



Research article

Zero tillage and agronomic biofortification enhanced fodder productivity, micronutrient enrichment and profitability of baby corn (*Zea mays* L.)

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Abstract

Conservation tillage and agronomic biofortification offer promising approaches to improve fodder productivity, nutritional quality, and profitability in dual-purpose crops. A field experiment was conducted during 2021-22 and 2022-23 at Karnal, India a sub-tropical zone, to evaluate the effects of tillage practices and zinc (Zn) and iron (Fe) biofortification on the productivity, micronutrient enrichment, and economics of baby corn (*Zea mays* L.). The experiment was laid out in a split-plot design with two tillage practices - conventional tillage and zero tillage - as main plots and seven agronomic biofortification treatments involving seed priming and foliar application of ZnSO₄ and FeSO₄ as sub-plot treatments. Results revealed that zero tillage significantly improved leaf area index, leaf-to-stem ratio, total fodder yield (40.2 t ha⁻¹), and micronutrient uptake, while reducing the cost of cultivation compared with conventional tillage. Among the biofortification treatments, combined Zn seed priming with Zn and Fe foliar spray [Zn(P)+Zn & Fe(S)] recorded the highest relative chlorophyll content, baby corn yield (1,871 kg ha⁻¹), total fodder yield (40.4 t ha⁻¹), Fe and Zn uptake, net returns (Rs 184,503 ha⁻¹), and B:C ratio (2.52), remaining statistically at par with Fe(P)+Fe and Zn(S). Fe seed priming coupled with Fe foliar spray [Fe(P)+Fe(S)] produced the highest Fe concentration, whereas Zn seed priming coupled with Zn foliar spray [Zn(P)+Zn(S)] recorded the highest Zn concentration in biomass. The results demonstrate that integrating zero tillage with combined Zn and Fe agronomic biofortification enhances fodder yield, micronutrient enrichment, and farm profitability.

Keywords: Agronomic biofortification, Baby corn, Fodder, Iron, Tillage, Zinc

Introduction

Livestock is an important component of Indian agriculture in terms of income, employment, equity, foreign exchange earnings, and sustainability. India has the highest livestock population (536.76 million) in the world and the share of livestock is around 5.5 and 31% to GVA and the agricultural economy, respectively (DAHD, 2025). Fodder demand increases with the ever-increasing livestock population, and fodder is an essential component because it curtails the major cost (65–70%) of livestock feeding (Meena *et al.*, 2023). In India, the area under fodder crops has declined significantly by approximately 23%, from 8.30 (2018-19) to 6.38 (2023-24) million hectares (DAHD, 2025). The area under fodder cultivation has been continuously decreasing from last 3 to 4 decades due to the maximum area devoted to the cultivation of food crops, to feed the ever-increasing

human population which is the major constraint to improving green fodders production. However, at same time India facing net deficit of green fodder by 11%, dry fodder by 24% (Roy *et al.*, 2019). Consequently, need to cultivate dual-purpose remunerative crop like baby corn to meet the requirements of food and fodder for ever increasing population of humans and livestock, respectively. Baby corn (*Zea mays* L.) production has been directly integrated with dairy farming in different countries because the fresh ear is used as human food and the rest (husk and green stalk) can be used as excellent fodder for livestock.

The optimization of tillage practices is attributed to improving soil health for better crop establishment. Conventional tillage practices often lead to soil erosion, water pollution, more water consumption, biodiversity reduction, low energy efficiency and contribution to

global warming (Jat *et al.*, 2012; Ram *et al.*, 2018). Therefore, in recent years, interest of farmers has increased in zero tillage, which causes minimum soil disturbance, improves soil biological activity, produces stable soil aggregates, maintains optimum proportions of respiration gases in the rooting zone, moderates organic matter oxidation, carbon sequestration, greater retention of soil moisture, and limits the re-exposure of weed seeds and their germination. This decreased energy consumption, reduction in the cost of cultivation, increased farm revenues, lower greenhouse gas emissions, as well as comprehensive natural resource conservation (Harish *et al.*, 2022).

Both zinc and iron are transition metals that have unpaired electrons; therefore, they are involved in oxidation-reduction reactions (Zargar *et al.*, 2015) and are required by plants, animals and humans for growth and metabolic processes. Zinc acts as a cofactor for various enzymes involved in carbohydrate metabolism, auxin synthesis, maintenance of the integrity of cellular membranes, protein synthesis, detoxification of superoxide radicals and imparting disease resistance in plants (Prasad, 2007). Iron plays an important role in the biosynthesis of chlorophyll, cell respiration, nitrate and sulphate reduction, electron transport chain, nitrogen fixation, photosynthesis and DNA replication (Zargar *et al.*, 2015). The extensive mining and continuous neglect of micronutrient replenishment lead to widespread micronutrient deficiency in soil, which is considered the main reason for low response of crops. Indian soil deficient of 51.2% in zinc and 19.2% in iron, respectively emerged as threats to sustaining quality and productivity of crops (Shukla *et al.*, 2021). There are many approaches for enhancing the concentration of micronutrients such as supplementation, conventional breeding, genetic engineering etc. However, these

techniques are too expensive and are inaccessible to farmers. Under such conditions, agronomic biofortification using fertilizers is a complementary solution. This method provides a cost-effective way for enhancing the micronutrient content in the edible parts of plants. The foliar application (Cakmak *et al.*, 2017 and Mir *et al.*, 2025) and seed priming of Fe and Zn has been reported to be better than the soil application (Prasad *et al.*, 2014; Bhardwaj *et al.*, 2022; Kannababu *et al.*, 2026) to combat malnutritional issue in animals. Therefore, a field study was conducted to explore the best methods for enriching fodder through agronomic biofortification techniques and to evaluate the impact of Zn and Fe fortification on the productivity and quality of baby corn fodder under different tillage practices in a semi-arid region of the Indo-Gangetic plains of north-west India.

Materials and Methods

Description of experimental site: The experiment was conducted in two consecutive years of 2021-22 and 2022-23 at Research Block of Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana (India) at an elevation of 245 metres above mean sea level with a latitude of 29°43' North and longitude of 76°58' East in the sub-tropical zone. During this investigation, the maximum temperature of 43.24 and 38.50°C were recorded in 23rd and 24th standard week of the year 2021-22 and 2022-23, respectively. The soil of experimental field (0–15 cm) was clay loam in texture, neutral in reaction (pH_{1:2}, 7.23), normal in electrical conductivity (0.315 dS m⁻¹), low in available nitrogen (196.4 kg ha⁻¹); and medium in organic carbon (0.52%), available phosphorus (18.6 kg ha⁻¹), potassium (210.3 kg ha⁻¹) and DTPA extracted iron (7.33 ppm) and zinc (0.56 ppm).

Inputs application and crop management: The land preparation involved one deep ploughing with a disc plough followed by two cross harrowing with a disc harrow and planking in conventional tilled plots, whereas in case of zero tilled plots, the seeds were directly sown using a zero-till drilled without ploughing. In zero tilled plots glyphosate (41% SL) @ 1.0 kg a.i. ha⁻¹ was sprayed one week before sowing of baby corn to control the germinated weed population. The recommended dose of fertilizers (150:60:40 kg/ha, N: P₂O₅: K₂O, respectively) were applied uniformly in all the treatments. The 1/3 of N and full dose of P₂O₅ and K₂O were applied at the time of sowing (basal) and remaining 2/3 of nitrogen was top dressed in equal two split dose at knee height stage and pre-tasselling stage. For priming, the seeds of baby corn were soaked in 0.5% solution of ZnSO₄ (21%) and FeSO₄ (19%) for 24 hours as per respective treatments, and after priming seeds were thoroughly rinsed with water and redried under shade. After drying, seeds were used for sowing. The VL Baby Corn-2 variety was used

Table 1. Treatments details

Symbols	Treatment details
Tillage practices	
CT	: Conventional Tillage
ZT	: Zero Tillage
Biofortification practices	
C	: Control
Zn _(p)	: 0.5% ZnSO ₄ priming (Seed)
Fe _(p)	: 0.5% FeSO ₄ priming (Seed)
Zn _(p) + Zn _(s)	: 0.5% ZnSO ₄ priming (Seed) + 0.5% ZnSO ₄ foliar spray
Fe _(p) + Fe _(s)	: 0.5% FeSO ₄ priming (Seed) + 0.5% FeSO ₄ foliar spray
Zn _(p) + Zn and Fe _(s)	: 0.5% ZnSO ₄ priming (Seed) + 0.5% ZnSO ₄ & FeSO ₄ foliar spray
Fe _(p) + Fe and Zn _(s)	: 0.5% FeSO ₄ priming (Seed) + 0.5% FeSO ₄ & ZnSO ₄ foliar spray

for experiment. The seed rate of 25 kg ha⁻¹ was used and sown at 50 cm row to row and 15 cm plant to plant spacing using a tractor drawn seed drill. A foliar spray of 0.5% solution of zinc sulphate (21%) and ferrous sulphate (19%) was practiced in respective treatments at 30 and 45 DAS of baby corn when the dew had evaporated. The others package of practices was followed as per standard for cultivation of baby corn.

Pre- and post-harvest observations: Five plants were chosen at random and tagged in the net plot area to measure morphological parameters across treatments. The leaf area index, relative chlorophyll content, and leaf-to-stem ratio were measured at harvest. The crop was manually harvested after four pickings of baby cobs. The net plot area was harvested separately from each plot and weighed. The husk yield was estimated after dehusking of baby cobs. The fresh chopped plant samples were collected and then samples were air-dried followed by oven dried at 60°C to a constant weight. The oven-dried fodder samples were ground to pass through 40 mesh sieves using a Macro-Wiley Mill, and then used for chemical analysis. The Fe and Zn content in plant samples were determined by the standard method described by Prasad *et al.* (2006). The nutrient uptake was estimated by multiplying nutrient content with dry matter yield.

Statistical analysis: All the data were analysed using analysis of variance (ANOVA) technique for split plot design on a pooled basis of two years (Gomez and Gomez, 1984). The significance of the treatments was tested using F-test at 5% level of significance ($p \leq 0.05$), and means were compared using the least significant difference (LSD) test ($\alpha \leq 0.05$).

Results and Discussion

Plant physiological parameters: The physiological parameters of baby corn, *viz.* relative chlorophyll content, leaf area index (LAI), and leaf: stem (L:S) ratio, were significantly influenced by tillage and biofortification (Table 2). Zero tillage (ZT) recorded significantly higher LAI (5.12) and L:S ratio (0.45) than conventional tillage (CT), likely due to improved soil structure, soil organic carbon, biological activity, nutrient availability, and soil moisture, which enhanced photosynthesis and plant growth (Parihar *et al.*, 2016).

Among biofortification treatments, Zn(P)+Zn & Fe(S) recorded the highest relative chlorophyll content (47.44), LAI (5.16), and L:S ratio (0.454), remaining statistically at par with Fe(P)+Fe & Zn(S) and superior to Zn(P)+Zn(S), Fe(P)+Fe(S), and the control. Highest relative chlorophyll content and LAI indicate enhanced chlorophyll synthesis and photosynthetic activity, resulting in vigorous canopy development and an increased L:S ratio, consistent with earlier findings (Kumar *et al.*, 2016). The improvement in

Table 2. Effect of tillage and agronomic biofortification practices on relative chlorophyll content, leaf area index (LAI), leaf to stem ratio (L:S ratio) and baby corn yield at harvest (mean of two years data)

Treatment	Relative chlorophyll content	LAI	L:S ratio	Baby corn yield (kg ha ⁻¹)
Tillage practices				
CT	45.6	4.88	0.428	1745
ZT	47.1	5.12	0.450	1838
SEM	0.43	0.06	0.005	31.1
LSD (P=0.05)	NS	0.22	0.021	NS
Biofortification practices				
Control	44.5	4.72	0.417	1667
Zn _(P)	45.6	4.95	0.434	1731
Fe _(P)	45.5	4.92	0.432	1721
Zn _(P) +Zn _(S)	47.1	5.08	0.446	1849
Fe _(P) +Fe _(S)	47.0	5.05	0.442	1835
Zn _(P) +Zn and Fe _(S)	47.4	5.16	0.454	1871
Fe _(P) +Fe and Zn _(S)	47.3	5.12	0.449	1863
SEM	0.71	0.09	0.008	53.1
LSD (P=0.05)	2.02	0.25	0.023	151.1

For treatment details see Table 1

relative chlorophyll content values was attributed to the combined effect of seed priming and foliar application of Zn and Fe. Zinc promotes chlorophyll and auxin (IAA) synthesis and serves as a component of carbonic anhydrase, enhancing CO₂ fixation, whereas iron is essential for chlorophyll formation, photosynthesis, and protein synthesis (Hassan *et al.*, 2019; Zulfikar *et al.*, 2020). Seed priming further improved early crop establishment, canopy development, and nutrient uptake, leading to greater photosynthate production (Chugh *et al.*, 2022; Kaur *et al.*, 2024). The higher L:S ratio under Zn and Fe biofortification resulted from increased leaf growth and biomass, as reported by Kumar *et al.* (2016).

Baby corn and fodder yields: The data on baby corn (without husk) and green fodder yield are presented in Table 2 and Fig 1. Tillage practices had no significant effect on baby corn yield; however, a numerically higher yield was recorded under ZT (1,838 kg ha⁻¹) than CT (1,745 kg ha⁻¹). Biofortification significantly influenced baby corn yield. The highest baby corn yield (1,871 kg ha⁻¹) was recorded with Zn(P)+Zn & Fe(S), which was statistically at par with Fe(P)+Fe and Zn(S), and significantly superior to Zn(P)+Zn(S), Fe(P)+Fe(S), and the control.

Husk yield was not significantly affected by tillage practices (Fig 1). However, green stover yield (dehusked plants) and total green fodder yield were significantly

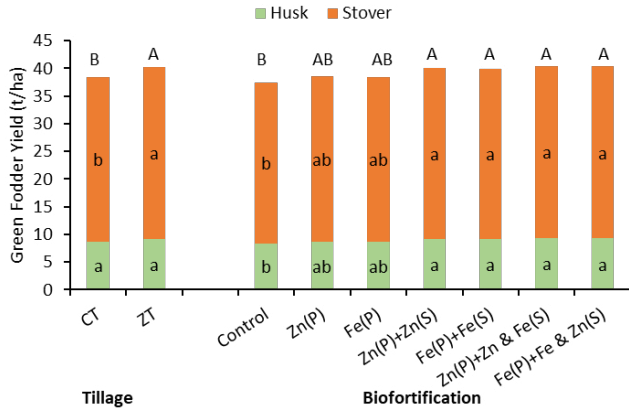


Fig 1. Effect of tillage and agronomic biofortification practices on the green fodder yield of baby corn. Stacked bars represent the total green fodder yield (husk + green stover). Different lowercase letters indicate significant differences within husk and green stover yields, whereas different uppercase letters indicate significant differences in total green fodder yield, according to the LSD test at $P \leq 0.05$; For treatment details see Table 1.

higher under ZT, recording 31.0 and 40.2 t ha⁻¹, respectively, compared with CT. Among the biofortification treatments, Zn(P)+Zn and Fe(S) produced the highest husk yield (9.3 t ha⁻¹), green stover yield (31.1 t ha⁻¹), and total fodder yield (40.4 t ha⁻¹), remaining statistically at par with Fe(P)+Fe and Zn(S), and significantly outperforming Zn(P)+Zn(S),

Fe(P)+Fe(S), and the control. Increased fodder yield resulted from improved plant growth traits, including plant height, LAI, and stem diameter, while the higher total fodder yield was due to the combined increase in husk and fodder yields. Similarly, Kumar *et al.* (2017) in maize and Dhaliwal *et al.* (2020) reported that zinc fertilization through soil and foliar application increased fodder productivity and quality as well as nutrient uptake in oats.

Micronutrient content: The Fe and Zn contents of husk and stover fodder were not significantly influenced by the tillage practices (Table 3). However, biofortification treatments significantly affected the Fe and Zn concentrations in both husk and stover. Among biofortification practices, the highest Fe content in husk (133.6 ppm) and stover (242.1 ppm) was recorded with Fe(P)+Fe(S), which was statistically at par with Fe(P)+Fe & Zn(S) and significantly higher than Zn(P)+Zn & Fe(S), Zn(P), Fe(P), Zn(P)+Zn(S), and the control. Similarly, the highest Zn content in husk (52.9 ppm) and baby corn fodder (41.84 ppm) was recorded with Zn(P)+Zn(S), which remained statistically at par with Zn(P)+Zn & Fe(S) and was significantly superior to Fe(P)+Fe & Zn(S), Zn(P), Fe(P), Fe(P)+Fe(S), and the control. Compared with the control, Fe(P)+Fe(S) and Zn(P)+Zn(S) increased Fe and Zn concentrations in stover by 31.2 and 30.4%, respectively. The improvement in micronutrient concentration was attributed to the combined effect of seed priming and foliar application, which enhanced the absorption,

Table 3. Effect of tillage and agronomic biofortification practices on micronutrient content and uptake of husk and baby corn fodder (mean of two years data)

Treatment	Iron				Zinc			
	Content (ppm)		Uptake (g ha ⁻¹)		Content (ppm)		Uptake (g ha ⁻¹)	
	Husk	Stover	Husk	Stover	Husk	Stover	Husk	Stover
Tillage practices								
CT	114.8	205.4	142	1244	45.1	35.6	56	215
ZT	116.3	209.4	156	1344	46.4	36.5	62	235
SEM	0.73	1.3	3.8	22.8	0.35	0.25	1.9	4.9
LSD (P=0.05)	NS	NS	NS	89.5	NS	NS	NS	19.3
Biofortification practices								
Control	103.7	184.6	120	1058	41.1	32.1	48	184
Zn _(P)	102.4	182.0	125	1100	42.6	33.3	52	201
Fe _(P)	107.1	190.5	130	1145	40.7	31.7	50	191
Zn _(P) +Zn _(S)	100.4	178.5	134	1138	52.9	41.8	71	267
Fe _(P) +Fe _(S)	133.6	242.1	176	1533	39.7	30.9	53	196
Zn _(P) +Zn and Fe _(S)	130.3	236.3	179	1543	51.8	41.4	71	270
Fe _(P) +Fe and Zn _(S)	131.2	237.7	179	1542	51.2	41.1	70	267
SEM	1.25	2.25	7.6	47.0	0.63	0.45	3.1	8.4
LSD (P=0.05)	3.55	6.39	21.6	133.8	1.79	1.28	8.9	23.8

For treatment details see Table 1

Table 4. Effect of tillage and agronomic biofortification practices on economics of baby corn cultivation (mean of two years data)

Treatment	Cost of cultivation (Rs ha ⁻¹)	Gross return (Rs ha ⁻¹)	Net return (Rs ha ⁻¹)	B:C ratio
Tillage practices				
CT	74864	241722	166858	2.23
ZT	71461	254061	182599	2.55
SEM	-	3871	3871	0.05
LSD (P=0.05)	-	NS	NS	0.21
Biofortification practices				
Control	72971	232294	159323	2.19
Zn _(P)	72983	240588	167605	2.30
Fe _(P)	72981	239313	166331	2.28
Zn _(P) +Zn _(S)	73208	254941	181733	2.49
Fe _(P) +Fe _(S)	73181	253298	180117	2.46
Zn _(P) +Zn and Fe _(S)	73408	257911	184503	2.52
Fe _(P) +Fe and Zn _(S)	73406	256894	183488	2.50
SEM	-	6583	6583	0.09
LSD (P=0.05)	-	18720	18720	0.26

For treatment details see Table 1

translocation, and assimilation of Fe and Zn in plant tissues, followed by their remobilization to the husk. The significant increase in mungbean grain nutrients with application of Zn, Fe and B has been reported by Dhaliwal *et al.* (2023). Kaur *et al.* (2024) observed that application of 1% foliar spray of FeSO₄ significantly enhanced Fe uptake and yield of fodder maize.

Micronutrient uptake: Fe and Zn uptake by husk was not significantly influenced by the tillage practices (Table 3). However, tillage practices significantly affected Zn uptake, with ZT recording higher Fe (1,344 g ha⁻¹) and Zn (235 g ha⁻¹) uptake in stover than CT. Among the biofortification treatments, Zn(P)+Zn & Fe(S) recorded the highest Fe uptake by husk (179 g ha⁻¹) and stover (1,542.56 g ha⁻¹), which was statistically at par with Fe(P)+Fe & Zn(S) and significantly higher than Fe(P)+Fe(S), Zn(P), Fe(P), Zn(P)+Zn(S), and the control. Similarly, the highest Zn uptake by husk (71.4 g ha⁻¹) and stover (270 g ha⁻¹) was recorded with Zn(P)+Zn and Fe(S), remaining statistically at par with Zn(P)+Zn(S) and Fe(P)+Fe and Zn(S) and significantly superior to Zn(P), Fe(P), Fe(P)+Fe(S), and the control. The higher Fe and Zn uptake under biofortification treatments was attributed to the combined effect of increased micronutrient concentration in plant tissues and higher dry matter yield. The soil and foliar application of Zn was highly effective in increasing nutrient uptake in cowpea, as reported by Kumar and Dhaliwal (2022) and Dhaliwal *et al.* (2023), who reported that the foliar application of Zn, Fe, and B improved nutrient uptake in mungbean.

Economics: The data on cost of cultivation (COC), gross returns, net returns, and benefit: cost (B:C) ratio were recorded (Table 4). The COC of baby corn was significantly influenced by tillage and biofortification practices. Numerically lower COC was recorded under ZT (Rs 71461 ha⁻¹) than CT (Rs 74864 ha⁻¹). Among the biofortification treatments, the highest COC (Rs 73408 ha⁻¹) was recorded with Zn(P)+Zn and Fe(S), while the lowest (Rs 72971 ha⁻¹) was observed in the control. The lower COC under ZT was mainly due to reduced tillage operations, whereas the higher COC under biofortification treatments resulted from the additional cost of seed priming and foliar application of Fe and Zn. Although tillage practices did not significantly affect economic returns, ZT recorded numerically higher gross returns (Rs 254061 ha⁻¹), net returns (Rs 182599 ha⁻¹), and B:C ratio (2.55) than CT (Rs 241722 ha⁻¹, Rs 166858 ha⁻¹, and 2.23, respectively). Biofortification significantly improved profitability. The highest gross returns, net returns, and B:C ratio (Rs 257911 ha⁻¹, Rs 184503 ha⁻¹, and 2.52, respectively) were obtained with Zn(P)+Zn and Fe(S), which remained statistically at par with Fe(P)+Fe & Zn(S) and significantly superior to Zn(P)+Zn(S), Fe(P)+Fe(S), and the control. The higher profitability under ZT was attributed to its lower cultivation cost, while the improved returns under biofortification resulted from enhanced productivity. The results are in agreement with the previous studies in fodder maize, in which the maximum cost of production was recorded in the order of CT>RB>ZT and vice versa in terms of net return and BC ratio reported by Ram *et al.* (2022). Similarly, Dhaliwal

et al. (2023) reported that the foliar application of Zn, Fe and B improved the economic outcomes of mungbean cultivation.

Conclusion

The present study demonstrated that zero tillage combined with agronomic biofortification significantly improved the productivity, nutritional quality, and profitability of baby corn. Findings indicate that cultivating baby corn under zero tillage with 0.5% ZnSO₄ foliar spray + seed priming followed by foliar application of 0.5% ZnSO₄ and FeSO₄ is an effective and sustainable strategy for enhancing the productivity, profitability, and micronutrient enrichment of fodder biomass.

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References

- Bhardwaj, A. K., S. Chejara, K. Malik, R. Kumar, A. Kumar and R. K. Yadav. 2022. Agronomic biofortification of food crops: an emerging opportunity for global food and nutritional security. *Frontiers in Plant Science* 13: 1055278.
- Cakmak, I., M. J. McLaughlin and P. White. 2017. Zinc for better crop production and human health. *Plant and Soil* 411: 1-4.
- Chugh, G., K. H. Siddique and Z. M. Solaiman. 2022. Iron fortification of food crops through nano fertilisation. *Crop and Pasture Science* 73: 736-748.
- DAHD, 2025. *Basic Animal Husbandry Statistics*. Ministry of Fisheries, Animal Husbandry & Dairying, Department of animal husbandry and dairying. GoI. pp. 1-220.
- Dhaliwal, S. S., A. S. Sandhu, A. K. Shukla, V. Sharma, B. Kumar and R. Singh. 2020. Bio-fortification of oats fodder through zinc enrichment to reduce animal malnutrition. *Journal of Agricultural Science and Technology* 10: 98-108.
- Dhaliwal, S. S., V. Sharma, A. K. Shukla, M. Kaur, J. Kaur, V. Verma, P. Singh, V. Barek, V. Gaber and A. Hossain. 2023. Biofortification of mungbean (*Vigna radiata* L. (Wilczek)) with boron, zinc and iron alters its grain yield and nutrition. *Scientific Reports* 13: 3506.
- Gomez, K. A. and A. Gomez. 1984. *Statistical Procedure for Agricultural Research- Hand Book*. John Wiley & Sons, New York.
- Harish, M. N., A. K. Choudhary, I. Bhupenchandra, A. Dass, G. A. Rajanna, V. K. Singh, R. S. Bana, T. Varatharajan, P. Verma, S. George, G. T. Kashinath, M. Bhavya, S. K. Chongtham, E. L. Devi, S. Kumar, S. H. Devi and T. L. Bhutia. 2022. Double zero-tillage and foliar-P nutrition coupled with bio-inoculants enhance physiological photosynthetic characteristics and resilience to nutritional and environmental stresses in maize-wheat rotation. *Frontiers in Plant Science* 13: 1-26.
- Hassan, N., S. Irshad, M. S. Saddiq, S. Bashir, S. Khan, M. A. Wahid, R. R. Khan and M. Yousra. 2019. Potential of zinc seed treatment in improving stand establishment, phenology, yield and grain biofortification of wheat. *Journal of Plant Nutrition* 42: 1676-1692.
- Jat, R. A., S. P. Wani and K. L. Sahrawat. 2012. Conservation agriculture in the semi-arid tropics: prospects and problems. *Advances in Agronomy* 117: 191-273.
- Kannababu, N., B. Gangaiah, M. Niveditha, R. Swarna, I. K. Das and C. Tara Satyavathi. 2026. Optimizing boron and zinc application strategies to enhance seed yield and quality traits in finger millet (*Eleusine coracana* (L.) Gaertn.). *Range Management and Agroforestry* 47: 203-213.
- Kaur, M., H. K. Oberoi, S. S. Dhaliwal and K. Rani. 2024. Impact of biofortification with iron (Fe) micronutrient on maize fodder in semi-arid region of Indo-Gangetic plains of India. *Journal of Plant Nutrition* 47: 1-12.
- Kumar, B. and S. S. Dhaliwal. 2022. Zinc biofortification of dual-purpose cowpea [*Vigna unguiculata* (L.) Walp.] for enhancing the productivity and nutritional quality in a semi-arid region of India. *Archives of Agronomy and Soil Science* 68: 1034-1048.
- Kumar, R., D. K. Rathore, B. S. Meena, Ashutosh, M. Singh, U. Kumar and V. K. Meena. 2016. Enhancing productivity and quality of fodder maize through soil and foliar zinc nutrition. *Indian Journal of Agricultural Research* 50: 259-263.
- Kumar, R., M. Singh, B. S. Meena, H. Ram, C. M. Parihar, S. Kumar, M. R. Yadav, R. K. Meena, U. Kumar and V. K. Meena. 2017. Zinc management effects on quality and nutrient yield of fodder maize (*Zea mays*). *Indian Journal of Agricultural Sciences* 87: 29-33.
- Meena, R. K., P. S. Hindoriya, R. Kumar, H. Ram, M. Singh and D. Kumar. 2023. Quality, productivity and profitability of diversified fodder-based cropping systems for year-round fodder production in Indo-gangetic plains of India. *Range Management and Agroforestry* 44: 152-159.
- Mir, N.M., B.A. Alie, S. Ahmad, S. S. Bhat and Z. A. Dar. 2025. Legume integration and zinc fortification enhanced yield and quality of maize-based forage systems. *Range Management and Agroforestry* 46: 114-122.
- Parihar, C. M., S. L. Jat, A. K. Singh, B. Kumar, Y. Singh, S. Pradhan, V. Pooniya, A. Dhauja, V. Choudhary, M. L. Jat, R. K. Jat and O. P. Yadav. 2016. Conservation agriculture in irrigated intensive maize-based

- systems of north-western India: Effects on crop yields, water productivity and economic profitability. *Field Crops Research* 193: 104-116.
- Prasad, R. 2007. *Crop Nutrition- Principles and Practices*. New Vishal, Publication, New Delhi. pp. 1-272.
- Prasad, R., Y. S. Shivay and D. Kumar. 2014. Agronomic biofortification of cereal grains with iron and zinc. *Advances in Agronomy* 125: 55-91.
- Prasad, R., Y. S. Shivay, D. Kumar and S. N. Sharma. 2006. Learning by doing exercises in soil fertility (A practical manual for soil fertility). Division of Agronomy, IARI, New Delhi. pp. 1-68.
- Ram, H., R. K. Singh, G. Pal, D. K. Agarwal and R. Kumar. 2018. Effect of tillage practices and genotypes on growth, seed yield and nutrient uptake in wheat (*Triticum aestivum*). *Indian Journal of Agricultural Sciences* 88: 1765-69.
- Ram, H., R. Kumar, R. K. Meena, R. Malik, Mallikarjun and A. Saxena. 2022. Effect of tillage and nitrogen management on yields, profitability and nitrogen balance of baby corn (*Zea mays*). *Indian Journal of Agricultural Sciences* 92: 115-118.
- Roy, A. K., R. K. Agrawal and N. R. Bhardwaj. 2019. *Indian Fodder Scenario: Redefining State Wise Status*. ICAR- AICRP on Forage Crops and Utilization, IGRI, Jhansi. pp. 1-21.
- Shukla, A. K., S. K. Behera, C. Prakash, A. Tripathi, A. K. Patra, B. S. Dwivedi, V. Trivedi, C. S. Rao, S. K. Choudhari, S. Das and A. K. Singh. 2021. Deficiency of phyto-available sulphur, zinc, boron, iron, copper and manganese in soils of India. *Scientific Reports* 11: 19760.
- Zargar, S. M., R. Mahajan, S. Farhat, M. Nazir, R. A. Mir, M. Nazir, R. K. Salgotra and S. A. Mallick. 2015. Understanding the role of iron and zinc in animals and crop plants from genomics perspective. *Current Trends in Biotechnology and Pharmacy* 9: 182-196.
- Zulfiqar, U., M. Maqsood, S. Hussain, and M. Anwar-ul-Haq. 2020. Iron nutrition improves productivity, profitability, and biofortification of bread wheat under conventional and conservation tillage systems. *Journal of Soil Science and Plant Nutrition* 20: 1298-1310.