**RESEARCH PAPER**

**Influence of Micronutrients and Plant Growth Regulators on Growth and Seed Yield of Cowpea [*Vigna unguiculata* (L.) Walp.]**

**Abstract**

The present study was carried out during the summer season of 2023–24 at the Vegetable Research Farm, Department of Horticulture (Vegetable and Floriculture), Bihar Agricultural College, Sabour, Bhagalpur, to assess the impact of varying levels of micronutrients and plant growth regulators (PGRs) on the seed yield and quality of cowpea (Vigna unguiculata (L.) Walp.). The experiment was laid out in a factorial randomized block design (RBD) with three replications and twenty five treatments. The treatments comprised five levels of micronutrients *viz*., M₀ (control), M₁ (Zn @ 75 ppm), M₂ (Zn @ 100 ppm), M₃ (Fe @ 100 ppm), and M₄ (Fe @ 125 ppm) and five levels of PGRs *viz*., P₀ (control), P₁ (GA₃ @ 100 ppm), P₂ (GA₃ @ 150 ppm), P₃ (NAA @ 50 ppm), and P₄ (NAA @ 75 ppm). Foliar applications were carried out at 35 and 60 days after sowing. Results indicated that the interaction treatment M₂P₂ (Zn @ 100 ppm + GA₃ @ 150 ppm) significantly enhanced yield attributes viz*.*, seed yield per plant (20.94), pod length (35.28 cm), number of seeds per pod (11.08), 100 seed weight (17.77 g) and total seed yield (14.54 q/ha). However, plant height, number of branches, days to first flowering, 50% flowering, and first pod picking were not significantly affected. The M₄P₂ (Fe @ 125 ppm + GA₃ @ 150 ppm) treatment recorded the highest plant height (58.40 cm) and number of branches (5.90). Based on the findings, the M₂P₂ treatment emerged as the most effective combination for maximizing cowpea seed yield, highlighting its potential for improved seed production strategies.

**Keywords:** Cowpea, micronutrients, plant growth regulators, NAA, GA3

**Introduction**

Cowpea (Vigna unguiculata (L.) Walp.) is an important legume crop belongs to the family Leguminaceae with subfamily Papilionaceae native to Central Africa and an important leguminous crop (Sirisha *et al*., 2022). It is predominantly cultivated during the summer and rainy seasons. Cowpea holds substantial socio-economic importance and is referred by various local names such as Lobia (Hindi), Bora (Bihar), black-eyed pea, Southern pea, chowla and barbati, indicating its widespread use and cultural relevance (Saravaiya *et al*., 2014). It is annual herbaceous plant known for its drought hardy nature with large tap root system and alternate trifoliate leaves with ovate leaflets. In India, during 2022-23 cowpea is grown over an area about 58000 ha with an average production of 4.8 lakh tons and average productivity is 8.44 t/ha (DPD, 2022). Cowpea is often termed as "poor man's meat" is highly esteemed for its rich nutritional profile, particularly its protein content. Mature seeds contain 23–32% protein, 50–60% carbohydrates, and 1% fat, 24.8% protein, 63.6% carbohydrates, 1.9% fat, and 6.3% fiber, along with vital vitamins such as thiamine, riboflavin, and niacin (Jose *et al*., 2014; Kirse and Karklina, 2015). It also has the useful ability to fix atmospheric nitrogen up to 150 kg per hectare through its root nodules in symbiotic association with Rhizobium bacteria (Chattopadhyay *et al.,* 2007).

A major constraint in productivity is the limited availability of essential nutrients (Siddiqui *et al.,* 2015). The role of plant nutrients, particularly micronutrients is critical for improving cowpea seed yield and quality. Foliar application of micronutrients has been shown to be highly effective, ensuring up to 90% nutrient utilization (Manasa and Devaranavadagi, 2015). Zinc is an essential micronutrient that plays a crucial role in numerous enzymatic and physiological processes within plants. A deficiency in zinc disrupts the production of growth hormones, leading to reduced internodal elongation and the development of smaller leaves. Similarly, iron is vital for chlorophyll biosynthesis and maintenance and is a key component of the enzyme nitrogenase, which is indispensable for biological nitrogen fixation (Yadav *et al*., 2002). Iron deficiency remains one of the major constraints limiting crop productivity. Hence, it is imperative to explore strategies that enhance the root uptake of these micronutrients. The application of zinc and iron fertilizers in cowpea cultivation offers a promising and sustainable approach to mitigating these nutrient-related challenges and improving crop performance.

In addition to nutrients, plant growth regulators (PGRs) play a pivotal role in modulating physiological processes such as root development, flowering and fruit enlargement, and photosynthetic efficiency, thereby boosting overall plant productivity. Gibberellic acid (GA₃) has been found to be highly effective in promoting various physiological and developmental processes in plants, including stem elongation, seed germination, fruit development, biomass accumulation, and overall yield. Its efficacy is particularly notable when applied as a foliar spray (Deotale *et al*., 1998). Similarly, Naphthalene Acetic Acid (NAA) enhances the source–sink relationship and modifies the translocation of photosynthates, thereby contributing to improved flower and fruit retention as well as effective seed filling during the later stages of crop development (Sarvaiya *et al*., 2021). To attain optimal vegetative growth and efficient distribution of assimilates to developing pods, the application of plant growth regulators (PGRs) presents a promising strategy, as they influence plant growth dynamics, modify plant architecture, and ultimately contribute to yield enhancement. However, limited research has been conducted in this area. Therefore, the present study was undertaken to evaluate the effects of foliar application of micronutrients and PGRs on the growth, yield, and seed quality of cowpea.

**Materials and Methods**

The present research was carried out during the summer season of 2024 at the Vegetable Research Farm, Department of Horticulture (Vegetable and Floriculture), Bihar Agricultural University (BAU), Sabour, Bhagalpur, Bihar. The experimental site comprised of well-drained sandy loam soil with a neutral pH of 7.6. The cultivar Kashi Nidhi was used as planting material. The experiment was laid out in a factorial randomized block design (RBD) with three replications and 25 treatment combination, comprising five levels of micronutrients *viz*, (M0- control, M1-Zn @75 ppm, M2-Zn@ 100 ppm, M3-Fe@100 ppm& M4-Fe@125ppm) as well as five levels of PGRs viz, P0 (Control), P1 (GA3 @ 100ppm), P2 (GA3 @150 ppm), P3 (NAA @ 50 ppm) and P4 (NAA @ 75 ppm). Each treatment plot measured 1.5 × 2.5 m with a inter row and intra row spacing of 50 cm × 30 cm. Sowing of cowpea seed done in plot measured 1.5 × 2.5 m with 50 and 30 cm row to row and plant to plant distance, respectively. The solutions were prepared from their respective stock solutions using distilled water. Micronutrient and plant growth regulator treatments, comprising five levels each, were administered through foliar application at two growth stages: 35 and 60 days after sowing (DAS). Five plants in each plot were randomly selected for recording observations on growth, yield and yield attributing traits. Various observations like morphological, floral and yield parameters in the study were recorded during study period. Statistical analysis of the recorded data was conducted as per the standard procedures described by Panse and Sukhatme to determine the significance of treatment effects.

**RESULTS AND DISCUSSION**

**Growth parameters**

### ****Plant height****

The plant height of cowpea was significantly affected by foliar application of micronutrients and plant growth regulators. Among the micronutrient treatments, the highest plant height (52.57 cm) was observed with zinc sulphate (ZnSO₄) at 100 ppm (M2), which was significantly superior to the other treatments. The enhanced growth under Zn application can be attributed to its vital role in plant physiological and biochemical processes. In contrast, the control treatment (M0) recorded the minimum plant height (45.05 cm), underscoring the importance of zinc supplementation for optimal growth. These findings are consistent with the results reported by Kumar and Bohra (2014) in baby corn and Chauhan *et al*. (2023) in cowpea. In case of PGRs, gibberellic acid (GA₃) at 150 ppm (P2) resulted the tallest plants (53.64 cm), significantly outperforming the control (P0), which recorded a plant height of 45.77 cm. The growth-promoting effect of GA₃ is attributed to its role in stimulating cell division and elongation, enhancing stem growth, and influencing key physiological processes related to plant development. Similar results were reported by Singh *et al.* (2015) and Sharma *et al.* (2024) in garden pea. Similarly, significant interaction effects among micronutrient and PGRs treatments were also recorded. The combination of FeSO₄ at 125 ppm and GA₃ at 150 ppm (M4P2) resulted in the maximum plant height (58.40 cm), which was statistically at par with ZnSO₄ at 100 ppm combined with GA₃ at 150 ppm (M2P2), having plant height 55.40 cm while the lowest plant height (38.12 cm) was recorded in the control (M0P0), indicating a synergistic effect of micronutrients and PGRs in enhancing plant growth. These results corroborate the findings of Chauhan *et al*. (2023) in cowpea.

### ****Number of branches per plant****

Foliar micronutrient application led to a significant increase in the number of branches per plant. The highest number of branches (5.24) was recorded with foliar application of ZnSO₄ at 100 ppm (M2), which was statistically at par to FeSO₄ at 125 ppm (M4) and 100 ppm (M3), recording 5.02 and 5.00 branches, respectively. The improvement in branching may be attributed to zinc’s role in enhancing photosynthetic efficiency and enzymatic activities, including those of dehydrogenase, protease, and peptidase. The lowest number of branches (4.42) was observed in the control (M0), indicating that micronutrient deficiencies limit vegetative growth. Similar findings have been reported by Ismail and Elnour (2016) who also found significant variation in number of branches per plant in cowpea. Among PGR treatments, GA₃ at 150 ppm (P2) led to the highest number of branches (5.46), significantly higher than the control (P0), which recorded 3.96 branches. The increased branching under GA₃ treatment can be ascribed to enhanced cell division and elongation in meristematic tissues, which stimulates vegetative development. The interaction effect of micronutrients and PGRs further emphasized the synergistic relationship between the combinations. The combination of FeSO₄ at 125 ppm and GA₃ at 150 ppm (M4P2) produced the highest number of branches per plant (5.90), followed by M2P2 (5.72) and M3P2 (5.60) while the minimum number of branches (3.40) was recorded in the control (M0P0). The superior performance of these combinations is likely due to enhanced cell division, improved photosynthetic activity, and better nutrient assimilation, which collectively promote increased branching. These findings are supported by Noor *et al.* (2017) in French bean.

**Effect of micronutrients and PGRs on days to first flowering, days to 50% flowering and days to first pod picking**

The application of micronutrients and plant growth regulators (PGRs) significantly influenced flowering and pod picking in cowpea. Among the micronutrient treatments, foliar application of ZnSO₄ at 100 ppm (M2) resulted in the earliest onset of reproductive stages, recording the minimum days to first flowering (36.90 days), 50% flowering (45.76 days), and first pod picking (57.90 days). This superior performance may be attributed to the critical role of zinc in enzymatic activity and hormonal regulation, particularly in auxin biosynthesis, which is known to promote floral initiation and reproductive development.

Similarly, under foliar application of GA₃ at 150 ppm (P2) significantly hastened the phenological events. The treatment led to the least days to first flowering (34.40 days), 50% flowering (43.93 days), and first pod picking (55.36 days). This might be due to GA3, which is known to stimulate floral initiation and pod development by promoting cell division and elongation, accelerating the transition from vegetative to reproductive phases. The interaction among different treatments of micronutrients and PGRs had significant effects. The combined application of ZnSO₄ at 100 ppm with GA₃ at 150 ppm (M2P2) resulted in the earliest days to first flowering (31.60 days), 50% flowering (40.05 days) and first pod picking (52.25 days). This synergistic effect indicates that optimal levels of micronutrients in conjunction with growth regulators can significantly expedite the reproductive cycle of cowpea. In contrast, the control treatment (M0P0) consistently recorded the highest number of days for all phenological traits, reflecting delayed flowering and maturity due to the absence of growth-promoting inputs. These results are in alignment with the findings of Kumawat *et al.* (2019) in okra, who also reported enhanced reproductive efficiency under the influence of zinc and gibberellic acid. Emongor (2007) reported that the foliar application of GA3 improved the growth and flowering in vegetable cowpea as compared to control.

**Table 1. Effect of different level of micronutrients and PGRs on plant height (cm)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 38.12 | 45.10 | 49.02 | 46.20 | 46.80 | **45.05** |
| **Zn@75 ppm (M1)** | 48.00 | 49.60 | 52.20 | 47.00 | 49.60 | **49.28** |
| **Zn@100ppm (M2)** | 49.95 | 53.30 | 55.40 | 49.40 | 54.80 | **52.57** |
| **Fe@100ppm (M3)** | 46.80 | 54.60 | 53.20 | 49.80 | 47.80 | **50.44** |
| **Fe@125 ppm (M4)** | 46.00 | 51.00 | 58.40 | 47.20 | 48.40 | **50.20** |
| **MEAN** | **45.77** | **50.72** | **53.64** | **47.92** | **49.48** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **1.84** | **1.84** | **4.11** |  |  |  |
| **CV (%)** | **5.07** | | | | | |

**Table 2. Effect of different level of micronutrients and PGRs on number of branches per plant**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 3.40 | 4.80 | 4.90 | 4.20 | 4.80 | **4.42** |
| **Zn@75 ppm (M1)** | 3.80 | 5.40 | 5.20 | 4.40 | 5.20 | **4.80** |
| **Zn@100ppm (M2)** | 4.00 | 5.50 | 5.72 | 5.40 | 5.60 | **5.24** |
| **Fe@100ppm (M3)** | 4.20 | 5.20 | 5.60 | 4.70 | 5.30 | **5.00** |
| **Fe@125 ppm (M4)** | 4.40 | 5.00 | 5.90 | 5.00 | 4.80 | **5.02** |
| **MEAN** | **3.96** | **5.18** | **5.46** | **4.74** | **5.14** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **0.18** | **0.18** | **0.42** |  |  |  |
| **CV (%)** | **5.26** | | | | | |

**Table 3. Effect of different level of micronutrients and PGRs on days to first flowering (days)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 45.20 | 38.60 | 37.50 | 37.80 | 42.60 | **40.34** |
| **Zn@75 ppm (M1)** | 43.00 | 36.00 | 34.70 | 40.90 | 39.60 | **38.84** |
| **Zn@100ppm (M2)** | 41.80 | 34.80 | 31.60 | 38.52 | 37.80 | **36.90** |
| **Fe@100ppm (M3)** | 43.60 | 36.80 | 34.90 | 40.80 | 41.02 | **39.42** |
| **Fe@125 ppm (M4)** | 43.80 | 36.20 | 33.30 | 38.40 | 40.60 | **38.46** |
| **MEAN** | **43.48** | **36.48** | **34.40** | **39.28** | **40.32** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **1.75** | **1.75** | **3.95** |  |  |  |
| **CV (%)** | **6.16** | | | | | |

**Table 4. Effect of different level of micronutrients and PGRs on 50%flowering**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 56.25 | 48.63 | 47.51 | 49.23 | 52.60 | **50.84** |
| **Zn@75 ppm (M1)** | 53.02 | 46.91 | 43.70 | 48.34 | 49.62 | **48.32** |
| **Zn@100ppm (M2)** | 51.42 | 43.24 | 40.05 | 46.00 | 48.10 | **45.76** |
| **Fe@100ppm (M3)** | 54.31 | 47.22 | 45.02 | 49.80 | 51.33 | **49.54** |
| **Fe@125 ppm (M4)** | 52.15 | 45.83 | 43.35 | 46.45 | 51.02 | **47.76** |
| **MEAN** | **53.43** | **46.37** | **43.93** | **47.96** | **50.53** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **1.96** | **1.96** | **4.39** |  |  |  |
| **CV (%)** | **5.50** | | | | | |

**Table 5. Effect of different level of micronutrients and PGRs on days to first pod picking**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 65.97 | 61.72 | 59.82 | 61.77 | 62.85 | **62.43** |
| **Zn@75 ppm (M1)** | 63.60 | 56.97 | 55.82 | 61.72 | 61.89 | **60.00** |
| **Zn@100ppm (M2)** | 62.25 | 55.68 | 52.25 | 60.06 | 59.26 | **57.90** |
| **Fe@100 ppm (M3)** | 64.20 | 56.87 | 55.10 | 61.65 | 60.20 | **59.60** |
| **Fe@125 ppm (M4)** | 63.80 | 57.95 | 53.80 | 60.27 | 60.60 | **59.28** |
| **MEAN** | **63.96** | **57.84** | **55.36** | **61.09** | **60.96** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **2.38** | **2.38** | **5.33** |  |  |  |
| **CV (%)** | **5.47** | | | | | |

**Table 6. Effect of different level of micronutrients and PGRs on number of pods per plant**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 22.52 | 27.00 | 29.20 | 27.70 | 27.20 | **26.72** |
| **Zn@75 ppm (M1)** | 23.50 | 30.20 | 33.20 | 28.20 | 29.20 | **28.86** |
| **Zn@100ppm (M2)** | 24.80 | 33.60 | 35.82 | 29.60 | 32.60 | **31.28** |
| **Fe@100ppm (M3)** | 23.40 | 31.85 | 31.40 | 28.02 | 28.40 | **28.61** |
| **Fe@125 ppm (M4)** | 26.50 | 32.01 | 34.65 | 26.80 | 28.80 | **29.75** |
| **MEAN** | **24.14** | **30.93** | **32.85** | **28.06** | **29.24** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **1.21** | **1.21** | **2.72** |  |  |  |
| **CV (%)** | **5.72** | | | | | |

**Table 7. Effect of different level of micronutrients and PGRs on pod length (cm)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 21.88 | 25.10 | 26.90 | 26.02 | 27.88 | **25.56** |
| **Zn@75 ppm (M1)** | 22.56 | 28.56 | 30.66 | 27.78 | 28.08 | **27.53** |
| **Zn@100ppm (M2)** | 25.38 | 29.60 | 35.28 | 28.44 | 32.48 | **30.24** |
| **Fe@100ppm (M3)** | 23.78 | 28.04 | 31.26 | 27.91 | 28.70 | **27.94** |
| **Fe@125 ppm (M4)** | 22.25 | 29.44 | 33.24 | 25.10 | 24.24 | **26.85** |
| **MEAN** | **23.17** | **28.15** | **31.47** | **27.05** | **28.28** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **1.45** | **1.45** | **3.24** |  |  |  |
| **CV (%)** | **7.17** | | | | | |

**Table 8. Effect of different level of micronutrients and PGRs on number of seed per pod**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 6.80 | 8.00 | 10.50 | 7.80 | 8.40 | **8.30** |
| **Zn@75 ppm (M1)** | 7.10 | 9.60 | 10.81 | 8.01 | 8.16 | **8.74** |
| **Zn@100ppm (M2)** | 7.80 | 9.90 | 11.80 | 8.12 | 9.52 | **9.43** |
| **Fe@100ppm (M3)** | 7.50 | 8.90 | 10.70 | 8.00 | 9.24 | **8.87** |
| **Fe@125 ppm (M4)** | 7.20 | 9.80 | 11.50 | 8.31 | 8.20 | **9.00** |
| **MEAN** | **7.28** | **9.24** | **11.06** | **8.05** | **8.70** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **0.37** | **0.37** | **0.83** |  |  |  |
| **CV (%)** | **5.76** | | | | | |

**Table 9. Effect of different level of micronutrients and PGRs on seed yield per plant (g)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 12.97 | 14.29 | 16.06 | 14.74 | 14.06 | **14.42** |
| **Zn@75 ppm (M1)** | 13.53 | 17.77 | 18.68 | 15.81 | 15.60 | **16.28** |
| **Zn@100ppm (M2)** | 14.56 | 18.34 | 20.94 | 17.64 | 18.15 | **17.93** |
| **Fe@100ppm (M3)** | 13.20 | 17.36 | 18.01 | 15.26 | 16.77 | **16.12** |
| **Fe@125 ppm (M4)** | 14.61 | 18.06 | 18.85 | 16.20 | 18.28 | **17.20** |
| **MEAN** | **13.77** | **17.16** | **18.51** | **15.93** | **16.57** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **0.63** | **0.63** | **1.42** |  |  |  |
| **CV (%)** | **5.30** | | | | | |

**Table :10. Effect of different level of micronutrients and PGRs on total yield q/ha**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 8.64 | 10.37 | 10.56 | 9.66 | 9.73 | **9.79** |
| **Zn@75 ppm (M1)** | 9.20 | 11.28 | 12.16 | 11.45 | 11.11 | **11.04** |
| **Zn@100ppm (M2)** | 9.84 | 12.57 | 14.54 | 11.76 | 12.05 | **12.15** |
| **Fe@100ppm (M3)** | 9.62 | 11.78 | 12.12 | 10.15 | 11.66 | **11.07** |
| **Fe@125 ppm (M4)** | 10.46 | 11.99 | 12.78 | 11.16 | 10.08 | **11.29** |
| **MEAN** | **9.55** | **11.60** | **12.43** | **10.84** | **10.93** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **0.44** | **0.44** | **0.95** |  |  |  |
| **CV (%)** | **5.52** | | | | | |

**Table 11. Effect of different level of micronutrients and PGRs on harvest index (%)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 28.80 | 30.02 | 32.99 | 30.10 | 29.74 | **30.33** |
| **Zn@75 ppm (M1)** | 30.65 | 33.52 | 34.52 | 32.71 | 32.01 | **32.68** |
| **Zn@100ppm (M2)** | 31.82 | 34.84 | 37.16 | 34.26 | 35.19 | **34.65** |
| **Fe@100ppm (M3)** | 30.51 | 33.77 | 34.48 | 31.64 | 32.51 | **32.58** |
| **Fe@125 ppm (M4)** | 31.04 | 34.05 | 35.73 | 31.23 | 34.00 | **33.21** |
| **MEAN** | **30.56** | **33.24** | **34.98** | **31.99** | **32.69** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **1.42** | **1.42** | **3.17** |  |  |  |
| **CV (%)** | **5.93** | | | | | |

**Seed Yield Attributes**

**Number of pods per plant**

The application of micronutrients and plant growth regulators (PGRs) significantly affected the number of pods per plant in cowpea. Among the micronutrient treatments, ZnSO₄ at 100 ppm (M2) recorded the highest number of pods (31.28), which was significantly superior to the control (M0), which registered only 26.72 pods. Amongst PGRs, GA₃ at 150 ppm (P2) produced the highest number of pods per plant (32.85), whereas the control (P0) recorded the lowest (24.14). Although the interaction effect was statistically non-significant, the combination of ZnSO₄ at 100 ppm and GA₃ at 150 ppm (M2P2) yielded the highest number of pods (35.82) followed by FeSO₄ at 125 ppm and GA₃ at 150 ppm (M4P2) with 34.65 pods. This enhancement in pod number may be attributed to zinc's critical role in tryptophan synthesis, a precursor for auxin, which regulates flower and pod development. Additionally, GA₃ likely enhanced the net photosynthetic rate, number of branches, and vegetative biomass, collectively contributing to greater pod formation. These results are consistent with findings by Nabi *et al.,* (2014) and Ismail, Elnour (2016) in cowpea and Choudhary et al. (2023) in garden pea.

**Pod length**

Pod length was significantly influenced by both micronutrients and PGRs. The foliar application of ZnSO₄ at 100 ppm (M2) produced the longest pods (30.24 cm), whereas the control (M0) resulted in the shortest (25.56 cm). Amongst PGRs, maximum pod length (31.47 cm) was recorded with GA₃ at 150 ppm (P2) which was significantly better over the control (23.17 cm). The interaction among micronutrients and PGRs, with the combination M2P2 (ZnSO₄ @ 100 ppm × GA₃ @ 150 ppm) reported the longest pods (35.28 cm) which was statistically at par with M4P2 (FeSO₄ @ 125 ppm × GA₃ @ 150 ppm). This might be due to the action of zinc, which is known to enhance auxin production, cell elongation, nutrient uptake, and enzyme activity, which directly contribute to the elongation of pods. Whereas GA₃ also promotes cell division and elongation, thereby increasing pod size while the shortest pods (21.88 cm) were observed under control (M0P0). These results align with the findings of Ali *et al.,* (2014) in mung bean and Mavdiya *et al.,* (2023) in cowpea.

**Number of seeds per pod**

The number of seeds per pod was also significantly influenced by treatments. Among micronutrients, ZnSO₄ at 100 ppm (M2) recorded the highest number of seeds per pod (9.43), which was statistically at par with FeSO₄ at 125 ppm (M4) with 9.00 seeds while the control (M0) exhibited the lowest number of seeds per pod (8.30). Amongst the PGRs application, GA₃ at 150 ppm (P2) showed a significant increase in number of seeds per pod (11.06), while the control (P0) produced the least number of seeds per pod (7.28). The interaction effect showed that M2P2 combination resulted in the maximum number of seeds per pod (11.80), followed by M4P2 (11.50) while the lowest number of seeds per pod (6.80) was recorded in M0P0. The increase in seeds per pod may be due to zinc's involvement in auxin biosynthesis and reproductive development, including pollen viability and fertilization efficiency. GA₃ likely contributed by enhancing flowering and fruit set. Similar observations were reported by Ismail and Elnour (2016) and Nazeer *et al.,* (2020) in pea.

**Seed yield per plant**

The foliar application of micronutrients and PGRs had significant effect on the seed yield per plant. The highest seed yield per plant (17.93 g) was recorded with ZnSO₄ at 100 ppm (M2) which was significantly better over the control (14.42 g). Similarly, GA₃ at 150 ppm (P2) resulted in the highest seed yield (18.51 g), whereas the control (P0) recorded the lowest (17.16 g). The interaction M2P2 (ZnSO₄ @ 100 ppm × GA₃ @ 150 ppm) reported the highest seed yield (20.94 g), while M0P0 had the lowest (12.97 g). The observed yield improvement may be linked to increased photosynthetic efficiency, branching, pod number, and seeds per pod. The synergistic effect of micronutrients and PGRs promoted overall growth and reproductive development, culminating in greater productivity. Similar study was also observed by Srikant (2003) who reported the significantly highest seed yield per plant (7.33 g) with GA3 at 40 ppm in cluster bean and Priyanka *et al.* (2023) reported in cowpea.

**Seed yield per plot and seed yield per hectare**

The highest seed yield per plot (456.07 g) and seed yield per hectare (12.15 q/ha) was recorded with ZnSO₄ at 100 ppm (M2) while the lowest yield were observed in the control treatment (M0). Among PGRs, maximum seed yield per plot (466.47 g) and seed yield per hectare 12.43 q/ha was recorded with GA₃ at 150 ppm (P2). Interaction among different micronutrients and PGRs recorded the maximum seed yield per plot (545.67 g) and per hectare (14.54 q/ha) under (M2P2), demonstrating a significant synergistic interaction while the control (M0P0) had the lowest yield. This increase in yield may be attributed to enhancements in vegetative growth, reproductive development, and nutrient use efficiency, driven by both zinc and gibberellic acid. These findings are consistent with the reports of Noor *et al.* (2017), Nazeer *et al.* (2020) and Mavdiya *et al.* (2023) in cowpea.

### ****Effect on harvest index****

The harvest index (HI), representing the ratio of economic yield to total biological yield was significantly influenced by the application of micronutrients and plant growth regulators (PGRs). Under foliar application of ZnSO₄ at 100 ppm (M2) recorded the highest harvest index (34.65), significantly better over the control (M0), which showed the lowest value (30.33). Similarly, the application of GA₃ at 150 ppm (P2) significantly enhanced the harvest index (34.98) as compared to the control (P0). The interaction among micronutrients and PGRs treatments showed significant effect on harvest index. The combination of ZnSO₄ @ 100 ppm and GA₃ @ 150 ppm (M2P2) recorded the maximum harvest index (37.16), indicating a synergistic effect. This enhancement can be attributed to zinc’s vital role in improving photosynthetic efficiency, nutrient absorption, and overall plant vigor, contributing to higher reproductive output relative to total biomass. GA₃ enhances vegetative and reproductive growth by promoting cell elongation, seed development, and fruit set, thus improving harvest efficiency. Similar findings reported that foliar application of Fe and Zn fertilizer to cowpea plants increased the yield component (Ali *et al*., 2014 and Mona and Azab, 2016)

**Conclusion**

Micronutrients such as zinc and iron are essential for achieving optimal plant growth and productivity, particularly in the context of increasing deficiencies attributed to intensive modern agricultural practices. These elements play vital roles in enzymatic functions, chlorophyll synthesis and maintenance, and biological nitrogen fixation, highlighting their critical importance in plant metabolism. The present study demonstrated that foliar application of these micronutrients effectively alleviated nutrient deficiencies, leading to notable enhancements in growth parameters and yield-related traits. Among the various treatments, the foliar application of zinc at 100 ppm in combination with gibberellic acid (GA₃) at 150 ppm, administered at 35 and 60 days after sowing, was found to be the most effective. This treatment resulted in the highest seed yield, improved net economic returns, and the most favorable benefit-cost ratio, thereby indicating its strong potential for improving both agronomic performance and economic viability in cowpea seed production systems.

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1.

2.

3.

**Option 1**

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