PLANT SCIENCE TODAY
Vol 12(3): 1-8
https://doi.org/10.14719/pst.4391

eISSN 2348-1900

RESEARCH ARTICLE

Intercropping maize with tomato plants improved the yield and fruit quality of tomato plants grown under salinity stress

Rana Choukri[1], Abderrahmane Rahhou[1]*, Mohamed Faize[2], Mostapha Maach[1,4], Mohamed Fardouch[1], Manuel Rodriguez Concepcion[3], Ali Skalli[1], Mustapha Akoudad[1] & Mourad Baghour[1]

[1]Laboratory OLMAN-BPGE, Multidisciplinary Faculty of Nador, Mohamed First University – Oujda, 62700 Nador, Morocco
[2]Laboratory of Plant Biotechnology, Ecology and Ecosystem Valorization, URL CNRST10, Faculty of Sciences, University ChouaibDoukkali, El Jadida, Morocco
[3]Institute for Plant Molecular and Cell Biology, CSIC, Valencia, Spain
[4] Research Institute in Horticulture and Seeds (IRHS), University of Angers, Angers, France

*Correspondence email - abderahmane.rahhou@ump.ac.ma

Received: 14 October 2024; Accepted: 02 May 2025; Available online: Version 1.0: 23 July 2025; Version 2.0: 31 July 2025

Cite this article: Rana C, Abderrahmane R, Mohamed F, Mostapha M, Mohamed F, Manuel R C, Ali S, Mustapha A, Mourad B. Intercropping maize with tomato plants improved the yield and fruit quality of tomato plants grown under salinity stress. Plant Science Today. 2025; 12(3): 1-8. https://doi.org/10.14719/pst.4391

Abstract

Climate change represents a significant challenge for agriculture and food security. This phenomenon contributes substantially to food insecurity by increasing the frequency and severity of abiotic stresses such as salinity. Salt stress can unfavorably influence plant development and efficiency of numerous crops, particularly in arid and semi-arid zones. Different strategies and procedures can be utilized to moderate the negative impact of intemperate salt concentration within the soil. Here, the saltiness resistance of 2 *Solanum lycopersicum* L. varieties (Karima and Jade) grown in an intercropping system with maize was assessed by measuring fruit production and quality. Our results show that chlorophyll a was higher in the intercropping tomato than in the monoculture plants in both control (T_0 = 0 mM NaCl) and NaCl-treated varieties (T_1= 125 mM NaCl). Moreover, in intercropping systems, the variety of Karima was less affected by NaCl treatment. However, for Jade variety, its intercropping with maize increased its production under both normal and salinity stress conditions. Regarding fruit quality, pH value of Karima was higher in intercropped plants under NaCl treatment, while the Brix value was less affected by NaCl and intercropping conditions. Finally, intercropping practices significantly influenced Na^+ and K^+ accumulation and Karima variety showed the capacity to accumulate more K^+ and less Na^+.

Keywords: fruit quality; growth parameters; intercropping; maize; salinity tolerance; tomato

Introduction

Climates alter proceed to extend the recurrence and seriousness of different abiotic stresses such as extraordinary temperatures, drought and salinity. Moreover, it contributes altogether to the interruption of salt water into agricultural soils, particularly in coastal regions as a result of the sea level rise and may also increase soil and groundwater salinity by excessive utilization of groundwater in arid and semi-arid regions (1). It is estimated that at least 900 million ha, or approximately 7 % of the world's land area, are affected by salinity (2). Salinity is considered as one of the most serious factors limiting plant growth and crop productivity by affecting various physiological and biochemical parameters of plants (3).

Soil salinity refers to the concentration of soluble salts in the soil, commonly measured by electrical conductivity (EC) in deciSiemens per meter (dS/m). Saline soils are defined by an EC of 4 dS/m or higher. In contrast, sodicity relates specifically to the presence of sodium ions, assessed through the sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP). Sodic soils have an SAR greater than 13 mmolc L^{-1} or an ESP of 15 % or more. While salinity affects plant growth by reducing water uptake, sodicity impacts soil structure, leading to reduced permeability. Monitoring EC is crucial, as elevated salinity can impair plant growth and soil health (4).

Electrical conductivity serves as a key indicator of soil salinity; higher EC values indicate greater salt concentrations. Monitoring and managing EC is crucial, as excessive salinity can impair plant growth, reduce microbial activity and degrade soil structure (5).

Various strategies have been developed to reduce salt tress, including breeding, marker-assisted selection, genetic engineering and genome editing (6). In addition, some eco-friendly cropping practices, such as mulching, the use of plant growth regulators and intercropping, have been used to improve tolerance to different types of stresses and to conserve environmental sustainability and biodiversity.

Various studies have reported that intercropping practices may alleviate the negative impacts of many biotic and abiotic stresses such as drought, salinity, extreme temperatures, soil nutrient limitations and pest control (7, 8). In addition, the financial advantages of intercropping are evident through increased net returns and benefit-cost ratios. In a maize-faba bean study, intercropping systems yielded a 13 % to 42 % higher economic return compared to sole maize cropping. This boost in income is attributed to the diversified produce and more efficient resource utilization inherent in intercropping systems (9).

Furthermore, agro-ecological intercropping can improve soil salt solubility by producing organic acids through root excretion; mitigate secondary salinization and surface soil evaporation and increase soil protection and increases crop productivity through its impacts on the physical, chemical and biological properties of the soil (10,11). Moreover, its role extends to combating global warming by reducing N_2O and CH_4 emission (12). In addition, some other agricultural practices like biochar application can help alleviate salinity stress and enhance plant morphology by improving soil properties and nutrient retention; however, its high cost remains a challenge for large-scale use (13, 14).

Previous research suggested that selecting appropriate species, genotypes and row combinations could be a promising agricultural approach to valorize salt-affected lands (15). The objective of any investment is to recover funds and maximize benefits (16). Intercropping recent studies have reported the beneficial effect of cultivation of halophytic plants at the same time or prior to the cultivation of crop plants (intercropping) on desalination of the soil and therefore, improving salt tolerance, plant mineral nutrition and favoring crop yield (17, 18).This practice reduces Na^+ uptake in crops and improves soil properties, leading to increased productivity (11, 19). While intercropping can mitigate salinity stress, it may introduce shade stress, negatively impacting plant growth and quality (20).

In recent years, many studies have reported the importance of using halophytes to remediate saline soils, which decrease water consumption and improve soil quality (21). Intercropping with halophytes or salt-tolerant crops decreases salt accumulation improves soil properties and enhances crop productivity in saline soils (11). However, intercropping may lead to shade stress characterized by low red: far-red (R:FR) ratio and low light intensity, reducing plant growth, quality and productivity due to altered light quality and competition for light among plants (20, 22).

According to the Food and Agriculture Organization (FAO), global tomato production has been on a steady rise over the past decades. In 2022, the worldwide production of tomatoes reached approximately 186 million tonnes, making it the most produced vegetable globally. In Morocco, tomato production was reported at 1.39 million MT in 2022 (23).

In this context, the tomato *Solanum lycopersicum* L. A popular vegetable known as a source of nutrient and it was widely used in the service of studies such as biotechnology and agricultural practices to studying their resistance to a range of environmental stresses (24).

Given the increasing impact of soil salinity on agricultural productivity, the intercropping of tomato-maize offers a sustainable, cost-effective strategy to improve crop resilience, optimize resource use and enhance economic returns in salt-affected regions. The aim of this study was to demonstrate the potential effect of tomato-maize intercropping on tomato by improving plant growth, fruit yield and fruit quality under saline conditions.

Materials and Methods

Plant material and growth conditions

The experiment was conducted in a plastic greenhouse at Mohamed Premier University (Nador, Morocco) in March 2021. The climate was semi-arid and the nearby area was intensively used for agriculture. The 2 varieties (Jade, Karima) of tomato and the maize variety (Blancato) used for this experiment were first germinated in alveolar plates filled with black peat. Once they reached the leaf stage, they were repotted into cups, all in a culture chamber with a photoperiod of 8 hr/16 hr and a temperature of 24 °C. After 3 weeks, the pots were moved to the greenhouse to begin the salt stress experiment. Two batches were established for the salt stress experiment: monoculture (-IC) and intercropping (+IC) utilizing maize plants and 2 treatments 0 mM (T0) and 125 mM (T1) of NaCl were opted.

Plant sampling and analysis

Following transplanting (70 days), the plants in both trials were carefully taken out of their substrate. After rinsing, the plant components (fruits, leaves, stems and roots) were blotted on filter paper. According to Lichtenthaler, plant leaf fresh matter was utilized at each sampling to determine the following: leaf weight, yield and chlorophyll concentration (25).

To determine the effect of salt stress on fruit quality and mineral composition of the studied varieties Karima and Jade treated with 120 mM NaCl and cultivated either in sole cropping or intercropping farming systems, the pH and total soluble solids (TSS), Na^+, K^+ and lycopene have been measured using the following instruments respectively: INE-PHSJ-3F pH Meter, PAL-1 ATAGO refractometer, Horiba LAQUA compact ionometer.

Statistical analysis

The statistical analysis was carried out with the help of Statgraphics Centurion 19. To evaluate the differences between treatments, Analysis of variance was utilized to assess variations between treatments and significance was attributed to plant genotypes at $P \leq 0.05$. In the Figures, distinct letters indicate significant differences based on Duncan's multiple range test (DMRT).

Results and Discussion

The effect of salinity stress treatments on chlorophyll, a content of tomato plants grown in both monoculture and intercropped with maize is shown on the Fig. 1. Salt stress significantly ($p<0.05$) reduced chlorophyll concentration in both varieties Karima and Jade. However, under intercropped crops systems (IC), the chlorophyll content of Karima was higher in both control and NaCl treatment compared to sole crops (SC). In previous studies, researchers have found that changes in light availability have significant effects on chlorophyll contents, which decrease as light levels

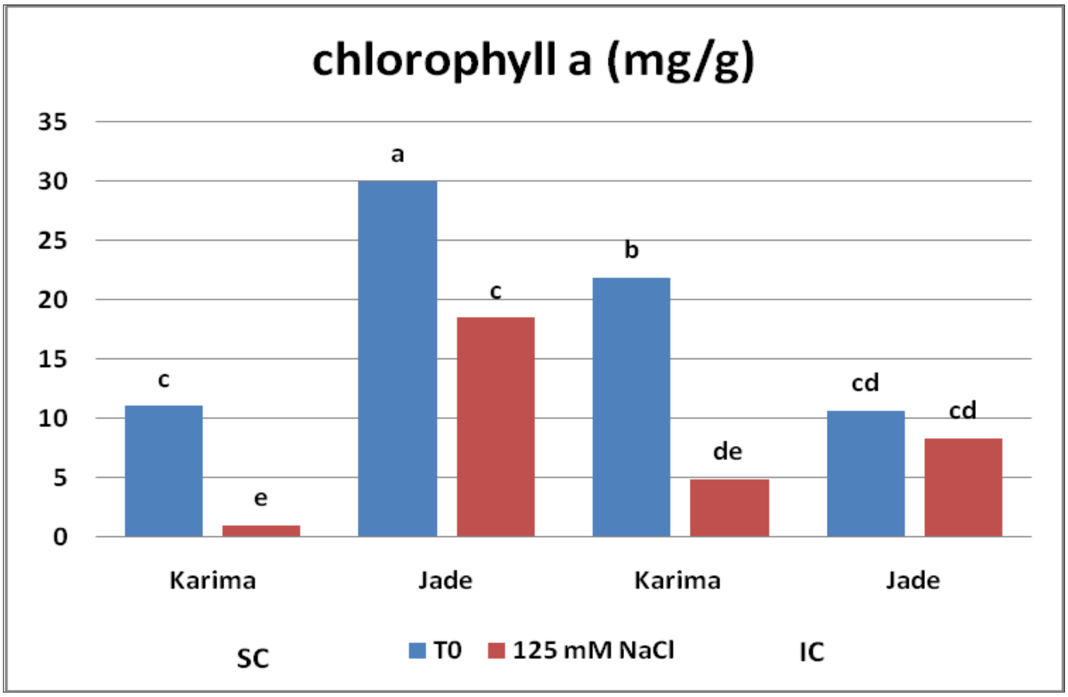

Fig. 1. Effect of NaCl (125 mM) on the chlorophyll a content of tomato plants grown either as a sole crop (SC) or as an intercrop with maize (IC).

fall (26). Other study has detailed an increment in chlorophyll levels and a decrease within the photosynthetic rate for the intercropping spring tomato compared to the monoculture tomato (27).

Recently, 'Campbell 33' tomato variety was affected by shade generated when grown at high density, as evidenced by reduced photosynthetic pigments and net photosynthesis (28). Similar results have been reported by (20) and (29) who reported that shade led to reduce chlorophyll content and net photosynthetic rate, when compared to plants grown under normal light condition. Rewrite the sentence and place the reference at the end. However, under our experimental conditions, the effect of shade on chlorophyll content greatly depends on plants' genotype, Karima being positively affected by intercropping under both control and saline conditions (20, 29). Other studies on the effect of shade on tomato plants reported that shade decreased chlorophyll content (30). Also, it was reported that increasing shade resulted in increasing tomato fruit yield with best results when applying 35 %s shade (30).

To investigate the effect of intercropping tomato (base crops) and maize (component crops) on tomato salt tolerance, we measured the crop yield and fruit quality of 2 tomato varieties (Jade and Karima) grown under control conditions (0 mM NaCl) and in the presence of 125 mM NaCl. The results (Fig. 2) showed significant differences ($p<0.05$) between the 2 varieties and the 2 treatments. Under non-saline conditions, Karima produced higher yield in both intercropping and sole cropping systems compared to Jade variety (Fig. 2). In addition, in intercropping system, the observed reduction in yield of Karima was only 20 % under

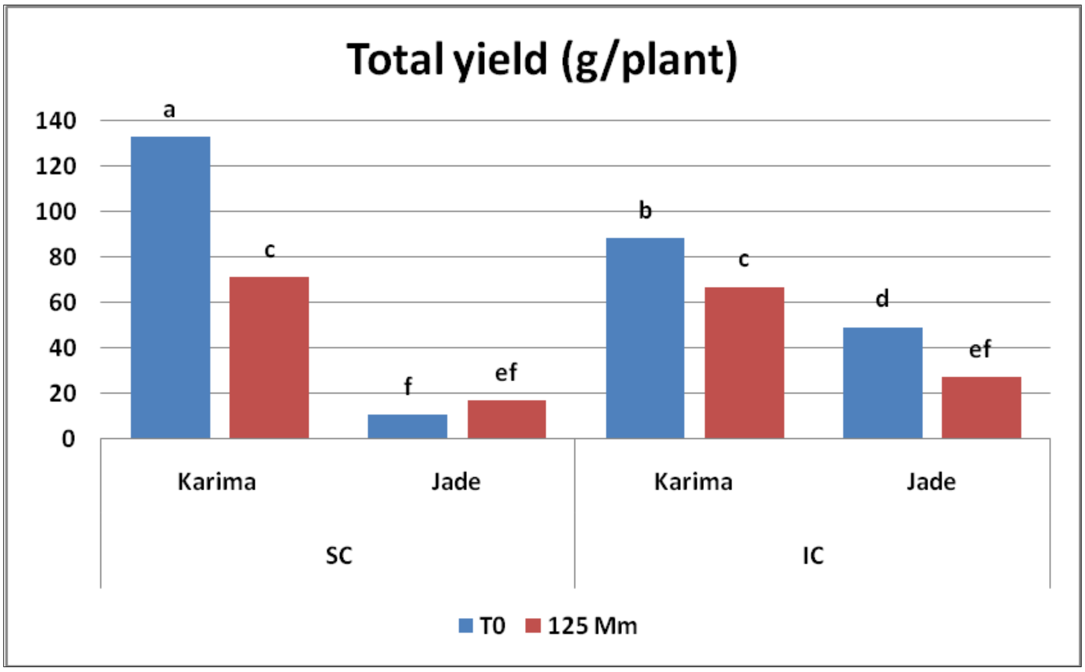

Fig. 2. Effect of salt treatment (125 mM) on total yield (g/plant) of tomato plants in sole crop (SC) and in intercropping (IC) with maize.

NaCl treatment, however under sole cropping this reduction was by almost 36 %.

In a recent study, they found that the tomato variety 'Campbell 33' was affected by shade resulting from high-density cultivation by increasing plant height, thinning stems, decreasing root biomass and reducing photosynthetic pigments and net photosynthesis (28). Previously, it has been found that severe shading conditions significantly decreased the soybean yield and yield components (31, 32). In spring tomato, authors reported a decrease in total yield and an increase in net income than did monoculture (27). In the present study, intercropping treatment improved salt tolerance of both tomato varieties. Opposite results have been observed, suggesting that shade didn't affect tomato fruit yield and can be used to improve fruit quality such as reducing sun burn (33).

Furthermore, intercropping of maize enhanced quality of tomato under salt stress suggesting that rhizosphere microbial communities and mycorrhizal association contribute to the improved performance of tomato plants under salinity stress in maize cultivation systems such as maize-soybean cropping, which have been shown to influence the structure and function of rhizosphere soil microbial communities, potentially improving nutrient uptake and stress resistance in plants (34). Certain bacteria, like *Bacillus* species, can mitigate salinity stress in plants. For instance, *Bacillus* sp. PM31 has been found to enhance growth and reduce oxidative stress in maize under saline conditions, suggesting potential benefits in intercropping systems (35). Also, Arbuscular Mycorrhizal (AM) fungi have been documented to alleviate salt stress in various plants, including tomatoes, by enhancing water uptake, maintaining ion balance and improving overall plant health (36).

Results of measured pH and total soluble solids (TSS) content in Karima and Jade variety showed significant differences ($p<0.05$) between the 2 varieties and the 2 treatments (Fig. 3). pH was less affected by salinity treatment. Thus, the pH of Karima under intercropping, which increased by NaCl treatment, the pH of Jade under intercropping and that of Karima and Jade in sole cropping was negatively affected by salinity. Regarding the total soluble sold (TSS) content, NaCl treatment increased TSS value in both varieties grown either in sole cropping or intercropping systems. These values are

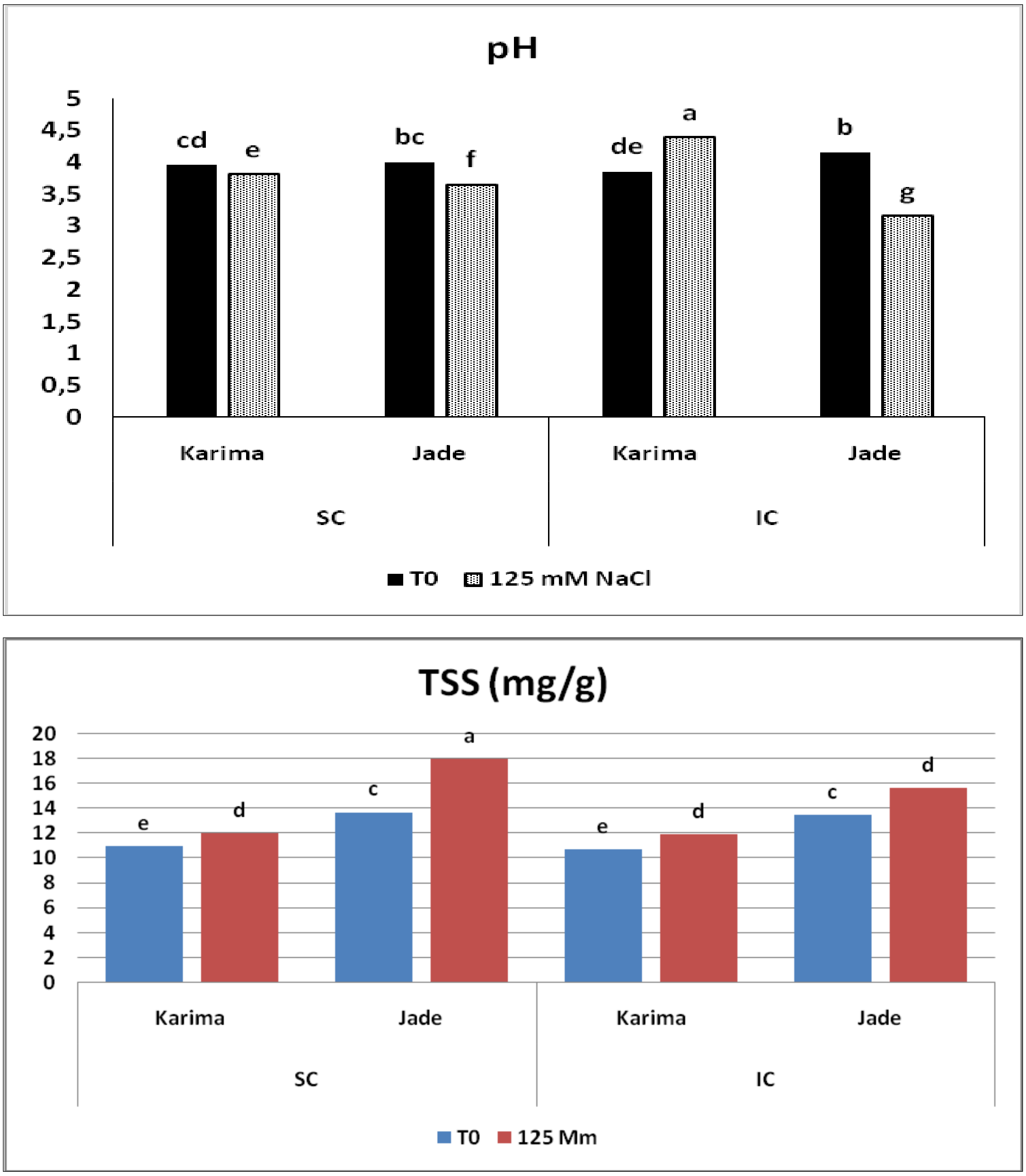

Fig. 3. Effect of salt treatment on pH and total soluble sold (TSS) in fruits of tomato in sole crop culture (SC) and in intercropping with maize (IC).

comparable to those reported in tomato plants grown either with or without NaCl (cv. MicroTom) (3, 37, 38). Previously, it have found that planting density can affect the ascorbic acid and soluble solid content of tomato plants (39). According to these authors, tomato fruits cultivated at higher planting densities had lower levels of ascorbic acid and higher levels of total soluble solids. The increased TSS content was caused by the advantages of shading tomato plants, which included lowering air temperature, soil temperature and radiation levels. This helped the plants adapt with heat stress (40).

The results of Na^+ and K^+ minerals are illustrated in the Fig. 4, revealing significant differences ($p<0.05$) between the 2 varieties and conditions. Under control conditions, Karima variety accumulates less NaCl under both monoculture and intercropped. Salinity treatment increased Na^+ content in both varieties and this increase is more pronounced in the Jade plants. The main ionic stress brought on by high salinity is caused by the toxicity of sodium (Na^+). Apart from its harmful impact, an elevated external Na^+ concentration inhibits the absorption of potassium (K^+), a vital mineral nutrient, resulting in inadequate cellular K^+ levels for enzymatic processes and osmotic regulation.(37, 41, 42). Results in this work suggest that the effect of intercropping on Na^+ accumulation depends on each variety and was more efficient for Karima plants treated with 125 mM NaCl, which was reduced by 26 % compared to monoculture plants. Previously, it was found that shading did not alleviate the negative effects of salinity on growth and Na^+ accumulation in orange trees (43). In the plants, K+ is closely related to fruit yield and quality and it's a key factor in the maintenance of osmotic adjustment and cell turgor and plays an important role in enzyme activation, photosynthesis and respiration; assimilate transport, protein metabolism and stomatal regulation (44, 45, 46). Our results showed that NaCl treatment increased K^+ content in both varieties cultivated either in low or in high density with maize (Fig. 4). Under intercropping conditions, Karima variety was more efficient in accumulating higher concentrations of K^+ under salinity stress conditions. These results suggest that intercropping could play an important role in improving fruit quality and increasing salinity tolerance of Karima variety under NaCl stress.

Similarly, it was reported that peanut/maize intercropping enhances the uptake of nutrients in peanut shoots such as P and K (19). Also, previous studies showed that shading increased fruit and foliar nutrient contents in bell pepper (40). Recently, it was obtained higher nitrogen, phosphorus and potassium uptakes in the intercropping systems compared to sole crops (47).Regarding the results of lycopene in this experiment (Fig. 5), salinity stress increased the lycopene content in Jade variety grown in monoculture and in Karima under intercropping systems.

These results are consistent with those reported, who have suggested that lycopene concentration expanded beneath high salt stress in both commercial cultuvar and a tomato landrace (48). Similarly, it was detailed that direct saltiness had a positive impact on lycopene collection (49).

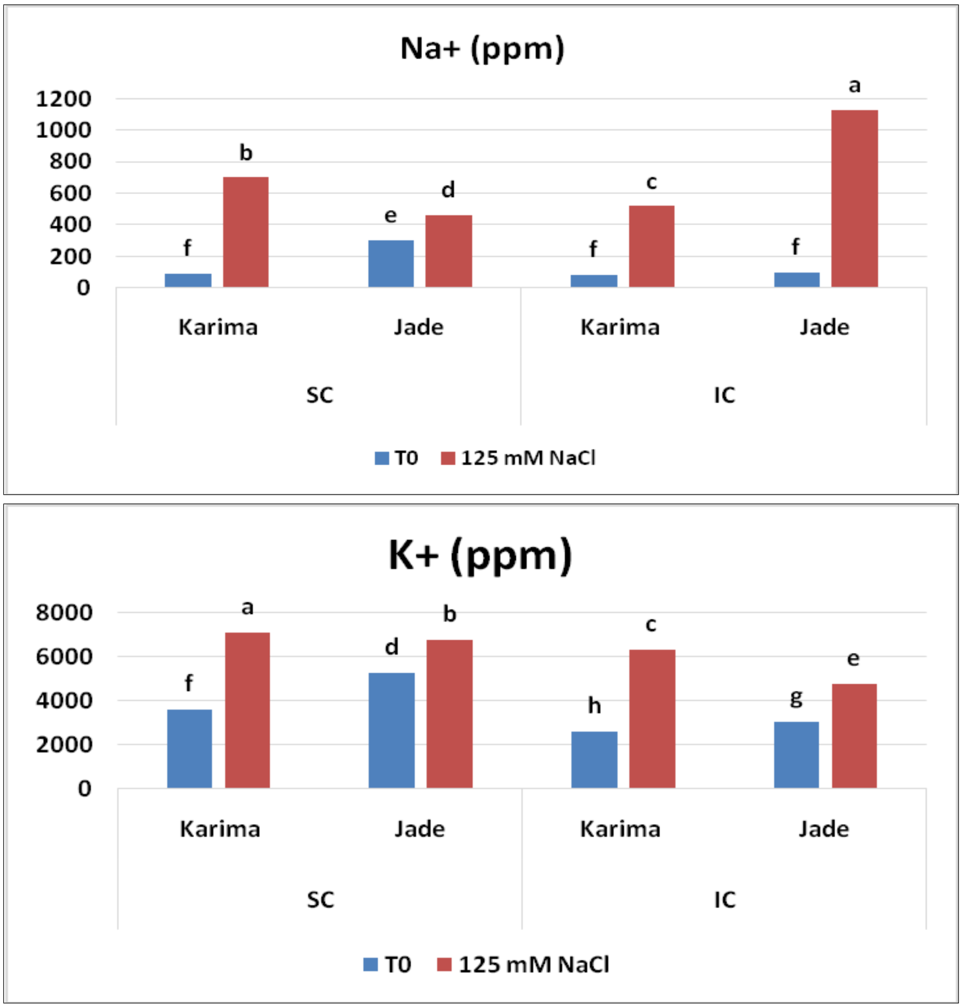

Fig. 4. Effect of salt treatment on Na^+ and K^+ in fruits of tomato in sole crop (SC) and in intercropping with maize (IC).

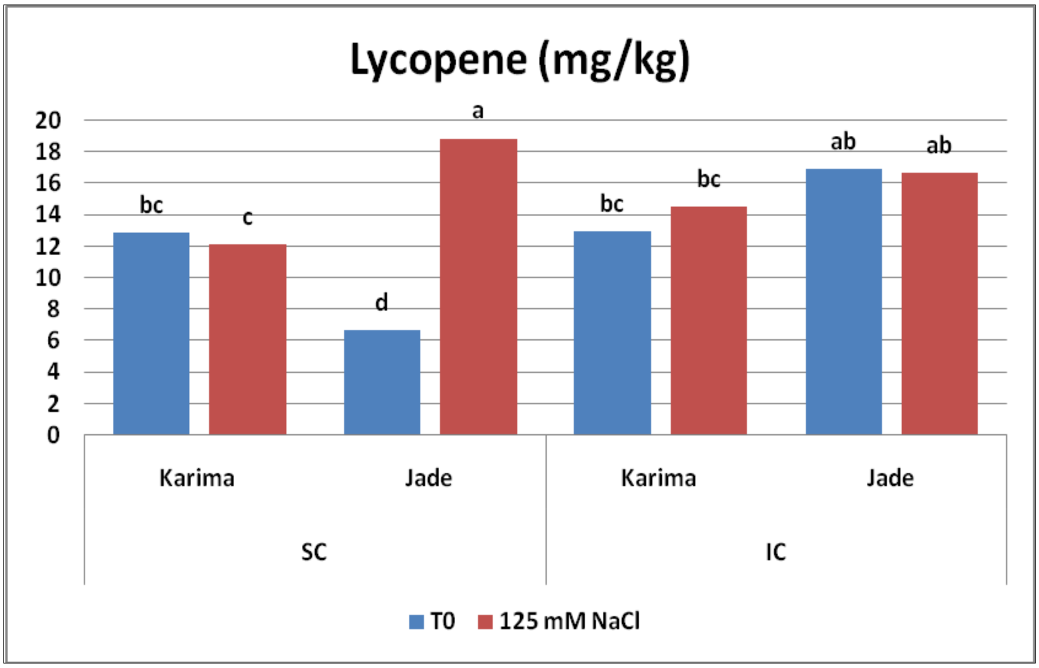

Fig. 5. Effect of salt treatment (125 mM) on Lycopene content (mg/kg) in fruits of tomato in sole crop (SC) and in intercropping with maize (IC).

Lycopene is the most carotenoid found in natural products and is mindful for the characteristic ruddy color watched at the aging arrange (38). Lycopene plays an important role in fruit selection and is well known for its antioxidant properties, with its action as a potent free radical scavenger (50).

The financial advantages of intercropping are evident through increased net returns and benefit-cost ratios. In a maize-faba bean study, intercropping systems yielded a 13 % to 42 % higher economic return compared to sole maize cropping. This boost in income is attributed to the diversified produce and more efficient resource utilization inherent in intercropping systems (9).

While small-scale intercropping trials provide valuable insights into plant interactions and stress tolerance, their direct applicability to commercial agriculture remains limited due to scaling challenges, edge effects and economic feasibility concerns (51). In addition, there are other agricultural practices such as the cultivation of biochar, a high-carbon, fine-grained product derived from the pyrolysis of biomass, which is a sustainable solution for agriculture and is known to improve soil quality and sequester carbon; its adoption in commercial agriculture remains limited due to economic factors (52).

Conclusion

In summary, intercropping generally boosted chlorophyll a level in tomatoes compared to monoculture. The variety of Karima exhibited high salt tolerance, while Jade showed increased production when intercropped with maize. Fruit quality assessments indicated higher pH values in Karima under NaCl stress (125 mM NaCl) in intercropping conditions, while Brix values were less affected by NaCl and intercropping. Additionally, intercropping influenced Na^+ and K^+ accumulation, with higher K^+ and lower Na^+ contents in Karima variety. These findings emphasize intercropping as a promising approach to reducing salinity stress and enhancing the resilience of tomato production in challenging environments. Additionally, while small-scale intercropping serves as a cost-effective method to boost tomato yield and quality under salinity stress; its adoption in commercial farming remains limited due to economic constraints and financial viability concerns.

Acknowledgements

Mourad Baghour was supported by funding from the Ministere de l'Education Nationale, de la Formation Professionnelle, de l'Enseignement Superieur et de la Recherche Scientifique (MENFPESRS, Morocco; Convention N °3) within the framework of PRIMA Project (UToPIQ-PCI2021-121941).

Authors' contributions

RC conceived and planned the experiments, carried out the experiment and wrote the article. AR wrote the article. MF conceived and planned the experiments and carried out the experiment. MM revised the manuscript. MF revised the manuscript. MRC wrote the article. AS wrote the article. MA revised the manuscript. MB conceived and planned the experiments, carried out the experiment and wrote the article. All authors discussed the results and contributed to the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Ethical issues: None

References

1. Dasgupta S, Hossain MdM, Huq M, Wheeler D. Climate change and soil salinity: The case of coastal Bangladesh. Ambio. 2015;44

(8):815–26. https://doi.org/10.1007/s13280-015-0681-5

2. Bijalwan P, Shukla YR, Sharma U. Bell pepper (*Capsicum annuum* L.) grown on raised bed, plastic mulch and sprayed with NAA@ 15 ppm: Effects on crop growth, yield, soil moisture and temperature. IJCS. 2021;9(1):3340–6. https://doi.org/10.22271/chemi.2021.v9.i1au.11752
3. Baghour M, Akodad M, Dariouche A, Maach M, Haddaji HE, Moumen A, et al. Gibberellic acid and indole acetic acid improves salt tolerance in transgenic tomato plants overexpressing LeNHX4 antiporter. Gesunde Pflanz. 2023;75(3):687–93. https://doi.org/10.1007/s10343-022-00734-y
4. Khan A, Khan AA, Samreen S, Irfan M. Assessment of sodium chloride (NaCl) induced salinity on the growth and yield parameters of *Cichorium intybus* L. Nat Env Poll Tech. 2023;22(2):845–52. https://doi.org/10.46488/NEPT.2023.v22i02.026
5. Hasan S, Irfan M, Khan A. Role of zinc oxide nanoparticles in alleviating sodium chloride- induced salt stress in sweet basil (*Ocimum basilicum* L.). J Appli Biol and Biotech. 2024;12(6): https://doi.org/10.7324/JABB.2024.188250
6. Kaur N, Kaur G, Pati PK. Deciphering strategies for salt stress tolerance in rice in the context of climate change. In: Hasanuzzaman M, Fujita M, Nahar K, Biswas JK, editors. Advances in Rice Research for Abiotic Stress Tolerance [Internet]. Woodhead Publishing; 2019. p. 113–132. Available from: https://doi.org/10.1016/B978-0-12-814332-2.00006-X
7. Sheha AM, El-Mehy AA, Mohamed AS, Saleh SA. Different wheat intercropping systems with tomato to alleviate chilling stress, increase yield and profitability. Annals of Agri Sci. 2022 Jun 1;67(1):136–45. https://doi.org/10.1016/j.aoas.2022.06.005
8. Raza MA, Zhiqi W, Yasin HS, Gul H, Qin R, Rehman SU, et al. Effect of crop combination on yield performance, nutrient uptake and land use advantage of cereal/legume intercropping systems. Field Crops Res. 2023;304:109144. https://doi.org/10.1016/j.fcr.2023.109144
9. Gidey T, Berhe DH, Birhane E, Gufi Y, Haileslassie B. Intercropping maize with faba bean improves yield, income and soil fertility in semiarid environment. Scientifica. 2024;2024(1):2552695. https://doi.org/10.1155/2024/2552695
10. Mucha AP, Almeida CMR, Bordalo AA, Vasconcelos MTSD. LMWOA (low molecular weight organic acid) exudation by salt marsh plants: Natural variation and response to Cu contamination. Estuarine, Coastal and Shelf Sci. 2010;88(1):63–70. https://doi.org/10.1016/j.ecss.2010.03.008
11. Liang J, Shi W. Cotton/halophytes intercropping decreases salt accumulation and improves soil physicochemical properties and crop productivity in saline-alkali soils under mulched drip irrigation: A three-year field experiment. Field Crops Res. 2021;262:108027. https://doi.org/10.1016/j.fcr.2020.108027
12. Gui D, Zhang Y, Lv J, Guo J, Sha Z. Effects of intercropping on soil greenhouse gas emissions - A global meta-analysis. Sci of The Total Environ. 2024;918:170632. https://doi.org/10.1016/j.scitotenv.2024.170632
13. Marousek J, Gavurova B, Marouskova A. Cost breakdown indicates that biochar production from microalgae in Central Europe requires innovative cultivation procedures. Energy Nexus. 2024;16:100335. https://doi.org/10.1016/j.nexus.2024.100335
14. Marousek J, Kolar L, Vochozka M, Stehel V, Marouskova A. Novel method for cultivating beetroot reduces nitrate content. J Cleaner Prod. 2017;168:60–62. https://doi.org/10.1016/j.jclepro.2017.08.233
15. Kurdali F, Janat M, Khalifa K. Growth, nitrogen fixation and uptake in Dhaincha/Sorghum intercropping system under saline and non-saline conditions. Commun Soil Sci Plant Anal [Internet]. 2003 Nov 1 [cited 2025 Mar 2]; Available from: https://www.tandfonline.com/doi/abs/10.1081/CSS-120024780
16. Pavolova H, Tomas, Kysela K, Klimek M, Hajduova Z, Zawada M. The analysis of investment into industries based on portfolio managers. AMS. 2021;(26):161–70. https://doi.org/10.46544/AMS.v26i1.14
17. Atzori G, Nissim GW, Mancuso S, Palm E. Intercropping salt-sensitive *Lactuca sativa* L. and salt-tolerant *Salsola soda* L. in a saline hydroponic medium: An agronomic and physiological assessment. Plants. 2022;11(21):2924. https://doi.org/10.3390/plants11212924
18. Simpson CR, Franco JG, King SR, Volder A. Intercropping halophytes to mitigate salinity stress in watermelon. Sustain. 2018;10(3):681. https://doi.org/10.3390/su10030681
19. Inal A, Gunes A, Zhang F, Cakmak I. Peanut/maize intercropping induced changes in rhizosphere and nutrient concentrations in shoots. Plant Physiol and Biochem. 2007;45(5):350–56. https://doi.org/10.1016/j.plaphy.2007.03.016
20. Hussain S, Iqbal N, Rahman T, Liu T, Brestic M, Safdar ME, et al. Shade effect on carbohydrates dynamics and stem strength of soybean genotypes. Environ and Experi Bot. 2019;162:374–82. https://doi.org/10.1016/j.envexpbot.2019.03.011
21. Wang Y, Wang S, Zhao Z, Zhang K, Tian C, Mai W. Progress of Euhalophyte adaptation to arid areas to remediate salinized soil. Agri. 2023;13(3):704. https://doi.org/10.3390/agriculture13030704
22. Hussain S, Iqbal N, Brestic M, Raza MA, Pang T, Langham DR, et al. Changes in morphology, chlorophyll fluorescence performance and Rubisco activity of soybean in response to foliar application of ionic titanium under normal light and shade environment. Sci of The Total Environ. 2019;658:626–37. https://doi.org/10.1016/j.scitotenv.2018.12.182
23. Food and Agriculture Organization of the United Nations (FAO) [Internet]. 2022 [cited 2025 Mar 2]. Available from: https://www.fao.org/faostat/en/#data/FBS: %20FOOD %20BALANCES %20- %20FOOD %20AND %20AGRICULTURE %20ORGANIZATION %20OF %20THE %20UNITED %20NATIONS %20FAO/visualize
24. Gerszberg A, Hnatuszko-Konka K, Kowalczyk T, Kononowicz AK. Tomato (*Solanum lycopersicum* L.) in the service of biotechnology. Plant Cell Tiss Organ Cult. 2015;120(3):881–902. https://doi.org/10.1007/s11240-014-0664-4
25. Lichtenthaler HK. Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. In: Methods in Enzymology [Internet]. Academic Press; 1987 [cited 2022 Apr 19]. p. 350–382. Available from: https://doi.org/10.1016/0076-6879(87)48036-1
26. Li T, Liu LN, Jiang CD, Liu YJ, Shi L. Effects of mutual shading on the regulation of photosynthesis in field-grown sorghum. J Photochem and Photobiol B: Biol. 2014;137:31–38. https://doi.org/10.1016/j.jphotobiol.2014.04.022
27. Liu T, Cheng Z, Meng H, Ahmad I, Zhao H. Growth, yield and quality of spring tomato and physicochemical properties of medium in a tomato/garlic intercropping system under plastic tunnel organic medium cultivation. Scientia Horticulturae. 2014;170:159–68. https://doi.org/10.1016/j.scienta.2014.02.039
28. Esserti S, Billah REK, Venisse JS, Smaili A, Dich J, Es-sahm I, et al. Chitosan embedded with ZnO nanoparticles and hydroxyapatite: synthesis, antiphytopathogenic activity and effect on tomato grown under high density. Scientia Horticulturae. 2024;326:112778. https://doi.org/10.1016/j.scienta.2023.112778
29. Yao X, Li C, Li S, Zhu Q, Zhang H, Wang H, et al. Effect of shade on leaf photosynthetic capacity, light-intercepting, electron transfer and energy distribution of soybeans. Plant Growth Regul. 2017;83(3):409–16. https://doi.org/10.1007/s10725-017-0307-y
30. El-Gizawy AM, Gomaa HM, El-Habbasha KM, Mohamed SS. Effect of different shading levels on tomato plants 1. Growth, flowering and chemical composition. Acta Hortic. 1993;(323):341–48. https://doi.org/10.17660/ActaHortic.1993.323.31
31. Wu Y, Gong W, Yang F, Wang X, Yong T, Yang W. Responses to shade and subsequent recovery of soya bean in maize-soya bean relay strip intercropping. Plant Prod Sci. 2016;19(2):206–14.

https://doi.org/10.1080/1343943X.2015.1128095

32. Iqbal N, Hussain S, Ahmed Z, Yang F, Wang X, Liu W, et al. Comparative analysis of maize–soybean strip intercropping systems: a review. Plant Prod Sci. 2019;22(2):131–42. https://doi.org/10.1080/1343943X.2018.1541137
33. Abdel-Mawgoud AMR, El-Abd SO, Singer SM, Abou-Hadid AF, Hsiao TC. Effect of shade on the growth and yield of tomato plants. Acta Hortic. 1996;(434):313–20. https://doi.org/10.17660/ActaHortic.1996.434.38
34. Benitez MS, Ewing PM, Osborne SL, Lehman RM. Rhizosphere microbial communities explain positive effects of diverse crop rotations on maize and soybean performance. Soil Biol and Biochem. 2021;159:108309. https://doi.org/10.1016/j.soilbio.2021.108309
35. Ali B, Hafeez A, Afridi MS, Javed MA, Sumaira, Suleman F, et al. Bacterial-mediated salinity stress tolerance in maize (*Zea mays* L.): A fortunate way toward sustainable agriculture. ACS Omega. 2023 ;8(23):20471–87. https://doi.org/10.1021/acsomega.3c00723
36. Boorboori MR, Lackoova L. Arbuscular mycorrhizal fungi and salinity stress mitigation in plants. Front Plant Sci [Internet]. 2025 Jan 17 [cited 2025 Mar 2];15:Article 1311677. Available from: https://doi.org/10.3389/fpls.2024.1504970
37. Maach M, Baghour M, Akodad M, Galvez FJ, Sanchez ME, Aranda MN, et al. Overexpression of LeNHX4 improved yield, fruit quality and salt tolerance in tomato plants (*Solanum lycopersicum* L.). Mol Biol Rep. 2020;47(6):4145–53. https://doi.org/10.1007/s11033-020-05499-z
38. Maach M, Boudouasar K, Akodad M, Skalli A, Moumen A, Baghour M. Application of biostimulants improves yield and fruit quality in tomato. Intern J Vegetable Sci. 2021;27(3):288–93. https://doi.org/10.1080/19315260.2020.1780536
39. Denise DSM, Maristela W, Jose ES, Diego RDS, Ryan NS, Roberta MNP. Planting density and number of stems for ecological crop determinate growth tomato. Afr J Agric Res. 2018;13(12):544–50. https://doi.org/10.5897/AJAR2018.13039
40. Diaz-Perez JC. Bell pepper (*Capsicum annum* L.) crop as affected by shade level: microenvironment, plant growth, leaf gas exchange and leaf mineral nutrient concentration. HortSci. 2013;48(2):175–82. https://doi.org/10.21273/HORTSCI.48.2.175
41. Tester M, Davenport R. Na^+ tolerance and Na^+ transport in higher plants. Annals of Bot. 2003;91(5):503–27. https://doi.org/10.1093/aob/mcg058
42. Munns R, Tester M. Mechanisms of salinity tolerance. Annual Rev Plant Biol. 2008;59:651–81. https://doi.org/10.1146/annurev.arplant.59.032607.092911
43. Garcia-Sanchez F, Syvertsen J, Martinez V, Melgar J. Salinity tolerance of 'Valencia' orange trees on rootstocks with contrasting salt tolerance is not improved by moderate shade. J Experi Bot. 2006;57(14):3697–706. https://doi.org/10.1093/jxb/erl121
44. Liu J, Hu T, Feng P, Yao D, Gao F, Hong X. Effect of potassium fertilization during fruit development on tomato quality, potassium uptake, water and potassium use efficiency under deficit irrigation regime. Agri Water Manag. 2021;250:106831. https://doi.org/10.1016/j.agwat.2021.106831
45. Osakabe Y, Yamaguchi-Shinozaki K, Shinozaki K, Tran LSP. ABA control of plant macroelement membrane transport systems in response to water deficit and high salinity. New Phytologist. 2014;202(1):35–49. https://doi.org/10.1111/nph.12613
46. Pettigrew WT. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiologia Plantarum. 2008;133(4):670–81. https://doi.org/10.1111/j.1399-3054.2008.01073.x
47. Fan Y, Wang Z, Liao D, Raza MA, Wang B, Zhang J, et al. Uptake and utilization of nitrogen, phosphorus and potassium as related to yield advantage in maize-soybean intercropping under different row configurations. Sci Rep. 2020;10(1):9504. https://doi.org/10.1038/s41598-020-66459-y
48. Massaretto IL, Albaladejo I, Purgatto E, Flores FB, Plasencia F, Egea-Fernandez JM, et al. Recovering tomato landraces to simultaneously improve fruit yield and nutritional quality against salt stress. Front Plant Sci [Internet]. 2018 Nov 30 [cited 2025 Mar 2];9:Article 1774. Available from:https://doi.org/10.3389/fpls.2018.01778
49. Leiva-Ampuero A, Agurto M, Matus JT, Hoppe G, Huidobro C, Inostroza-Blancheteau C, et al. Salinity impairs photosynthetic capacity and enhances carotenoid-related gene expression and biosynthesis in tomato (*Solanum lycopersicum* L. cv. Micro-Tom). Peer J. 2020;8:e9742. https://doi.org/10.7717/peerj.9742
50. Gerster H. The potential role of lycopene for human health. J American College of Nutri. 1997;16(2):109–26. https://doi.org/10.1080/07315724.1997.10718661
51. Brooker RW, Bennett AE, Cong WF, Daniell TJ, George TS, Hallett PD, et al. Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. New Phytologist. 2015;206(1):107–17. https://doi.org/10.1111/nph.13132
52. Marousek J, Strunecky O, Stehel V. Biochar farming: defining economically perspective applications. Clean Techn Environ Policy. 2019;21(7):1389–95. https://doi.org/10.1007/s10098-019-01728-7

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.