Journal of Agroforestry and Environment

Volume 17, Issue 1, 2024

Journal DOI: https://doi.org/10.55706/jae
Journal homepage: www.jagroforenviron.com

Soil Applied Zinc Fertilizer Enhanced Yield and Yield Components of Wheat

Ashikuzzaman, Swapan Kumar Paul, Md. Towkir Ahmed, Sinthia Ahmed Upama, Md. Romij Uddin and Uttam Kumer Sarker*

Department of Agronomy, Bangladesh Agricultural University, Bangladesh.

*Correspondence: uttam@bau.edu.bd , Tel: +8801716809747

Received: 02/05/2024

Accepted: 27/06/2024

Available online: 30/06/2024

Abstract: Zinc (Zn) deficiency significantly affects the yield and quality of crops across vast areas of cultivable land globally, given the essential role of micronutrients in plant metabolic processes. A field experiment was conducted at the Agronomy Field Laboratory (AFL), Bangladesh Agricultural University (BAU), Mymensingh, from November 2019 to March 2020 to evaluate the effects of zinc and its application methods on the yield components of different wheat varieties. The experiment included three wheat varieties: BARI Gom-30, BARI Gom-31, and BARI Gom-32. It also examined six levels of Zn: 0 kg ha^{-1}, seed soaking (SS) with 0.57% ZnSo4.7H_2O (aq), SS with 1% ZnSo4.7H_2O (aq), soil application (SA) of 4 kg ha^{-1} Zn, SA of 8 kg ha^{-1} Zn, and foliar spray (FS) of 0.5% ZnSo4 at 25 and 50 days after sowing. The experiment was designed as a randomized complete block design (RCBD) with three replications. The highest plant height (PH) (99.66 cm), the number of total tillers (NTT) plant^{-1} (4.86), spike length (SL) (10.41 cm), the number of effective tillers (NET) plant^{-1} (4.00), the number of grains spike^{-1} (NGS) (43.53), 1000-grain weight (TGW) (51.47 g), grain yield (GY) (4.12 t ha^{-1}), straw yield (SY) (5.27 t ha^{-1}), biological yield (BY) (9.39 t ha^{-1}), and harvest index (HI) (43.93%) were achieved in BARI Gom-32 with the application of 8 kg Zn ha-1. The findings indicate that the wheat variety BARI Gom-32 attained its maximum yield with the application of 8 kg Zn ha-1. However, further experiments in different locations are necessary before making final recommendations.

Keywords: Wheat varieties; Soil application of Zinc; Grain Yield; Harvest Index.

INTRODUCTION

Wheat (*Triticum aestivum* L.), a staple in global diets originating from the grass Triticum, is cultivated in various varieties worldwide. In 2023, the average yield of wheat was 3.693 t ha^{-1}, marking a 7.07% increase from 2022 (BBS, 2023). Wheat boasts a higher protein content than other cereals, and its quality is influenced by the gluten strength in its flour, ranging from weak to strong, which determines the flour's processing quality and market value (Goesaert *et al.* 2005). Nutritional components of wheat include starch (60-68%), protein (8-15%), and other constituents like fat, sugar, cellulose, minerals, and vitamins (Meena *et al.* 2013).

Several factors, such as low-quality seed, salinity, waterlogging, insufficient use of fertilizers, inadequate irrigation, high input costs, poor farmer education, and a lack of micronutrients and organic fertilizers, contribute to low wheat production. Micronutrient deficiencies, particularly widespread in Asia, are exacerbated by factors such as calcareous soils, high pH, low organic content, salt stress, prolonged droughts, high bicarbonate levels in irrigation water, and imbalanced NPK fertilization, impeding crop productivity (Ahmadikhah *et al.* 2010; Sharma & Chaudhary, 2007). Adequate micronutrient supply is essential as it enhances nutrient availability and positively influences cell physiology, reflected in the crop yield (Adediran *et al.* 2004).

Zinc, a vital trace element for plants (Broadley *et al.* 2007), animals (Ren *et al.* 1999), and humans (Salgueiro *et al.* 2000), is crucial yet often deficient in wheat, especially in developing countries. Wheat grains should ideally contain 45.00 mg·kg^{-1} zinc to meet human dietary needs (Liu, 2017), but typically only have about 28.48 mg·kg^{-1}, which is below the recommended standard (Wang *et al.* 2018). Zinc levels in wheat grains can be enhanced through strategic foliar applications at stages like booting and milking, significantly improving the agronomic traits, zinc content, and bioavailability, thus boosting the nutritional quality of the grains (Abdoli *et al.* 2016).

Soil zinc deficiency is prevalent worldwide, leading to significant agricultural and economic losses. Zinc plays a critical role in various plant metabolic processes, including photosynthesis, pollen development, protein synthesis, cell membrane integrity, and disease resistance, and it also increases the levels of antioxidant enzymes and chlorophyll in plant tissues (Hussain *et al.* 2015; Chauhan *et al.* 2014). Effective zinc management, such as foliar applications during critical growth stages like the milky stage of grain development, has been shown to maximize zinc accumulation in the grains, which is essential for enhancing grain yield in zinc-deficient areas (Cakmak, 2008; Peck *et al.* 2008; Hao *et al.* 2003).

Given the global challenge of zinc deficiency and its impact on health, increasing the zinc concentration in wheat grains is essential for improving crop productivity and human health. This research aims to explore the main and interactive effects of different zinc application methods on wheat varieties, addressing the critical need for enhanced zinc intake through fundamental agricultural practices.

MATERIALS AND METHODS

Experimental site

From November 2019 to March 2020, a study was conducted at the AFL of BAU in Mymensingh. This research aimed to assess the impact of zinc and its application methods on the productivity and yield components of different wheat varieties. The field site is situated at 24°75' N latitude and 90°50' E longitude, 18 meters above sea level. The soil type is a non-calcareous dark grey floodplain from the Sonatola Soil Series, located in the Agro-Ecological Zone 9 of the Old Brahmaputra Floodplain. It features a nearly neutral pH of 6.5, modest organic content, and moderate fertility levels (FAO & UNDP, 1988). The site's elevation is moderate, and it has a silty loam soil texture. It experiences a tropical climate, with high temperatures and substantial rainfall during the Kharif season (April to September), and cooler, drier conditions during the Rabi season (October to March).

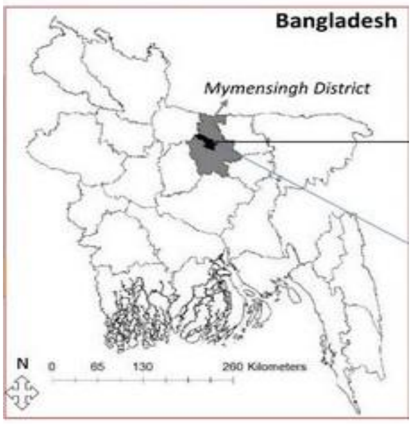

Figure 1. Map of the study area

Experimental treatments

The experiment comprised two components: Factor A included three wheat verities viz., BARI Gom-30 (V_1), BARI Gom-31 (V_2), and BARI Gom-32 (V_3); Factor B consisted of six zinc application methods: Control (T_1), SS with 0.57% $ZnSO_4 \cdot 7H_2O$ (T_2), SS with 1% $ZnSO_4 \cdot 7H_2O$ (T_3), SA of 4 kg ha^{-1} Zn (T_4), SA of 8 kg ha^{-1} Zn (T_5), and FA of 0.5% $ZnSO_4$ at 25 and 50 days after sowing (T_6).

Experimental materials

For this study, seeds of BARI Gom-30, BARI Gom-31, and BARI Gom-32 were obtained from the Regional Agricultural Research Station (RARS) of the Bangladesh Agricultural Research Institution (BARI) near Jamalpur.

Crop husbandry

Land preparation for the experiment commenced on November 10, 2019, utilizing a tractor-drawn plow followed by three cycles of plowing and cross-plowing with a country plow. Subsequent laddering ensured the soil reached the appropriate tilth. The field's edges and levees were manually shaped with a spade, and larger clods were broken down with a wooden hammer. The land was divided into unit plots with specific spacing, which were spaded the day before seeding. A basal dose of N-P-K-S fertilizer was integrated into the soil at the rates of 120, 24, 90, and 15 kg ha^{-1}, respectively, according to BARC guidelines from 2018. Two-thirds of the nitrogen and all the phosphorus, potassium, and sulfur were applied during the last stage of land preparation, with the remaining nitrogen added 35 days after sowing. Foliar applications of 0.5% $ZnSO_4$ solution (100g dissolved in 10L of water) were applied at 25 and 50 days after sowing as per the treatment protocols.

Seeding occurred on November 21, 2019, by placing two pre-soaked seeds into each hole at the designated spacing. The seeding rate was maintained at 120 kg ha^{-1} in both continuous and raised bed systems with 20 cm line spacing. After seeding, the soil was used to cover the seeds, which were then gently pressed down by hand. Two irrigation events were scheduled, the first on December 11, 2019, during the crown root initiation stage, and the second on January 1, 2020, during the early booting stage. The crop reached full maturity and was harvested on March 12, 2020. For yield assessment, one square meter from each plot was harvested. The harvested crops were bundled, tagged, and transported to the threshing floor. Prior to harvest, five hills from each plot were randomly selected for data collection on yield-contributing factors. After harvest, the wheat was sun-dried for four days, threshed, cleaned, and further dried. Yield parameters were then measured at a 14% moisture content and recorded in tons per hectare (t ha^{-1}). Each sample was individually packed and labeled accordingly.

Harvesting and data collection

Before harvesting, five plants were randomly chosen from each plot (excluding those near the borders) for data collection on crop performance and yield-contributing traits. The collected metrics included PH (cm), NTT plant^{-1}, NET plant^{-1}, PL (cm), NGS, TGW (g), SL (cm), GY (t

DOI: https://doi.org/10.55706/jae1708

ha^{-1}), and SY (t ha^{-1}). Additionally, BY (t ha^{-1}) and HI (%) were also assessed.

Statistical analysis

Prior to harvesting, data on plant height, tillers, panicle length, grain size, and weight were collected from five random plants per plot. Yield measurements included grain yield, straw yield, biomass yield, and harvest index, standardized to a moisture content of 14%. Statistical analysis was conducted using ANOVA, with significant differences determined by Duncan's New Multiple Range Test (Gomez & Gomez, 1984).

Table 1. The morphological features of the experimental plot

Constituents	Characteristics
Location	AFL, BAU
Soil Series	Sonatola
Soil Tract	Old Brahmaputra Alluvium
Land type	Medium High Land
General soil type	Non-calcareous dark grey floodplain
Agro-ecological zone	Old Brahmaputra Floodplain (AEZ-9)
Topography	Fairly level
Soil type and colour	Dark grey Terrace Soil
Drainage	Moderate
Depth of inundation	Above the flood level
Drainage condition	Well drained

Table 2. The physical characteristics of the experimental field

Constituents	Results
Particle size analysis	2.57
Bulk density (g/ce)	1.42
Porosity (%)	44.7
Sand (%) (0.0-0.02mm)	21.75
Silt (1%) (0.02-0.002mm)	66.60
Clay (%) (<0.002mm)	11.65
Soil textural class	Silt loam
Colour	Dark grey
Consistency	Grounder

Table 3. The chemical properties of the experimental field

Constituents	Results
Soil pH	6.8
Organic matter (%)	1.30
Total nitrogen (%)	0.101
Available phosphorus (ppm)	27
Exchangeable potassium (me %)	0.12
Available Sulphur (ppm)	22.7

RESULT AND DISCUSSION

Effects of varieties on yield and yield contributing characters of wheat

Varietal differences significantly influenced both yield and yield-related traits. BARI Gom-32 showed the highest PH (98.76 cm), NTT plant^{-1} (4.56), NET plant^{-1} (3.71), SL (10.98 cm), NGS (41.14), TGW (49.29 g), BY (9.10 t ha^{-1}), and HI (43.65%). Conversely, BARI Gom-31 recorded the lowest values for yield-contributing characters, including PH at 89.22 cm, NTT plant^{-1} (3.63), NET plant^{-1} (2.98), TGW (29.05 g), and BY (8.07 t ha^{-1}) (Table 4). The other parameters were statistically similar between BARI Gom-30 and BARI Gom-32. Rahman *et al.* (2010) studied four wheat varieties: Kanchan, Protiva, Gourab, and Sotabdi. They observed significant varietal effects on yield-contributing factors such as GY, SY, NTT plant^{-1}, NET plant^{-1}, NGS, and TGW. Similarly, Nivedita *et al.* (2021) reported variations in yield and yield-contributing characteristics among wheat varieties. Dianjun *et al*. (2015) conducted a field experiment in the North China Plain. They demonstrated that optimal nitrogen management for two winter wheat cultivars significantly enhanced post-anthesis biomass and yield without causing yield losses. They recommended that selecting cultivars with larger spikes combined with optimal nitrogen management could be an effective strategy for improving wheat production.

DOI: https://doi.org/10.55706/jae1708

Table 4. Effect of varieties on yield and yield contributing characters of wheat

Variety	PH (cm)	NTT plant^{-1}	NET plant^{-1}	SL (cm)	NGS	TGW (g)	BY (t ha^{-1})	HI (%)
V_1	94.78 b	4.03 b	3.26 b	10.47 b	37.57 b	36.03 b	8.44 b	42.73 b
V_2	89.22 c	3.63 c	2.98 c	10.18 b	36.53 b	29.05 c	8.07 c	42.40 b
V_3	98.76 a	4.56 a	3.71 a	10.98 a	41.14 a	49.29 a	9.10 a	43.65 a
LSD (0.05)	2.97	0.19	0.17	0.35	2.45	1.16	0.22	0.82
Level of Significance	**	**	**	**	**	**	**	**
CV%	4.66	7.07	7.90	5.00	9.43	4.51	3.82	2.82

Here, in this column, values labeled with the same letter or without any letter are not significantly different. However, values labeled with different letters indicate significant differences according to the Duncan's Multiple Range Test (DMRT), ** - Significant at 1% level of probability, V_1 - BARI Gom-30, V_2 - BARI Gom-31, V_3 - BARI Gom-32

Effects of zinc application on yield and yield contributing characters of wheat

Applying different zinc levels did not significantly affect PH, SL, and NGS in the wheat varieties. However, it significantly affected the NTT plant^{-1}, NET plant^{-1}, TGW, BY, and HI. The maximum values for NTT plant^{-1} (4.26), NET plant^{-1} (4.26), TGW (42.23 g), BY (8.76 t ha^{-1}), and HI (43.24%) were obtained from 8 kg Zn ha^{-1}. The minimum values for NTT plant^{-1} (3.86), NET plant^{-1} (3.13), TGW (35.06 g), BY (8.33 t ha^{-1}), and HI (42.72%) were observed when seeds were soaked with 1% $ZnSO_4 \cdot 7H_2O$ (Table 5). Chaure *et al.* (2019) observed that applying $ZnSO_4$ at a rate of 30 kg ha^{-1}, in conjunction with the recommended fertilizer dosage, markedly affected PH, dry matter accumulation, NGP, and overall yield. In their research, control treatment wheat shoots contained 38 mg kg^{-1} of zinc, while the roots had 119 mg kg^{-1}. When Zn was applied to the soil at 600 mg kg^{-1}, there was a 40-fold increase in zinc concentration in both shoots and roots (Zajaczkowska *et al*. 2020). Furthermore, Aziz *et al*. (2019) discovered that using a zinc application method involving 1% foliar ZnSO4 combined with 1% priming and 15 kg ha^{-1} soil Zn led to an increased GY in wheat, particularly in the Zincol variety, which produced more productive tillers and spikes m^{-2}.

Table 5. Effect of zinc on yield and yield contributing characters of wheat

Treatment	PH (cm)	NTT plant^{-1}	NET plant^{-1}	SL (cm)	NGS	TGW (g)	BY (t ha^{-1})	HI (%)
T_1	94.91	4.06 ab	3.26 ab	10.51	38.00	37.02 b	8.51 ab	42.81
T_2	93.12	4.00 ab	3.26 ab	10.42	37.82	36.35 bc	8.46 ab	42.90
T_3	92.67	3.86 b	3.13 b	10.36	37.46	35.06 c	8.33 b	42.72
T_4	94.76	4.17 a	3.42 a	10.7	39.22	40.58 a	8.66 a	42.96
T_5	96.07	4.26 a	3.48 a	10.74	39.53	42.23 a	8.76 a	43.24
T_6	93.98	4.08 ab	3.35 ab	10.52	38.46	37.50 b	8.50 ab	42.93
LSD (0.05)	4.21	0.27	0.25	0.50	3.46	1.64	0.31	1.16
Level of Significance	NS	**	**	NS	NS	**	**	**
CV%	4.66	7.07	7.90	5.00	9.43	4.51	3.82	2.82

Here, in a column, figures with same letter (s) do not differ significantly as per DMRT, ** - Significant at 1% level of probability, NS - Not significant, T_1 - Control, T_2 - SS with 0.57% $ZnSo_4.7H_2O$ (aq), T_3 – SS with 1% $ZnSo_4.7H_2O$ (aq), T_4 - 4kg ha^{-1} Zn, T_5 - 8kg ha^{-1} Zn, T_6 - FS of 0.5% $ZnSo_4$ at 25 and 50 days after sowing.

Interaction of variety and Zinc application on yield and yield contributes of Wheat

The interaction between variety and zinc application had a non-significant effect on PH and NGS but significantly affected other yield-contributing characters. The highest values for NTT plant^{-1} (4.86), NET plant^{-1} (4.00), SL (11.29 cm), TGW (53.18 g), GY (4.12 t ha^{-1}), SY (5.27 t ha^{-1}), BY (9.39 t ha^{-1}), and HI (43.93%) were obtained from the interaction of BARI Gom-32 and 8 kg Zn ha^{-1}. Conversely, the minimum values for NTT plant^{-1} (3.86), NET plant^{-1} (3.13), SL (8.92 cm), TGW (35.06 g), GY (2.91 t ha^{-1}), SY (4.08 t ha^{-1}), BY (7.11 t ha^{-1}), and HI (40.89%) were recorded for BARI Gom-31 with seed soaking in 1% $ZnSO_4 \cdot 7H_2O$ (aq.). Zhou *et al.* (2019) discovered that applying 50 µM of zinc to the wheat varieties H27 and L979 reduced cadmium concentrations by 17%, with L979 exhibiting a greater proportion of cadmium in the soluble fraction. This reduction impacted photosynthesis, root growth, and antioxidant production. Additionally, Arafat *et al.* (2016) reported that the wheat varieties Siran-2010, Atta Habib, and Janbaz yielded the highest grain outputs. Applying zinc at a rate of 10.5 kg ha^{-1} maximized yields, with the side dressing method proving the most effective, followed by the broadcast method. They concluded that the optimal strategy for enhancing wheat yield involves cultivating the Siran-2010 variety with a side dressing of zinc.

DOI: https://doi.org/10.55706/jae1708

Table 6. Interaction effect between varieties and zinc application on yield and yield contributing characters of wheat

Interaction	PH (cm)	NTT Plant^{-1}	NET Plant^{-1}	SL (cm)	NGS	TGW (g)	BY (t ha^{-1})	HI (%)
V_1T_1	91.48	3.73 e-h	3.13 d-g	10.34 cde	37.06	30.29 gh	8.28 e-h	42.58
V_1T_2	94.12	4.00 d-g	3.26 c-f	10.40 b-e	37.20	33.41 ef	8.36 d-g	42.64
V_1T_3	93.66	3.86 d-h	3.20 def	10.37 cde	37.13	32.19 fg	8.34 d-g	42.6
V_1T_4	96.20	4.20 cde	3.33 cde	10.62 a-e	38.00	40.46 d	8.57 def	42.72
V_1T_5	98.20	4.26 bcd	3.40 b-e	10.65 a-e	38.06	44.03 c	8.71 cde	43.22
V_1T_6	95.00	4.13 c-f	3.26 c-f	10.42 a-e	38.00	35.80 e	8.40 d-g	42.63
V_2T_1	95.00	4.13 c-f	3.26 c-f	10.42 a-e	38.00	35.80 e	8.40 d-g	42.63
V_2T_2	86.73	3.46 h	2.86f g	10.03 de	35.86	26.43 j	7.93 gh	42.33
V_2T_3	86.07	3.40 h	2.73 g	9.94 e	35.66	26.40 j	7.78 h	42.2
V_2T_4	89.07	3.60 gh	3.00 efg	10.22 cde	36.40	28.84 hij	8.15 fgh	42.34
V_2T_5	90.36	3.66 fgh	3.06 d-g	10.29 cde	37.00	29.48 ghi	8.19 e-h	42.57
V_2T_6	88.11	3.53 gh	3.00 efg	10.20 cde	36.26	27.36 ij	7.97 gh	42.34
V_3T_1	98.25	4.33 bcd	3.40 b-e	10.78 a-e	38.93	44.98 c	8.85 bcd	43.23
V_3T_2	98.52	4.53 abc	3.66 abc	10.84 a-d	40.40	49.20 b	9.11 abc	43.74
V_3T_3	98.28	4.33 bcd	3.46 bcd	10.78 a-e	39.60	46.60 bc	8.88 a-d	43.35
V_3T_4	99.01	4.73 ab	3.93 a	11.25 ab	43.26	52.45 a	9.27 ab	43.82
V_3T_5	99.66	4.86 a	4.00 a	11.29 a	43.53	53.18 a	9.39 a	43.93
V_3T_6	98.84	4.60 abc	3.80 ab	10.96abc	41.13	49.36 b	9.13 abc	43.81
$LSD_{(0.05)}$	7.29	0.47	0.44	0.87	6.00	2.85	0.54	2.01
Level of Significant	NS	**	**	**	NS	**	**	**
CV%	4.66	7.07	7.90	5.00	9.43	4.51	3.82	2.82

Here, in a column, figures with same letter (s) do not differ significantly as per DMRT, ** - Significant at 1% level of probability, NS - Not significant, V_1 - BARI Gom-30, V_2 - BARI Gom-31, V_3 - BARI Gom-32, T_1 - Control, T_2 - SS with 0.57% $ZnSo_4.7H_2O$ (aq), T_3 - SS with 1% $ZnSo_4.7H_2O$ (aq), T_4 - 4kg ha^{-1} Zn, T_5 - 8kg ha^{-1} Zn, T_6 - FS of 0.5% $ZnSo_4$ at 25 and 50 days after sowing.

Effect of variety on GY and SY

The study revealed that different wheat varieties significantly influenced GY and SY. BARI Gom-32 achieved the highest GY (3.97 t ha^{-1}), followed by BARI Gom-30 (3.61 t ha^{-1}). The lowest GY (3.42 t ha^{-1}) was observed in BARI Gom-31 (Figure 2). BARI Gom-32 also obtained the highest SY (5.13 t ha^{-1}), followed by BARI Gom-30 (4.83 t ha^{-1}) (Figure 3).

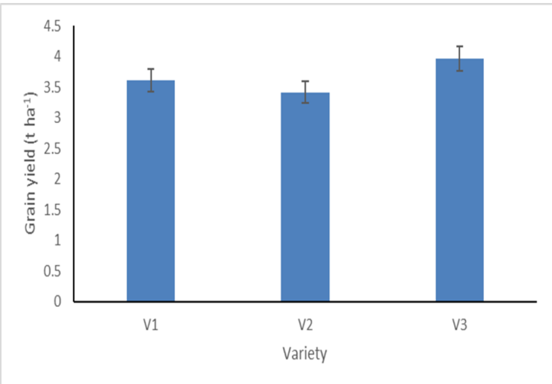

Figure 2. Effect of variety on GY
Here, V_1 - BARI Gom-30; V_2 - BARI Gom-31; V_3 - BARI Gom-3.

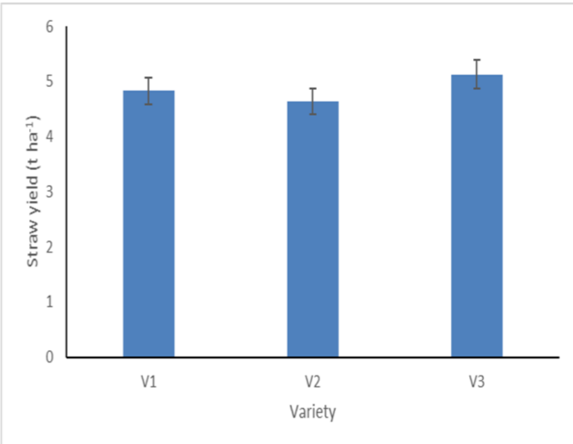

Figure 3. Effect of variety on SY (t ha^{-1})
Here, V_1 - BARI Gom-30; V_2 - BARI Gom-31; V_3 - BARI Gom-32

Effect of different methods of zinc application on GY and SY of wheat

Different zinc levels significantly influenced the GY and SY of wheat. Among the treatments, applying 8 kg Zn resulted in the highest GY at 3.79 t ha^{-1}, while the lowest GY, at 3.56 t ha^{-1}, occurred when seeds were soaked with 1% ZnSO4.7H2O (Figure 4). Additionally, the highest SY was observed at 4.97 t ha^{-1} in the treatment with 8 kg Zn ha^{-1}, and the lowest SY, at 4.77 t ha^{-1}, was associated with SS in 1% ZnSO4.7H2O (aq) (Figure 5).

DOI: https://doi.org/10.55706/jae1708

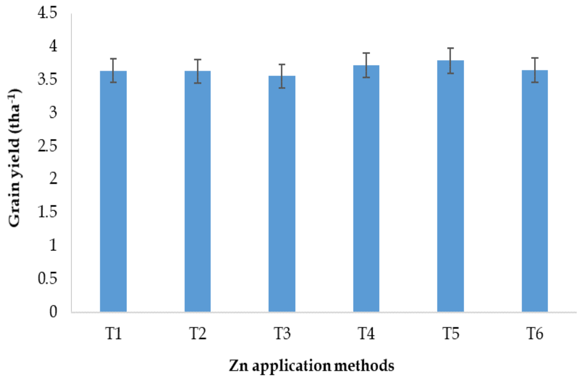

Figure 4. Effect of different methods of zinc application on GY of wheat

Here, T_1 - Control, T_2 - SS with 0.57% ZnSo4. 7H2O (aq), T_3 - SS with 1% ZnSo4. 7H2O (aq), T_4 - 4kg ha^{-1} Zn, T_5- 8kg ha^{-1} Zn, T_6 - FS of 0.5% ZnSo4 at 25 and 50 days after sowing.

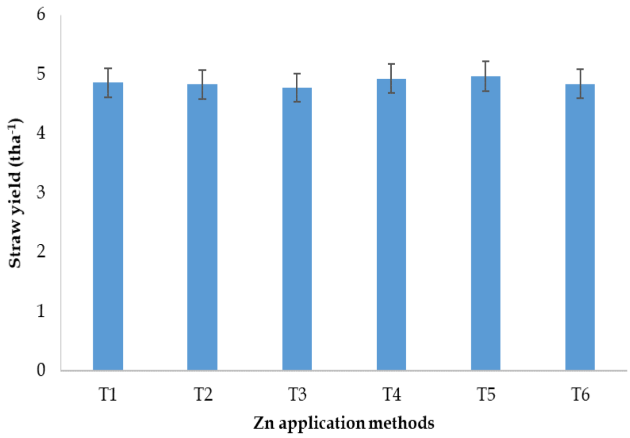

Figure 5. Effect of different methods of zinc application on SY of wheat

Here, T_1 - Control, T_2 - SS with 0.57% ZnSo4. 7H2O (aq), T_3 - SS with 1% ZnSo4. 7H2O (aq), T_4 - 4kg ha^{-1} Zn, T_5- 8kg ha^{-1} Zn, T_6 - FS of 0.5% ZnSo4 at 25 and 50 days after sowing.

CONCLUSION

In conclusion, the findings from this study indicate that the wheat variety BARI Gom-32, when supplemented with 8 kg Zn ha^{-1}, can achieve maximum yields. However, further research is necessary across different agroecological zones (AEZs) in Bangladesh before establishing a country-wide recommendation on the optimal zinc dosage. This additional investigation will be crucial for validating the results and ensuring their applicability on a national scale.

Acknowledgements

The authors extend their appreciation to University Grants Commission of Bangladesh for financial support.

Conflict of Interest

The authors have declared no conflicts of interest.

REFERENCES

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

Adediran, J.A., Taiwo, L.B., Akande, M.O., Idowu, O.J., Sobulo, R.A. 2004. Application of organic and inorganic fertilizer for sustainable yield of maize and cowpea in Nigeria. Journal of Plant Nutrition, 27(7): 1163-1181.

Ahmadikhah, A., Narimani, H., Rahimi, M.M., Vaezi, B. 2010. Study on the effects of foliar spray of micronutrient on yield and yield components of durum wheat. Archives of Applied Science Research, 2(6): 168-176.

Arafat, Y., Shafi, M., Khan, M.A., Adnan, M., Basir, A., Rahman, I., Arshad, M., Abid, K., Saleem, N., Romman, M., Rahman, Z., Shah, J.A. 2016. Yield response of Wheat cultivars to zinc application rates and methods. Pure and Applied Biology, 5(4): 1260-1270.

Aziz, N., Anwar, S., Kashmir, S., Ahmad, J., Saeed, B., Khan, S. 2019. Response of wheat varieties.

BBS (Bangladesh Bureau of Statistics). 2023. 45 years Agriculture Statistics of Major Crops (Aus, Amon, Boro, Jute, Potato and Wheat).

BARC (Bangladesh Agricultural Research Council). 2018. Fertilizer Recommendation Guide. Farmgate, Dhaka-1215.

Broadley, M.R., White, P.J., Hammond, J.P., Zelko, I., Lux, A. 2007. Zinc in plants. New Phytologist, 173: 677–702.

Cakmak, I. 2008. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? Plant and Soil, 302(1): 1-17.

Chauhan, T.M., Javed Ali, S.P., Singh, I., Singh, S.B. 2014. Effect of Nitrogen and Zinc nutrition on yield, quality and uptake of nutrients by Wheat. Annals of Plant and Soil Research, 98-10.

Chaure, P.R., Gite, P.A., Katkar, R.N., Konde, N.M., Deshmukh, D., Pal, A. 2019. Effect of zinc application on growth characters and yield of wheat (Triticum aestivum L.). International Journal of Applied Research, 5(9): 174-177.

Dianjun, L., Feifei, L., Junxiao, P., Zhenling, C., Chunqin, Z., Xinping, C., Mingrong, H., Zhenlin, W. 2015. The effects of cultivar and nitrogen management on wheat yield and nitrogen use efficiency in the North China Plain. Field Crop Research, 171: 157-164.

FAO and UNDP. 1988. Land resources Appraisal of Bangladesh for Agricultural Development, Report 2. Agro-Ecological Regions of Bangladesh. BARC/UNDP, New Airport Road, Farmgate, Dhaka, 1207, 212-221.

Goesaert, H., Brijs, K., Veraverbeke, W.S., Courtin, C.M., Gebruers, K., Delcour, J.A. 2005. Wheat flour constituents: How they impact bread quality, and how to impact their functionality. Trends in Food Science and Technology, 16: 12–30.

Gomez, M.A., Gomez, J.A. 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons, New York, Chichester, Brisbane, Toronto, 97-215.

Hao, M.D., Wei, X.R., Dang, T.H. 2003. Effect of long-term applying zinc fertilizer on wheat yield and zinc absorption by wheat in dryland. Journal of Ecology and Environmental Sciences, 12(1): 46-48.

Hussain, A., Muhammad, A., Zahir, A.Z., Muhammad, A. 2015. Prospects of Zinc Solubilizing Bacteria for Enhancing Growth of Maize. Pakistan Journal of Agricultural Science, 52(4): 915-922.

Liu, D.Y. 2017. Zinc Nutrition of High-Yielding Wheat and Maize and Its Management on Calcareous Soil. Beijing: China Agricultural University.

Meena, B.L., Singh, A.K., Phogat, B.S., Sharma, H.B. 2013. Effects of nutrient management and planting systems on root phenology and grain yield of wheat. Indian Journal of Agricultural Science, 83(6): 627-632.

Nivedita, K., Fayaz, A. 2021. Effect of different levels of FYM and varieties on yield and yield attributes of Wheat. International Journal of Botany Studies, 6(5): 543-546.

Peck, A.W., McDonald, G.K., Graham, R.D. 2008. Zinc nutrition influences the protein composition of flour in bread wheat (Triticum aestivum L). Cereal Science, 47(2): 266–274.

Rahman, M.A., Hossain, S.J., Hossain, M.B., Amin, M.R., Sarkar, K.K. 2010. Effect of variety and culture method on the yield and yield attributes of wheat. International Journal of Sustain Crop Production, 5(3): 17-21.

Ren, D.X., Yin, S., Xu, Q.M., Hu, S.M., Zhao, X.F. 1999. Effect of different levels of Ca, Fe, Zn in diet on the nutritional status and reproduction of female rats. Acta Nutrimental Sinical, 21:28–33.

Salgueiro, M.J., Zubillaga, M., Lysionek, A., Sarabia, M.I., Caro, R., Paoli, D.T., Hager, A., Weill, R., Boccio, J. 2000. Zinc as an essential micronutrient: a review. Nutrition Research, 20:737–55.

Sharma, J.C., Chaudhary, S.K. 2007. Vertical distribution of micronutrient cations in relation to soil characteristics in lower Shivalik's of Solan district in North-West Himalayas. Journal of Indian Society of Soil Science, 55: 40-44.

Wang, M., Kong, F., Liu, R., Fan, Q., Zhang, X. 2018. Zinc in wheat grain, processing, and food. Frontiers in Nutrition, 7:124.

Zajaczkowska, A.A., Korzeniowska, J., Sienkiewicz-Cholewa, U. 2020. Effect of Soil and Foliar Silicon Application on the Reduction of Zinc Toxicity in Wheat. Department of Weed Science and Tillage Systems in Wroclaw, Institute of Soil Science and Plant Cultivation-National Research Institute in Pulawy, Orzechowa 61, 50-540 Wroclaw, Poland.

Zaman, S.M.H., Rahman, K., Howlar, M. 1982. Simple Lessons from Biometry. Bangladesh Rice Research Institute, Joydebpur, Gazipur, 171.

Zhou, Z., Zhang, B., Liu, H., Liang, X., Ma, W., Shi, Z., Yang, S. 2019. Zinc effects on cadmium toxicity in two wheat varieties (Triticum aestivum L.) differing in grain cadmium accumulation. Ecotoxicology and Environmental Safety, 183.

DOI: https://doi.org/10.55706/jae1708