*/--+

Available online freely at www.isisn.org

Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 2023 20(4):1049-1059. **OPEN ACCESS**

Micronutrients zinc, boron and silicon application and sowing time enhance rice yield production and grain under semiarid climatic conditions

Muhammad Tahir Ahsan[1], Muhammad Hamza Latif[1], Annam Yar[2], Esha Niaz[3], Dr Saba Tabasum[4], Tayyaba Sanaullah[5], Muntha Sittara[6,]Muhammad Salman Hameed[7],Shamim Akhtar[8],Muhammad Waseem Zulifqar[9]and Muhammad Usman[10]

[1]Department of Agronomy, University of Agriculture, Faisalabad, **Pakistan**
2Deparment of Agronomy Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, **Pakistan**
[3]Department of Botany University of Agriculture Faisalabad, **Pakistan**
[4]Department of Plant Breeding and Genetics, College of Agriculture, University of Sargodha, **Pakistan**
[5]Department of Botany, Emerson University Multan, **Pakistan**
[6]Division of Science and Technology University of Education, Lahore, **Pakistan**
[7]National Key Laboratory of Green Pesticide, International Joint Research Center for Intelligent Biosensor Technology and Health, Central China Normal University, Wuhan 430079, P.R. **China**
[8]Entomological Research Institute, Ayub Agricultural Research Institute. Faisalabad, **Pakistan**
[9]Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, **Pakistan**
[10]Department of Entomology, University of Agriculture, Faisalabad, **Pakistan**

***Correspondence:** musman6053@gmail.com **Received 13 September 2023, Revised: 10 November 2023, Accepted: 14 November 2023 e-Published: 19 November 2023**

Maximum demands of staple food led to maximum nutrient application to increase rice cropping production which may affect the yield and quality of rice crops under semiarid environmental conditions. A study was conducted to evaluate the effect of boron, zinc and silicon application on the productivity of direct seeded rice. The field experiment was carried out at the Agronomic research area, Department of Agronomy, University of Agriculture, Faisalabad during the summer season 2019. The trial was laid out in randomized complete block design (RCBD) under factorial arrangements having three replications. Optimum soil moisture conditions were kept at the time of sowing. The experiment was comprised of 16 treatment combinations made from two times of foliar sprays (40 DAS and 60 DAS) and eight different micronutrient combinations Control, boron (0.01 M), zinc (0.025 M), Silicon (1 %), boron (0.01 M) + zinc (0.025 M), zinc (0.025 M) + silicon (1 %), silicon (1 %) + boron (0.01 M), boron (0.01 M) + zinc (0.025 M) + silicon (1 %). Results revealed that boron, zinc and silicon application and timings significantly affect the yield and yield components of direct seeded rice. Treatment boron (0.01 M) + zinc (0.025 M) + silicon (1 %) application at 60 DAS significantly increased the total number of productive tillers, 1000 grain weight and paddy yield. A significant decline in the percentage of sterile spikelet and opaque kernel was also observed as compared to other treatments. Treatment boron (0.01 M) + zinc (0.025 M) + silicon (1 %) application at 60 DAS did not affect significantly plant height and biological yield of direct seeded rice. This research shows that micronutrients, boron, zinc and silicon are highly effective fertilizers to enhance rice production and improve grain quality as well.

Keywords: Direct seeded rice, opaque kernel, sterile spikelet, semiarid climate, harvest index

INTRODUCTION

The ever-enhancing global population needs more care for the precise use of input resources like water, seeds and fertilizers, etc. Rice is a unique crop as it can be grown in wet as well as in humid regions of the world, where other crops cannot survive. There is an abundance of such wet and humid areas across Asia and North America (Chauhan et al.2017). It is one of the fittest human food crops on earth, directly or indirectly providing food for more than half of the world's population, almost 3 billion people deal with rice every day (Mohanty, 2013). World rice production demand is assumed to increase by 25% in 2025, in order to keep pace with the growing population (Maclean *et al.*2002). It contains several essential energy rich compounds like fats, proteins, amino acids, iron, thiamine, riboflavin, niacin and calcium (Juliano, 1993). Various research groups are focusing on the development of suitable formulations for combating the weed problem of this technology, but there are several other issues resulting in decreased yield of rice crop when it is sown with the DSR technique (Chauhan and Opena, 2012). Direct sown rice suffers from poor grain filling, early maturity and lack of pollination. However, this system has been proven least costly and well suited to the farming community in Pakistan (Farooq *et al.*2006b). Several European countries including the USA and Australia practice direct sowing of rice on a considerable area as it escapes from all the costs involved with transplanting. Direct seeding under zero/ reduced tillage is an excellent resource conservation technology (RCT) nowadays because of its several exceptional benefits over puddled transplanted rice (Hanjar and Quereshi, 2010; Mahajan et al.2012). Including 40% savings in the cost of labor required for growing nursery and seedling transplant, up to 60 % reduction in water requirements as water required for nursery raising, puddling and several other losses are prevented, 7-10 days early maturing character of direct seeded rice make its feasible for the farmer to sow wheat timely and also the reduction in the amount of emitted greenhouse gases result in prevention of environmental destruction (Kumar and Ladha, 2011; *Farooq* et al. 2011).

Micronutrient deficiency is said to be one of the main reasons behind the continuously decreasing outputs of rice production systems in many countries (Schiller *et al.*2001). Most of the soils in Pakistan are salt affected (Ghafoor et al.2022) and the availability of several cationic micronutrients depends directly on their solubility in soil solutions, pH and oxidation-reduction potential in root zone (Zhu *et al.*2004). Nutrient uptake and availability are also dependent on the characteristics of binding sites on inorganic and organic particles (Ghafoor et al.2021). Therefore, under saline conditions, micronutrient concentration in soil and plants acts differently depending upon plant species and soil types. Zhu et al. (2004) described that micronutrient deficiencies are often observed under low water and salt stress, which also results in high pH of the soils. Hussain *et al.* (2012) proved that growth and grain yield in rice crops were significantly influenced by the application of B in soils limiting B availability to plant roots. According to Remesh and Rani (2017) Boron delivery to crop through soil or foliar way has significant influence on yield parameters and nutrient acquisition of wetland rice. Mohan et al.2017 stated that foliar zinc application together with iron, boron and silicon recorded more plant height, number of tillers m^{-2} and leaf area index.

Zinc has a very vital role in plant metabolic processes because it influences several multi-functional enzymes including carbonic anhydrase and hydrogenase. It also has a significant role in the maintenance of ribosomal segments and cytochrome synthesis (Hafeez et al.2013). Plants depend on Zn in order to regulate gene expression which is the main component of the environmental stress tolerance mechanism (Rehman et al.2018). Especially in rice plant Zn deficiency causes developmental anomalies which are easily visible as its deficiency symptoms including stunted growth, loss of green color and spikelet sterility (Farooq et al., 2018). Zinc regulates the synthesis of auxin an essentially required growth hormone and it is a main component of tryptophan which is a precursor for indole acetic acid (Kumar et al.2016). Soils deficient in zinc are found everywhere in the world and almost all cultivated crops are susceptible to Zn deficiency. Rice crop responds positively to the application of Zn-containing fertilizers (Ram et al.2016).The submerged soils are also well known for being deficient in available Zn for plant roots; mainly due to the reaction of zinc with free sulfide (Esfandiari et al.2016). Zinc deficiency is commonly seen in both Dry direct seeded aerobic (Gao et al.2007) as well in conventional puddled (Dobermann et al.2003) rice production systems. Several chemical soil factors such as redox potential, pH and the presence of Fe, Mn, P and Zn in soil solution influence zinc availability in the root zone.in case zinc precipitates as zinc sulphide at low redox potential, as Zn $(OH)_2$ with the increase in soil pH (Kumar et al.2016).

Boron deficiencies prevail over much wider cultivated soils and crops as compared to any other essential micronutrient (Farooq *et al.*2018). Deficiency of B has been reported in 132 different crops and 80 countries around the globe. Dealing with B deficiency is of immense importance because it has a direct effect on plant flowering and reproductive stages thereby affecting economic yields (Ahmad et al.2009). Boron is responsible for pollen viability, seed setting and grain filling in various rice cultivars (Ahmad et al.2012). It is considered as more positively Influential during reproductive than vegetative growth of rice (Rasheed, 2009). Its deficiency symptoms in rice plants include whitish discoloration and twisting of younger leaves, weak stem, short and a smaller number of tillers, sometimes plants are also unable to produce viable seeds (Bassil *et al.*2004). Stem and leaves in rice are flaccid when there is a sufficient supply of Boron (Bell and Dell, 2008). It has several important functions in plants such as maintaining cell wall integrity while facilitating the growth of pollen tubes and seed germination in grain crops like cereals (Bolanos *et al.*2004). It has a role in cell growth and panicle development of rice plants (Ahmad *et al.*2009).

Silicon is generally known as a significantly beneficial nutrient for rice cultivation as it is required in surplus amounts for rice growth (Tavakkoli et al.2011). It is estimated that about 20 kg of silicon is absorbed from the soil by rice crop for each 100 kgs of grain are produced (Nascimento et al.2018). Among all the microelements utilized by plants, silicon is the only consistent micronutrient present in concentrations similar to those of other macronutrients (Etesami and Jeong, 2018). Its concentration in whole dry matter of different plant parts ranges between 0.1 and 10 percent (Ullah *et al.*2018). Silicon compounds are major part of different cellular components (cell walls, cell lumens and intercellular spaces) Also it is accumulated above and beneath the cuticle layers. The significance of silicone application in crop health and growth has been evaluated in several silicon-accumulating crops (Tavakkoli et al.2011). Research findings proved that sufficient supply of silicon to plant roots can enhance the tolerance of farm crops especially rice against biotic as well as abiotic stresses (Ullah et al.2018). Silicon absorption by plants decreases the rate of chewing insect incidence such as that of stem borer; it is a result of plant tissue un-digestible or by damaging mandibles of chewing insects, A Low level of plant available silicon makes it more susceptible to fungal disease, germs attack and lodging that affect crop quality and yields negatively (Hall et al.2019; Chanchal et al.2016). Lodging causes direct loss in rice yield and grain quality as it is one of the major constraints in rice production system (Singh et al.2006).

Keeping in consideration above studies concluded that DSR is an efficient resource utilizing, economical and farmer's friendly technology for the cultivation of rice as an entrepreneurship. Micronutrient (B, Zn, Si) application as well as time of application for nutrients have substantial impact on quality, yield and yield contributing traits in direct seeded rice production system. Partial research is available about the effects of boron, zinc and silicon on rice crop. Present experiment is planned to increase rice yield and development through different combination of micronutrients zinc, boron and silicon under semiarid environment. Current research objectives were to different sowing times and micronutrients rates best for rice production under semiarid environmental conditions to secure food security under climate changing trend.

MATERIALS AND METHODS

Experimental site, design and. Soil physical-chemical properties

An experiment was conducted during summer season, 2019 at the Agronomic Research Area, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan (31°30'N, 73°05'E and 214 meter above mean sea level). The experiment was laid out in randomized complete block design (RCBD) with factorial arrangement having three replications. The net plot size was maintained 6.5 m × 1.8 m. The soil at which experiment was conducted was sandy clay loam, which belongs to Lyallpur soil series. The soil samples were collected from the site of experiment with the help of soil auger to a depth of 0-30 cm before sowing of seed and fertilizer application. The EC, available P and available K were measured by following saturation extract methods (US Salinity Lab Staff 1954), Olsen procedure, flame photometer method respectively (US Salinity Lab Staff 1954). Available total N (%) and organic method were measured by Kjeldahl and Walkley-Black method (Ryan et al. 2013). The pre soil analysis reports showed that soil has EC, pH, soil organic matter, available P and K, N%, SAR, ESP and available Mo 1.50 dsm^{-1}, 8.2, 1.05, 8.1 ppm, 180 ppm, 0.040%, 7, 6 and 0.07 ppm respectively. The factor A included time of applications (T) T_1: 40 Days after sowing (DAS) and T_2: 60 Days after sowing (DAS), while factor B consists of micronutrients (M)M_1: Control, M_2: Boron (0.01 M), M_3: Zinc (0.025 M), M_4:Silicon (1 %), M_5: Boron (0.01 M) + Zinc (0.025 M), M_6: Zinc (0.025 M) + Silicon (1 %), M_7: Silicon (1 %) + Boron (0.01 M) and M_8: Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) respectively.

Meteorological data

During the period of crop (2019), the meteorological data were collected from Agro-meteorological Cell, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan (Figure 1,2 and 3).

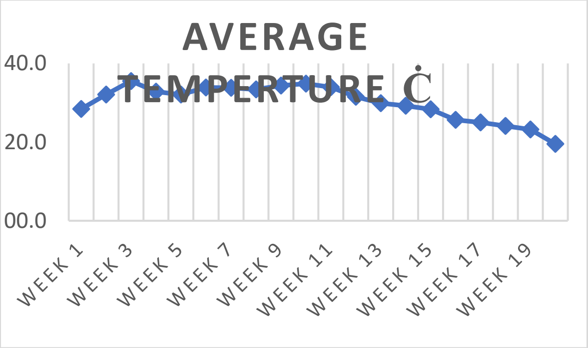

Figure 1: Averages of temperature during summer 2019

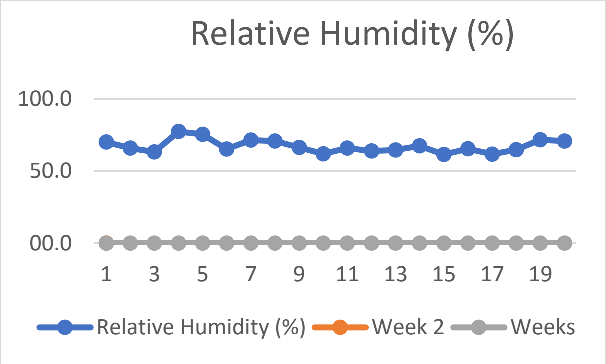

Figure 2: Averages of relative humidity during summer 2019

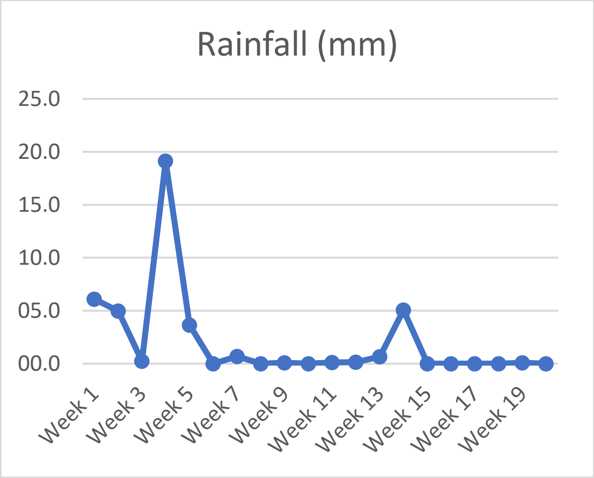

Figure 3: Averages of rain fall during summer 2019.

Land preparation, pesticide and weeds management

The experimental field was prepared by pulverizing the soil with cultivator followed by the planker, the tractor drawn implements were used for land preparation. Firstly, field was cultivated by the tractor mounted rotavator, containing wheat as a previous crop. After rotavating the previous crop stubbles, seed of sesbania and rice were broadcasted in the field. After a month, the germinated sesbenia and rice seed were rotavated in the field. Soil sampling was done in zigzag pattern by auger and analyzed from soil laboratory of Fauji Fertilizer Company Limited. After that, ploughing was carried out twice by cultivator followed by planking for the preparation of required seedbed. In direct seeded rice, weeds were controlled by applying pre-emergence herbicide “Council” @ 75g/acre immediately after the sowing of crop and two weeding were done at 20 and 40 days after sowing for removing weeds manually. There was no serious problem of insect-pest except mild incidence of stem borer which was controlled timely by applying Cartap hydrochloride (Calden-G) @ 20 kg ha^{-1}.

Sowing time, seed rate and treatment

Certified seeds of Basmati variety Chenab Basmati 2016 were collected from Engro fertilizer, Pakistan. Before sowing of seed, the seeds were treated with fungicide, Topsin M @ 2.5g/kg seed and seed were soaked for twenty-four hours in solution. Certified seeds of above stated variety were sown at seed rate of 30 kg ha^{-1} in direct seeded rice production system. Manual hand drill was used for the sowing of seeds maintaining 22.5 cm row to row distance. In order to minimize the seepage losses, the main plots were separated with a bund to avoid flow of water between the direct-seeded rice plots. Seed was sown by manual drill in dry soil and irrigation was given by flooding method. Pre-sowing irrigation was given to the field for preparation of seed bed and water was given as per need to maintain soil moisture was maintained near saturation from sowing to milking stage.

Procedures for growth and yield parameters

At the time of harvesting, height of five primary tillers were measured by random selection of primary tillers from each plot and then average was calculated from the base of plant up to the flag leaf tip with the help of meter rod. The productive tillers were counted from an area of 1 m^2 randomly selected from each plot and then average was taken. For taking 1000-grain weight, an automatic electric balance was used to record the 1000-grain weight of each plot in the laboratory. Biological yield was measured from sun-dried samples by including the straw and kernels. Weight from each plot was converted into t/ha^{-1}. The kernel was separated from straw for measuring grain yield. After which the samples were sun dried for removal of moisture for two days. Weight of the sundried samples were taken using weighing balance and then converted into t/ha^{-1}. Harvest index (%) is the ratio of grain yield to biological yield and multiplied with hundred.

Grain quality

Normal kernels attain full size, show normal starch compaction and allow light to pass through them. These kernels were computed by deducting all the abnormal kernels from total spikelet number and were marked as clear translucent and without any chalky spots. Abortive kernels look gloomy and light cannot pass through them. Abortive kernels are those kernels in which fertilization take place, but these kernels do not attain full size due to growth stoppage during early stage of grain formation. By separating all the kernels on working board, abortive kernels were counted and then average was taken which is latterly converted into percentage.

Statistical Analysis

The collected data were analyzed by using the Fisher’s analysis of variance function of Statistix 8.1 statistical computer package and the treatment’s means was separated by using Tukey’s honestly significance test (HSD) procedure at 5% level of probability (Abdi and Williams., 2010).

RESULTS

Agronomic rice parameters

Optimum plants height means optimum vigor and health of a crop, which is directly proportional with the establishment of healthy root system and availability of essential nutrients to the plants (Figure 4). Results also revealed that statistically significant differences were not found with respect to micronutrients (Zn, B, Si) and time of its application. Our results are identical to the finding of Sarkar (2014) who concluded that plant height was significantly influenced by various cultivars of rice due to varietal variation and in case of planting method, the results were against the finding of Mohan *et al.*(2017) who concluded that plant height was significantly influenced by the foliar application of zinc, boron and silicon yielded in maximum plant height (Table 1). The variations in plant height of rice cultivars are due several reasons i.e. genetic variation, nutrient availability and its adaptation to locality. The maximum number of productive tillers m^{-2} (384) were recorded in 60 DAS treatments and was minimum (347) in 40 DAS rice treatment. Analysis of variance indicates that productive tillers in different micronutrients and its time of application varied (Table 2). In case of micronutrient combinations, maximum productive tillers m^{-2} (440) were obtained when Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) were applied followed by Zinc (0.025 M) + Silicon (1 %) (408), while minimum productive tillers m^{-2} was recorded in control treatment (260). The minimum productive tillers m^{-2} was recorded in control (230) followed by (231) Boron (0.01 M) + Silicon (1 %) 40 DAS. The findings of study are similar to the findings of Mohan *et al.*(2017) who concluded that Zn, B, Si application resulted in a greater number of productive tillers as compared to control (Figure 5). In case of time of application, the results are similar to the findings of Mustafa et al.(2011) and Kulhare et al.(2017) who concluded that foliar spray at reproductive stage results in a greater number of productive tillers as compared to its application during vegetative growth. The 1000 grain weight of rice is pivotal yield contributing parameter in rice grain production (Figure 6). Maximum 1000-grain weight was recorded in treatments that were applied 60 days after sowing (DAS) (25.41 g) and minimum 1000-grain weight was recorded in 40DAS treatment means (23.24 g). Among different nutrient combinations treatment Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) gave Maximum 1000-grain weight (31.74 g), followed by Boron (0.01 M) + Zinc (0.025 M) application (29.99 g), while minimum 1000 grain weight was recorded in control treatment (19.02 g). Scientists also claimed that 1000 grain weight of cultivars of rice is different due to variation in genetic characters, environment conditions and nutrient availability (Ahmad, 2017). The results are similar to the findings of Ahmad et al. (2013) who reported that more 1000 grain weight was production with the foliar application at flowering stage in rice as compare to other treatments and results are not in line to those of Boonchuay et al. (2013) who stated that there was no difference in 1000 grain weight under different application times. In case of micronutrient combinations, the results were similar to the findings of Mohan *et al*. (2017) who reported difference in 1000 grain weight under different micronutrient application due to variation in availability of essential elements during critical growth period. Maximum biological yield was observed in Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) treatment (17.55 t ha^{-1}), followed by Boron (0.01 M) + Zinc (0.025 M) (17.03 t ha^{-1}) and minimum biological yield was recorded in control (12.63 t ha^{-1}). Data also indicated that the significant effect of interaction between time of micronutrient spray and their combinations on biological yield. The maximum biological yield was recorded in Silicon (1 %) application 40 DAS (19.48 t ha^{-1}) and Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) at 60 DAS (19.08 t ha^{-1}), followed by Zinc (0.025 M) application 60 DAS (18.28 t ha^{-1}). While the minimum biological yield was recorded in control treatments at both 40 and 60 DAS treatments (12.49 and 12.76 t ha^{-1}). Less insect pest and disease incidence due to silicon application and more vigorous growth due to zinc and boron application could be the reason behind more biological yield with the application of Silicon (1 %) application 40 DAS and Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) at 60 DAS lead to maximum production of grain and straw in direct seeded rice (Mohan *et al.*2017). Direct seeded rice has dense root system, so there are rare chances of lodging in direct seeded rice and maximum contribution of flag leaf to grain formation leads to enhanced biological yield of rice (Nawaz et al.2016). These results are similar to the findings of khan et al. (2002) who reported significant influence of micronutrient application on biological yield due to variation in micronutrient application.

Analysis of variance and means shown in (Table 5) indicated that the effect of different timings during crop growth (vegetative and reproductive) of micronutrient application was significant on grain yield (Figure 4). Maximum grain yield was recorded in 60 DAS treatments (5.35 tons per hectare) and it was minimum in 40 DAS treatments (4.81 tons per hectare). Analysis of variance indicated that the effect of micronutrient combinations was highly significant on grain yield. Maximum grain yield was recorded with Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) application (6.69 tons per hectare), followed by Boron (0.01 M) + Zinc (0.025 M) application (6.48 tons per hectare) and minimum grain yield was recorded in control (3.53 tons per hectare). Paddy yield was higher with the application of Zinc, Boron and Silicon at reproductive stage of rice crop as compared to its application during vegetative growth period in direct seeded rice due to minimum competition for nutrients during critical period. Due to less weed competition and optimum nutrient availability, maximum production of grain was achieved. Higher paddy yield was obtained with Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) after 60 DAS application due to higher number of spikelet per panicle, greater number of branches, more panicle length and more 1000-grain weight in this treatment which might be due to longer growing period for development of plants and more translocation of photosynthates towards panicle in transplanted rice which ultimately resulted in more yield (Akbar et al.2004; Mohan et al.2017). Analysis of variance showed that the effect of micronutrient combinations and time of application was non-significant on harvest index. In case of time of foliar spray, maximum harvest index was recorded in 60DAS treatments (25.74) and it was minimum in 40 DAS treatments (22.50) (Table 6).

Maximum harvest index was recorded in Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) (27.78), followed by Boron (0.01 M) + Zinc (0.025 M) (27.71) and minimum harvest index was recorded in control (20.22). Analysis of variance indicated that with respect to interaction between micronutrient combinations and time of application results was significant. Maximum harvest index was recorded in Silicon (1 %) @ 40 DAS (33.64), followed by Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) application at 60 DAS (28.23). While minimum harvest index was recorded in control (16.36).

Table 1: Means comparison of plant height (cm) of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	88.00	111.00	99.50
Boron (0.01 M)	92.67	122.3	107.50
Zinc (0.025 M)	101.67	112.67	107.17
Silicon (1 %)	99.70	103.00	101.35
Boron (0.01 M) + Zinc (0.025 M)	114.67	105.67	109.67
Zinc (0.025 M) + Silicon (1 %)	119.33	115.67	117.50
Silicon (1 %) + Boron (0.01 M)	99.33	107.00	103.17
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	102.33	119.00	110.67
Mean	102.21 B	111.92 A	

HSD value (Time of Application) = 6.8

Table 2: Means comparison of Total no. of productive tillers (m^{-2}) of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	230 B	290 AB	260 C
Boron (0.01 M)	296 AB	455 A	376 AB
Zinc (0.025 M)	378 AB	370 AB	374 AB
Silicon (1 %)	364 AB	433 A	399 A
Boron (0.01 M) + Zinc (0.025 M)	385 AB	373 AB	379 AB
Zinc (0.025 M) + Silicon (1 %)	438 A	378 AB	408 A
Silicon (1 %) + Boron (0.01 M)	231 B	345 AB	288 BC
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	455 A	425 A	440 A
Mean	347 B	384 A	

HSD value (Time of Application) = 34, HSD value (Micronutrients) =107, HSD value (Time of Application × Micronutrients) =17

Table 3: Means comparison of 1000-grain weight (g) of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	19.44	18.60	19.02 C
Boron (0.01 M)	23.05	27.33	25.19 BC
Zinc (0.025 M)	20.61	24.93	22.77 C
Silicon (1 %)	17.04	23.19	20.11 C
Boron (0.01 M) + Zinc (0.025 M)	29.60	30.37	29.99 AB
Zinc (0.025 M) + Silicon (1 %)	24.70	21.53	23.12 C
Silicon (1 %) + Boron (0.01 M)	22.373	22.93	22.65 C
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	29.10	34.38	31.74 A
Mean	23.24 B	25.41 A	

HSD value (Time of Application) = 2.00, HSD value (Micronutrients) =6.40

Table 4: Means comparison of Biological yield (t ha^{-1}) of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	12.49 H	12.76 GH	12.63 C
Boron (0.01 M)	13.91 DEFG	17.11 ABCD	15.51 AB
Zinc (0.025 M)	13.34 EFGH	18.28 AB	15.81 AB
Silicon (1 %)	19.48 A	15.11 BCD	14.80 B
Boron (0.01 M) + Zinc (0.025 M)	16.68 ABCDE	17.38 ABC	17.03 A
Zinc (0.025 M) + Silicon (1 %)	17.37 ABC	14.78 CDEFG	16.07 AB
Silicon (1 %) + Boron (0.01 M)	13.24 FGH	15.88 BCDEF	14.56 BC
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	16.03 BCDEF	19.08 AB	17.55 A
Mean	15.32	15.67	

HSD value (Micronutrients) =2.06, HSD value (Time of Application × Micronutrients) =3.33

Table 5: Means comparison of Paddy yield (t ha^{-1}) of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	3.19 DE	3.1 E	3.53 C
Boron (0.01 M)	3.88 CDE	6.42 ABC	4.75 BC
Zinc (0.025 M)	4.04 CDE	5.70 ABCDE	4.87 BC
Silicon (1 %)	5.46 ABCDE	4.65 BCDE	5.06 ABC
Boron (0.01 M) + Zinc (0.025 M)	7.17 AB	5.80 ABCDE	6.48 AB
Zinc (0.025 M) + Silicon (1 %)	5.62 ABCDE	3.94 CDE	4.78 BC
Silicon (1 %) + Boron (0.01 M)	4.00 CDE	4.94 ABCDE	4.47 C
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	5.90 ABCD	7.47 A	6.69 A
Mean	4.81 B	5.35 A	

HSD value (Time of Application) = 0.54, HSD value (Micronutrients) =1.73, HSD value (Time of Application × Micronutrients) =2.81

Table 6: Means comparison of Harvest index % of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	18.31	16.36	20.22
Boron (0.01 M)	22.11	28.87	22.62
Zinc (0.025 M)	22.10	22.46	22.28
Silicon (1 %)	20.26	33.64	26.95
Boron (0.01 M) + Zinc (0.025 M)	31.16	24.28	27.71
Zinc (0.025 M) + Silicon (1 %)	23.28	19.37	21.32
Silicon (1 %) + Boron (0.01 M)	21.20	22.54	21.87
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	27.32	28.23	27.78
Mean	22.50	25.74	

HSD value (Time of Application × Micronutrients) =15.36

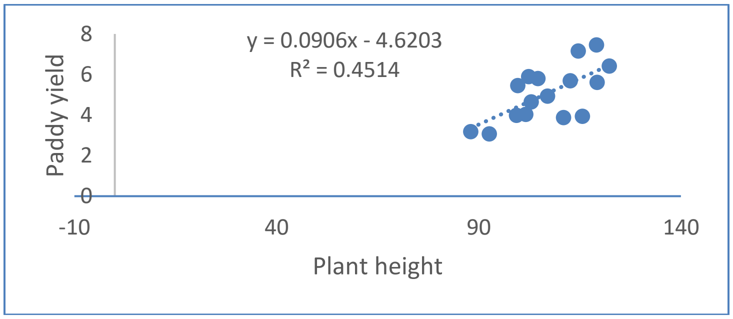

Figure 4: Relationship between plant height and paddy yield

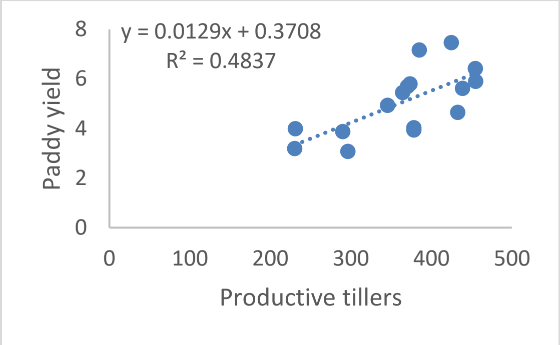

Figure 5: Relationship between productive tillers and paddy yield

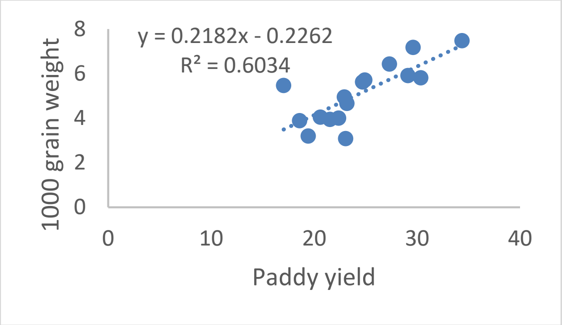

Figure 6: Relationship between 1000 grain weight and paddy yield

Grain quality of rice crop

Unfilled and sterile spikelet are distinguished easily (Hanifuzzaman et al.2022). Analysis of variance indicated that sterile spikelete (%) in time of application was significant. Statistically maximum sterile spikelet % was counted when micronutrients were applied 40 DAS (9.41 %) and minimum sterile spikelet % was observed in treatment 60DAS (8.74 %) (table 7 and 8). Analysis of variance also indicated that the effect of different micronutrient combinations was significant on sterile spikelet (%). In such case the maximum sterile spikelet % were recorded in control (11.86 %), followed by Zinc (0.025 M) + Silicon (1 %) (8.83%) and Silicon (1 %) + Boron (0.01 M) (8.46 %). Statistically minimum sterile spikelet % was noted in Zinc (0.025 M) + Boron (0.01 M) + Silicon (1 %) (6.61 %). Analysis of variance indicated highly significant results with respect to nutrient combinations and application timings interaction. Maximum sterile spikelet % was recorded in control (12.71 %), followed by Silicon (1 %) application 40 DAS (11.10). Opaque kernels gain full size and are bigger in size than abortive kernels due to continuous development at later growth stages. These do not become translucent due to lack of carbohydrates and overall dull chalky structure doesn't permit light to pass. Analysis of variance indicated that the effect of Zn, B, SI application at different growth stages was highly significant on opaque kernel percentage. Statistically maximum opaque kernels were recorded when micronutrients were applied 40 DAS (8.41 %) and minimum opaque kernel were recorded in 60 DAS treatment (7.62 %). Maximum opaque kernels were recorded in control (10.6%), followed by Boron (0.01 M) (9.41%) and Zinc (0.025 M) application (8.70 %) and it was minimum in Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) (5.98 %) (tables 4.13 a & b). Analysis of variance also indicated that effect of opaque kernel with respect to interaction of micronutrient application and timings of spray in direct seeded rice was also highly significant result. Maximum opaque kernels were recorded in control 40 DAS (11.35 %), followed by Boron (0.01 M) @ 400 DAS (9.78 %). While minimum opaque kernels were recorded in Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) spray at 60 DAS (4.91 %). While minimum sterile spikelet % were recorded in Zinc (0.025 M) + Boron (0.01 M) + Silicon (1 %) application 40 and 60 DAS (6.46 % and 6.76). Our results were similar to the findings of Rehman et al.(2016) who concluded that spikelet sterility decreased significantly among with the application of B. Our results are also in line with Hanifuzzaman et al. (2022) who showed that boron and zinc improved grain yield and quality significantly. Sofi et al. (2021) depicted that boron increased rice yield under temperate environment effectively.

Table 7: Means comparison of Sterile spikelet (%) of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	12.71 A	10.54 ABC	11.86 A
Boron (0.01 M)	9.81 BC	6.98 DE	8.39 CD
Zinc (0.025 M)	10.867	9.36 BCD	10.12 AB
Silicon (1 %)	11.10 AB	9.93 BC	10.52 A
Boron (0.01 M) + Zinc (0.025 M)	6.69 E	7.19 DE	6.94 DE
Zinc (0.025 M) + Silicon (1 %)	8.91 BCDE	8.74 BCDE	8.83 BC
Silicon (1 %) + Boron (0.01 M)	8.71 BCDE	8.21 CDE	8.46 CD
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	6.46 E	6.76 E	6.61 E
Mean	9.41 A	8.47 B	

HSD value (Time of Application) = 0.48, HSD value (Micronutrients) =1.53, HSD value (Time of Application × Micronutrients) =2.48

Table 8: Means comparison of Opaque kernels (%) of micronutrient combinations and time of application

Micronutrients	Time of Application		Mean
	40 Days After Sowing	60 Days After Sowing	
Control	11.35 A	9.85	10.6 A
Boron (0.01 M)	9.78 B	9.04 BC	9.41 B
Zinc (0.025 M)	9.05	8.35 CDE	8.70 C
Silicon (1 %)	5.90 HI	7.11 FG	6.51 E
Boron (0.01 M) + Zinc (0.025 M)	7.87 DEF	7.85 DEF	7.86 D
Zinc (0.025 M) + Silicon (1 %)	8.66 CD	6.34 GH	7.50 D
Silicon (1 %) + Boron (0.01 M)	7.58 DEF	7.49 EF	7.54 D
Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %)	11.88 ABC	4.91 I	5.98 E
Mean	8.41 A	7.62 B	

HSD value (Time of Application) = 0.21, HSD value (Micronutrients) =0.68, HSD value (Time of Application × Micronutrients) =1.09

CONCLUSIONS

Application of micronutrients 60 days after sowing in direct seeded rice showed best results in all treatments and significantly increased the yield contributing traits of rice. Foliar application Boron (0.01 M) + Zinc (0.025 M) + Silicon (1 %) and Boron (0.01 M) + Zinc (0.025 M) in comparison with the other combinations performed best, caused decline in the spikelet sterility and poor grain filling. it has also enhanced the yield and yield contributing traits of rice in agro-climatic conditions of Faisalabad. So, mixture of micronutrients with boron, silicon and zinc may also be suggested for farmers to reduce the nutrients losses, soil productivity and enhance sustainability of rice production systems. Future experiments like modeling of rice production and coating of micronutrients under climate change scenarios may also suggest for rice cropping systems.

Supplementary materials

The supplementary material / supporting for this article can be found online and downloaded at DOI:10.1016/j.fcr.2017.11.004.

Author contributions

Muhammad Tahir Ahsan and Muhammad Hamza Latif design the research design Shamim Akhtar, Muhammad Waseem Zulifqar and Muhammad Usman helped in writing the research paper while other authors helped in proof reading and statistics.

Funding statement

This study was not funded.

Institutional Review Board Statement

The study was approved by the Bioethical Committee of the Ayub Agricultural Research Institute. Faisalabad, Pakistan.

Informed Consent Statement

Not applicable.

Data Availability Statement

All of the data is included in the article/Supplementary Material.

Acknowledgments

Thanks to all authors for their worthy contribution.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Ahmad, A., M. Afzal, A.U.H. Ahmad and M. Tahir. 2013. Effect of foliar application of silicon on yield and quality of rice (*Oryza sativa* L). Cercetari agronomice in Moldova.

Abdi, H. and L.J. Williams, 2010. Tukey's honestly significant difference (HSD) test. Encyclopedia of Research Design. Thousand Oaks, CA: Sage, pp. 1–5. 46: 21-28.

Ahmad, A., M. Tahir, E. Ullah, M. Naeem, M. Ayub, H. Rehman, and M. Talha. 2012. Effect of silicon and boron foliar application on yield and quality of rice. Pak. J. Life Soc. Sci. 10: 161-165.

Ahmad, N. 2017. Growth and yield response of rice genotype to different regimes under direct seeded conditions. M. Sc (hons.) Thesis, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan.

Ahmad, W., A. Niaz, S. Kanwal, Rahmatullah and M.K. Rasheed. 2009. Role of boron in plant growth: a review. J. Agric. Res. 47: 1122–1134.

Akbar, N. and Ehsanullah. 2004. Agro-economic efficiency of different direct sown techniques in fine rice (*Oryza sativa* L.). Pak. J. Agri. Sci. 41: 3-4.

Bassil, E., H. Hu and P.H. Brown. 2004. Use of phenylboronic acids to investigate boron function in plants. Possible role of boron in transvacuolar cytoplasmic strands and cell-to-wall adhesion. Plant Physiol. 136: 3383-3395.

Bell, R.W. and B. Dell. 2008. Micronutrients for sustainable food, feed, fiber and bioenergy production. International Fertilizer Industry Association (IFA).

Bolanos, L., K. Lukaszewski, I. Bonilla and D. Blevins. 2004. Why boron? Plant Physiol. Bioch. 42: 907-912.

Boonchuay, P., I. Cakmak, B. Rerkasem and C. Prom-U-Thai. 2013. Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. J. Soil Sci. Plant Nutr. 59: 180-188.

Chanchal Malhotra, C., R. Kapoor and D. Ganjewala. 2016. Alleviation of abiotic and biotic stresses in plants by silicon supplementation. Scientia. 13: 59-73.

Chauhan, B.S. and J. Opena. 2012. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. Field Crop Res. 137: 56–69.

Chauhan, B.S., K. Jabran and G. Mahajan. 2017. Rice production worldwide. Gewerbestrasse: Springer International Publishing AG.

Dobermann, A., C. Witt, S. Abdulrachman, H. Gines, R. Nagarajan and T. Son. 2003. Estimating Indigenous Nutrient Supplies for Site-Specific Nutrient Management in Irrigated Rice. Agron. J. 95: 924-935.

Esfandiari, E., M. Abdoli, S.B. Mousavi and B. Sadeghzadeh. 2016. Impact of foliar zinc application on agronomic traits and grain quality parameters of wheat grown in zinc deficient soil. Indian J. Plant Physiol. 21: 263-270.

Etesami, H. and B.R. Jeong. 2018. Silicon (Si): Review and future prospects on the action mechanisms in alleviating biotic and abiotic stresses in plants. Ecotox. Environ. Safe. 147: 881-896.

Farooq, M., A. Ullah, A. Rehman, A. Nawaz, A. Nadeem, A. Wakeel, F. Nadeem and K.H. Siddique. 2018. Application of zinc improves the productivity and biofortification of fine grain aromatic rice grown in dry seeded and puddled transplanted production systems. Field Crops Res. 216: 53-62.

Farooq, M., A. Ullah, A. Rehman, A. Nawaz, A. Nadeem, A. Wakeel, F. Nadeem and K.H. Siddique. 2018. Application of zinc improves the productivity and biofortification of fine grain aromatic rice grown in dry seeded and puddled transplanted production systems. Field Crops Res. 216: 53-62.

Farooq, M., K.H.M. Siddique, H. Rehman, T. Aziz, J.L. Dong and A. Wahid. 2011. Rice direct seeding: Experiences, challenges and opportunities. Soil Till. Res. 111: 87-98.

Gao, X. 2007. Bioavailability of zinc to aerobic rice.

Ghafoor, I., MHR. Rahman., M. Ali., M. Afzal., W. Ahmed., T. Gaiser and A. Ghaffar. 2021. Slow-release nitrogen fertilizers enhance growth, yield, NUE in wheat crop and reduce nitrogen losses under an arid environment. ESPR 28(32), pp.43528-43543.

Ghafoor, I., MU. Hasnain., RM. Ikram., MA. Khan., R. Iqbal., MI. Hussain and AE. Sabagh. 2022. Effect of slow release nitrogenous fertilizers on dry matter accumulation, grain nutritional quality, water productivity and wheat yield under an arid environment. Sci. Rep. 12(1), pp.1-10.

Hafeez, B., Y.M. Khanif and M. Saleem. 2013. Role of zinc in plant nutrition-a review. J. Exp. Agric. Int. 374-391.

Hall, C.R., J.M. Waterman, R.K. Vandegeer, S.E. Hartley and S.N. Johnson. 2019. The Role of Silicon in Anti-herbivore Phyto-hormonal Signalling. Front. Plant Sci. 10: 1132.

Hanifuzzaman, M., FJ. Uddin., MG. Mostofa., SK. Sarkar., SK. Paul and MH. Rashid. 2022. Effect of zinc and boron management on yield and yield contributing characters of Aus rice (*Oryza sativa*). *Research on Crops*, *23*(1)

Hanjar, M.A. and M.E. Quereshi. 2010. Global water crisis and food security in an era of climate change. Food Policy. 35: 365-377.

Hussain, M., M.A. Khan, M.B. Khan, M. Farooq and S. Farooq. 2012. Boron application improves growth, yield and net economic return of rice. Rice Sci. 19: 259-262.

Juliano, B.O. (1993). Rice in human nutrition (No. 26). Int. Rice Res. Inst..

Khan, M.U., M. Qasim and M. Jamil. 2002. A system of farming response of rice to zinc fertilizer in calcareous soils of D.I. Khan. Asian J. Plant Sci. 1:

105-112.

Kulhare, P.S., G.S. Tagore and G.D. Sharma. 2017. Effect of foliar spray and sources of zinc on yield, zinc contentand uptake by rice grown in a vertisol of central India. Int. J. Chem. Stud. 5: 35-38.

Kumar, L., N.L. Meena and U. Singh. 2016. Zinc transporter: Mechanism for improving Zn availability in Biofortification of Food Crops. Springer Sci. Rev. pp: 129-146.

Kumar, V. and J.K. Ladha. 2011. Direct Seeding of Rice: Recent Developments and Future Research Needs. International Rice Research Institute, India Office, Pusa, New Delhi, India. Adv. Agron. 111: 299-360.

Maclean, J.L., D.C. Dawe, B. Hardy and G.P. Hettel. (eds). 2002. Rice almanac (Third Edition). Philippines, IRRI, WARDA, CIAT and FAO.

Mahajan, G., B.S. Chauhan, J. Timsina, P.P. Singh and K. Singh. 2012. Crop performance and water- and nitrogen-use efficiencies in dry-seeded rice in response to irrigation and fertilizer amounts in northwest India. Field Crops Res. 134: 59-70.

Mohan, A., A. Tiwari, M. Kumar, D. Pandey, A. Singh and B. Singh. 2017. Effect of foliar spray of various nutrients on performance of rainfed rice (*Oryza sativa* L.). Int. J. Pharmacogn. Phytochem. 6: 2252-2256.

Mohan, A., A. Tiwari, M. Kumar, D. Pandey, A. Singh and B. Singh. 2017. Effect of foliar spray of various nutrients on performance of rainfed rice (*Oryza sativa* L.). Int. J. Pharmacogn. Phytochem. 6: 2252-2256.

Mohanty, S. 2013. Trends in global rice consumption. Rice Today. 12: 44-45.

Mustafa, G., A.N. Ehsanullah, S.A. Qaisrani, A. Iqbal, H.Z. Khan, K. Jabran, A.A. Chattha, , R. Trethowan, T. Chattha and B.M. Atta. 2011. Effect of zinc application on growth and yield of rice (*Oryza sativa* L.). Intl. J. Agro. Vet. Med. Sci. 5: 530-535.

Nascimento, A.M., F.A. Assis, J.C. Moraes and B.H.S.D. Souza. 2018. Silicon application promotes rice growth and negatively affects development of Spodoptera frugiperda (JE Smith). J. Appl. Entomol. 142: 241-249.

Nawaz, F., M.Y. Ashraf, R. Ahmad, E.A. Waraich, R.N. Shabbir and R.A. Hussain. 2016. Selenium supply methods and time of application influence spring wheat (*Triticum aestivum* L.) yield under water deficit conditions. Crops soil Res. 155: 643-656.

Rasheed, M. K. (2009). Role of boron in plant growth: a review. J. Agric. Res. 47: 329-338.

Rehman, A., M. Farooq, A. Nawaz and R. Ahmad. 2016. Improving the performance of short-duration basmati rice in water-saving production systems by boron nutrition. Ann. Appl. Biol. 168: 19-28.

Rehman, A., M. Farooq, L. Ozturk, M. Asif and K.H. Siddique. 2018. Zinc nutrition in wheat-based cropping systems. Plant Soil. 422: 283-315.

Remesh, R. and B. Rani. 2017. Effect of boron application through soil and foliar methods on the yield attributes and nutrient uptake of wet land rice. Agric. 12: 301-304.

Ryan, J., G, Estefan., R. Sommer. 2013. Methods of soil, plant and water analysis: A manual for the West Asia and North Africa region. Eds International Center for Agricultural Research in the Dry Areas Beirut Lebanon pp. 170-176.

Schiller, J. M., B. Linquist, K. Douangsila, P. Inthapanya, B.D. Boupha, S. Inthavong and P. Sengxua. 2001. Constraints to rice production systems in Laos. 433-2016-33586.

Singh, K., R. Singh, J.P. Singh, Y. Singh and K.K. Singh. 2006. Effect of level and time of silicon application on growth, yield and its uptake by rice (*Oryza sativa* L). Indian J. Agric. Sci. 76: 410-413.

Sofi, ka., a. Gulzar., t. Islam and r. Gulzar. 2021. Response of boron nutrition on growth and yield of rice grown under temperate conditions of kashmir valley. *Asian j. Adv. Res.*, pp.7-11.

Tavakkoli, E., G. Lyons, P. English and C.N. Guppy. 2011. Silicon nutrition of rice is affected by soil pH, weathering and silicon fertilisation. J. PLANT Nutr. SOIL SC. 174: 437-446.

Ullah, H., P.D. Luc, A. Gautam and A. Datta. 2018. Growth, yield and silicon uptake of rice (*Oryza sativa* L) as influenced by dose and timing of silicon application under water-deficit stress. Arch. Agron. soil Sci. 64: 318-330.

US Salinity Lab Staff. 1954. Diagnosis and improvement of saline and alkali soils. Agric Hand Book No 60:142–143

Zhu, Z., G. Wei, J. Li, Q. Qian and J. Yu. 2004. Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). Plant Sci. 167: 527-533.