

Effects of salinity concentrations at different stages on growth, yield and grain quality of ST24 rice variety in pot-planted condition

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ARTICLE INFO	ABSTRACT
Research Paper Received: August 30, 2023 Revised: December 05, 2023 Accepted: December 09, 2023 Keywords Rice quality Salinity concentration ST24 rice variety *Corresponding author Pham Thi Thuy Duong Email: pttduong@hcmuaf.edu.vn	Saltwater intrusion has posed a complex and detrimental impact on rice cultivation in the Mekong Delta. The ST24 is the rice variety with prominent quality, which is being admired by both domestic and international markets. The assessment of salt tolerance at various growth stages aids farmers in minimizing losses during cultivation. This study was carried out to evaluate the effects of salinity concentrations and stages on growth, yield and rice quality of ST24 rice variety in the Summer-Autumn crop in 2023. The rice plants were grown in pots and placed in a greenhouse throughout the experiment. A two-factor experiment was arranged in a complete randomized design (CRD) with three replications. The first factor included three salinity concentrations: 2‰, 4‰, and 6‰, while the second factor comprised three growth stages: the seedling stage, tillering stage, and heading stage. The results indicated that the concentrations and stages of salinization significantly affected the growth, yield and grain quality of ST24 rice variety. The growth parameters tended to decrease as the salinity concentrations increased. The actual yield reached 220.1, 113.5, 46.2 g/plot at salinity concentrations of 2‰, 4‰ and 6‰, respectively. The yield of rice plants was least affected by salinity at the seedling stage (252.8 g/plot) and were most severely affected by salinity at the heading stage (46.8 g/plot). Increasing salinity from 2‰ to 6‰ did not affect gelatinization (at level 2.0), but reduced the size of grains.

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1. Introduction

Rice is a major cereal crop of Vietnam which plays an important role in ensuring food security and export. The Mekong Delta is the largest rice production area of Vietnam, with the total area of rice fields reaching nearly 2 million ha, accounting for 46.9% of the country's rice land

area (Nguyen et al., 2015). However, occasional saltwater intrusion into the river and canal systems in the Mekong Delta has become a major issue, getting more complicated and frequent in recent years due to climate change (Pham et al., 2021), which seriously threatens rice production of the region.

Salinity has negative effects to the quality and potential yield of crops including rice (Muchate, et al., 2016; Kopittke et al., 2019). Many studies indicated that salinity in irrigation water causes inhibition of plant growth and development, thereby negatively affecting yield through impeding the absorption of water and nutrients by plants (Shawquat et al., 2015; Hashem et al., 2018; Rahman et al., 2021), inducing oxidative stress (Hasanuzzaman et al., 2021), inhibiting cellular metabolic activity, and damaging organelles (Benito et al., 2014; Ning et al., 2018; Mohsin et al., 2020). However, plant susceptibility to salinity can change significantly by growth stage (Rad et al., 2012; Zhang et al., 2017). At the same time, salinity concentration can also change drastically throughout the season.

Therefore, the assessment of the salinity tolerance of rice makes an important contribution to helping farmers apply appropriate techniques for cultivation under salinity conditions, in order to ensure economic efficiency. The capacity of plants to flourish, advance, and yield within diverse salinity conditions mirrors the salt tolerance of each crop (Munns & Tester, 2008). The ST24 is a Vietnamese elite rice variety with exceptional rice quality, favored by domestic and foreign consumers; however, salt susceptibility of this rice variety has not been studied in detail. For that reason, this study was carried out to evaluate the effects of salinity concentrations at different stages on growth, yield and grain quality of ST24 rice variety in pot-planted conditions.

2. Materials and Methods

2.1. Time and place of the study

The study was carried out from March to July 2023, at the experimental farm of the Department of Physiology and Biochemistry,

Faculty of Agronomy, Nong Lam University Ho Chi Minh City, Vietnam.

2.2. Experimental materials

- The ST24 rice variety has a growth period of 105 to 110 days, an average height between 110 and 115 cm, low falling rate, potential yield reaching 8 to 9 tons/ha.

- Topsoil was taken from the soil layer with a depth of 0 to 30 cm in the rice growing area in Vung Liem district, Vinh Long province.

- HD Organic Vina organic fertilizer (25% organic matter) was produced and distributed by Hai Duong Co., Ltd, sea salt (81.6% NaCl), KOH 95% (India).

- Plastic tanks have dimensions ($216 \times 110 \times 35$ cm, length $\times$ width $\times$ height), plastic pots ($17 \times 13 \times 25$ cm, mouth diameter $\times$ bottom diameter $\times$ height); equipment including EC Hanna meter (Italy), Opti-Sciences handheld chlorophyll meter (USA), straight ruler, Mitutoyo electronic caliper (Japan), Ohaus electronic scale (USA), SPAD-502Plus (Japan).

2.3. Experimental layout

A two-factor experiment was arranged in a complete randomized design (CRD) with three replications. The first factor included three salinity concentrations (factor N): 2‰, 4‰ and 6‰, and the second factor included three salinity stages (factor T): seedling stage, tillering stage and heading stage.

The experiment consisted of 9 treatments, with 3 replicates corresponding to 27 plots; Each plot has 25 pots and each pot has 2 plants; The total number of pots in the experiment was 675 pots and 1,350 plants.

2.4. Experimental method

Soil used in the experiment was taken from the topsoil layer (0 to 30 cm in depth) in the rice growing area. Soil was placed in plastic pots with a depth of 20 cm (the top of the pot was 5 cm higher than the soil surface). Organic fertilizer was applied to the soil with the amount of 50 g/pot at 15 days before sowing. Seeds were soaked in warm water (50°C) for 24 h and incubated in damp towels for another 48 h to crack the coats, then sown directly into pots with the quantity 4 seeds/pot. The pots were then put in plastic tubs. Each tub was divided into 3 separated watertight cells, lined with plastic to be used as 3 different experimental plots. Water was supplied into each cell and maintained at the soil surface. After sprouting, the seedlings were pruned to 2 plants/pot. The experiment was placed in a greenhouse to ensure all treatments were not affected by rainwater.

For the salinity treatments, sea salt was used to prepare saline waters at different concentrations depending on treatments. The saline waters were used in place of groundwater to fill the cells at different periods depending on treatments: from 15 to 30 DAS (days after sowing) for the seedling stage; from 30 to 50 DAS for the tillering stage; from 50 to 65 DAS for the heading stage. The salinity concentration was checked every three days by measuring electrical conductivity (EC) of the water with an EC meter and adjusting with groundwater or saline water to maintain EC at 3.2, 6.4 or 9.6 dS/m, corresponding to salinity of 2‰, 4‰ or 6‰. After the salinity treatment periods, the saline water was replaced by well water. To harvest when about 85 to 90% of the seeds were ripe.

2.5. Parameters

Growth parameters included length of root (cm), height of plant (cm), number of tillers (tillers/plant), number of leaves (leaves/plant), chlorophyll content index of leaf (SPAD index), survival rate (%), stem fresh and dry weight (g/plant), root fresh and dry weight (g/plant).

Yield parameters included number of panicles (panicles/plant), number of grains (grains/panicle), weight of 1,000 grains (g), rate of firm grains (%), actual yield (g/plot).

Rice grain quality parameters included length (cm) and width (cm) of grains, whiteness of grains and gelatinization of grains by SES scale (IRRI, 1996).

2.6. Data analysis

Data were averaged by Microsoft Excel 2010 software; ANOVA analysis and the Duncan's multiple range test at the significance level $\alpha = 0.05$ by SAS 9.4 software.

3. Results and Discussion

According to Munns & Tester (2008), growth was a measure used to assess the salt tolerance of crops in salinity conditions. The growth parameters of ST24 rice plants at harvest, including length of root, height of plant, number of leaves, number of tillers, leaf chlorophyll content index and survival rate, were presented in Table 1.

Table 1. Effects of salinity concentrations at different stages on growth parameters of ST24 rice variety at harvest

Parameters	Salinity concentrations (‰) (N)	Salinity stages (T)			Average (N)
		Seedling	Tillering	Heading	
Length of root (cm)	2	28.5	17.2	23.7	23.2 ^A
	4	24.7	12.5	18.8	18.7 ^B
	6	17.9	6.9	12.5	12.4 ^C
	Average (T)	23.7 ^A	12.2 ^C	18.4 ^B	
CV (%) = 10.9; $F_N = 67.5^{**}$; $F_T = 76.7^{**}$; $F_{NT} = 0.1^{ns}$					
Height of plant (cm)	2	79.4	83.7	90.8	84.6 ^A
	4	72.0	79.0	90.5	80.5 ^A
	6	71.7	66.3	86.5	74.8 ^B
	Average (T)	74.4 ^B	76.3 ^B	89.2 ^A	
CV (%) = 6.7; $F_N = 7.6^{**}$; $F_T = 20.7^{**}$; $F_{NT} = 1.7^*$					
Number of tillers (tillers/ plant)	2	9.5	7.7	10.4	9.2 ^A
	4	8.1	6.1	9.8	8.0 ^B
	6	6.3	4.8	10.1	7.0 ^C
	Average (T)	7.9 ^B	6.2 ^C	10.1 ^A	
CV (%) = 10.8; $F_N = 13.9^{**}$; $F_T = 31.5^{**}$; $F_{NT} = 2.7^{ns}$					
Number of leaves (leaves/ plant)	2	47.4	52.3	72.3	57.3 ^A
	4	40.8	56.7	68.9	55.5 ^A
	6	33.7	41.4	71.9	49.0 ^B
	Average (T)	40.6 ^C	50.1 ^B	68.3 ^A	
CV (%) = 11.3; $F_N = 4.6^*$; $F_T = 58.4^{**}$; $F_{NT} = 2.3^{ns}$					
Chlorophyll content index of leaf (SPAD index)	2	37.0	32.3	30.2	33.1 ^A
	4	30.7	32.1	28.3	30.4 ^B
	6	29.8	30.9	27.5	29.4 ^B
	Average (T)	32.5 ^A	31.8 ^A	28.6 ^B	
CV (%) = 7.6; $F_N = 6.1^*$; $F_T = 6.7^{**}$; $F_{NT} = 1.7^{ns}$					
Rate (%) of survival plants	2	78.0	73.3	68.0	73.1 ^A
	4	71.3	54.0	46.0	57.1 ^B
	6	56.7	44.7	34.7	45.4 ^C
	Average (T)	68.7 ^A	57.3 ^B	49.6 ^C	
CV (%) = 12.0; $F_N = 35.3^{**}$; $F_T = 16.8^{**}$; $F_{NT} = 1.1^{ns}$					

*In the same group, numbers with the same character are statistically insignificant difference; ns: non-significant; significant difference at $P \leq 0.05$ (°) or $P \leq 0.01$ (**).*

The results of Table 1 illustrated that the growth of ST24 rice variety was significantly affected by the salinity concentrations in irrigation water and the stage of salinity treatment. The higher the salinity in irrigation water was, the lower the growth of rice plants was. The root length of rice plants decreased correspondingly when increasing the salt concentration, the shortest reached 12.4 cm. Length of root (12.4 cm), height of plant (74.8 cm), number of leaves (49.0 leaves/plant), number of tillers (7.2 tillers/plant), and survival rate (45.4%) was lowest when the salinity was 6‰. Khan et al. (1997) concluded that salinity affects growth, photosynthesis and mineral ion accumulation of different rice varieties, thereby reducing the growth parameters of rice. The growth parameters decreased more as salt stress was executed later in the growth cycle. The

leaf SPAD index (28.6 CCI) and the survival rate (49.6%) were lowest when the plants were subjected to salinity at the heading stage.

The interaction between the concentration and the stage of salinity also affected growth parameters of ST24 rice variety (Figure 1). At a salt concentration of 6‰ applied at the seedling stage, the rice plants had the lowest number of leaves (33.7 leaves/plant). Because at this time, the vegetative growth of the plant was not complete, saltwater irrigation interfered with the absorption of water and nutrients, thus inhibiting the elongation as well as new leaf forming. In addition, the survival rate decreased sharply when the plants were irrigated with 6‰ saline water at the heading stage. The leaf chlorophyll content index was not statistically different under the influence of the interaction between the concentrations and the stages of salinity, fluctuating from 27.5 to 37.0.

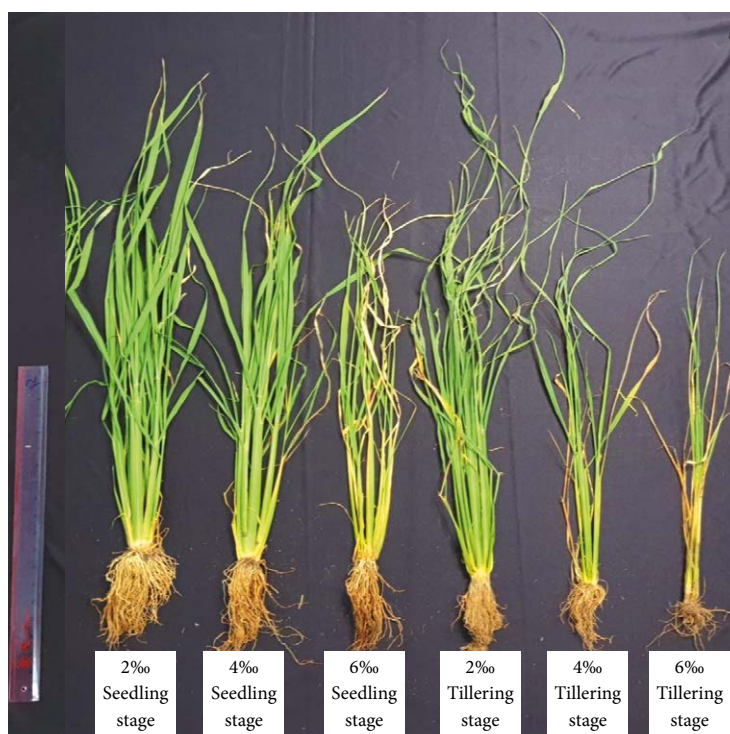


Figure 1. Morphology of ST24 rice variety was watered at different salinity concentrations at seedling and tillering stages at 50 days after sowing.

Salinity also affected the stem and root biomass of rice plants. The differences in stem and root biomass of ST24 at harvest time because of

the influence of different salinity concentrations and stress periods were presented in Table 2.

Table 2. Effects of salinity concentrations at different stages on biomass of stem and root of ST24 rice variety at harvest

Parameters	Salinity concentrations (‰) (N)	Salinity stages (T)			Average (N)
		Seedling	Tillering	Heading	
Fresh biomass of stem (g/ plant)	2	76.1	61.2	59.7	65.7 ^A
	4	60.5	48.8	44.0	51.1 ^B
	6	50.3	33.4	35.1	39.6 ^C
	Average (T)	62.3 ^A	47.8 ^B	46.2 ^B	
CV (%) = 9.9; $F_N = 57.3^{**}$; $F_T = 26.3^{**}$; $F_{NT} = 0.3^*$					
Dry biomass of stem (g/ plant)	2	17.5	14.9	14.2	15.5 ^A
	4	13.9	11.2	10.6	11.9 ^B
	6	12.0	7.8	8.5	9.4 ^C
	Average (T)	14.5 ^A	11.3 ^B	11.1 ^B	
CV (%) = 9.8; $F_N = 59.0^{**}$; $F_T = 22.1^{**}$; $F_{NT} = 0.4^{ns}$					
Fresh biomass of root (g/ plant)	2	38.1	18.9	23.2	26.7 ^A
	4	29.6	11.3	18.7	19.9 ^B
	6	19.6	4.9	13.0	12.5 ^C
	Average (T)	29.1 ^A	11.7 ^C	18.3 ^B	
CV (%) = 12.5; $F_N = 75.1^{**}$; $F_T = 114.8^{**}$; $F_{NT} = 4.7^{ns}$					
Dry biomass of root (g/ plant)	2	10.4	5.1	6.1	7.2 ^A
	4	8.0	3.1	4.9	5.3 ^B
	6	5.0	1.3	3.6	3.3 ^C
	Average (T)	7.8 ^A	3.1 ^C	4.9 ^B	
CV (%) = 14.4; $F_N = 60.0^{**}$; $F_T = 85.7^{**}$; $F_{NT} = 2.9^{ns}$					

In the same group, numbers with the same character are statistically insignificant difference; significant difference at $P \leq 0.05$ () or $P \leq 0.01$ (**).*

The results of Table 2 indicated that fresh and dry weights of stems and roots showed statistically significant differences among treatments. In the same period of saline treatments, the higher the salinity concentration in the irrigation water was, the lower the fresh and dry biomass of

stems and roots were. At the time of harvest, the average fresh and dry weights of stems were the lowest, at 39.6 and 9.4 g/plant, respectively, when irrigated with 6‰ saline water. This was consistent with the influence of salinity on plant growth parameters. When watering with high

salinity concentrations, root length, plant height, number of leaves and number of tillers were reduced considerably, thus reducing stem and root biomasses. The results by Ologundudu et al. (2014) also demonstrated that the dry weights of leaves and roots of rice decreased with increasing salinity concentration in water. The fresh and dry weight of roots was also the lowest at 6‰ salinity, at 12.5 and 3.3 g/plant, respectively.

Significant differences among stem and root biomasses of the treatments were observed. Fresh and dry biomass of stems of ST24 rice variety were the lowest (33.4 and 7.8 g/plant, respectively) when irrigated with 6‰ saline water at tillering stage. Besides, the rice plants which were irrigated with 6‰ saline water at tillering stage also the lowest in terms of fresh and dry biomass of roots (4.9 and 1.3 g/plant, respectively). At the tillering stage, the plants needed to absorb water and nutrients for metabolism to form new plant growth parts. However, increasing salinity in irrigation water inhibited the activity of enzymes and damaged plant metabolism due to excessive accumulation of Na^+ ions (Benito et al., 2014; Hashem et al., 2018; Isayenkov & Maathuis, 2019), thereby causing declines in growth of stems and roots.

Yield is an important factor of primary concern in crop and rice production. Another effect of salinity on plants is reducing photosynthetic activity, affecting carbohydrate synthesis and yield. The yield components of ST24 rice variety under different salinity concentrations applied at different growth stages were presented in Table 3.

The results of Table 3 showed that the yield components and actual yield of ST24 rice variety showed remarkable changes under different salinity concentrations at different stages of growth. When applied at the same stage,

the higher the salt concentration in irrigation water was, the lower the yield components of rice were. Rice plants saw the lowest values in terms of number of panicles (4.1 panicles/plant), number of grains (58.3 grains/plant), weight of 1,000 grains (12.9 g), rate of firm grain (51.4%) and actual yield (46.2 g/plot) at salinity of 6‰. These results agreed with the studies of Singh et al. (2008), Hasamuzzaman et al. (2009), and Khatun & Flowers (1995) which concluded that salinity significantly reduced the rate of firm grains and weight of 1,000 grains of rice. Kronzucker & Britto (2011) proposed that the sodium content in saltwater inhibits carbohydrate metabolism during growth and panicle formation, which is the main cause of yield reduction.

The yield components of rice were also significantly different when irrigated with saline water at different stages. For the same salt concentration, plants experiencing salinity at the seedling stage were least affected, while salinity at the heading stage affected the plants the most in terms of yield components. When irrigated with saline water at the heading stage, the average actual yield was 46.8 g/plot.

Regarding the interaction of salinity concentrations and stress periods, plants irrigated with 6‰ saline water at the heading stage had the lowest yield components and actual yield. Conversely, the yield of ST24 rice variety when irrigated with 2‰ saline water at the seedling stage had the highest actual yield among stress treatments (383.5 g/plot) while the lowest actual yield (8.1 g/plot) was found in treatment of 6‰ salinity applied at the heading stage. The results of Grattan et al. (2002) also showed that salinity at or above 3.0 dS/m considerably affects rice yield.

Table 3. Effects of salinity concentrations at different stages on yield components and yield of ST24 rice variety

Parameters	Salinity concentrations (‰) (N)	Salinity stages (T)			Average (N)
		Seedling	Tillering	Heading	
Number of panicles (panicles/plant)	2	7.2	5.8	7.7	6.9 ^A
	4	6.2	4.2	5.2	5.2 ^B
	6	4.6	3.0	4.7	4.1 ^C
	Average (T)	6.0 ^A	4.2 ^B	5.9 ^A	
	CV (%) = 12.1; F _N = 42.0 ^{**} ; F _T = 17.9 ^{**} ; F _{NT} = 1.1 ^{ns}				
Number of grain (grain/panicle)	2	106.0 ^a	81.1 ^{bc}	68.0 ^c	85.0 ^A
	4	97.9 ^{ab}	65.1 ^{cd}	58.4 ^d	73.8 ^B
	6	81.8 ^{bc}	40.7 ^f	53.2 ^e	58.3 ^C
	Average (T)	95.2 ^A	62.3 ^B	59.9 ^B	
	CV (%) = 6.5; F _N = 12.9 ^{**} ; F _T = 108.5 ^{**} ; F _{NT} = 15.1 ^{**}				
Weight of 1,000 grains (g)	2	21.4 ^a	18.4 ^b	14.1 ^c	18.0 ^A
	4	20.5 ^a	14.5 ^c	10.4 ^e	15.1 ^B
	6	18.5 ^b	12.2 ^d	8.0 ^f	12.9 ^C
	Average (T)	20.1 ^A	15.0 ^B	10.8 ^C	
	CV (%) = 5.5; F _N = 87.0 ^{**} ; F _T = 293.8 ^{**} ; F _{NT} = 4.9 [*]				
Rate (%) of firm grain	2	75.5 ^a	71.8 ^a	61.9 ^b	69.7 ^A
	4	75.3 ^a	60.7 ^b	45.7 ^c	60.6 ^B
	6	71.4 ^a	47.8 ^c	34.9 ^d	51.4 ^C
	Average (T)	74.0 ^A	60.1 ^B	47.5 ^C	
	CV (%) = 4.5; F _N = 103.0 ^{**} ; F _T = 216.5 ^{**} ; F _{NT} = 4.9 ^{**}				
Actual yield (g/plot)	2	383.5 ^a	167.3 ^c	109.5 ^d	220.1 ^A
	4	268.0 ^b	49.7 ^e	22.9 ^{ef}	113.5 ^B
	6	107.0 ^d	23.6 ^{ef}	8.1 ^f	46.2 ^C
	Average (T)	252.8 ^A	80.2 ^B	46.8 ^C	
	CV (%) = 21.3; F _N = 95.5 ^{**} ; F _T = 151.9 ^{**} ; F _{NT} = 10.5 ^{**}				

In the same group, numbers with the same character are statistically insignificant difference; ns: non-significant; significant difference at $P \leq 0.05$ () or $P \leq 0.01$ (**).*

Besides yield, rice quality is a matter of great concern to producers and consumers. The ST24 rice variety is favored by the market due to its exceptional quality with glutinous texture. Therefore, the parameters of rice quality of ST24 rice variety under different salinity concentrations at different growth stages were evaluated and presented in Table 4.

Table 4. Effects of salinity concentrations and stages to quality of ST24 rice variety

Parameters	Salinity concentrations (‰) (N)	Salinity stages (T)			Average (N)
		Seedling	Tillering	Heading	
Length of grain (mm)	2	8.12 ^a	8.08 ^{ab}	8.06 ^b	8.09 ^A
	4	8.12 ^a	8.08 ^{ab}	7.88 ^c	8.03 ^B
	6	8.10 ^{ab}	8.04 ^b	7.68 ^d	7.94 ^C
	Average (T)	8.11 ^A	8.07 ^B	7.87 ^C	
	CV (%) = 0.41; $F_N = 46.58^{**}$; $F_T = 133.94^{**}$; $F_{NT} = 27.45^{**}$				
Width of grain (mm)	2	1.80 ^a	1.80 ^a	1.77 ^{bc}	1.79 ^A
	4	1.81 ^a	1.77 ^{bc}	1.75 ^d	1.78 ^{AB}
	6	1.78 ^{ab}	1.76 ^{cd}	1.74 ^d	1.76 ^B
	Average (T)	1.80 ^A	1.78 ^B	1.75 ^C	
	CV (%) = 0.60; $F_N = 4.12^*$; $F_T = 41.43^{**}$; $F_{NT} = 2.68^*$				
Whiteness grain level	2	3.0	3.0	3.0	3.0
	4	3.0	3.0	5.0	3.7
	6	5.0	5.0	7.0	5.7
	Average (T)	3.5	3.5	4.5	
Gelatinization grain level	2	2.0	2.0	2.0	2.0
	4	2.0	2.0	2.0	2.0
	6	2.0	2.0	2.0	2.0
	Average (T)	2.0	2.0	2.0	

In the same group, numbers with the same character are statistically insignificant difference; significant difference at $P \leq 0.05$ () or $P \leq 0.01$ (**).*

The results of Table 4 demonstrated that the size of rice grains was significantly different among treatments, while the gelatinization of rice grains were not affected by salinity. Length and width of rice grains tended to decrease at higher salinity concentrations. Rice grains had the lowest length (7.94 mm), width (1.76 mm) when the plants were watered the salinity concentration of 6‰. When supplied with salt water at the heading stage, rice grains also had the lowest length (7.87 mm), width (1.75 mm). Whiteness score fluctuated between 3.0 and 5.7 when rice plants were watered at different salinity concentrations. The gelatinization of rice grains was high (at level 2.0). Gelatinization was the process of breaking the starch chain in the rice grain (Liu et al., 2009), which determines the time and energy required to cook the rice (Hoang et al., 2021). Therefore, the ST24 rice variety needs a long time to cook.

4. Conclusions

The growth and yield parameters of ST24 rice variety in the pot-planted condition were significantly affected by the different salinity concentrations and application stages. Root length, plant height, number of leaves, number of tillers, chlorophyll content index of leaf, and survival rate decreased corresponding increasing salt concentration in irrigating water. The actual yield reached 220.1, 113.5, 46.2 g/plot at salinity concentrations of 2‰, 4‰ and 6‰, respectively. Under saline conditions, rice plants had the highest (252.8 g/plot) and the lowest actual yield (46.8 g/plot) when experiencing salinity at the seedling stage and heading stage, respectively. The gelatinization of rice remained high and was not affected by the salt concentrations and salinity application stages; The rice grain size decreased with the higher salinity concentrations and the later stages of salinity treatment.

Conflict of interest

The authors whose names are listed above certify that they have no any conflict of interest declaration.

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