**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.), an important leguminous crop belongs to the Fabaceae or leguminoceae family is well-known for its remarkable adaptability to diverse agro-climatic conditions, particularly in humid tropical and subtropical regions. It is predominantly cultivated during the summer and rainy seasons. Cowpea holds substantial socio-economic importance and is referred to 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 (Gupta *et al.,* 2017). India ranks second in global vegetable production, accounting for 15.6% of the global area and 14.4% of total vegetable production, with an output of 187.47 million tons (Anonymous, 2017). Globally, cowpea production stands at approximately 4.5 million metric tons annually (Diouf, 2014). Often termed the "poor man's meat," cowpea is highly esteemed for its rich nutritional profile, particularly its protein content. Mature seeds contain 24.8% protein, 63.6% carbohydrates, 1.9% fat, and 6.3% fiber, along with vital vitamins such as thiamine, riboflavin, and niacin (Shaw, 2007). Its inherent resilience to drought and marginal soils is further enhanced by its symbiotic association with Rhizobium bacteria, enabling biological nitrogen fixation that contributes approximately 150 kg of nitrogen per hectare, thereby improving soil fertility and supporting sustainable agricultural systems (Chattopadhyay *et al.,* 2007).

The role of plant nutrients, particularly micronutrients is critical for improving cowpea seed yield and quality. A major constraint in productivity is the limited availability of essential nutrients (Siddiqui *et al.,* 2015). Foliar application of micronutrients has been shown to be highly efficient, ensuring up to 90% nutrient utilization (Manasa and Devaranavadagi, 2015). Among these, zinc and iron are in-dispensable, zinc facilitates photosynthesis, nitrogen metabolism, and growth hormone synthesis, whereas iron is essential for chlorophyll formation and biological nitrogen fixation. Deficiencies in these elements can significantly limit crop yield. Therefore, the application of zinc and iron fertilizers serves as a sustainable means to enhance cowpea growth, yield, and nutritional value (Divyashree *et al.,* 2018).

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) is particularly effective in promoting stem elongation, seed germination, and fruit development, especially when applied as a foliar spray (Dijkstra and Kuiper, 1989; Asghar *et al.,* 1997). Similarly, Naphthalene Acetic Acid (NAA) enhances plant height, leaf number, and seed yield by improving photosynthesis, respiration, and assimilates mobilization (Cho and Prinyawiwathul, 2008). Both GA₃ and NAA are thus valuable tools in enhancing crop productivity (Khan *et al.,* 2002; Singh *et al.,* 2015).

The primary objective of the present study was to evaluate the impact of micronutrients and plant growth regulators on the growth parameters and quality seed yield of cowpea [*Vigna unguiculata* (L.) Walp.].

**Materials and Methods**

A field experiment was undertaken 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 well-drained sandy loam soil with a neutral pH of 7.6. The cultivar Kashi Nidhi was used for this study. Agronomic practices are followed as per the package of practices. The experiment employed the cowpea variety ‘Kashi Nidhi,’ which was sown in the third week of March 2024 using a factorial randomized block design (RBD) with three replications Each treatment plot measured 1.5 × 2.5 m with a inter row and intra row spacing of 50 cm × 30 cm. The study consisted of 25 treatment combinations involving 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). 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, flowering, yield and yield attributing parameters. During the experimentation regular irrigation, weeding, hoeing, plant protection measures etc. were employed as per need basis of crops. 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 application of micronutrients and plant growth regulators (PGRs) had a significant effect on the plant height of cowpea. 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 Singh *et al.,* (2013) in other crops and Ramesh and Kumar (2018) in cowpea.

In case of PGRs, gibberellic acid (GA₃) at 150 ppm (P2) produced 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 observations have been made by Singh *et al.,* (2015) in garden pea, Sharma *et al.,* (2024), and Emongor (2007) in cowpea.

Significant interaction effects between micronutrient and PGR 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. The lowest 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 Singh and Singh (2012) in cowpea.

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

Micronutrient application also exhibited a significant influence on the number of branches per plant. The highest number of branches (5.24) was recorded with 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 trends have been reported by Ismail and Elnour (2016) 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. These findings are in agreement with those reported by Noor *et al.,* (2017) in French bean.

The interaction effect of micronutrients and PGRs further emphasized the synergistic relationship between the two. 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). 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 key phenological traits in cowpea, including days to first flowering, 50% flowering, and first pod picking. 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, among the PGR treatments, 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). Gibberellic acid 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 between micronutrient and PGR treatments exhibited pronounced effects. The combined application of ZnSO₄ at 100 ppm with GA₃ at 150 ppm (M2P2) resulted in the earliest phenological development, with the minimum 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.,* (2013) in cowpea, who also reported enhanced reproductive efficiency under the influence of zinc and gibberellic acid.

**Table 1. Effect of different level of micronutrients and PGRs on plant heights (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/ plants.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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** | | | | | |

**Table 12. Effect of different level of micronutrients and PGRs on 100 seed weight (g)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Control**  **(P0)** | **GA3@100 ppm**  **(P1)** | **GA3@150 ppm**  **(P2)** | **NAA@50 ppm**  **(P3)** | **NAA@75 ppm**  **(P4)** | **Mean** |
| **Control M0** | 12.70 | 13.77 | 13.83 | 12.97 | 12.83 | **13.22** |
| **Zn@75 ppm (M1)** | 13.73 | 13.90 | 16.13 | 13.77 | 13.97 | **14.30** |
| **Zn@100ppm (M2)** | 13.80 | 15.70 | 17.77 | 14.23 | 15.93 | **15.49** |
| **Fe@100ppm (M3)** | 13.83 | 13.67 | 13.93 | 13.87 | 14.90 | **14.04** |
| **Fe@125 ppm (M4)** | 14.02 | 13.73 | 16.03 | 14.77 | 14.67 | **14.64** |
| **MEAN** | **13.62** | **14.15** | **15.54** | **13.92** | **14.46** |  |
|  | **M** | **P** | **M×P** |  |  |  |
| **CD at 5%** | **0.67** | **0.67** | **1.50** |  |  |  |
| **CV (%)** | **6.38** | | | | | |

**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. Similarly, 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), closely 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 Pandey *et al.,* (2004) in garden pea and by Ismail and Elnour (2016) in cowpea.

**Pod length**

Pod length was significantly influenced by both micronutrients and PGRs. The 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). GA₃ at 150 ppm (P2) significantly improved pod length (31.47 cm) over the control (23.17 cm). A significant interaction was observed between micronutrients and PGRs, with the combination M2P2 (ZnSO₄ @ 100 ppm × GA₃ @ 150 ppm) producing the longest pods (35.28 cm), statistically at par with M4P2 (FeSO₄ @ 125 ppm × GA₃ @ 150 ppm). Zinc is known to enhance auxin production, cell elongation, nutrient uptake, and enzyme activity, which directly contribute to the elongation of pods. GA₃ also promotes cell division and elongation, thereby increasing pod size. The shortest pods (21.88 cm) were observed in the untreated 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 seed count (9.43), which was statistically at par with FeSO₄ at 125 ppm (M4) with 9.00 seeds. The control (M0) exhibited the lowest seed number (8.30). PGR application with GA₃ at 150 ppm (P2) showed a significant increase in seed count (11.06), while the control (P0) produced the least (7.28). The interaction effect was significant, with M2P2 recording the maximum number of seeds per pod (11.80), followed by M4P2 (11.50). The lowest number of seeds (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), Singh and Prasad (2014), and Nazeer *et al.,* (2020) in legumes.

**Seed yield per plant**

Both micronutrient and PGR applications significantly impacted seed yield per plant. ZnSO₄ at 100 ppm (M2) produced the highest yield (17.93 g), significantly exceeding 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) yielded 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.

**Seed yield per plot and per hectare**

ZnSO₄ at 100 ppm (M2) resulted in the highest seed yield per plot (456.07 g) and per hectare (12.15 q/ha). The lowest yields were observed in the control treatment (M0). Among PGRs, GA₃ at 150 ppm (P2) also significantly improved yields, recording 466.47 g per plot and 12.43 q/ha. The combination treatment M2P2 recorded the maximum seed yield per plot (545.67 g) and per hectare (14.54 q/ha), demonstrating a significant synergistic interaction. The control (M0P0) had the lowest yield in both metrics. 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 Singh *et al.,* (2018) in garden pea, Mavdiya *et al.,* (2023), Noor *et al.,* (2017), Nazeer *et al.,* (2020), Singh and Singh (2013), and Kumar *et al.,* (2015) 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). Among the treatments, ZnSO₄ at 100 ppm (M2) recorded the highest harvest index (34.65), significantly superior to the control (M0), which showed the lowest value (30.33). Likewise, the application of GA₃ at 150 ppm (P2) significantly enhanced the harvest index (34.98) compared to the untreated control (P0).

The interaction between micronutrient and PGR treatments was significant. 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. These findings are supported by the results of Singh and Yadav (2018) in cowpea and Noor *et al.,* (2017), who reported similar trends in legumes.

### ****Effect on 100-seed weight****

A significant variation in 100-seed weight was observed under the influence of different micronutrients and PGRs. Among the micronutrients, ZnSO₄ @ 100 ppm (M2) yielded the highest 100-seed weight (15.49 g), while the lowest weight (13.22 g) was recorded in the control (M0). Similarly, GA₃ @ 150 ppm (P2) recorded the highest 100-seed weight (15.54 g), markedly superior to the untreated control (P0).

Although the interaction effect between micronutrients and PGRs was statistically non-significant, the treatment combination M2P2 (ZnSO₄ @ 100 ppm × GA₃ @ 150 ppm) resulted in the highest observed 100-seed weight (17.77 g). This improvement can be ascribed to the role of zinc in enhancing seed filling and quality through improved enzymatic function, pollen viability, and nutrient mobilization. Additionally, gibberellic acid enhances enzyme activity, particularly the synthesis of hydrolytic enzymes like amylases, which facilitate starch breakdown into simple sugars, thereby contributing to better seed development and increased weight. These results align with the findings of Gopalakrishnan *et al.,* (2020) in legumes and Sharma *et al.,* (2014) in cowpea.

**Conclusion**

Based on the findings, it can be concluded that the integrated application of micronutrients and plant growth regulators (PGRs) had a significant influence on the vegetative growth and yield-contributing traits associated with cowpea seed production. The foliar application of micronutrients at the rate of Zn@100ppm, in combination with GA3@150 ppm applied at 35 and 60 days after sowing, proved to be the most effective treatment. This combination resulted in the highest seed yield, enhanced net returns, and a superior benefit-cost ratio, thereby demonstrating its potential for maximizing economic and agronomic efficiency in cowpea seed production.

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