*Original Research Article*

# Effect of Zinc Fertilization on Zinc Transformations and Yield of Blakgram Grown in Inceptisols

## Abstract

A field experiment was conducted to study the effect of zinc fertilization on zinc transformation under blakgram crop grown on Inceptisols at Agricultural College Farm, Bapatla during *Rabi*, 2021. The experiment was laid out in a split plot design with three main treatments of zinc levels application (0, 25 and 50 kg Zn ha$^{-1}$) and five sub treatments of blackgram varieties (LBG 752, LBG 787, TBG 104, GBG 1 and PU 31) replicated three times. The various Zn fractions *viz.*, water soluble plus exchangeable Zn (WS+EX-Zn), organically complexed Zn(OCX-Zn), amorphous sesquioxide bound Zn(AMOX-Zn), crystalline sesquioxide bound Zn(CRYOX-Zn), residual Zn(Res-Zn) and total Zn were studied during different (pod development and harvest) stages of the crop. The results of experiment showed that the WS+EX-Zn, OCX-Zn, AMOX-Zn and CRYOX-Zncontent in soil significantly increased with increased levels of Zn application. Residual Zn was dominant fraction among all zinc fraction. Further, the concentration of WS+EX-Zn and OCX-Zn of soil significantly enhanced the yield of blackgram.

**Keywords:** Zinc levels, blackgram varieties and zinc fractions

## Introduction

Zinc is an important micronutrient which is involved in many physiological functions of the plant. When the supply of plant available zinc is insufficient, crop yields are reduced and the quality of crop products is frequently impaired. Zinc deficiency is observed in almost all the crops and soils, mostly in calcareous, sandy soils and peat soils. Supply of Zn fertilizers can temporarily help **to offset** plant Zn deficiency symptoms. Information on availability of soil zinc and its fractions and their distribution is essential for understanding its chemical reactions and bioavailability. In general, the order of preponderance of different zinc fractions in soil is water soluble plus exchangeable zinc (WS+EX-Zn) <organically bound zinc (OCX-Zn) < amorphous sesquioxide bound zinc (AMOX-Zn) < crystalline bound zinc (CRYOX-Zn) < residual zinc (Res-Zn) < total Zn. These fractions are in a state of dynamic equilibrium among different fractions and were influenced by different factors like pH, free $CaCO_3$, CEC, organic carbon, clay, free $Fe_2O_3$ etc. Hence, this study was taken with an objective of zinc fertilization on zinc transformations under blackgram grown soils.

## Materials and methods

A field experiment was conducted at Agricultural College Farm, Bapatla during *Rabi*, 2021. The experimental soil was clay in texture, very slightly alkaline in reaction (pH 7.42) and non-saline (EC 0.57 dSm$^{-1}$), medium in organic carbon (OC 5.7 5.7 g kg$^{-1}$), available $P_2O_5$ (39 kg ha$^{-1}$), $K_2O$ (302 kg ha$^{-1}$), Zn (1.18 mg kg$^{-1}$), Fe (5.34mg kg$^{-1}$) and Mn (3.67mg kg$^{-1}$). The available N content (213 kg ha$^{-1}$) was low and available Cu (2.2 mg kg$^{-1}$) was high in concentration.The experiment was laid out in split plot design with fifteen treatments replicated thrice. The main plot treatments comprising three levels of Zn levels application*viz*., $M_1$ – 0 kg Zn ha$^{-1}$, $M_2$- 25 kg Zn ha$^{-1}$ and $M_3$ - 50 kg Zn ha$^{-1}$ and sub plot treatments comprising five blackgram varieties namely, $S_1$ - LBG 752, $S_2$ - LBG 787, $S_3$ - TBG 104, $S_4$ - GBG 1 and $S_5$ - PU 31. A common dose of 100 % RDF *i.e*., 20:50:0 kg ha$^{-1}$ N and $P_2O_5$ are applied at the time of sowing as basal dose through urea and SSP respectively. Zinc sulphate was supplied through zinc sulphate hepta hydrate (ZnSO□.7$H_2$O) to all main treatments (M□, M□ and M□) at threelevels (0, 25 and 50 kg ha$^{-1}$) to the respective plots as per the treatments as basal before sowing.

The blackgram crop was planted in the second week of November. The crop was raised with all the standard package of practices and protection measures also timely carried out as they required. Soil samples from 0 to 15 cm depth were collected at pod development and harvest stages of blackgram. These samples were analyzed using standard procedures in the laboratory. The sequential extraction of soil Zn fractions namely, WS+EX-Zn, OCX-Zn, AMOX-Zn, CRYOX-Zn and Res-Zn were carried out as per the procedure given by Murthy (1982) and later modified by Mandal and Mandal (1986). The data were analyzed statistically as suggested by Panse and Sukhathme (1978) for split plot design.

## Results and discussions

### Effect of different levels of zinc application and blackgram varieties on Zn transformations

### Water Soluble and Exchangeable Zinc (WS+EX-Zn)

Data pertaining to the effect of zinc fertilization on water soluble and exchangeable zinc was presented in the Table 1 and the results revealed the water soluble and exchangeable zinc in soil was significantly influenced by the levels of zinc application at different growth stages of crop. Among the main plots, the significant buildup of WS+EX-Zn content (1.38 and 1.23 mg kg$^{-1}$) was observed under the treatment $M_3$ (50 kg Zn ha$^{-1}$) followed by treatment $M_2$ (25 kg Zn ha$^{-1}$) (1.16 and 1.03 mg kg$^{-1}$) and lowest in $M_1$ (control) (0.87 and 0.75 mg kg$^{-1}$) at pod development and harvest stages of crop, respectively. WS+EX-Zn content was dramatically decreased from initial to harvest stage of crop. This might be due to zinc in largely accessible form, which is readily available to plant for biological uptake. These results were in agreement with the findings of Yadav *et al*. (2013), Tabassum *et al*. (2014), Nadaf *et al*. (2015) and Yashona *et al*. (2019). Percentage of contribution of WS+EX-Zn to total zinc was lowest among all Zn fraction in present investigation might be due to presence of high clay content, elevated pH, sesquioxides and buffering capacity of soil. Similar results were demonstrated by Veeranagappa *et al*. (2011).

Among varieties, the highest WS+EX-Zn concentration (1.18 and 1.06 mg kg$^{-1}$, respectively) was recorded with variety PU 31 ($S_5$) and the lowest value (1.08 and 0.93, respectively) was observed with variety GBG 1 ($S_4$) at pod development and harvest stages, respectively. Zinc application rates and blackgram varieties had no significant interactive effect on WS+EX-Zn content of soil at different crop growth stages

## Organically Complexed Zinc (OCX-Zn)

The results of organically complexed Zinc (OCX-Zn) were presented in Table 2 and the data revealed that the organically complexed zinc in soil was influenced significantly by the application of different doses of Zn fertilizer and it ranged from 1.90 to 2.66 mg kg$^{-1}$ and 1.81 to 2.52 mg kg$^{-1}$ at pod development and harvest stages of crop, respectively among main plot treatments. Significant higher concentration of OCX-Zn was recorded in the treatment $M_3$ (50 kg ha$^{-1}$) (2.66 and 2.52 mg kg$^{-1}$) which was on par with $M_2$ (25 kg ha$^{-1}$) (2.55 and 2.42 mg kg$^{-1}$) and lowest in $M_1$ (control) ($M_1$- 1.90 and 1.81 mg kg$^{-1}$) at pod development and harvest stages of the crop, respectively. These results were in agreement with Raghuwanshi *et al.* (2017), Gajbhiye *et al.* (2018) and Yashona *et al.* (2019). Irrespective of level of Zn application, the OCX-Zn concentration in soil decreased with time (Ilavarasi *et al.*, 2019). Similar to WS+EX-Zn, this form of Zn also contributed very less to total Zn. This might be due to presence of medium range of organic carbon content in experimental soil. Similar results were reported by Preetha and Stalin (2014).

Organically complexed zinc was non significantly differed among all varieties of blackgram. PU 31 variety ($S_5$ - 2.47 and 2.32 mg kg$^{-1}$) recorded highest OCX-Zn content and lowest value with GBG 1 ($S_4$- 2.24 and 2.15 mg kg$^{-1}$) at pod development and harvest stages of crop, respectively. The interaction effect of Zn levels and blackgram varieties found non-significant at different growth stages of crop.

## Amorphous Sesquioxide Bound Zinc (AMOX-Zn)

There was a significant difference in amorphous sesquioxide bound zinc content of soil with the application of different levels of Zn application but not by blackgram varieties at all stages of crop and data presented in the Table 3. The AMOX-Zncontent ranged from 2.29 to 2.70 and 2.78 to 3.03 mg kg$^{-1}$ at pod development and harvest stages of crop, respectively and highest content was observed in $M_3$ (50 kg ha$^{-1}$) (2.70 and 3.03 mg kg$^{-1}$, respectively) which was on par with treatment $M_2$ (25 kg ha$^{-1}$) (2.58 and 2.90 mg kg$^{-1}$, respectively). While lowest content of AMOX-Zn was recorded in $M_1$ (control) (2.29 and 2.78 mg kg$^{-1}$, respectively). Kamali *et al.* (2011) and Yashona *et al.* (2019) also reported similar results.

The mean values pertaining to soil AMOX-Zn content under five varieties of blackgram showed non-significant. AMOX-Zn content (2.64 and 2.93 mg kg$^{-1}$) contents in soil at pod development and harvest stage, respectively were highest under PU-31 ($S_5$) and lowest (2.47 mg kg$^{-1}$) in LBG 787 ($S_1$) and GBG 1 ($S_4$) at pod development stage of crop. Whereas, lowest AMOX-Zn content (2.87 mg kg$^{-1}$) was observed in GBG 1. Interaction effect of zinc rates and blackgram varieties on content of AMOX-Zn in soil was found non-significant.

## Crystalline Sesquioxide Bound Zinc (CRYOS-Zn)

Data regarding to crystalline sesquioxide bound zinc content of soil at different stages of crop was presented in the Table 4 and revealed that CRYOS-Zn fraction was significantly influenced by increasing levels of Zn application and it ranged from 1.95 to 4.11 and 1.87 to 4.01 mg $kg^{-1}$ at pod development and harvest stage, respectively. CRYOS-Zn was significantly highest in $M_3$ (50 kg Zn $ha^{-1}$) (4.11 and 4.01 mg $kg^{-1}$) followed by $M_2$ (25 kg $ha^{-1}$) (3.15 and 3.06 mg $kg^{-1}$) and lowestin control ($M_1$) (1.95 and 1.87 mg kg-1) at pod development and harvest stage of the crop, respectively. The findings are in close agreement with those reported by Kamali *et al*. (2011) and Yashona *et al*. (2019). Crystalline sesquioxide bound zinc was the second most dominant form of zinc after Res-Zn in present experimental soil. This might be due to presence of high amounts of crystalline iron oxides in soil. These results were in corroborate with the findings of Wijebandara *et al*. (2011) and Ilavarasi *et al*. (2019)

There was no significant difference in mean values of CRYOS-Zn content at all stages of crop. At pod development stage, CRYOS-Zn was highest in PU 31 variety ($S_5$ - 3.12) and lowest with GBG 1 ($S_4$ - 3.02). Whereas at harvest stage, highest CRYOS-Zn content was recorded in PU 31 ($S_5$ - 3.02) and lowest in LBG 752 ($S_1$ - 3.02 mg $kg^{-1}$). However, the interaction effect of main and subplots treatments was found non-significant

## Residual Zinc (RES-Zn)

The results were furnished in the Table 5 indicated that the effect different levels of Zn application and blackgram varieties on residual zinc content of soil at different growth stages of crop was found non-significant. Among the main plots, the residual zinc concentration ranged from 79.1 to 81.0 mg $kg^{-1}$ and 78.5 to 80.6 mg $kg^{-1}$ at pod development and harvest, respectively. Treatment $M_3$ (50 kg Zn $ha^{-1}$) recorded highest residual Zn whereas lowest was observed in $M_1$ (control). It was observed that different doses of Zn application had very little effect on the change in concentration of RES-Zn content of soil. The concentration and percentage of contribution of RES-Zn to total zinc was found higher than other fractions of zinc in soil. The Res-Zn content was distributed non-significantly in soil among all blackgram varieties. However, the highest Res-Zncontent (81.2 and 80.8 mg $kg^{-1}$) was found with variety PU 31 ($S_5$) and lowest (79.0 and 78.7 mg $kg^{-1}$) in GBG 1 ($S_4$) at pod development and harvest stage, respectively. However, the interaction effect of levels of Zn application and blackgram varieties on Res-Zn content in soil was found statistically non-significant.

## Total Zinc

The data furnished in Table 6 indicated there was no significant influence on the concentration of total zinc in soil at different growth stages of crop by the application of different rates of zinc and blackgram varieties was found to be non-significant. In main plot treatments, the total Zn content ranged from 86.2 to 91.8 mg $kg^{-1}$ and 85.7 to 91.4 mg $kg^{-1}$ at pod development and harvest stages of crop, respectively and the maximum concentration was registered under the treatment $M_3$ (50 kg Zn $ha^{-1}$) while lowest in $M_1$ (control). Zinc transformation in soil largely controlled by many factors like rate of zinc application, organic matter, soil pH, sesquioxides, clay content, etc., which bring considerable changes in chemical and electrochemical properties of soil results transformation of zinc in soil (Ilavarasi *et al.*, 2019). Among sub plot treatments, at pod development stage, the highest total zinc content was observed with the variety PU 31 ($S_5$) (90.6 and 90.2 mg $kg^{-1}$) and minimum concentration (87.9 and 87.6 mg $kg^{-1}$) was noted with GBG 1 ($S_4$) at pod development and harvest stages of crop, respectively. The interaction effect of treatments was recorded nonsignificant on total zinc fraction at all stages of crop was found non-significant.

## Effect of different levels of zinc application on yield of different blackgram varieties

### Seed yield

From the data furnished in Table 7 revealed that seed yield of different blackgram varieties was significantly affected by different doses of Zn application at various growth stages of crop. The highest seed yield (997 kg $ha^{-1}$) was recorded under the treatment $M_3$(50 kg Zn $ha^{-1}$) but it was at par with yield of $M_2$ (25 kg $ha^{-1}$) (968 kg $ha^{-1}$). The percent increase of seed yield of $M_3$ and $M_2$ over $M_0$ was 25 % and 22 %, respectively. The seed yield of blackgram increased might be due to the enhancement of pod formation and subsequent increase in the number of seeds per pod (Roy *et al.*, 2013). The increase in seed yield due to application of Zn was also attributed to enhanced synthesis of carbohydrates and their transportation to reproductive parts (Peddababu *et al.* 2007).

Among varieties, significantly higher seed yield was recorded by the variety PU 31 ($S_5$ - 988 kg $ha^{-1}$) which was on par with variety LBG 752 ($S_1$ - 961 kg $ha^{-1}$) and TBG 104 ($S_3$ - 926 kg $ha^{-1}$) and seed yield of this treatments was significantly superior over the rest of all other varieties *i.e.*, LBG 787 ($S_2$ - 877 kg $ha^{-1}$) and GBG 1 ($S_4$ - 849 kg $ha^{-1}$). However, the interaction effect of zinc levels and blackgram varieties was found non-significant.

### Haulm yield

Data presented in Table 8 indicated that haulm yield of blackgram as influenced by different levels of zinc application and blackgram varieties were found to be significant. Treatment $M_3$ (50 kg Zn $ha^{-1}$) recorded significantly higher haulm yield (2170 kg $ha^{-1}$) over control ($M_1$) (1995 kg $ha^{-1}$) but statistically at par treatment with $M_2$ (25 kg Zn $ha^{-1}$) (2127 kg $ha^{-1}$). The percent increase of haulm yield of $M_3$ and $M_2$ over $M_0$ was 8.7 % and 6.6 %, respectively. Higher haulm yield of blackgram may due to involvement of zinc in physiological process and synthesis of photosynthates in plant (Tabassum *et al.*, 2013). Zinc application resulted in early growth of seedling and superior nutrition which leads to enhanced dry matter production ultimately its increased haulm yield of crop. Similar increase trend was reported by Chaudary and Sinha (2007) and Jat *et al.* (2021). Among sub plot treatments, significantly higher haulm production was recorded by the variety LBG 752 ($S_1$- 2230 kg $ha^{-1}$) which was on par with LBG 787 ($S_2$- 2144) and PU 31 ($S_5$ - 2098) and it was significantly superior over rest of varieties.

While the lowest value of haulm yield was noted with the variety GBG 1 ($S_4$-2001 kg ha$^{-1}$). However, the interaction of Zn levels and blackgram varieties on haulm yield of backgram was found non-significant.

## Conclusion

All the Zn fractions (except residual and total-Zn) were significantly increased by different rates of Zn application but the effect of varieties was found non-significant. Highest values of all Zn fractions were recorded at rate of 50 kg Zn ha$^{-1}$ ($M_3$) while lowest at "no zinc" application ($M_1$). The concentration of organically bound-Zn and amorphous sesquioxide bound-Zn under $M_3$ treatment was on par with $M_2$ at all stages of crop. The order of dominance of different fractions of zinc in soil both at pod development and harvest stages crop was in the order: water soluble plus exchangeable zinc <organically complexed zinc < amorphous sesquioxide bound zinc < crystalline bound zinc < residual zinc< total Zn. Yield of blackgram was positively correlated with the concentration of water soluble plus exchangeable Zn and organically complexed Zn in soil. Application of zinc @ 50 kg ha$^{-1}$ significantly affected the yield of blackgram and it was ***at par*** with the application of Zn @ 25 kg ha-1 and was highly correlated with the concentration of water soluble plus exchangeable Zn and organically complexed Zn compared to concentration of all other Zn fractions. Hence, application of 25 kg ha$^{-1}$ Zn is sufficient to meet crop demand in farmers fields.

**Table 1. Effect of rate of zinc application and blackgram varieties on water soluble plus exchangeable Zn (mg kg$^{-1}$) in soil at different growth stages of blackgram**

| Zn levels (kg ha$^{-1}$) | Water soluble plus exchangeable-Zn (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pod development stage | | | | | | Harvest stage | | | | | |
| | Blackgram varieties | | | | | Mean M | Blackgram varieties | | | | | Mean M |
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| **$M_1$** | 0.89 | 0.84 | 0.86 | 0.86 | 0.91 | **0.87** | 0.75 | 0.71 | 0.75 | 0.69 | 0.82 | **0.75** |
| **$M_2$** | 1.19 | 1.12 | 1.17 | 1.11 | 1.20 | **1.16** | 1.02 | 1.03 | 1.05 | 0.99 | 1.04 | **1.03** |
| **$M_3$** | 1.43 | 1.35 | 1.39 | 1.28 | 1.44 | **1.38** | 1.33 | 1.18 | 1.26 | 1.10 | 1.30 | **1.23** |
| **Mean S** | **1.17** | **1.10** | **1.14** | **1.08** | **1.18** | | **1.03** | **0.97** | **1.02** | **0.93** | **1.06** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 0.02 | | 0.08 | | | 7.69 | 0.02 | | 0.11 | | | 10.9 |
| **S** | 0.02 | | NS | | | 7.19 | 0.03 | | NS | | | 9.58 |
| **M X S** | 0.05 | | NS | | | | 0.06 | | NS | | | |
| **S X M** | 0.05 | | NS | | | | 0.06 | | NS | | | |

**Table 2. Effect of rate of zinc application and blackgram varieties on organically bound- Zn (mg kg$^{-1}$) in soil at different growth stages of blackgram**

| Zn levels (kg ha$^{-1}$) | Organically complexed-Zn (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pod development stage | | | | | | Harvest stage | | | | | |
| | Blackgram varieties | | | | | Mean M | Blackgram varieties | | | | | Mean M |
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| **$M_1$** | 1.85 | 1.72 | 2.03 | 1.91 | 2.00 | **1.90** | 1.75 | 1.66 | 1.97 | 1.85 | 1.83 | **1.81** |
| **$M_2$** | 2.65 | 2.55 | 2.55 | 2.36 | 2.63 | **2.55** | 2.51 | 2.44 | 2.44 | 2.22 | 2.52 | **2.42** |
| **$M_3$** | 2.81 | 2.65 | 2.61 | 2.45 | 2.79 | **2.66** | 2.66 | 2.53 | 2.39 | 2.40 | 2.61 | **2.52** |
| **Mean S** | **2.44** | **2.31** | **2.40** | **2.24** | **2.47** | | **2.30** | **2.21** | **2.27** | **2.15** | **2.32** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 0.06 | | 0.25 | | | 10.4 | 0.04 | | 0.16 | | | 7.30 |
| **S** | 0.06 | | NS | | | 7.54 | 0.04 | | NS | | | 6.44 |
| **M X S** | 0.10 | | NS | | | | 0.08 | | NS | | | |
| **S X M** | 0.11 | | NS | | | | 0.09 | | NS | | | |

**Table 3. Effect of rate of zinc application and blackgram varieties on amorphous sesquioxide bound-Zn (mg kg$^{-1}$) in soil at different growth stages of blackgram**

| Zn levels (kg ha$^{-1}$) | Amorphous sesquioxide bound-Zn (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pod development stage | | | | | | Harvest stage | | | | | |
| | Blackgram varieties | | | | | Mean M | Blackgram varieties | | | | | Mean M |
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| **$M_1$** | 2.43 | 2.37 | 2.21 | 2.20 | 2.25 | **2.29** | 2.69 | 2.90 | 2.88 | 2.71 | 2.72 | **2.78** |
| **$M_2$** | 2.53 | 2.50 | 2.54 | 2.51 | 2.84 | **2.58** | 2.98 | 2.90 | 2.77 | 2.91 | 2.91 | **2.90** |
| **$M_3$** | 2.74 | 2.53 | 2.72 | 2.69 | 2.83 | **2.70** | 3.03 | 2.87 | 3.07 | 3.00 | 3.17 | **3.03** |
| **Mean S** | **2.57** | **2.47** | **2.49** | **2.47** | **2.64** | | **2.90** | **2.89** | **2.91** | **2.87** | **2.93** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 0.06 | | 0.23 | | | 9.27 | 0.04 | | 0.18 | | | 6.29 |
| **S** | 0.07 | | NS | | | 8.45 | 0.06 | | NS | | | 6.26 |
| **M X S** | 0.12 | | NS | | | | 0.10 | | NS | | | |
| **S X M** | 0.13 | | NS | | | | 0.11 | | NS | | | |

**Table 4. Effect of rate of zinc application and blackgram varieties on crystalline sesquioxide bound-Zn (mg kg-1) in soil at different growth stages of blackgram**

| Zn levels (kg ha$^{-1}$) | Crystalline sesquioxide bound-Zn (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pod development stage | | | | | | Harvest stage | | | | | |
| | Blackgram varieties | | | | | Mean M | Blackgram varieties | | | | | Mean M |
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| **$M_1$** | 1.99 | 1.93 | 1.91 | 1.94 | 1.97 | **1.95** | 1.85 | 1.86 | 1.91 | 1.86 | 1.89 | **1.87** |
| **$M_2$** | 3.18 | 3.11 | 3.17 | 3.05 | 3.23 | **3.15** | 3.00 | 3.06 | 3.07 | 3.04 | 3.12 | **3.06** |
| **$M_3$** | 4.11 | 4.07 | 4.11 | 4.08 | 4.16 | **4.11** | 3.97 | 4.01 | 4.01 | 3.98 | 4.06 | **4.01** |
| **Mean S** | **3.10** | **3.03** | **3.06** | **3.02** | **3.12** | | **2.94** | **2.98** | **3.00** | **2.96** | **3.02** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 0.04 | | 0.19 | | | 6.19 | 0.08 | | 0.32 | | | 10.8 |
| **S** | 0.06 | | NS | | | 6.60 | 0.08 | | NS | | | 8.83 |
| **M X S** | 0.12 | | NS | | | | | | NS | | | |
| **S X M** | 0.12 | | NS | | | | | | NS | | | |

**Table 5. Effect of rate of zinc application and blackgram varieties on residual-Zn (mg kg-1) in soil at different growth stages of blackgram**

| Zn levels (kg ha$^{-1}$) | Residual-Zn (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pod development stage | | | | | | Harvest stage | | | | | |
| | Blackgram varieties | | | | | Mean M | Blackgram varieties | | | | | Mean M |
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| **$M_1$** | 79.3 | 79.4 | 79.4 | 77.1 | 80.5 | **79.1** | 78.7 | 78.7 | 78.7 | 76.5 | 79.8 | **78.5** |
| **$M_2$** | 78.3 | 81.2 | 80.7 | 79.7 | 81.5 | **80.3** | 78.3 | 81.1 | 80.7 | 79.6 | 81.5 | **80.2** |
| **$M_3$** | 80.1 | 80.7 | 82.2 | 80.3 | 81.6 | **81.0** | 79.7 | 80.3 | 81.8 | 79.9 | 81.2 | **80.6** |
| **Mean S** | **79.2** | **80.4** | **80.8** | **79.0** | **81.2** | | **78.9** | **80.1** | **80.4** | **78.7** | **80.8** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 1.61 | | NS | | | 7.79 | 2.13 | | NS | | | 10.3 |
| **S** | 2.36 | | NS | | | 8.84 | 2.31 | | NS | | | 8.71 |
| **M X S** | 4.09 | | NS | | | | 4.02 | | NS | | | |
| **S X M** | 4.00 | | NS | | | | 4.18 | | NS | | | |

**Table 6. Effect of rate of zinc application and blackgram varieties on total-Zn (mg kg-1) in soil at different growth stages of blackgram**

| Zn levels (kg ha$^{-1}$) | Total-Zn (mg kg$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pod development stage | | | | | | Harvest stage | | | | | |
| | Blackgram varieties | | | | | Mean M | Blackgram varieties | | | | | Mean M |
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| **$M_1$** | 86.5 | 86.3 | 86.4 | 84.1 | 87.6 | **86.2** | 85.7 | 85.9 | 86.2 | 83.6 | 87.1 | **85.7** |
| **$M_2$** | 87.9 | 90.5 | 90.2 | 88.7 | 91.4 | **89.7** | 87.7 | 90.6 | 90.0 | 88.8 | 91.1 | **89.6** |
| **$M_3$** | 91.2 | 91.3 | 93.0 | 90.8 | 92.9 | **91.8** | 90.7 | 90.9 | 92.5 | 90.4 | 92.4 | **91.4** |
| **Mean S** | **88.5** | **89.3** | **89.8** | **87.9** | **90.6** | | **88.0** | **89.1** | **89.6** | **87.6** | **90.2** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 1.63 | | NS | | | 7.11 | 2.18 | | NS | | | 9.49 |
| **S** | 2.35 | | NS | | | 7.90 | 2.32 | | NS | | | 7.83 |
| **M X S** | 4.04 | | NS | | | | 4.02 | | NS | | | |
| **S X M** | 4.00 | | NS | | | | 4.21 | | NS | | | |

**Table 7. Effect of different levels of zinc application and blackgram varieties on seed yield (kg ha$^{-1}$) of blackgram**

| Zn levels (kg ha$^{-1}$) | Seed yield (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | **Blackgram varieties** | | | | | **Mean M** |
| | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | |
| **$M_1$** | 829.9 | 756.0 | 819.0 | 720.7 | 852.7 | **795.7** |
| **$M_2$** | 1009 | 938.8 | 933.7 | 933.4 | 1026 | **968.4** |
| **$M_3$** | 1043 | 937.2 | 1026 | 894.6 | 1086 | **997.5** |
| **Mean S** | **961.1** | **877.3** | **926.3** | **849.6** | **988.4** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 15.1 | | 59.3 | | | 6.35 |
| **S** | 23.0 | | 67.3 | | | 7.51 |
| **M X S** | 39.9 | | NS | | | |
| **S X M** | 38.7 | | NS | | | |

**Table 8. Effect of different levels of zinc application and blackgram varieties on haulm yield (kg ha$^{-1}$) of blackgram**

| Zn levels (kg ha$^{-1}$) | Haulm yield (kg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | **Blackgram varieties** | | | | | **Mean M** |
| | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | |
| **$M_1$** | 829.9 | 756.0 | 819.0 | 720.7 | 852.7 | **795.7** |
| **$M_2$** | 1009 | 938.8 | 933.7 | 933.4 | 1026 | **968.4** |
| **$M_3$** | 1043 | 937.2 | 1026 | 894.6 | 1086 | **997.5** |
| **Mean S** | **961.1** | **877.3** | **926.3** | **849.6** | **988.4** | |
| | **SEm±** | | **CD (p=0.05)** | | | **CV (%)** |
| **M** | 15.1 | | 59.3 | | | 6.35 |
| **S** | 23.0 | | 67.3 | | | 7.51 |
| **M X S** | 39.9 | | NS | | | |
| **S X M** | 38.7 | | NS | | | |

## References

Chaudary, S.K and Sinha, N.K. 2007. Effect of Levels of Nitrogen and Zinc Application on Grain Yield and their Uptake in Transplanted Rice. *Oryza*. 44(1): 44-47.

Gajbhiye, P.N., Bulbule, A.V and Kumbhar, C.T. 2018. Effect of Zinc Fertilizer Levels and Application Methods on Zinc Fractions and Grain Yield of Maize. *International Journal of Current Microbiology and Applied Sciences.*7(11): 1-12.

Ilavarasi, R., Baskar, M., Gomadhi, G and Ramesh, T. 2019. Dynamics of Zinc in Sodic Soil with Zinc Enriched Organics. *International Journal of Current Microbiology and Applied Sciences.* 8(1): 2355-2361.

Jat, G., Sharma, S.K., Meena, R.H, Jain, D., Chaoudhary, R., Chaoudhary, R.S and Yadav, S.K. 2021. Amelioration of Zinc Deficiency in Blackgram (*Vigna mungo* L.) through Soil Applied Zinc in Typic Hapliustepts Soil of Rajasthan. *Journal of Environmental Biology*. 42(6): 1554-1559.

Kamali, S., Ronaghi, A and Karimian, N. 2011. Soil Zinc Transformation as Affected by Applied Zinc and Organic Materials. *Communications in Soil Science and Plant Analysis*. 42: 1038-1049.

Nadaf, S.A and Chidanandappa, H.M. 2015. Effect of Zinc and Boron Application on Distribution and Contribution of Zinc Fractions to the Total Uptake of Zinc by Groundnut (*Arachis hypogaea* L.) in Sandy Loam Soils of Karnataka, India. *Legume Research*. 38(5): 598-602.

Peddababu, P., Shanthi, M., Prasad, B.R and Minhas, P.S. 2007. Effect of Zinc in Rice-Blackgram Cropping System in Saline Soils. *The Andhra Agricultural Journal*. 54 (1-2): 47-50.

Preetha, P.S and Stalin, P. 2014. Different Forms of Zinc- their Relationship with Selected Soil Properties and Contribution Towards Plant Availability and Uptake in Maize Growing Soils of Erode District, Tamil Nadu. *Indian Journal of Science and Technology*. 7(7): 1018-1025.

Raghuwanshi, N., Sharma, B.L., Uikey, I and Prajapati, S. residual and cumulative effect of zinc on yield, quality of soyabean (Glycine max L.) and various pools of zinc in a vertisol of Madya Pradesh, cv. JS 97-52. International Journal of Bio-resources and Stress Management. 8(3): 444-449.

Roy, P.D., Narwal, R.P., Malik, R.S., Saha, B.N and Kumar, S. 2013. Impact of Zinc Application Methods on Green Gram (*Vigna radiate* L.) Productivity and Grain Zinc Fortification. *Jornal of Environmental Biology*. 35: 851-854.

Tabassum, S., Jeet, S., Kumar, R., Dev, C.M., Kumar, P and Rehana. 2014. Effect of Organic Manure and Zinc Fertilization on Zinc Transformation and Biofortification of Crops in Vertisols of Central India. *Journal of Agricultural Science*. 6(8): 2014.

Veeranagappa, P., Prakasha, H.C., Vijay Mahanthesh, Ashoka, K.R., Mahendra Kumar, M.B and Nagaraj. 2011. Impact of Zinc Enriched Compost on Availability of Zinc and Zinc Fractions, Nutrient Uptake and Yield of Rice. *Advanced Research Journal of Crop Improvement*. 2(2): 203-207.

Wijebandara, D.M.D.I., Dasog, G.S., Patil, P.L and Manjunath, H. 2011. Zinc Fractions and their Relationships with Soil Properties in Paddy Growing Soils of Northern Dry and Hill Zones of Karnataka. *Journal of the Indian Society of Soil Science*. 59 (2): 141-147.

Yadav, B., Khamparia, R.S and Kumar, R. 2013. Effect of Zinc and Organic Matter Application on Various Zinc Fractions under Direct-Seeded Rice in Vertisols. *Journal of the Indian Society of Soil Science*. 61(2): 128-134.

Yashona, D.S., Mishra, U.S and Aher, S.B. 2019. Effect of Rate and Mode of Zinc Application on Zinc Dynamics in Typic Haplustalfs under Rainfed Conditions. *Journal of the Indian Society of Soil Science.* 67 (4): 450-457.