GERMINATION AND IN VIVO AMINO ACID BALANCE STRATEGIES OF OAT (*Avena sativa*) SEEDS UNDER SALINE-ALKALI STRESS SIMULATED WITH NaCl AND $NaHCO_3$

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Abstract. The current experiment was investigated to determine the effect of saline-alkali stress on germination indices and amino acid concentrations of *Avena sativa.* The study was comprised of different levels (0, 50, 100 and 200 mmol L^{-1}) of salinity (NaCl) and alkaline ($NaHCO_3$) stress. The seeds were subjected to stress treatments and the changes in biological and physiological indices of oat seedlings were determined. The results showed that the biological indices of oat seed germination had some regularity in response to salinity stress. The increasing salts concentration decreased germination rate, germination potential, germination index, vigor index length of germ and radicle, biomass and water content of germ and radicle. Further, both stresses also changed the concentration of different amino acids. Therefore, saline-alkali stress can reduce the germination and seedling vigor of *Avena sativa.* The present study provides reference for the selecting the oat seeds to be grown on saline-alkali soils.
Keywords: *amino acids, biomass, germination, salinity, seedling vigor*

Introduction

Saline and alkali soils significantly reduce crop productivity in the world (Yadav et al., 2011; Hussain et al., 2019). These abiotic stresses have affected the global agricultural land about 8.31×10^8 hm^2 (Gao et al., 2011). In China, the presence of saline-alkali soil declines the soil efficiency in 70% (3.7×10^6 hm^2) of the Songnen Plains of Northeast China (Gao et al., 2011). Numerous researchers have documented the growing threat of lowering the soil efficiency due to the presence of salinity and alkalinity soils (Bui, 2017; Fatima et al., 2021). Crops growing on such soils fail in their physiological functions, water relations, and osmotic adjustment, leading to the high Na^+ ion accumulation (Shahid et al., 2020).

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Moreover, less plant nutrition uptake from salt-alkaline-affected soils decreased the plant growth and yield (Guo et al., 2020). Researchers have found that saline or alkalinity issues significantly impact the germination stage, and crops that are tolerant to these stresses demonstrate significant germination potential (Vu et al., 2015; Lamichhane et al., 2018; Chadha et al., 2019; dos Santos Lopes et al., 2021; Hassanisaadi et al., 2022).

The stage of seed germination into seedlings is the most vulnerable stage in the life history of seed plants, and the salt tolerance during this stage partially reflects the overall salt tolerance of plants to some extent. Protease hydrolyzes storage protein to free amino acid during seed germination, and decarboxylation or transamination further transformed into soluble nitrogen and energy. The increase of free amino acids plays an osmotic regulatory role in maintaining the water potential of plants (Khan et al., 2020). Amino acids play a role as osmoregulatory substances in plants. Free amino acids are important organic solutes for osmoregulation in cytoplasm and an important material basis for plant stress resistance under stress conditions.

During seed germination, storage proteins in endosperm or cotyledon are hydrolyzed into simple nitrogen-containing compounds by enzyme and transported to the embryo to synthesize structural proteins of new cells. Therefore, during germination, although the total nitrogen content in seeds may be slightly lost due to exosmosis, and there is no significant change before and after germination, the nitrogen morphology changes greatly. During germination, protein nitrogen decreases rapidly, while ammonia nitrogen increases significantly. Protease and peptidase catalyzed the hydrolysis of storage protein in seeds. Protease hydrolyzes proteins to amino acids and peptides; Peptidases break down endogenous and hydrolyzed peptides into amino acids (Mazorra-Manzano et al., 2018).

Oat is an annual crop of the genus Oat of the Poaceae family Poa, which has not strict cultivation soil requirements and good salt-alkali resistance. Oat is a traditional crop widely cultivated in arid and semi-arid salt-alkali soil areas, but there are few studies on the growth and physiological changes of oat under salt-alkali stress (Egamberdieva et al., 2019).

Therefore, we can speculate that alkali stress is more harmful to the growth and physiology of oat than salt stress, but the effects on the physiological mechanism and components of oat's resistance to salt-alkali stress and the tradeoff relationship between amino acids are still unclear. In this paper, the neutral salt NaCl and basic salt $NaHCO_3$ were used to stress oat seeds. The purpose was to compare and explore: (1) the influence of the two-salt stresses on the aboveground and underground trade-offs during seed germination; (2) The influence of two kinds of salts on seed germination process and the relationship between various amino acid contents in the body; (3) Saline-alkali tolerance mechanism and adaptation strategy under two kinds of salt stress.

Material and methods

Plant materials

The planned study was executed in the state breeding laboratory in Northeast Normal University, China in 2023. The Baiyan 2 was used as test material and it is spring-sown cultivar with appreciable ability to withstand harsh conditions and

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produce biomass. This cultivar also has a growth period of 80-85 days and thousand grain weight of 30 grams.

Stress treatment

In accordance with the international seed inspection procedures, 30 petri dishes were used in the germination bed and divided into 8 groups, of which 2 groups were the control group and the other groups were treated differently. 3 replicates were set in each group. 2 layers of filter paper were laid in the dish and 10mL of corresponding treatment liquid was added to saturation, while the control group was treated with the same amount of distilled water. Full and uniform oat seeds were selected and disinfected with 99.75% ethanol solution for 30 seconds, and the petri dishes were cleaned using deionized water and placed in the oven for 3 hours at 120 ℃ (Arifeen, 2007). Deionized (dH_2O) water was used as the blank (control) and three concentration gradients of 50, 100 and 200 mol L^{-1} were set in the experimental group. 50 seeds were uniformly placed on filter paper, and the petri dishes were kept in controlled room having constant temperature of 20 ℃, with secondary light (12-hours day and night period, respectively). The lost water is replenished by weighing every day to ensure that the salt concentration is basically unchanged. The germination seeds were treated for 7 days.

Determination of germination indices

Germination number was counted every day, germination potential was measured on the 4th day, germination rate was measured on the 7th day, and germ length and radicle length were measured on the 7th day (radicle and germ were randomly selected and 10 complete buds were quickly measured). Then put it in the oven at 110℃ for 10 minutes, and then adjust the temperature to 80 °C until it is constant weight, and weigh the dry weight (dry weight refers to the total dry weight of the 10 complete buds of the germ and radicle measured above). The contents of various amino acids were measured by dry sample.

The germination rate was calculated by the formula $Gr= n/N\times100\%$, where n was the number of germination and N was the total number of seeds. The germination potential is the germination rate on day 4. The germination index is calculated according to the formula $Gi= \sum Gt/Dt$, where Gt is the number of germination days and Dt is the corresponding number of days. Vitality index = $Gi\times S$, where S is the length of seedlings (1).

Determination of amino acid content

The samples containing 10-20 mg of protein (about 50-100 mg, accurate to 0.1 mg) added with 20 ml anaerobic, 6 mol L^{-1} hydrochloric acid 10-15 ml and 3-4 drops of newly distilled phenol. Then tubes were placed in refrigerator and freeze for 3-5 minutes. Then it is connected to the suction pipe of the vacuum pump, pumped vacuum (close to 0 Pa), and then filled with high-purity nitrogen. Then vacuum and filled with nitrogen, repeated three times, seal or tighten the screw cap in the nitrogen filled state, put the sealed hydrolysis tube in a constant temperature drying oven at 110±1 ℃, removed and cooled after hydrolysis for 22 h; opened the hydrolysis tube, filter the hydrolysate, rinsed the hydrolysis tube with deionized water for several times, and transferred all the hydrolysate to a 50 ml volumetric

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bottle with deionized water. Absorb 1ml of filtrate in a 5 ml volumetric bottle, dry with a vacuum dryer at 40-50 ℃, the residue is dissolved with 1-2 ml water, and then dried, repeated twice, and finally steamed; dissolve in 1ml buffer with pH 2.2 for instrument determination.

Statistical analysis of data

The recorded observations were analyzed by two-way analysis of variance (ANOVA) by using SPSS26.0 and treatment means were compared at $p \leq 0.05$ level.

Results

Effects of NaCl and NaHCO3 on oat seed germination

With the increase of NaCl and $NaHCO_3$ concentrations, the germination potential and germination rate were decreased, and the effects of $NaHCO_3$ stress on germination potential and germination rate were greater than those of NaCl stress at the same concentration. NaCl showed significant ($P<0.05$) difference at 200 mmol L^{-1}, whereas, the threshold level for $NaHCO_3$ was about 50 mmol L^{-1} (*Fig. 1A, B*).

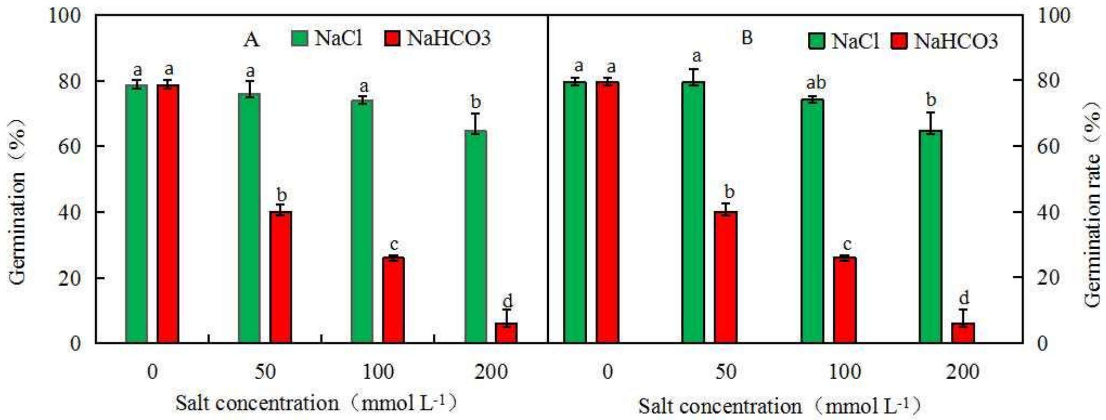

Figure 1. *Effects of NaCl and $NaHCO_3$ stresses on oat seed germination. Note: Different letters indicate significant difference between different treatments ($p<0.05$). The data is mean (n=3) with ± standard error*

Effects of NaCl and $NaHCO_3$ stress on aboveground and subsurface parts of oat

Less concentration (50 and 100 mmol L^{-1}) of NaCl stress showed non-significant ($P>0.05$) effect that was similar with control treatment. Contrarily, a significant ($P>0.05$) effect of NaCl stress was recorded at 200 mmol L^{-1}. On other hand, the concentration of $NaHCO_3$ stress greater than 50 mmol L^{-1} was significant ($P< 0.05$) with control (*Fig. 2*) indicating that alkali stress was greater than salt stress on oat length. Similar trend was recorded for biomass and water contents at germination stages (*Fig. 2*).

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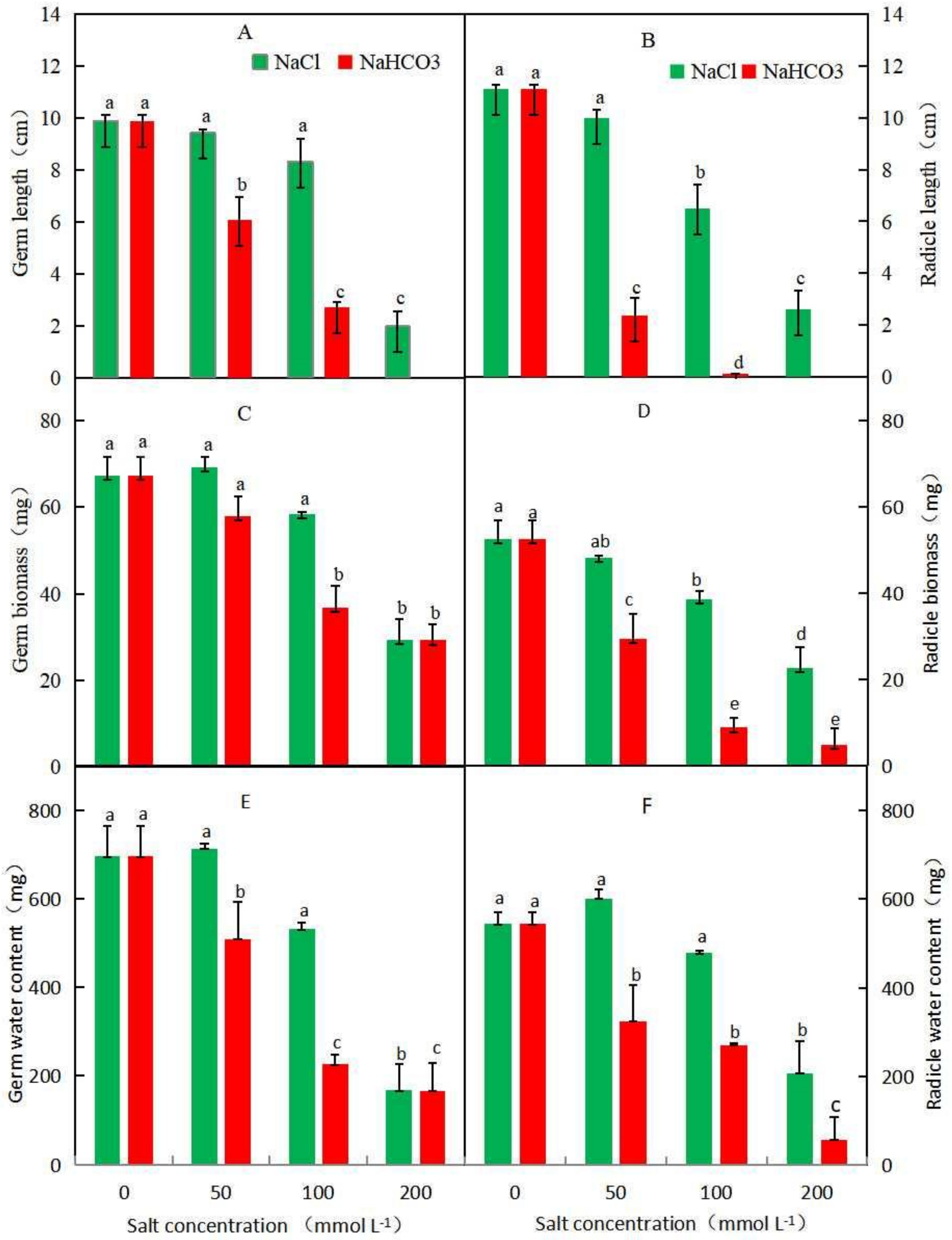

***Figure 2.** Effects of NaCl and $NaHCO_3$ stresses on aboveground and subsurface parts of oat. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

Effects of NaCl and $NaHCO_3$ on root-shoot ratio of oat

Under NaCl stress, there was no significant difference in the ratio between 50-100 mmol L^{-1} and the control (P>0.05), and there was a significant difference in the ratio between 200 mmol L^{-1} and the control (P<0.05), under $NaHCO_3$ stress, there were

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significant differences in the ratio between the groups with the concentration greater than 50 mmol L^{-1} and the control group (P>0.05) (*Figure 3A*).

Under NaCl stress, the ratio between 50-200 mmol L^{-1} and the control was not significantly different (P>0.05), but under $NaHCO_3$ stress, the ratio between all groups and the control was significantly different ($P<0.05$) (*Figure 3B*).

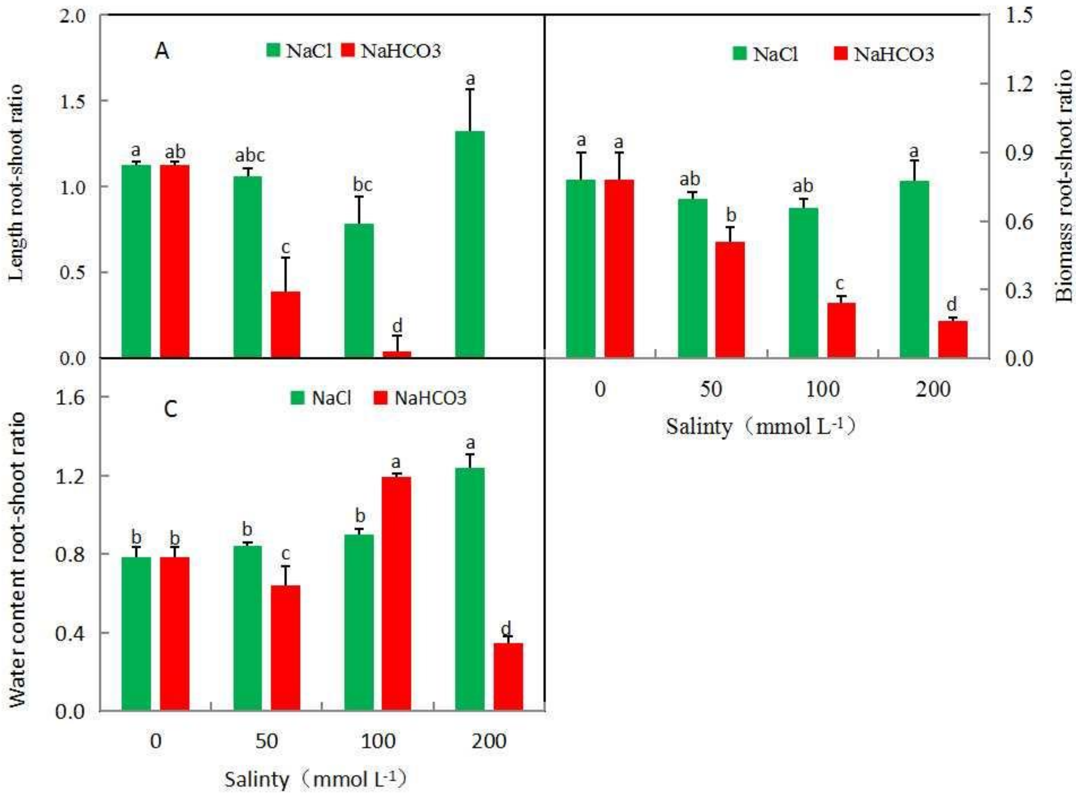

***Figure 3.** Effects of NaCl and $NaHCO_3$ stress on root-shoot ratio of oat. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

Under NaCl stress, there was no significant difference in the ratio between 50-100 mmol L^{-1} and the control (P>0.05), and there was a significant difference in the ratio between 200 mmol L^{-1} and the control ($P<0.05$), under $NaHCO_3$ stress, there were significant differences between the concentration and control ratio among all groups ($P<0.05$) (*Figure 3C*). The difference between 100 mmol L^{-1} and 200 mmol L^{-1} was very significant.

Effects of NaCl and $NaHCO_3$ stress on various amino acids in oat

Under NaCl stress, there was no significant difference in aspartic acid content between the control and the concentration of 50 mmol L^{-1} (P > 0.05), while there was significant difference between the Asparagine content and the control at the concentration of 100 mmol L^{-1} to 200 mmol L^{-1} (P < 0.05). Under $NaHCO_3$ stress, there were no significant differences in aspartic acid content between the control group and the concentration of

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50 mmol L^{-1} ($P > 0.05$), but significant differences between the aspartic content and the control group at 100 mmol L^{-1} ($P<0.05$) (*Fig. 4A*)

Under NaCl stress, 50 mmol L^{-1} was significantly higher than control ($P<0.05$), glutamic acid content decreased with increasing concentration, and there were significant differences among all groups ($P<0.05$), under $NaHCO_3$ stress, there was no significant difference in glutamic acid content between the control group and the concentration at 50 mmol L^{-1} ($P >0.05$), and at 100 mmol L^{-1} ($P>0.05$). Compared with the control group and 50 mmol L^{-1} concentration, the difference was significant ($P>0.05$) (*Fig. 4B*).

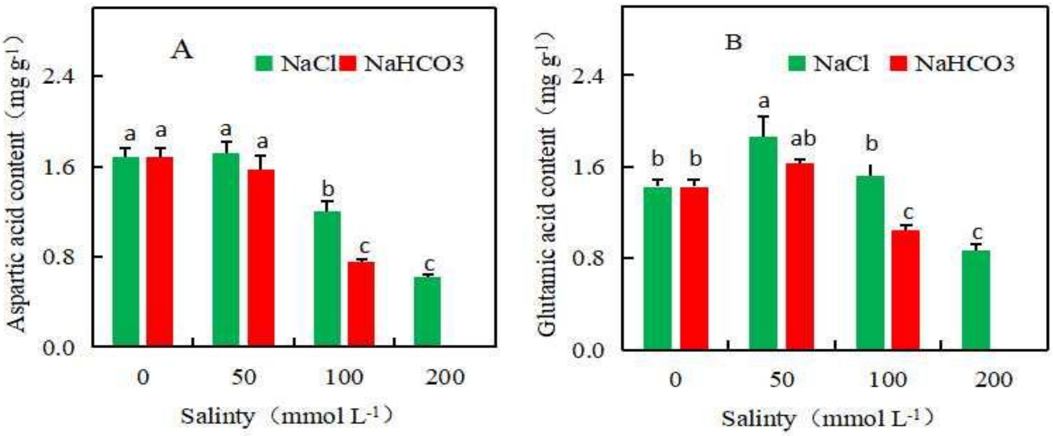

Figure 4. *Effects of NaCl and $NaHCO_3$ stress on acidic amino acids in oat. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

Under NaCl stress, there was no significant difference in histidine content between 50-100 mmol L^{-1} and control ($P > 0.05$), while there was significant difference between 100-200 mmol L^{-1} and control ($P < 0.05$). Under $NaHCO_3$ stress, there was no significant difference in histidine content between NaCl and control ($P > 0.05$). At the concentration of 50-100 mmol L^{-1}, the ratio of histidine content to control was significantly different ($P<0.05$) (*Figure 5A*).

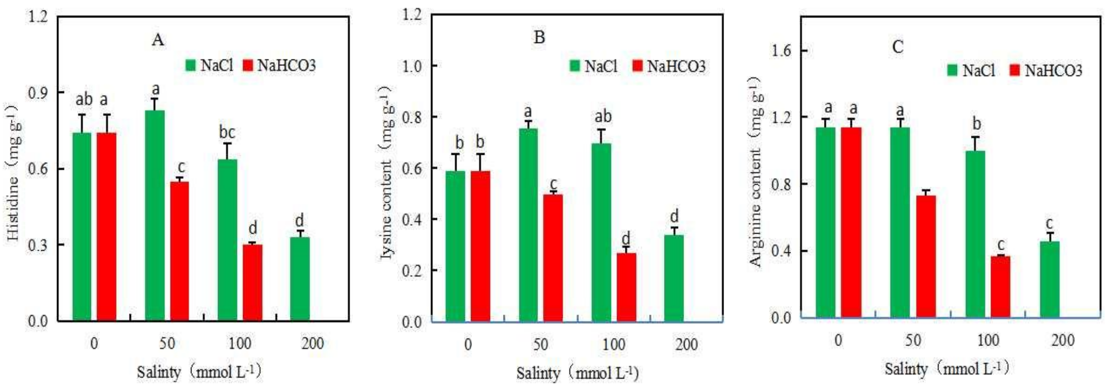

Figure 5. *Effects of NaCl and $NaHCO_3$ stress on alkaline amino acids in oat. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

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Under NaCl stress, there were significant differences among all groups (P<0.05), at 50 mmol L^{-1} lysine content was significantly different from that of control (P<0.05), when the concentration was 50 and 200 mmol L^{-1}, the ratio of lysine content was significantly different from that of the control (P<0.01), and when the concentration was 50 mmol L^{-1} under $NaHCO_3$ stress, the lysine content was not significantly different from that of the control (P<0.05), 100 mmol L^{-1}, the difference was significant compared with the control (*Figure 5B*).

Under NaCl stress, there were significant differences among different concentrations (P<0.05), the concentration of arginine decreased with the increase of concentration, and the concentration of 50 mmol L^{-1} and 200 mmol L^{-1} had significant difference compared with the control (P<0.05), at 100mmol L^{-1}, there was no significant difference in the ratio of arginine to the control (P>0.05), under $NaHCO_3$ stress, there was no significant difference in the ratio of arginine to the control at the concentration of 50 mmol L^{-1} (P >0.05), and at 100 mmol L^{-1}, there was significant difference in the ratio of arginine to the control (P<0.05) (*Figure 5C*).

Under NaCl stress, there were significant differences in glycine content among all groups when the concentration was 50-200 mmol L^{-1} (P<0.05), the glycine content was significantly different from the control at 50 mmol L^{-1} (P<0.05), under $NaHCO_3$ stress, there was no significant difference between glycine content and control at 50 mmol L^{-1} (P>0.05), and significant difference between glycine content and control at 100 mmol L^{-1} (P<0.05) (*Fig. 6A*).

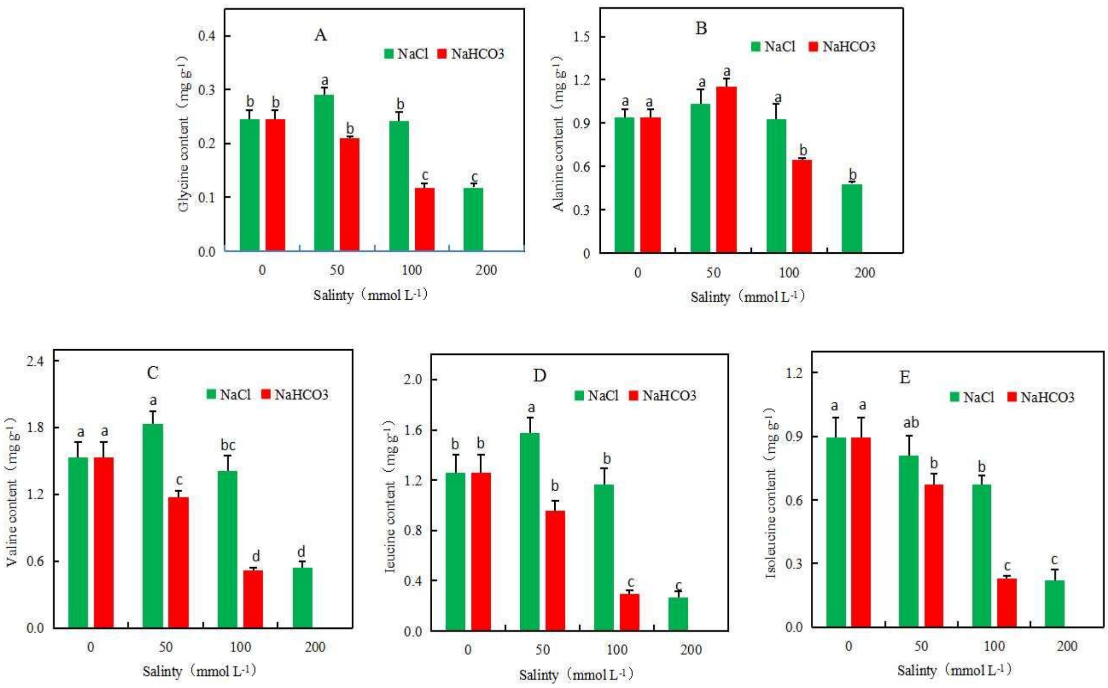

Figure 6. *Effects of NaCl and $NaHCO_3$ stress on neutral aliphatic amino acid content. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

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Under NaCl stress, there was no significant difference in alanine content (alanine content) between 50-100 mmol L^{-1} and control (P>0.05), while there was significant difference between alanine content and control at 200 mmol L^{-1} concentration (P<0.05). Under $NaHCO_3$ stress, there was no significant difference between alanine content and control (P<0.05). Alanine content was not significantly different from control at concentration of 50 mmol L^{-1} (P>0.05), but significantly different from control at concentration of 100 mmol L^{-1} (P<0.05) (*Fig. 6B*).

Under NaCl stress, there was no significant difference between the ratio of valine content and the control at the concentration of 50-100 mmol L^{-1} (P>0.05), while the ratio of valine content and the control at the concentration of 200 mmol L^{-1} (P<0.01). Under $NaHCO_3$ stress, the ratio of valine content was significantly different from the control (P<0.01). At the concentration of 50-100 mmol L^{-1}, the ratio of valine content to control was significantly different (P<0.05) (*Fig. 6C*).

Under NaCl stress, there were significant differences among all groups (P<0.05). At 50 mmol L^{-1}, leucine content was significantly different from control (P<0.05), at the concentration of 50 and 200 mmol L^{-1}, the ratio of leucine content was significantly different from that of the control ($P < 0.01$), at the concentration of 50 mmol L^{-1} under $NaHCO_3$ stress, the ratio of leucine content was not significantly different from that of the control (P<0.05), 100 mmol L^{-1}, the difference was significant compared with the control (*Fig. 6D*).

Under NaCl stress, there was no significant difference in the ratio of isoleucine content between the control and the concentration of 50-100 mmol L^{-1} (P>0.05), while there was significant difference between the isoleucine content and the control at the concentration of 100-200 mmol L^{-1} (P<0.05). Under $NaHCO_3$ stress, there was no significant difference between the isoleucine content and the control (P<0.05). When the concentration was 50-100 mmol L^{-1}, the ratio of Isoleucine content was significantly different from that of control (P<0.05) (*Fig. 6E*).

Under NaCl stress, there was no significant difference in serine content under different concentrations (P>0.05). Under $NaHCO_3$ stress, when the concentration was 50-100 mmol L^{-1}, There was significant difference between serine content and control ratio ($P<0.05$) (*Fig. 7A*).

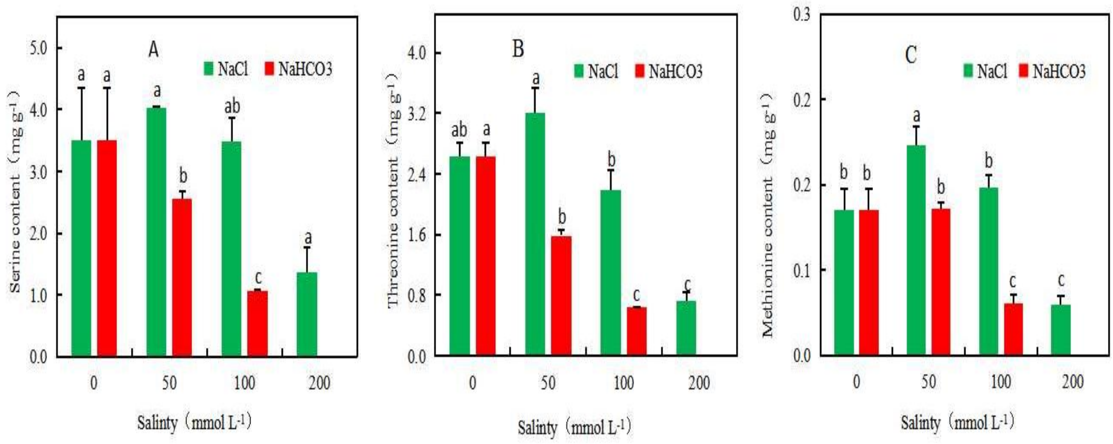

Figure 7. *Effects of NaCl and $NaHCO_3$ stress on neutral hydroxyl and sulfur-containing amino acids. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

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Under NaCl stress, there was no significant difference in the ratio of threonine content between the control and 50-100 mmol L^{-1} ($P>0.05$), while there was significant difference between the threonine content and the control at the concentration of 200 mmol L^{-1} ($P<0.05$). Under $NaHCO_3$ stress, there was no significant difference in the ratio of threonine content ($P<0.05$). There was no significant difference in threonine content between 50 mmol L^{-1} and control ($P>0.05$), and significant difference between 100 mmol L^{-1} and control ($P<0.05$) (*Fig. 7B*).

Under NaCl stress, there were significant differences among different concentrations ($P<0.05$), methionine content decreased with the increase of methionine concentration, when the concentration was 50 mmol L^{-1} and 200 mmol L^{-1}, the ratio of methionine content was significantly different from that of control ($P<0.05$), 100 mmol L^{-1}, there was no significant difference between the two groups ($P>0.05$). Under $NaHCO_3$ stress, there was no significant difference between the methionine content (methionine content) and the control group at 50 mmol L^{-1} concentration ($P>0.05$). At 100 mmol L^{-1}, the ratio was significantly different from that of control ($P<0.05$) (*Fig. 7C*).

Under NaCl stress, the contents of phenylalanine, tyrosine and proline were significantly different among all groups ($p<0.05$), 50 mmol L^{-1}, and the ratio of control was significantly different ($p<0.05$), when the concentration was 50 and 200 mmol L^{-1}, there was a significant difference in the ratio of phenylalanine, tyrosine and proline compared with the control ($P<0.01$), when the concentration was 50 mmol L^{-1} under $NaHCO_3$ stress, there was no significant difference in the contents of phenylalanine, tyrosine and proline compared with the control ($P<0.05$), 100 mmol L^{-1}, the difference was significant compared with the control. The change trend was consistent (*Fig. 8A, B, C*).

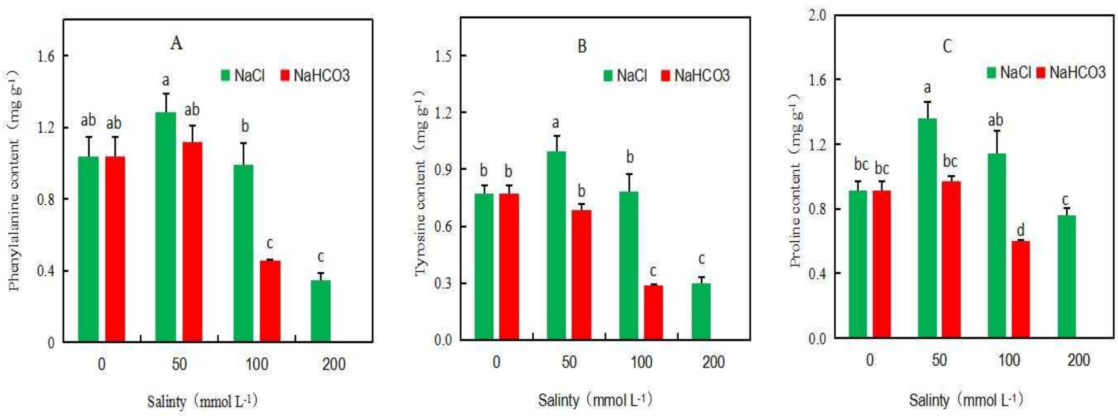

Figure 8. *Effects of NaCl and $NaHCO_3$ stress on aromatic or heterocyclic amino acids. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

Under NaCl stress, there were significant differences among different concentrations ($P<0.05$). With increasing salt concentration, total amount of amino acids decreased when the concentration was 50 mmol L^{-1} and 200 mmol L^{-1}, the ratio of total amino acids was significantly different from that of control ($P<0.05$), 100 mmol L^{-1}, there was no significant difference between the two groups ($P>0.05$). Under $NaHCO_3$ stress, there was no significant difference between the total amino acids and the control group at

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50 mmol L^{-1} concentration (P>0.05). At 100 mmol L^{-1}, the ratio was significantly different from that of control (P<0.05) (*Fig. 9*).

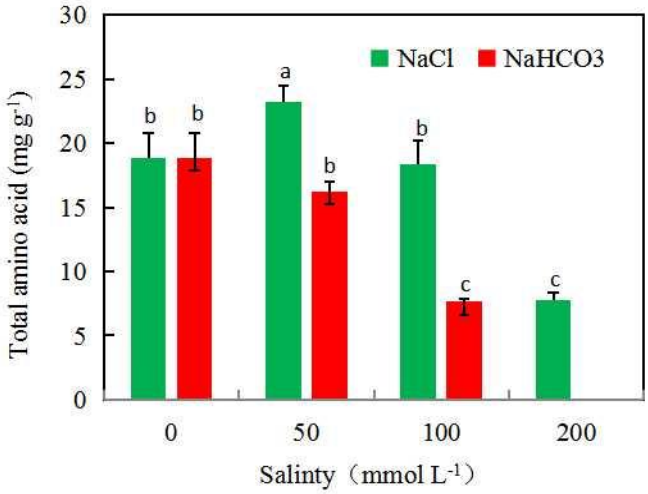

***Figure 9.** Effects of NaCl and $NaHCO_3$ stress on total amino acids. Note: Different letters indicate significant difference between different treatments (p<0.05). The data is mean (n=3) with ± standard error*

Discussion

Comparison of NaCl and $NaHCO_3$ stresses

The main factors of NaCl stress in neutral salt are ion toxicity mainly caused by Na^+ and physiological drought caused by osmotic stress which is caused by decreased water potential due to high concentration of salt) (Shahzad et al., 2019; Abrar et al., 2020). Alkaline salt $NaHCO_3$ stress also has the dual effect of high pH value in addition to the effect of salt (Liu and Saneoka, 2019; Yu et al., 2019). The effect of alkaline soil on crop plant is more stronger than the effect of salinity stress (Wang et al., 2022). All these findings supported our observations about the most detrimental effects of alkali stress compared to salt stress at germination stage of oat crop.

Inhibiting effect of saline and alkaline stresses on oat seed germination

Biomass serves as a comprehensive indicator of plant responses to saline and alkaline stresses, and is an accurate measure of resistance to these conditions (Geng et al., 2020). The present study showed better oat seed germination and growth at low level of stresses whereas, treatments with increased level of stresses significantly (P<0.01) inhibited the plant growth. Alkaline salt can jeopardize plant survival and impeded the growth of oat seedlings (Mu et al., 2015). Additionally, many plants have varying tolerance to alkalinity and salinity, however, the resistance of the same plant to saline or alkaline conditions varies across different growth periods (Liu et al., 2020). For same plant, its resistance to saline or alkaline is different in growth periods. Our results showed that under saline-alkali and alkaline stress, germination rate and germination potential decreased with the rise in salt stress, soil pH, and the increase of alkaline intensity had a more obvious effect on germination rate (*Figure 3A*, *Figure 3B*).

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NaCl and $NaHCO_3$ stress on dry weight and adaptation strategies between aboveground and underground parts

The development and physiological responses of various plant organs to salt and alkali stress vary depending on the species (Guo et al., 2015; Jia et al., 2019; Fang et al., 2021). Plants isolate salt ions in their roots or store them in stems and other organs to reduce transport and damage to other organs, or expel salt ions through special ion channels, giving them a high salt tolerance (Ketehouli et al., 2019). When comparing above-ground and below-ground salt tolerance in plants, studies have shown different results, such as betel nut, maize, and wheat (Chitnis et al., 2020). In this study, the growth and physiological response of seedlings under of oat NaCl stress showed different trends, that is, the length of radicle, especially the biomass, was reduced less than that of germ. Under NaCl stress, the roots of oat seedlings had a protective effect, but their tolerance to salt and alkali was stronger than that of stems and leaves.

Trade-offs and adaptation strategies of various amino acids under NaCl and $NaHCO_3$ stress

In the process of seed germination, the required nutrients are stored in the previous generation, in which the protein will be hydrolyzed into a variety of amino acids, amino acids in the cell metabolism has a variety of ways, one is through biosynthesis to form protein, the other is catabolism (Rosental et al., 2014). Higher plants need amino acids to synthesize proteins and other organic nitrides with the continuous growth of the body, and amino acids will not accumulate too much in the organic body. Previous researchers showed that the soluble protein decreases and protein hydrolysis predominates under water stress, thus free amino acid level increased (Živanović et al., 2020). The increase of free amino acid content plays an osmotic regulating role in maintaining plant water potential, and is also a form of plant energy storage under stress, avoiding excessive material consumption and alleviating the toxicity caused by decomposition products (Zanganeh et al., 2019). Many researchers have examined the impact of soil drought on amino acid levels in wheat leaves and seeds across various growth stages. Findings indicate that drought stress significantly elevates the concentration of free amino acids in wheat, with polar amino acids and proline exhibiting heightened sensitivity to such stress. Notably, soil drought during the seedlings stage has a more pronounced effect on free amino acids in wheat leaves compared to drought experienced during the flowering stage (Marček et al., 2019). Some scholars selected 10 wheat varieties that had been screened for many years to determine the content of 17 kinds of free amino acids in their flag leaves at jointing stage, and discussed the relationship between the content of free amino acids and the resistance of varieties to aphid (Akbar et al., 2014). The findings indicated a positive correlation between the levels of glutamic acid, alanine, lysine, and aspartic acid in various wheat varieties in response to aphid's attack. However, leucine, isoleucine, proline, and valine content had a negative correlation with aphid infestation rate. These results indicated that the higher the content of the first 4 kinds of free amino acids in wheat varieties, the weaker the resistance of wheat varieties.

Total free amino acids in oats increased, and decomposition of stored macromolecules produces small molecules of organic matter during plant seed germination, while salt and alkali inhibit hydrolase activity (Prates and Yu, 2017). Proteins are the most abundant and most complex biological macromolecules in living cells, and they are everywhere in the biological world and participate in almost all life activities and life processes (Benner,

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2010). Protein is the material basis of all life, and protein is synthesized by a variety of amino acids, in this sense, amino acids are essential for plant growth (Galili et al., 2016). But amino acid nutrition in higher plants has been poorly studied in the past.

Conclusion

In conclusion, seed germination index showed a regulatory response to saline-alkali stress. The increasing concentration of saline-alkali stress decreased the germination, potential, germination index, radicle growth and biomass production. Moreover, saline-alkali also changed the concentration of different amino acids. This study primarily assessed the effect of saline-alkali stress on germination. Therefore, more studies are needed to explore the impact of saline-alkali stress on plant physiology, biochemical and molecular responses.

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