alkalinity. In the S genotypes, it was reduced only at high level of salinity (EC 8 mS/cm), but the effect of alkalinity stress was not significant. The extent of reduction in amylose content in the T genotypes was 36.7% and 35.3% at EC 8 mS/cm and pH 9.8, whereas the ST genotypes showed respective reduction of 35.9% and 32.7%. However, in case of the S genotypes, the reduction of 28.8% was observed only at high (EC 8 mS/cm) salinity (Fig. 1). The T genotypes like IR36 had high amylose content of 18% with a least reduction of 7.1% at EC 8 mS/cm. whereas CSR10 had an increase of 7.4% at pH 9.8. The ST genotypes like CSR13 had the average amylose content and average reduction at both EC 8 mS/cm and pH 9.8, respectively (Table 2).

The total starch content in the T and ST genotypes was high (85.1% and 80.0%) as compared to the S genotypes (66.4%). Grain Starch content showed significant reduction at high salinity and alkalinity (EC 8 mS/cm and pH 9.8) in the T and ST genotypes and no effect on S genotypes. The T and ST genotypes showed high reduction (20.9% and 20.4%) as compared to the S genotypes (6.7%). Under the alkalinity stress, the T genotypes showed reduction of 17.1% at pH 9.5, whereas T, ST classes showed a reduction of 17.6% and 14.7% respectively at pH 9.8 (Fig. 1). There was no effect of alkalinity on the S genotypes.
Among the tolerant, short and bold genotypes, CSR13 showed the least starch content (57.2% and 68.9%) with a reduction of 28.0% and 27.1% at EC 8 mS/cm and pH 9.8, respectively. The S genotypes were severely affected by both salinity and alkalinity showing the highest reduction of 22.2% and 37.0% at EC 8 mS/cm and pH 9.8 as compared to T (12.7% and 20.0%) and ST genotypes (11.9% and 14.8%). Analysis of variance of various quality attributes showed highly significant F-values ($P < 0.0001$) for the genotypic differences and the given stress environments (Supplemental Table 2).

The tolerant genotype BR4-10 showed high gel consistency of 68.0 mm and 64.7 mm at EC 8 mS/cm and pH 9.8 in spite of its high starch content. Among

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### Table 2. Rice genotypes most tolerant to high salinity (EC 8 mS/cm) and high alkalinity stress (pH 9.8) and both stress.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Genotype Attribute</th>
<th>Salinity (EC 8 mS/cm)</th>
<th>Alkalinity (pH 9.8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reduction / Increase (%)</td>
<td>Reduction / Increase (%)</td>
<td>Reduction / Increase (%)</td>
</tr>
<tr>
<td>Physical attribute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head rice recovery (%) (&gt; 60%)</td>
<td>CSR11 63.9 -9.6</td>
<td>BR4-10 67.3 0.4</td>
<td>CSR11 69.6 0.6</td>
</tr>
<tr>
<td></td>
<td>CSR10 62.3 -2.8</td>
<td>Panvel-1 67.6 -7.7</td>
<td>CSR21 66.9 5.0</td>
</tr>
<tr>
<td></td>
<td>BR4-10 62.4 -9.1</td>
<td>CSR21 66.3 4.1</td>
<td>CO43 65.7 0.6</td>
</tr>
<tr>
<td></td>
<td>CSR13 62.4 -10.0</td>
<td>IR36 65.3 -4.0</td>
<td>CSR29 66.3 -9.5</td>
</tr>
<tr>
<td></td>
<td>CSR13 61.9 -14.2</td>
<td>CSR13 62.9 -8.9</td>
<td>CSR29 65.7 -3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR4-10 64.7 -3.5</td>
<td>BR4-10 64.7 -3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IR36 63.8 -6.3</td>
<td>IR36 63.8 -6.3</td>
</tr>
<tr>
<td>Ratio of length/width (&gt; 2.5)</td>
<td>P.Bas-1 3.5 -11.5</td>
<td>P.Bas-1 3.4 -11.4</td>
<td>P.Bas-1 3.6 -5.7</td>
</tr>
<tr>
<td></td>
<td>CSR30 3.3 -15.1</td>
<td>CSR30 3.1 -16.5</td>
<td>CSR30 3.1 -17.1</td>
</tr>
<tr>
<td></td>
<td>Bas 370 3.1 -7.0</td>
<td>Bas 370 3.0 -6.9</td>
<td>Bas 370 3.1 -5.1</td>
</tr>
<tr>
<td></td>
<td>CSR13 2.8 -6.4</td>
<td>CSR21 2.7 0.5</td>
<td>CSR21 2.7 2.2</td>
</tr>
<tr>
<td></td>
<td>CSR21 2.6 -6.1</td>
<td>CSR13 2.6 -11.1</td>
<td>CSR21 2.7 2.2</td>
</tr>
<tr>
<td>Chemical attribute</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amylose content (%) (18%–25%)</td>
<td>CSR11 22.2 -20.4</td>
<td>IR36 18.0 -7.1</td>
<td>CSR10 24.3 7.4</td>
</tr>
<tr>
<td></td>
<td>BR4-10 20.3 -20.8</td>
<td>BR4-10 18.1 -25.9</td>
<td>CSR11 25.1 -5.1</td>
</tr>
<tr>
<td></td>
<td>CSR13 22.7 -31.9</td>
<td>CSR13 18.3 -33.3</td>
<td>CSR13 24.0 -27.1</td>
</tr>
<tr>
<td></td>
<td>CSR1 22.7 -36.6</td>
<td>CSR27 18.6 -29.8</td>
<td>CSR18 20.8 -25.1</td>
</tr>
<tr>
<td>Low starch content (%) (&lt; 70%)</td>
<td>Bas 370 65.6 -5.6</td>
<td>Bas 370 57.0 -11.9</td>
<td>Pokkali 62.4 -19.4</td>
</tr>
<tr>
<td></td>
<td>CSR30 65.8 43.9</td>
<td>Bas 370 57.2 -16.7</td>
<td>CSR18 63.3 -12.1</td>
</tr>
<tr>
<td></td>
<td>CSR30 70.2 10.8</td>
<td>CSR13 59.5 -28.1</td>
<td>CSR13 65.6 -21.1</td>
</tr>
<tr>
<td>Soft gel consistency (mm) (&gt; 61mm)</td>
<td>CSR29 84.4 -12.9</td>
<td>CSR29 82.0 -12.7</td>
<td>CSR30 75.0 -8.5</td>
</tr>
<tr>
<td></td>
<td>CSR10 75.5 -18.6</td>
<td>CSR30 70.1 -14.6</td>
<td>CSR29 74.7 -20.6</td>
</tr>
<tr>
<td></td>
<td>CSR13 74.4 -15.2</td>
<td>BR4-10 68.0 -13.0</td>
<td>CSR21 64.0 -24.4</td>
</tr>
<tr>
<td></td>
<td>CSR30 73.2 -13.4</td>
<td>CSR22 74.7 -19.6</td>
<td>CSR13 68.7 -18.9</td>
</tr>
<tr>
<td></td>
<td>CSR2 69.3 -17.6</td>
<td>CSR13 64.0 -24.4</td>
<td>CSR13 68.7 -18.9</td>
</tr>
<tr>
<td></td>
<td>Bas 370 69.4 -19.2</td>
<td>CSR21 64.0 -24.4</td>
<td>CSR13 68.7 -18.9</td>
</tr>
</tbody>
</table>

* Rank 1, The genotypes having higher values for an attribute and are less affected by salinity or alkalinity. Rank 2, The genotypes having little lower values for an attribute and are more affected by salinity or alkalinity. The reduction /increase (%) of the attributes in saline or alkali soils are compared over the normal soil, which shows the effect of salinity or alkalinity on the genotypes for the particular attribute.
the ST genotypes, gel consistency of CSR29 was 82.0 mm at EC 8 mS/cm and 75.1 mm of CSR 30 at pH 9.8. Among the S genotypes, Bas 370 had 62 mm and 64 mm of gel consistency at EC 8 mS/cm and pH 9.8, respectively combined with minimum reduction due to high level of salinity and alkalinity (Table 2).

DISCUSSION

Rice grain quality is based on appearance, size and shape of the grain, behavior upon cooking, taste, tenderness and flavor of cooked rice (Juliano et al, 1964). Translucent grain with little or no white belly, intermediate amylose content, intermediate gel consistency and low starch content are the desired attributes of good quality rice (Khush et al, 1979).

In this study, as a general trend, head rice recovery was reduced by salinity stress whereas it was not affected by alkalinity stress. The appearance of milled rice is important to the consumer, which in turn makes it important to the producer and the miller. Thus grain size and shape are the first criteria for rice quality that breeders consider in developing new varieties for release and commercial production (Adair et al, 1966). In general, medium to long grains are preferred in the Indian subcontinent while the country is also replete with hundreds of short grain aromatic types and long grain basmati types, and the latter have the highest preference in both domestic and international markets.

Length of the grain is more variable and important than width and thickness or shape. Grains with short to medium long grains break less than long grains during milling. Thus, grain size and shape have direct effect on yields of head rice. Grain dimensions (L/W) were significantly reduced in the T genotypes even at low salinity or alkalinity, whereas in the ST genotypes, they were significantly reduced only at high level of salinity and alkalinity stress. There was no effect of any level of salinity and alkalinity on grain dimensions in the S genotypes probably because they are the long grained varieties. Denis et al (2005) showed that salinity reduces grain dimensions indicating salinity effects to occur during the hull development.

Of the chemical characteristics, amylose content is one of the most important criteria of grain quality of milled rice. Rice is grouped based on their amylose content into waxy (0%–2.0%), very low (2.1%–10.0%), low (10.1%–20.0%) intermediate (20.1%–25.0%) and high (25.1–33.0%) groups (Juliano 1979, Cruz and Khush, 2000). Juliano et al (1971) showed that rice with high amylose content show high volume expansion during cooking and cook dry, are less tender and become harder upon cooling whereas low amylose varieties cook moist and are sticky. In this study, the tolerant and semi-tolerant genotypes had slightly higher amylose content than the sensitive genotypes (P.Bas-1 and Bas 370), which had intermediate amylose content, generally more preferred in most
rice-growing areas of the world. Amylose content and gel consistency were affected even at low salinity of EC 4 mS/cm and it is thus important to screen for, in breeding programmes for evolving salt tolerant rice.

Higher values were observed for starch content in the tolerant genotypes as compared to the sensitive ones like P.Bas-1 and Bas370, which had long grain dimensions and less starch content under both salinity and alkalinity stress levels over normal. This was in accordance with the findings of Siscar-Lee et al (1990) and Tauronova (1978) who have found low starch content in Basmati long grain types and in rice grown in saline soils.

Varieties with softer gel consistency (> 61 mm) are preferred as the rice cooked is tender. Gel consistency of rice is normally soft, when the amylose content is less than 25%. In this study, all the genotypes of the three tolerant groups showed soft gel consistency. The results showed higher gel consistency in tolerant genotypes than the sensitive ones. The sensitive genotypes had an adverse effect of salinity and alkalinity, showing a reduction of 22.2% and 37.0% at EC 8 mS/cm and pH 9.8, whereas the tolerant genotypes had reduction of only 12.7% and 19.7%, respectively.

In summary, experimental results indicated that grain quality, especially amylose content and gel consistency were affected by salinity and alkalinity stress at EC 8 mS/cm and pH 9.8. Amylose content was affected even by low salinity (EC 4 mS/cm) and is thus an important parameter to screen for in rice breeding programs aimed at developing salt tolerant rice. Among the genotypes, the tolerant genotypes IR36 under high salinity, and CSR10 and CSR11 under alkali stress showed lesser reduction in amylose content. The tolerant genotypes BR4-10 and semi-tolerant CSR30, CSR29 and CSR13 showed better gel consistency under saline and alkali stress. In general, the quality of tolerant and semi-tolerant genotypes was less affected by saline and alkali stress as compared to sensitive genotypes.

Genotypes having the potential for the consumer’s preferences and their use for breeding programme in improving valuable grain quality traits are shown in Table 2. Based on the significant differences ($P = 0.05$), the two top ranking genotypic classes for tolerance to salinity, alkalinity or both the stress are shown in Table 2. The genotypes BR4-10, CSR21, IR36 and P.Bas-1 gave the best performance at high level of salinity and alkalinity for HRR, whereas CSR13, P.Bas-1, CSR30 and Bas 370 showed good performers for higher length to width ratio. For amylose content, IR36, BR4-10, CSR 13 and CSR27 performed well at high salinity and CSR10, CSR11 and CSR13 at high alkalinity. Good performers for low starch content were CSR30, Bas 370, CSR13, CSR1 and P.Bas-1. The genotypes CSR29, CSR30, BR4-10, CSR13, and Bas370 showed good performance for gel consistency having soft gels.

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SUPPLEMENTAL DATA

The following materials are available in the online version of this article at http://www.sciencedirect.com/science/journal/16726308; http://www.ricescience.org. Supplemental Table 1. Parentage, plant characteristics and ecological origin of the rice genotypes screened for tolerance to salinity and sodicity. Supplemental Table 2. Grain Quality parameters comparisons (paired t-test, $P = 0.05$) within a particular salinity or alkalinity level, among different tolerant groups of rice genotypes.

REFERENCES


