



The Alleviation of climate change effects on the performance of some rice varieties by Zn, Ca, and B application under aerobic cultivation



Amgad A. Elgamal¹, Usama A. AbdelRazek¹, Ahmed Abdel Haleem² and Bassiouni A. Zayed³

¹Agronomy department, faculty of Agriculture, Tanta University, Egypt

²Sakha agriculture research station, Agricultural Research Center, Sakha, Kafr Elsheikh, Egypt

³Rice Research Department, Field Crops Research Institute, Agricultural Research Center, Egypt

AEROBIC rice cultivation with nutrition balance is a resilient option to remediate the effects of climate change on rice productivity and cultivation. The field experiments were conducted during the 2021 and 2022 summer rice seasons, respectively, at the Research Farm of Sakha Agricultural Research Station, Kafr-el-Sheikh, Egypt. The study aimed to investigate the effect of foliar application using zinc, calcium, and boron on the productivity of anaerobic rice under climate change and its various effects. The experiment employed a strip plot design with four replications; genotypes were arranged on vertical plots, while the foliar applications were arranged horizontally. The results showed that there is a significant difference between the two examined types in terms of biochemical, physiological, crop physiological, yield characteristics, and grain yield. Giza 179 outperformed Sakha Super 300 on the previously described scales in aerobic conditions. The foliar spraying of studied micronutrients, either alone or in di- or tri-combinations, had a significant improvement in photosynthesis components, drought defense systems, including antioxidants and osmolytes, plant pigments, ion selectivity, yield attributes, and productivity compared with the control. The interaction effect was significant for most of the traits studied. This effect led to the effectiveness of the triple combination of zinc, calcium, and potassium with Giza 179, which enhanced and increased rice productivity, contributing to mitigating and adapting to the effects of climate change.

Keywords: Aerobic rice cultivation, Ca⁺² and B foliar application, ROS, antioxidants, grain yield.

Introduction

Egypt is one of the countries most affected by climate change, which threatens and reduces agricultural productivity, especially rice, leading to food shortages and poor sustainability. Egypt is one of the countries most affected by climate change, which threatens and reduces agricultural productivity, especially rice, leading to food shortages and poor sustainability. Although Egypt is located under the water poverty line, climate change has come to magnify the water seldom problem in Egypt in the terms of drought stress in particularly rice yields. Rice (*Oryza sativa*) is a semi-aquatic plant that is adapted to a broad range of aquatic conditions, as well as aerobic soil of uplands to anaerobic or waterlogged fields in lowlands of flood prone areas (Miro and Ismail, 2013). One resilient option to adapt rice under climate change combined with sharp freshwater shortage and high temperature

exploring aerobic rice cultivation (Zayed et al. 2023a). Nominating the relevant tolerant rice genotypes and /or varieties for aerobic conditions will ensure high rice grain yield with low total water applied for rice under the same conditions (Zayed et al. 2023b).

The aerobic rice cultivars may produce approximately 6-9t/ha compared to tolerant varieties under a recommended dose of fertilizers and optimal growth under lower water availability conditions (Parthasarathi et al. 2012 and Miro and Ismail, 2013). Zayed et al. (2023a&b) found that Giza 178, Giza179 and Gz93999 performed better under aerobic rice cultivation in Egypt since those varieties showed proper biochemical, agro-physiological and yield attributes criteria, which led to high grain yield with low water input (Abo-yousef, et al., 2024). Aerobic

*Corresponding author email: Mohammad Anwar Hossain (ahmed.abdelhaliem1989@gmail.com)

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rice production is a water-saving technique where seed is directly sown under aerobic field condition (Prasad, 2011; Bouman *et al.* 2005). Furthermore, the interaction between drought and Zn deficiency poses significant impact owing as less water availability may hamper the Zn transport toward roots. Furthermore, the higher yield can be obtained under optimal fertilizer application or foliar application of nutrients alone or in combination i.e., Ca²⁺, B and Zn-1 (Fergany, 2018). The transformation towards aerobic conditions inducing a reduction in soil moisture and Zn availability to rice displayed a significant impact on rice production (Gao *et al.* 2006). Additionally, Zn deficiency in Egyptian soils causing high soil pH is the main obstacle in rice production shifting aerobic rice cultivation.

The chlorophyll a & b, amino acids, carotenoids, yield indices, uptake of macronutrients, recovery of NPK, plant growth and development were significantly improved by Zn foliar application both under salt and drought stress conditions (Zayed *et al.* 2023a; El-Sobky *et al.* 2022; Zayed *et al.*, 2025). For proper growth and development of plants require the optimal supply of Zinc (Zn). Zn is an essential element for metabolic processes i.e., metabolism, protein, and lipid synthesis, enzyme activation, gene expression, and regulation and had a role for both structural and functional aspects of the cell membrane (Broadley *et al.* 2007; Okasha *et al.*, 2024). Calcium is playing a main key player in elevating stress tolerance in plants since it has a high ability to mitigate biotic and biotic stresses. Calcium (Ca²⁺) may significantly improve the uptake of both N and P moreover, it promotes root growth. Furthermore, the presence of Ca²⁺ cation the element present in the cell wall plays an integral part in cellular functioning and enzyme activities. Since Tripathy *et al.* (2018) found that Ca²⁺ spraying significantly increased hybrid rice yield and NPK plant uptake. Lakaew *et al.* (2020) found that foliar application of Calcium acetate on rice under heat stress reduced oxidative stress damage in terms of MAD increased the antioxidant system, raised plant total chlorophyll and rice grain yield. Boron plays a vital role in essential plant functions i.e., synthesis of cell wall, formation of indole acetic acid and membrane stability (Rehman *et al.* 2018). The Boron is responsible for several physiological and cellular processes including cell division, biotic stress

resistance, metabolism of macronutrients, plant growth and development (Ahmad *et al.* 2009).

In rice, the boron deficiency may cause panicle sterility owing to impairing pollen and another development, hindering pollen germination resulting lower grains per panicle and finally reduced grain yield and quality (Rehman *et al.* 2018). Rashid *et al.* (2007) recognized that applying B in the rate of 1kg ha⁻¹ as foliar spray significantly increased rice grain and straw yields, panicle weight, 1000 grain weight, filled grains, panicle number, and B % of leaf and grain as well as lowered sterility% in three rice varieties which were significantly differed in their response. Sheela *et al.* (2023) found that the different combinations of Ca-Mg-B significantly influenced the yield and yield components of rice. The application of boron resulted in increased yield when applied alone or along with calcium and magnesium. Calcium and magnesium also played direct positive roles as nutrient elements in improving yields of crops. The highest concentrations for Ca²⁺, Mg²⁺ and B at 800 kg, 120 kg, and 550 g ha⁻¹ were recorded, respectively. The lowest concentration was recorded under the control plot (Ca²⁺, Mg²⁺ and B). The foliar application of B, Ca²⁺ and Zn alone or in combination significantly and positively improved plant growth, yield attributes and production and quality of tomato under abiotic stress (Haleema *et al.* 2018). The present investigation evaluated the role of foliar application of Zn, B and Ca²⁺ in alleviation of limited water supply stressful of aerobic rice cultivation.

Materials and Methods

Field trails were undertaken at the experimental Farm of Sakha Agricultural Research Station, ARC, Kafr El-Sheikh, Egypt during years 2021 and 2022, respectively. The present investigation was aimed at increasing rice production under aerobic cultivation by addressing the more relevant varieties between Giza 179 and Sakha super 300 with more effective nutrients combination spray among, control, Zn, Ca²⁺, B, Zn+Ca²⁺, Zn+B, Ca²⁺+B and Zn+Ca²⁺+B. The investigated soil samples were obtained from experimental sites in a depth of 0-30cm and analysed according to Black *et al.* (1965) and the method of Horneck and Hanson, (1998). Analysis of the chemical and physical properties of soil is provided in Table 1.

Table 1. The mechanical and chemical analysis of the soil used in the experiment.

Soil analysis	2021	2022
Soil texture (%)	Clay	Clay
pH	8.05	8.25
ECe(dSm-1)	2.140	2.15
Organic matter %	0.96	0.97
Available NH ₄ mg kg ⁻¹	16.90	15.10
Available NO ₃ mg kg ⁻¹	13.00	13.20
Available P mg kg ⁻¹	14.00	14.50
Available K mg kg ⁻¹	310	320
Available Zn mg kg ⁻¹	1.1	1.0
Available B mg kg ⁻¹	0.20	0.19

Experiment Layout and Preparation of Land

The experiment was laid out in a strip plot design with four replications. The varieties namely; Giza179 and Sakha Super 300 were distributed in the vertical plots while the horizontal ones contained the nutrient treatments; eight sprayed nutrient combinations of Zinc (Zn), calcium (Ca+2), Boron (B), Zn+Ca+2, Zn+ B, Ca+2+B, Zn+Ca+2+B and control treatment . The solution of tested nutrient combinations was sprayed thrice at certain physiological stages of mid telling, heading stage, and booting. The concentration of tested nutrients and their combinations were 1% for both Zn and Ca+2 and 0.2% for B. For di-nutrient and tri-combinations. The sowing practice and recommendation package corresponding each planting method were applied according to RRTC, ARC and ministry of agriculture, Egypt

Data collection

Dry matter calculation: At the heading stage, dry matter production was estimated by sampling plants from five randomly selected hills in each plot. To determine the leaf area, leaves from three randomly selected hills were collected and measured by Portable Area Meter (Model LI- 3000A). The leaves area index (LAI) was then calculated based on these measurements .

Total photosynthetic pigments contents of leaves were decided from five disks were taken from the rice takes off. The shades were extricated by pounding in 85% aqueous acetone (20 ml) and a squeeze of CaCO₃ were included to the acetone arrangement some time recently pounding. After filtration the volume of acetone arrangement was total to 20 ml. The whole chlorophyll colors were decided by perusing the receptiveness on spectrophotometrically at 662, 644 and 470 nm and concentration of photosynthetic colors were calculated agreeing to the condition said by Lichtenthaler and Buschmann (2001).

Sampling material

The samples from different parts of plants i.e., whole plant or leaves were taken at flowering stage during the experimental period. Samples were taken from each treatment.

Chemical analysis

Rice leaves were taken randomly after flowering stage to carry out the chemical analysis including Na+1, K+1 as well as its ration according to Horneck and Hanson (1998) as follows:

Determination of pigments content: The total chlorophyll contents were measured as per method of Arnon (1949) and carotenoids contents were measured as per method of Robbelen (1957).

Extraction of antioxidant enzymes: The crude enzyme extract was undertaken for calculating catalase (CAT), peroxidase (POX) and malenaldehyd (MDA) activities according to Choudhury and Panda (2004).

Relative water content (RWC) Relative water content was determined according to the method of Schonfeld et al, (1988).

Net photosynthesis rate and Stomatal conductance (GS)

The stomatal conductance (gs) (units; mol m⁻² s⁻¹) was calculated at plant heading stage through portable photosynthesis measurement system (Li-Cor, Lincoln, NE, USA), following the method described by Hubbard et al. (2001).

Yield and yield attributes

At the time of harvesting, plant height was measured, the total number of panicles were counted from ten randomly selected hills. Ten random panicles from each plot were collected to estimate panicle length, the number of filled and unfilled grains per panicle, panicle weight, and 1000-grain weight. Grain and biological yields were measured, with grain yield adjusted to 14% moisture content. The yield for a 9 m² area was then calculated and expressed in tons per hectare.

Statistical analysis

The data were curated and statistical interpretation were made by using analysis of variance method as per method describe by Gomez and Gomez (1984) and Duncan (1955) on "COSTAT" statistical software package (Software, 1988). The multiple range test was employed for comparing the treatment means.

Results and Discussion

Photosynthesis and defence system traits

High photosynthesis potential and capacity of reasonable defence system development of any rice variety under abiotic stress could be considered as

evidence for its abiotic tolerance. Data in Tables 2, and 3 showed that the two tested rice varieties; Giza179 and Sakha super 300 showed a significant variation in their capacity of photosynthesis components; stomata conductance Net photosynthesis, relative water content, carotenoids, total pigments, and defence system content viz; antioxidants, osmolytes and MDA in both seasons. Giza179 rice variety showed highly significant and effective photosynthesis traits compared to Sakha super 300. Similar results were reported by Zayed et al, (2023) and Ali et al, (2024).

Table 2. Effect of foliar spray of elements on physiological traits of rice under aerobic conditions in 2021 and 2022 seasons.

Main effect	Stromal conductance (mol m ⁻² s ⁻¹)		Net photosynthesis		RWC%		Total pigments(mg/g.F.W)	
	2021	2022	2021	2022	2021	2022	2021	2022
Rice varieties (V)								
Giza 179	0.562a	0.579a	15.47a	15.61a	81.15a	80.18a	5.496a	5.548a
Sakha S. 300	0.536b	0.563b	15.21b	15.36b	78.19b	78.51b	5.887b	6.081b
LSD 0.05	0.081	0.207	0.37	0.21	0.99	1.053	0.048	0.355
Treatments								
Control	0.408ab	0.425c	12.30d	12.38e	76.07f	76.52d	4.993e	5.088d
Zn	0.566c	0.558b	14.42c	14.63d	77.95e	78.16c	5.637c	5.561c
Ca	0.538b	0.553ab	15.38bc	15.55d	78.63d	79.03bc	5.653f	5.561c
B	0.572b	0.584ab	15.97ab	15.63c	78.72d	79.43bc	5.677d	5.73bc
Zn+ Ca	0.601b	0.612ab	16.10ab	16.0bc	80.10c	79.93b	5.545g	5.933ab
Zn+ B	0.502a	0.613a	16.78a	16.42bc	80.25c	80.13ab	5.900h	5.985ab
B + Ca	0.602c	0.587bc	15.90ab	16.78ab	82.40b	81.27ab	6.0435b	6.203bc
Zn+ Ca+ B	0.60ab	0.635a	16.95ab	16.97a	83.23a	80.32a	6.084a	6.456a
LSD 0.05	0.066	0.169	0.45	0.92	0.808	2.493	0.039	0.290
Interaction	NS	NS	NS	NS	**	*	NS	NS

*, ** and ns indicate $P < 0.05$, $P < 0.01$ and not significant, respectively.

Foliar application of Zn, B and Ca²⁺ alone or in a combination at certain rice growth stages markedly improved and raised the photosynthesis parameters, defence system at different levels including antioxidants; APX, and CAT and osmolytes system (proline) compared to the control treatment (Table3). At the same time, application of Zn, B and Ca²⁺ via foliar alone or in a combination significantly declined the MAD cell concentration compared to the control treatment. The highest values of photosynthesis traits and measured antioxidants as well as proline cell content were

produced when rice plants were sprayed with the tri-combination of Zn, B and Ca²⁺. The tri-combination or Di-combination was at par regarding the current studied traits of photosynthesis and antioxidants as well as proline in both seasons. The data collected for plant pigments affected by the foliar spray of Zn, Ca, B showed a significant response in this concern. Applying such nutrients as foliar spray greatly increased total photosynthesis plant pigments in both seasons. The lowest means were recorded when rice plants did not receive any of the nutrients.

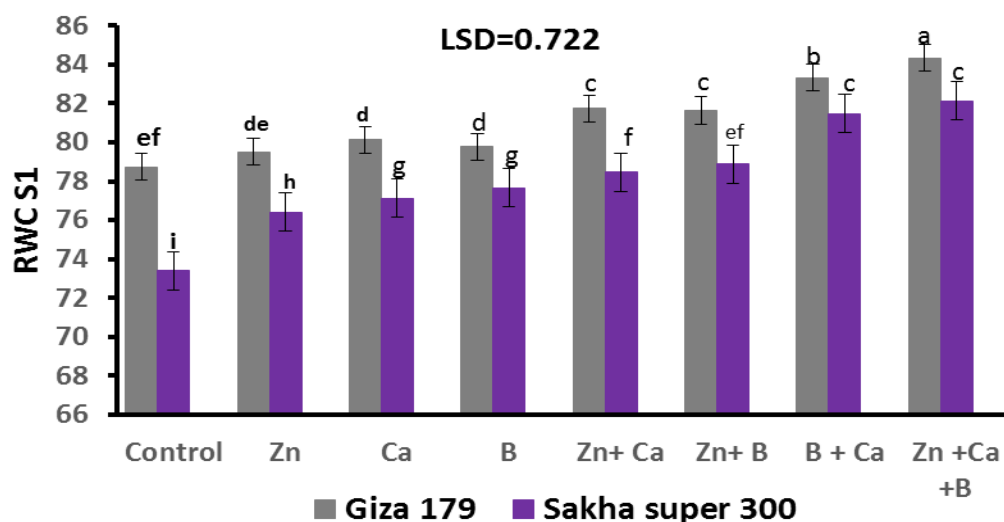
Table 3. Effect of foliar spray of elements on MDA and antioxidants system of rice under aerobic conditions in 2021 and 2022 seasons.

Traits Main effects	MDA (nmol ml ⁻¹ g ⁻¹ f wt.)		Catalase (μmol protein) ⁻¹ g ⁻¹ min		Peroxidase (μmol protein) ⁻¹ g ⁻¹ min		Proline content μmol g ⁻¹ f.w	
	2021	2022	2021	2022	2021	2022	2021	2022
Rice varieties								
Giza 179	0.293b	0.352b	3.040b	2.897a	45.45b	44.112a	0.619a	0.664a
S super 300	0.355a	0.479a	3.302a	2.592b	46.870a	42.795b	0.577b	0.6192b
LSD 0.05	0.073	0.130	0.105	0.114	2.250	1.252	0.025	0.130
Treatments								
Control	0.490a	0.669c	2.143g	1.985f	47.2ab	38.2e	0.450e	0.489d
Zn	0.309bcd	0.443b	3.523b	2.633d	42.25c	41.216d	0.529d	0.583c
Ca	0.332b	0.470ab	3.235de	2.458e	46.783b	43.25c	0.542d	0.590c
B	0.322bc	0.406ab	3.243d	2.683d	46.5b	44.083bc	0.535c	0.590c
Zn+ Ca	0.300cde	0.386ab	3.0133f	2.675d	46.683b	44.2ab	0.656bc	0.686b
Zn+ B	0.275e	0.361a	3.176e	3.088b	49.883a	45.333bc	0.677bc	0.691b
B + Ca	0.282dc	0.314a	3.373c	2.916c	45.5c	45.433ab	0.652ab	0.704a
Zn+ Ca+ B	0.285de	0.276ab	3.665a	3.516a	44.483ab	45.916a	0.745a	0.786a
LSD 0.05	0.059	0.106	0.086	0.093	1.837	1.022	0.042	0.021
Interaction	NS	NS	**	**	NS	NS	NS	NS

*, ** and ns indicate $P < 0.05$, $P < 0.01$ and not significant, respectively.

The interaction among selected rice varieties and nutrient treatments was found to significantly affect net relative water content and catalase (figs1-4) the highest measurement of most traits was recorded in Giza179

when it was sprayed with Di-combination or the tri-combination of zinc, boron and calcium. The combinations were also appropriate for Sakha super 300.

**Fig. 1. Interaction impact of rice varieties and nutrients foliar spray on RWC during first season.**

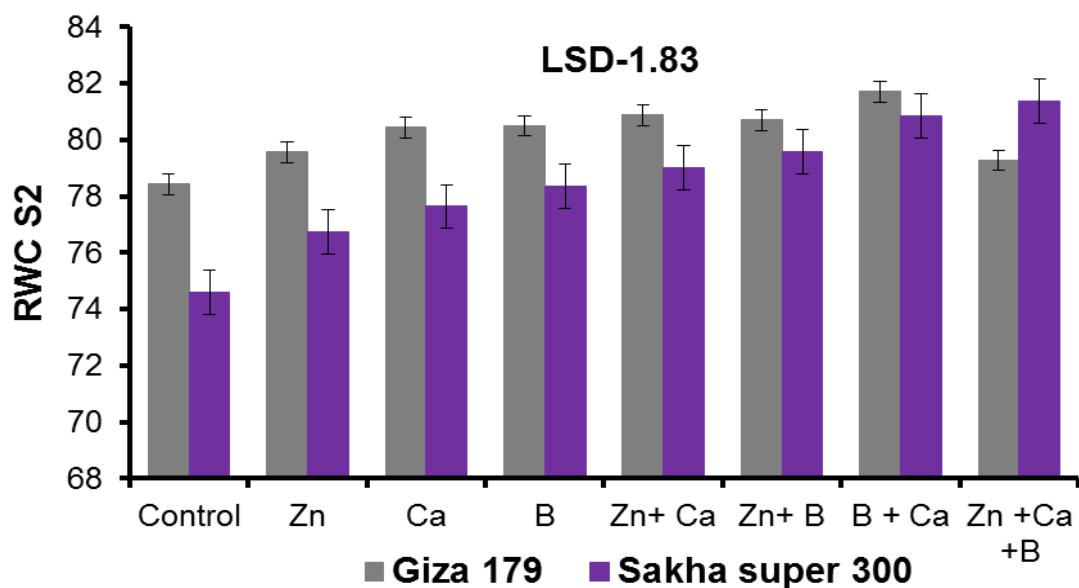


Fig. 2. Interaction impact of rice varieties and nutrients foliar spray on relative water contents during second season.

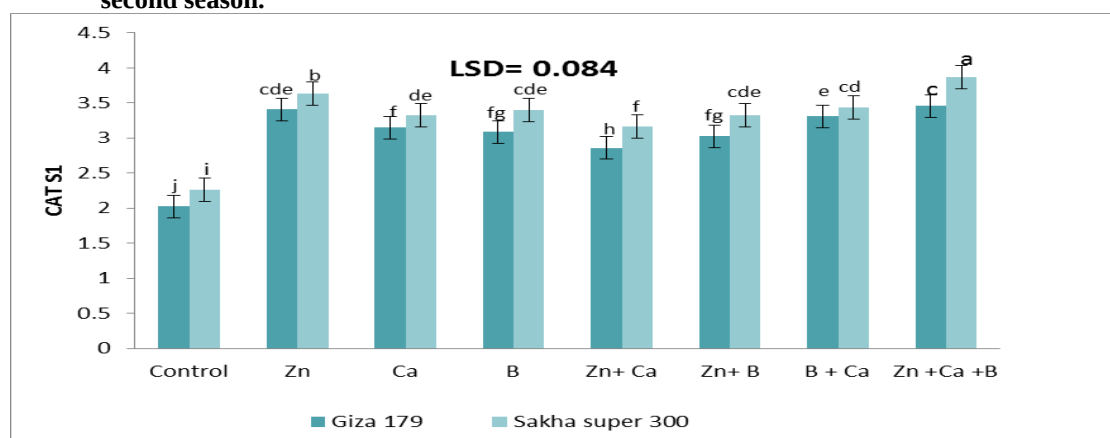


Fig. 3. Interaction impact of rice varieties and nutrients foliar spray on Catalase during first season.

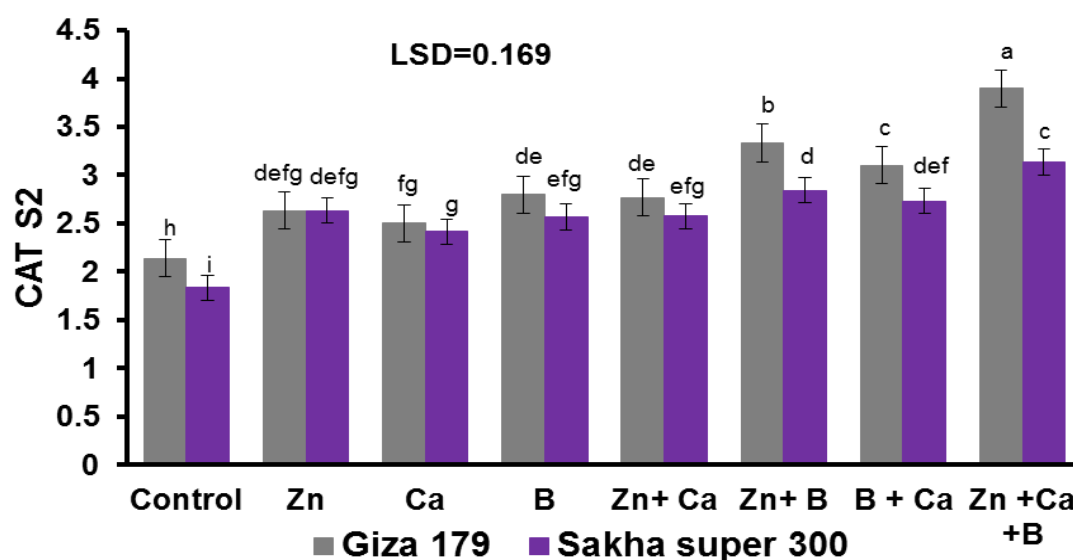


Fig. 4. Interaction impact of rice varieties and nutrients foliar spray on Catalase during second season.

K , Na leaf content and its ratio

Data arranged in Table 4 referred that the two investigated rice varieties significantly diversified in their ion selectivity under aerobic cultivation in terms of low water supply in both seasons. Giza179 rice variety gave the highest values of potassium (K^+), and the lowest values of sodium (Na^+), and

Na^+/K^+ ratio versus Sakha super 300 in both seasons. Interestingly, the addition of such nutrients showed high effectiveness to improve ion selectivity by adjusting nutrient uptake toward high K uptake against Na uptake via possessing specific antiporters on the cell membrane such as SOS group.

Table 4. Effect of treating with some elements on an ion selectivity of rice under aerobic conditions.

Main effect	Na(mg/g)		K(mg/g)		Na/K ratio	
	2021	2022	2021	2022	2021	2022
Rice varieties (V)						
Giza 179	4.653a	4.321b	18.629a	17.870a	0.233b	0.245b
Sakha super 300	3.854b	4.455a	16.694b	15.883b	0.253a	0.285a
LSD 0.05	0.197	0.098	0.858	0.100	0.003	0.004
Nutrient Spray (N)						
Control	5.41a	5.52a	16.23d	15.266f	0.332a	0.363a
Zn	4.968b	4.903b	17.423c	15.833e	0.287b	0.310b
Ca	4.643bc	4.598c	17.066c	16.35d	0.271bc	0.281c
B	4.425c	4.6c	17.033c	16.283d	0.259c	0.283c
Zn+ Ca	3.966d	4.25d	17.558c	17.25c	0.225d	0.246d
Zn+ B	3.783d	4.283d	17.733c	17.00c	0.212d	0.253d
B + Ca	3.51e	3.538e	18.75b	17.883b	0.187e	0.201e
Zn+ Ca+ B	3.336e	3.413e	19.5a	19.15a	0.171e	0.181f
LSD 0.05	0.160	0.080	0.700	0.082	0.002	0.003
Interaction	**	**	NS	NS	NS	NS

*, ** and ns indicate $P < 0.05$, $P < 0.01$ and not significant, respectively.

Regarding the effect of nutrient spray on the ion selectivity, it was observed that the nutrient spray had a significant effect on K^+ , Na^+ and their ratio in the first and second seasons (Table4). Continuously, a high K^+/Na^+ ratio was observed when rice plants grown under aerobic conditions were sprayed by tested nutrients at a certain rice growth compared to control treatment. The highest values of mentioned ion selectivity, K^+/Na^+ were produced when rice plants were treated by the thrice combination of Zn, Ca^{+2} and B with insignificant differences with those produced by di-combination of three tested nutrients. The lowest values of Na^+ efflux was produced when rice plants were sprayed by the three combination of Zn, Ca^{+2}

and B, while the highest means of Na^+ , and the least means of K^+/Na^+ ratio were recorded under control treatments in both seasons. These results are in harmony with those concluded by similar results were obtained by Zayed et al, (2023a&b), Ali et al, (2024) as well as Yousif et al, (2023.)

The interaction between rice varieties and nutrient spray treatments had a significant effect on sodium leaf content in the two seasons (5 and6). The interaction effect came to provide the fact that the tri-combination or di-combination spray of Zn, Ca and B with Giza179 recorded the best values of ion selectivity which produced the lowest values of sodium content.

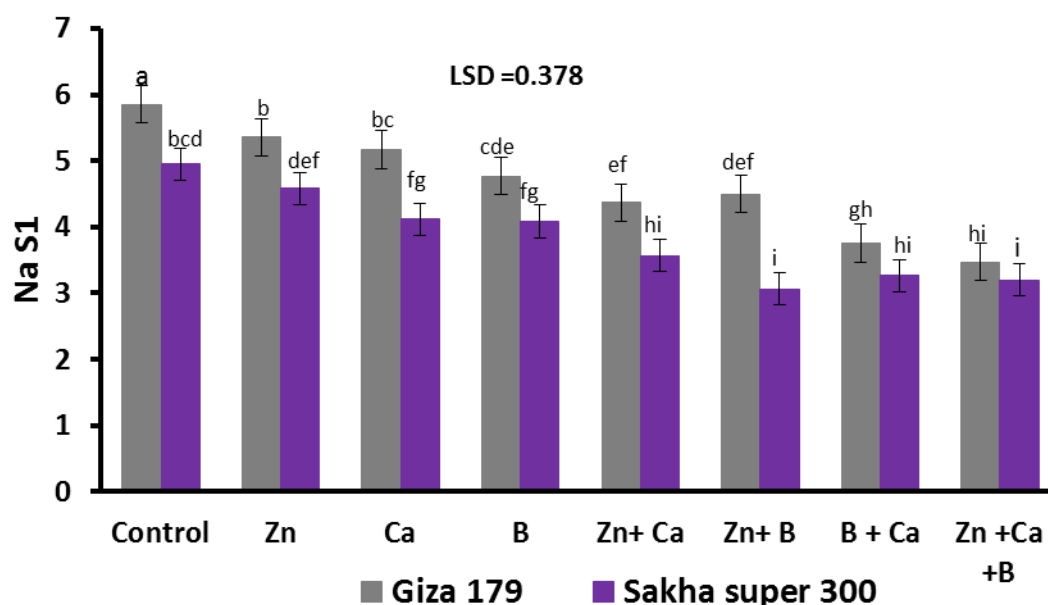


Fig. 5. Interaction impact of rice varieties and nutrients foliar spray on sodium leaf content during first season.

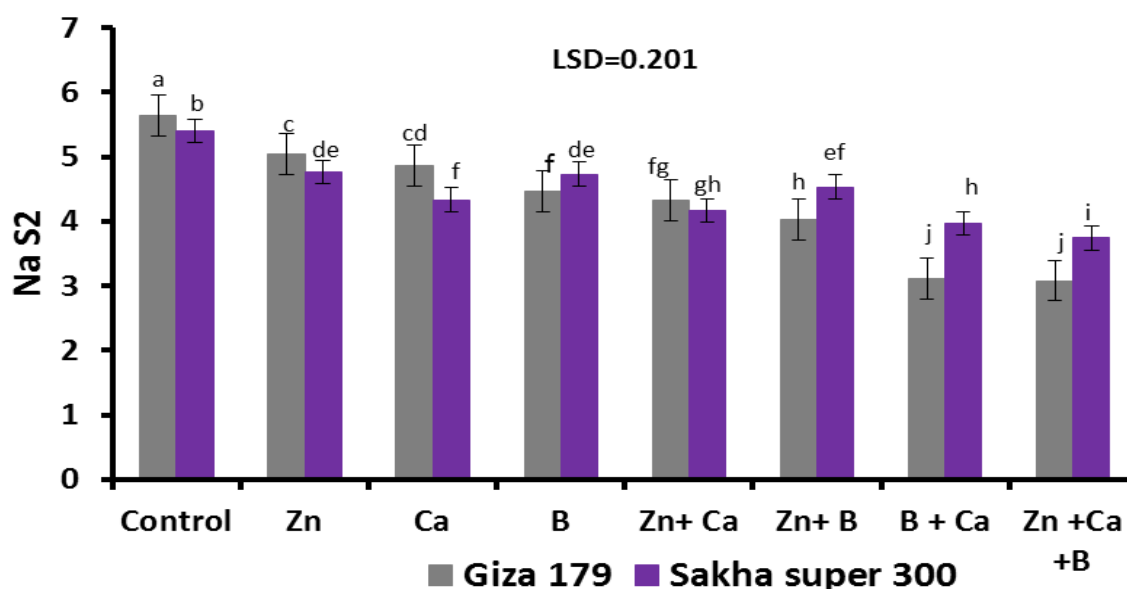


Fig. 6. Interaction impact of varieties and nutrients foliar spray on sodium leaf content during second season.

B. Growth, Yield and yield components

The collected data and its analysis variance related to yield and yield attributed to support great, marked and significant variation between the two studied varieties in both seasons (Tables 5-7). Giza179 rice variety significantly was superior to Sakha Super 300 in most measured parameter, LAI, grain yield, biological yield, harvest index and yield attributes: panicle length, panicle number, low unfilled grain in both study seasons except in, plant height, dry matter production, panicle weight, filled grains,

1000-grain weight. The current findings are in and agreement with those reported by Zayed et al, (2023a&b) and Ali et al, (2021).

With respect to the effect of foliated some micronutrients at certain rice growth stages on growth, yield and yield attributes, the results were arranged in Tables (Tables 5-7). There is distinct positive effect induced by the micronutrients spray on rice growth, yield and yield attributes in both seasons (Tables 5-7).

Table 5. Leaf area index, dry matter and plant height of rice as affect by foliar spray of elements under aerobic conditions in 2021 and2022 seasons.

Main effect	LAI		Dry matter		Plant height	
	2021	2022	2021	2022	2021	2022
Rice varieties (V)						
Giza 179	4.922a	5.489a	39.936b	44.616b	69.666b	88.737b
Sakha super 300	4.412b	4.554b	47.610a	48.262a	96.041a	100.133a
LSD 0.05	0.193	0.230	5.230	6.657	6.465	3.428
Nutrient Spray (N)						
Control	3.616e	3.983f	34.0e	31.666f	84.5abc	83.283f
Zn	4.186d	4.683e	46.566b	44.233d	87.666a	96.333bc
Ca	4.95b	4.683e	40.633c	40.616e	81.833bc	91.683e
B	4.506c	5.016cd	46.55b	47.933c	80cd	93.733de
Zn+ Ca	4.933b	4.983d	49.816a	49.016c	85.166ab	94.833cd
Zn+ B	4.616c	5.166c	49.833a	48.316c	82bc	96.333bc
B + Ca	5.083b	5.65b	37.766d	52.516b	85.333ab	98.416b
Zn+ Ca+ B	5.446a	6.008a	45.021b	57.216a	76.333d	100.866a
LSD 0.05	0.158	0.187	4.270	5.435	5.278	2.799
Interaction	**	**	NS	NS	NS	NS

** and ns indicate $P < 0.01$ and not significant, respectively. Means of each factor designated by the same latter are not significantly different at 5% level using Duncan's Multiple Range Test.

The highest means of plant height, LAI, dry matter production, panicle number, panicle weight, panicle length, filled grain and unfilled grains numbers/panicle, grain yield and biological yield and harvest index were produced when rice plant

were sprayed with the tri- combination of Zn+Ca+B without significant differences with Those produced by all di-combinations of tested nutrients in the first season and with those of Zn+ B combination in the second season in plant height (Table5-7)

Table 6. Yield components traits of rice as affect by foliar spray of elements under aerobic conditions in 2021 and2022 seasons.

Main effect	panicles / hill		Panicle weight (g)		Panicle length cm		Filled grains/ panicle	
	2021	2022	2021	2022	2021	2022	2021	2022
Varsities(V)								
Giza 179	27.141a	25.875a	3.259b	3.322b	19.954a	19.525a	110.737b	108.883b
Sakha super 300	14.954b	14.791b	3.777a	3.808a	18.995b	19.030b	124.504a	121.291a
LSD 0.05	0.467	1.536	0.127	0.173	0.209	0.139	8.125	2.359
Nutrients spray(N)								
Control	17.166b	16.000d	3.003b	3.03f	17.533b	17.5e	98.98d	102.5f
Zn	19.333b	18.333c	3.620c	3.725bc	19.733bc	19.583bc	105.2d	106.1e
Ca	19.85bc	20.333c	3.246a	3.38e	18.766cc	19.1d	113.0c	112.6d
B	22.15c	19.166c	3.326d	3.453de	19.183d	19.216cd	119.6c	115.2c
Zn+ Ca	21.35b	20.666b	3.483d	3.676cd	19.666d	19.183cd	122.95c	115.1bc
Zn+ B	22.083b	21.500b	3.646e	3.618bc	20.033e	19.483bcd	127.283b	120.8ab
B + Ca	21.933a	22.833a	3.808b	3.838ab	20.35e	19.86b	129.03b	121.1a
Zn+ Ca+ B	24.516b	23.833a	4.011a	3.803a	20.533a	20.433a	124.916a	127.0abc
LSD 0.05	0.381	1.254	0.103	0.141	0.171	0.112	6.634	1.926
Interaction	NS	NS	NS	NS	NS	NS	**	**

*, ** and NS indicate $P < 0.05$, $P < 0.01$ and not significant, respectively.

Table 7. Yield components and yields of rice affected by foliar spray of elements under aerobic conditions in 2021 and 2022 seasons.

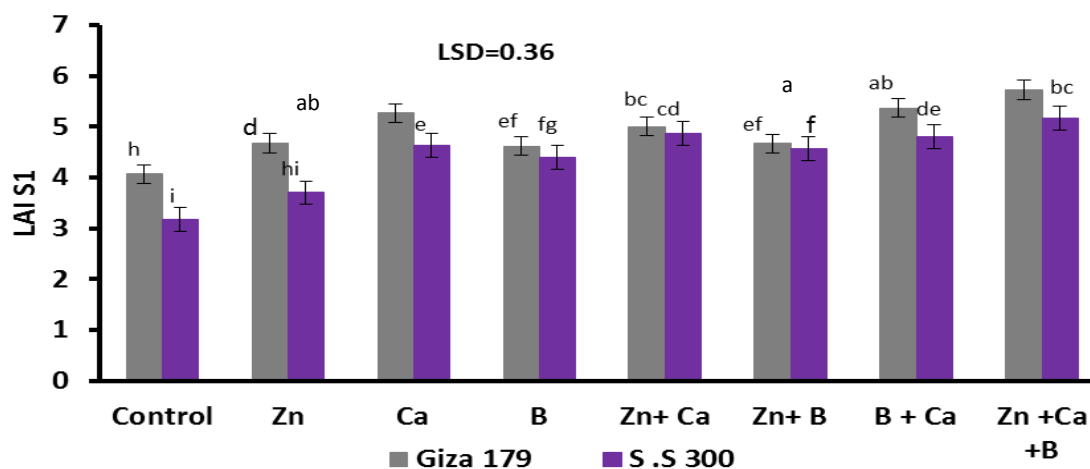
Main effect	Unfilled grains/ panicle		1000-grain weight(g)		Grain yield t/fed		Harvest index	
	2021	2022	2021	2022	2021	2022	2021	2022
Rice varieties (V)								
Giza 179	10.483b	15.325b	24.353b	24.483b	3.244a	3.256a	43.28a	47.608a
Sakha super 300	19.929a	26.370a	25.415a	25.545a	2.756b	2.870b	28.68b	41.178b
LSD 0.05	2.392	1.350	0.686	0.840	0.066	0.158	2.923	2.304
Nutrient Spray (N)								
Control	27.033a	26.370a	23.453c	23.583e	2.218b	2.114d	30.011de	30.866b
Zn	18.00b	23.55b	24.77d	24.900cd	2.766a	2.42c	35.603e	33.351a
Ca	16.65b	23.133b	24.653b	24.783d	3.088b	3.04c	37.223e	44.891b
B	15.35bc	22.55b	25.02b	25.15cd	2.866b	3.116b	35.683cd	47.593ab
Zn+ Ca	13.433cd	20.166c	24.853b	24.983cd	3.096b	3.152b	36.093bc	47.078a
Zn+ B	11.883de	18.633c	24.986b	25.116bc	3.106a	3.412a	35.56bc	50.786a
B + Ca	10.633ef	16.25d	25.536a	25.666ab	3.254b	3.508a	36.48ab	51.388c
Zn+ Ca+ B	8.666f	12.333e	25.803ce	25.933a	3.608b	3.746c	41.188a	49.191c
LSD 0.05	1.953	1.102	0.372	0.686	0.054	0.129	2.386	1.88
Interaction	NS	NS	NS	NS	**	**	NS	NS

*, ** and ns indicate $P < 0.05$, $P < 0.01$ and not significant, respectively. Means of each factor designated by the same letter are not significantly different at 5% level using Duncan's Multiple Range Test

The lowest values of growth criterion, yield attributes and yields were recognized when rice plants grown under aerobic cultivation did not foliar with any of nutrients just soil fertilization of NPK (Hubbard et al. (2001), Broadley et al. (2007), Rehman et al. (2018), Lakaew et al. (2020) and El-Sobky et al. (2022).)

The interaction between rice cultivars and nutrient spray treatment had a significant effect on leaf area index, filled grains number/ panicle and grain yield

t/fed in both seasons (figures 11-18). The highest values of LAI were produced by when Giza179 rice variety was sprayed by the combination of Zn+Ca+B. The highest values of panicle number, filled grains/panicle grain yield were produced by Giza179 when it sprayed with the combination of Zn+Ca+B in both seasons. The lowest values of LAI, Filled grains and grain yield were recorded when untreated plants of Sakha super 300 in both seasons (Figs 5-1).

**Fig. 8. Interaction impact of rice varieties and nutrients foliar spray on LAI content during first season.**

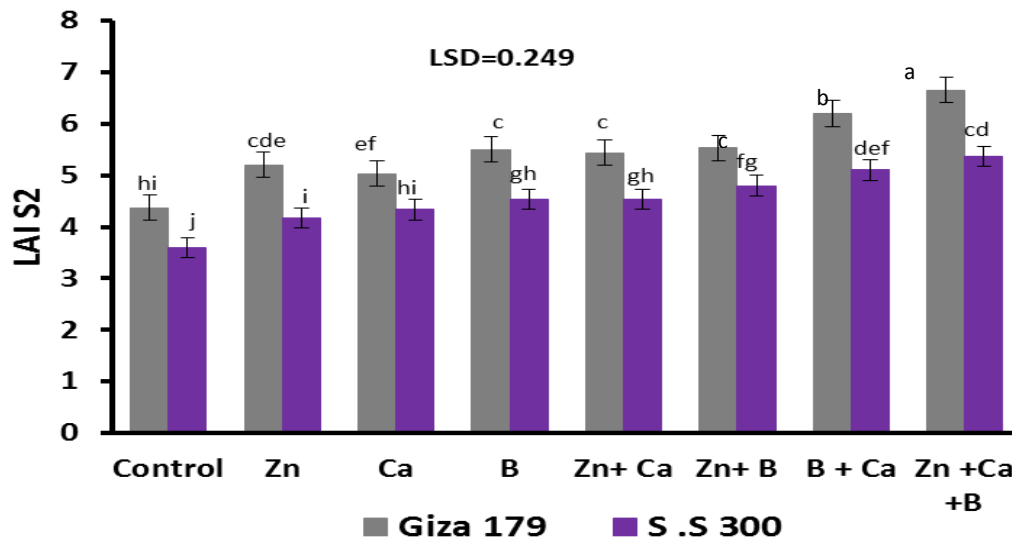


Fig. 9. Interaction impact of rice varieties and nutrients foliar spray on leaf area index content during second season.

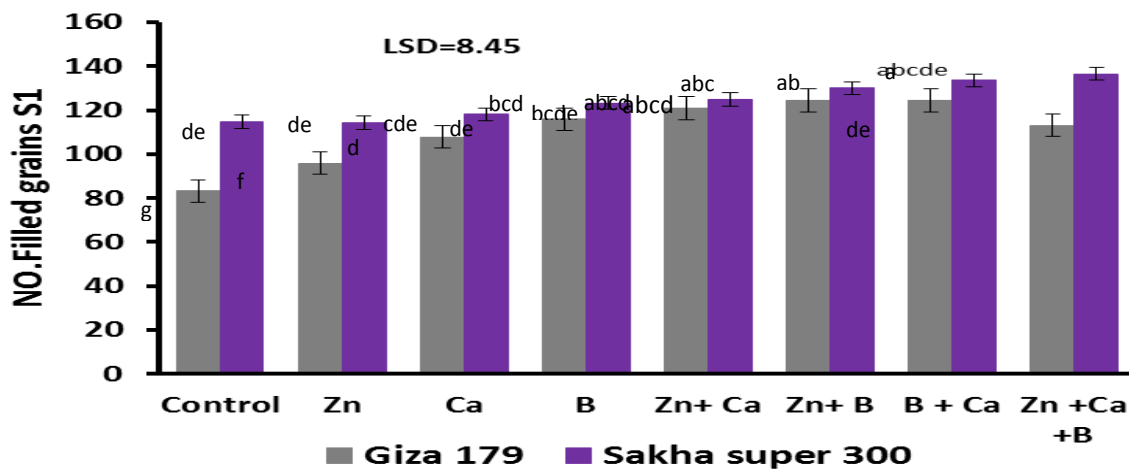


Fig. 10. Interaction impact of rice varieties and nutrients foliar spray on number of filled grains during first season.

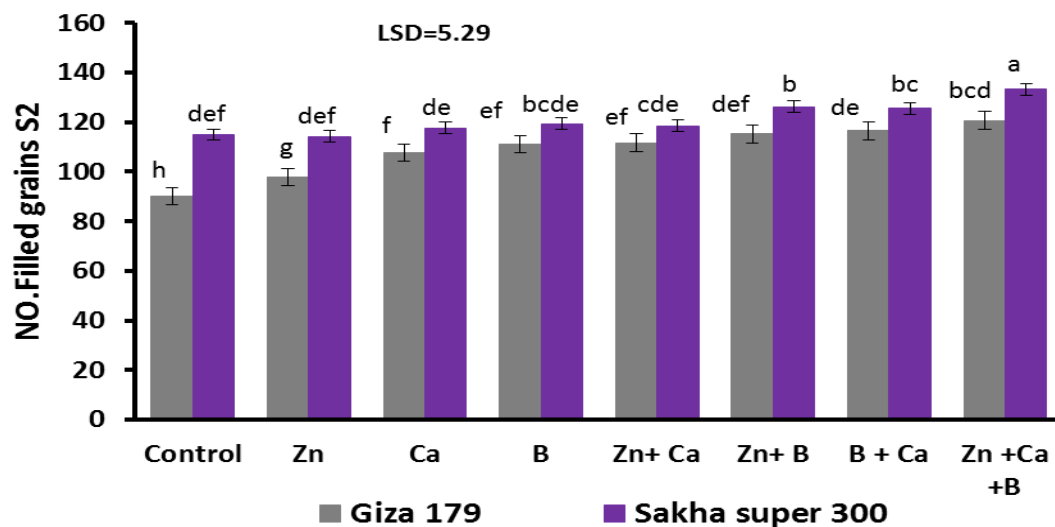


Fig. 11. Interaction impact of rice varieties and nutrients foliar spray on number of filled grains during second season.

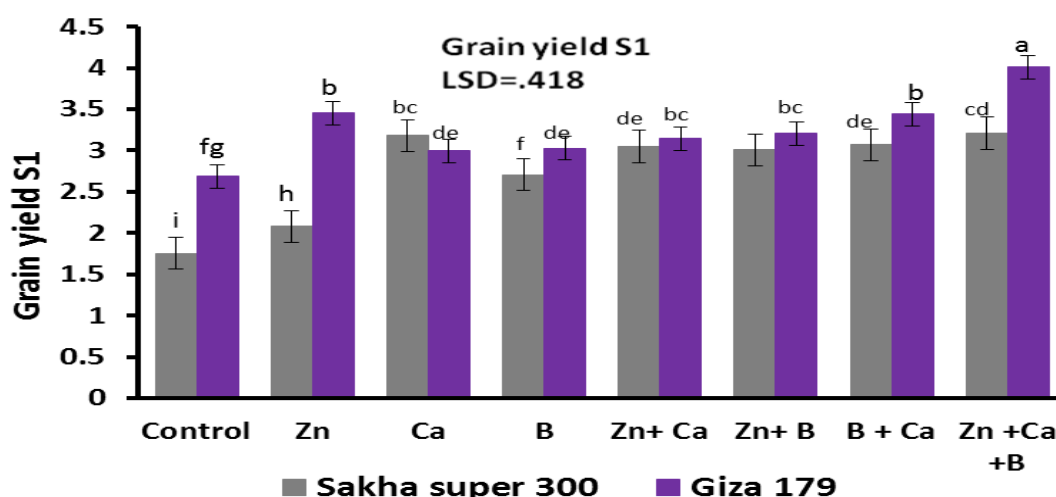


Fig. 12. Interaction impact of rice varieties and nutrients foliar spray on number of Grain yield t/fed during.

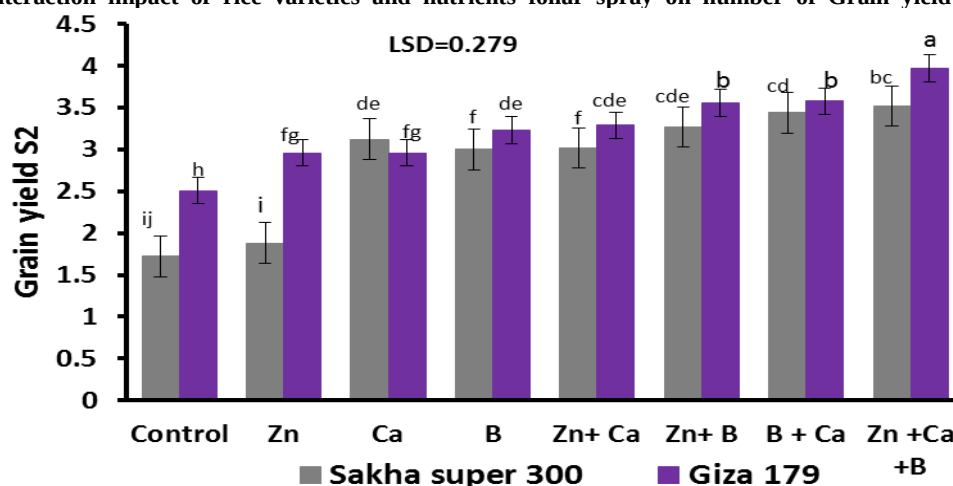


Fig. 13. Interaction impact of rice varieties and nutrients foliar spray on number of Grain yield t/fed during second season.

Discussion

Giza179 rice variety showed highly significant and effective photosynthesis parameters compared to Sakha super300. Giza179 rice variety had an effective genetic background and optimum structure, enabling it to have a high photosynthesis rate, high quantum of PS11 with optimum stomata conductance regulation plant pigments including total plant pigments that was combined with high antioxidants with low MDA and H₂O₂ in the terms of low phospholipids cell membrane damage as well as meta-Chandaria. Generally, Giza179 was very matching adapted to climate change and other abiotic stresses. Similar results were reported by Zayed et al, (2023a&b) and Ali et al, (2024). Giza179 could be considered as a resilient variety since it showed high affinity to adjust it ion selectivity under studied smart planting method compared to the Sakha super 300 rice variety.

Giza179 rice varieties gave the highest values of potassium (K⁺) and the lowest values of Sodium (Na⁺), and Na⁺/K⁺ ratio versus Sakha super 300. The ability of Giza179 to adapt its cell, shoot and root structure, metabolism and osmotic potential as well as its genetic background with potassium and calcium a channel anti-porters strengthened it to improve it ion selectivity. Improving ion selectivity of Giza 179 induced high K⁺ and Ca²⁺ uptake with a safe rate of Na uptake. Giza179 rice variety significantly was superior to Sakha Super 300 in all measured growth parameter, plant height, LAI, dry matter production, yields, grain yield, biological yield, harvest index and yield attributes: panicle length, panicle number, panicle weight, low unfilled grain. Interestingly, since the seed set of Giza179 was very high, it gave the lowest values of unfilled grains/panicle compared to Sakha Super 300

providing the superiority of Giza179 under climate change and water deficit. Giza179 excelled Sakha super 300 in photosynthesis, components, defence system development, ion selectivity and uptake as well as leaf area index (LAI), seed set and panicle number/ unit area, which enabled it to exert high grain yield combined with high harvest index. Under abiotic stresses including low water input in rice higher harvest index, more panicle numbers/unit area and discriminated net photosynthesis with well-stomata conductance and ion selectivity regulations and marked ability of ROS exertion declining all are close indicators for water deficit tolerance that was fact in Giza179 compared to Sakha super 300. The current findings are in agreement with those reported by Zayed et al, (2023a&b) and Ali et al, (2021).

Since aerobic conditions affect rice metabolism, photosynthesis operation and activity of different enzymatic systems as well as, cell structure and development such as division, cell wall, membrane integrity, applying some exogenous materials such as Zn, B, and Ca might vastly reform the disturbance. Foliar application of Zn, B and Ca+2 alone or in a combination at certain rice growth stages markedly improved and raised the photosynthesis parameters, defence system at different levels including antioxidants (SOD, APx, and CAT) and osmolytes system (proline). At the same time, application of Zn, B and Ca+2 via foliage alone or in combination significantly declined the MAD cell concentration. the tested three nutrients, Zn, B and Ca+2 showed significant role in rising and reforming restricted stressed photosynthesis owing to several positive effects such as keeping high cell integrity, low osmotic potential, regulating stomatal conductance, lowering photo oxidation, remediated oxidative stress and activating enzymatic and non-enzymatic antioxidants as well as ensuring high sources of energy in the terms of ATP (Marscher, 1995 and Sutulien et al, 2023). Under aerobic condition in the terms of low water supply in rice combined with some nutrients deficiency such as Zn, B and Ca+2, damaging the plant phloem transport, reducing sink capacity, and increasing sugar accumulation in the leaves, deficiency can cause down regulation of photosynthesis might be induced but applying such nutrient might be reformed and corrected those mentioned disturbance plant job and resealed high photosynthesis (Wimmer and Eichert, 2013). Several authors came to similar

findings such as Hubbard et al. (2001), Broadley et al. (2007), Lakaew et al. (2020) and El-Sobky et al. (2022).

The data collected on plant pigments in response to foliar spray treatment of Zn, Ca, B displayed a significant effect. Foliar application of these nutrients significantly enhanced the plant pigments including chlorophyll a & b, total chlorophyll, and carotenes. Additionally, the ratios of carotenes to chlorophyll and chlorophyll a & b were positively affected. The reduction of chlorophyll contents can be attributed to various factors among this activation of chlorophyllase enzymes may facilitate the breakdown of chlorophyll (Parida and Das, 2005). Alternatively, the inhibition of chlorophyll production can result from membrane degradation, affecting chlorophyll integrity. These processes contribute to oxidative stress, linked to the inactivation of the Rubisco enzyme, a core element for photosynthesis (Soussi et al, 1998). The alternation in chlorophyll ultrastructure may have the potential to reduce the chlorophyll contents (Rady, 2011). Moreover, carotenoids display antioxidant characteristics essential for preventing photo-oxidation (Mohammadi et al, 2019). In a separate investigation, Stefanov et al. (2021) recorded an elevation in carotenoids/chlorophyll in maize under salt stress and Roy et al (2019) reported similar results in rice. Addition such nutrients showed high effectiveness to improve ion selectivity by adjusting nutrient uptake toward high K⁺, Ca²⁺, Mg²⁺ and low Na⁺ in Continuously, high K⁺/Na⁺ and Ca²⁺/Na⁺ ratio was observed when rice plants grown under aerobic conditions were sprayed by tested nutrients at certain rice growth. Drought coupled with aerobic condition display restricted nutrients availability, uptake and translocations however, the foliar application became an effective approach. The nutrients can easily penetrate stoma and later cell reducing the drought stress condition. The nutrient uptake through foliar application is dependent on chemical properties, valency and its mobility (Akbarimehr et al, 2021 and Anwar et al, 2021). Furthermore, spraying such nutrients as previously detected showed apparent improvement in rice osmotic potential, rice defense systems and rice health with combined with probably good root system which induced high uptake and concentration of K⁺, Ca²⁺, P and N with low uptake of Ca²⁺. At the same time, its application induced low Na leaf

content and uptake owing to high concentration of both K^+ and Ca^{+2} which antagonized the Na^+ uptake and subsequently lowered Na concentration and boosted K^+/Na^+ ratio .

Boron regulates the chelation of metal ions via cell wall by influencing the associated charged functional groups. Metal cations i.e., bivalent and trivalent can bind to carboxyl groups ($-COOH$) whereas, the negatively charged groups in the component cell are found as pectin (Krzesłowska, 2011). Its noteworthy, the degree of esterification depends on ability of pectin to conjugate with metal ions. In addition, polysaccharides i.e., phenolic substances and proteins also contribute for chelation of metal ions (Krzesłowska, 2011). The boron treatment can alter the pectin degree of esterification and functional group contents. It has also been reported in some crops, the contents cellulose, lignin, protein and related components of cell wall are elevated under boron treatment. Under boron treatment, the physiological changes may influence the chelation of metal ions i.e., Cd^{2+} , Ca^{2+} and Al^{3+} which further impact their absorption, accumulation and tolerance by plants (Huang et al, 2021). Zinc has an effective role in regulating the concentration of auxin that raised most plants physiological and metabolic activities, which help plants, absorb more nutrients from the soil (Mian et al, 2021). Zinc increased photosynthesis process, the movement of photo assimilates, and the production of proteins (Shaaban et al, 2023). In addition to zinc act as a co-factor of most enzymes and have an effective role in cell division and protein synthesis (Dhaliwal et al, 2021). On the other hand, boron effects on transfer of water and nutrients from root to shoot, has a vital role in chlorophyll production and enhances the formation of carbohydrates as well as nutrients uptake and translocation (Shoja et al, 2018). These results are in harmony with that concluded by similar results was obtained by Zayed et al, (2023a&b) and Ali et al, (2024) as well as Yousif et al, (2023). As previously indicated during the current work, the foliar spray of Zn , Ca^{+2} and B as single or combination either di or tri one possessed benefit and effective impact to adapt and reform as well correct the illness effect of low water supply in aerobic rice system. Since, rising ROS concentration in rice plant under abiotic stresses including water is a main problem which hinders rice growth, metabolism and finally yield, applying

such nutrients via foliage induced more antioxidants to remove and eliminate those ROS, protecting cell development and health ensuring well growth, optimum yield attributes and finally higher grain yield. Continuously, applying such nutrients showed better photosynthesis components and contentment levels of plant pigments with their wise ratios as well as which created high net assimilation production pre and post heading with optimum leaf area index, delay senescence, high assimilate translocation and sufficient dry matter partitioning resulted in acceptable yield component and ultimately higher rice grain yield .

The limited water regime had significant impact on yield and yield related traits of plants with no exception to rice. The yield reduction is the outcome of reduced photosynthesis, drought, elevation in production of reactive oxygen species damaging cell membrane and organelles ultimately disrupting photosynthetic machinery (Shukry et al., 2022). The foliar supply of nutrients later uptake from leaves may reduce the negative impact of drought (Hubbard et al. (2001), Broadley et al. (2007), Rehman et al. (2018), Lakaew et al. (2020) and El-Sobky et al. (2022).

Zn and B played an integral role for cell division, elongation of meristematic tissues, membrane integrity, ions and water absorption (Akbarimehr et al, 2021). Moreover, Zn , B , and Ca influence during the reproductive development may cause sterility and yield owing to poor development of anther and pollen leading toward failure of pollen germination therefore, the exogenous application of these macronutrients during reproductive phase overcome the problem (Domingos et al, 2021 and Sharafi et al, 2021). The nutrients are essential components for the normal functioning of plants i.e., cell structure and metabolic structure (Nawaz et al, 2020). The supplementation of nutrients through foliar spray enhances the absorption of nutrients can significantly improve the yield and yield related traits (Sofi et al, 2021). The similar results were also reported by Ali et al. (2021) and reported bioavailability of macronutrients i.e., Zn , Ca and B maintain the fertility and reproduction of rice. The foliar application of nutrients improves synthesis and accumulation of photo-assimilates, reproduction and production of secondary metabolites. Moreover, the application of fertilizers enhanced 30% elevation for physiochemical and yield related traits in

Brassica napus (Aslam et al, 2021 and Salman et al, 2022).

Conclusion

It could be concluded that foliar application of some vital nutrient such as Zn, Ca and B at certain rice growth stages is more urgent which adapted rice under aerobic condition, remediated the hazard effect of, improved defence system, raised photosynthesis and plant pigments, rice yield components and finally rice grain yield under aerobic cultivation. The interaction effect came to provide the effectiveness of tri combination of Zn+Ca+2+B with Giza179 to get higher yield under aerobic rice cultivation contributing to the issue of climate change mitigation and adaption. The results of this current experiment could be applied on rice growing under similar abiotic stress such as salinity and heat stress particularly under apparent climate change to ensure rice high yield under such conditions.

Consent for publication:

All authors declare their consent for publication.

Author contribution:

The manuscript was edited and revised by all authors.

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