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ASSESSMENT OF ROLE OF PLANT GROWTH PROMOTERS AND NEW HERBICIDE FORMULATION ON THE PERFORMANCE OF *KHARIF* HYBRID MAIZE (*ZEA MAYS* L.)

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ABSTRACT

An agronomical experiment was conducted at Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, (U.P.) - 208002 India during two consecutive *kharif* seasons 2022 and 2023. The experiment was laid out in split plot design with three replications. Three plant growth promoters [*viz.* Gibberellic acid (P_1), Cytokinin + Enzymes (P_2) and Amino acid + Humic acid + Sea weed extract (P_3)] were allocated in main plots; whereas six herbicidal treatments [*viz.* Weedy check (W_1), Tembotrione 42%SC @ 120g a.i./ha (W_2), Halosulfuron methyl 75% WG @ 72g a.i./ha (W_3), Topramezone 33.6 SC @ 25.2g a.i./ha (W_4), Atrazine 50%WP @ 1kg a.i./ha (W_5) and Mesotrione 2.27%W + Atrazine 22.7%SC @ 750 ml a.i./ha (W_6)] were setup in sub plots. Pooled data of two years experimental results showed that, significantly maximum plant height (208.22cm), dry weight (306.85g), grain yield (6835.95 kg ha^{-1}), harvest index (34.26), nitrogen content in grain (1.65%) and protein content in grain (10.31%) along with higher net return (103362□ ha^{-1}) and B:C ratio (3.14) was recorded under the application of Amino acid + Humic acid + Sea weed extract (P_3). While, among herbicidal treatments, Tembotrione 42%SC @ 120g a.i./ha was recorded significantly maximum weed control efficiency (85.92% at 90 DAS) plant height (216.59cm), dry weight (317.78g) leaf area index (1281, 4778 and 5226) at 30, 60 and 90 DAS, respectively, grain yield (7600.45 kg ha^{-1}), harvest index (35.27), nitrogen content in grain (1.75%) and protein content in grain (10.95%). This treatment was also recorded maximum gross return (167803 □ ha^{-1}), net return (118518) and B:C ratio (3.40) in *kharif* maize.

Keywords: Growth, plant growth promoters, herbicide, maize and yield.

Introduction

Maize (*Zea mays* L.) is the veritably most important cereal crop in the world, due to high yield potential its known as the "Queen of Cereals". It ranks third among cereals worldwide, following rice and wheat. Globally, 2022-23 around 200.53 million hectares area is under maize along with 1157.53 million tonnes production and 5772.3 kg ha^{-1} productivity. In India around 10.74 million hectares area is under maize along with 38.09 million tonnes production and 3546.5 kg ha^{-1} productivity in 2022-23 (USDA, 2024). Maize is used as a chief for human food, livestock and fish feed, turmoil, and numerous artificial purposes. The turmoil of Maize beans and sweeteners has made it an important feedstock for ethanol (ethyl alcohol), which is being used as a bio-fuel. Maize grains have about 10 % proteins, 4 % oil, 70 % carbohydrates, 2.3 % crude fibre, 10.4 % albuminoids, and1.4 % ash. Maize grain has significant quantities of Vitamin A, nicotinic acid, phosphorous, Riboflavin and vitamin E. The Maize crop has furnished huge amounts of green fodder for cattle. This crop is extensively grown across a range of agro-ecological zones due to its rigidity. It is a rich source of raw material for industry for the preparation of by-products like corn starch, corn oil, dextrose, corn syrup, corn flakes, cosmetics, wax, alcohol and tanning material for leather industry (Khan *et al.* 2008).

Plant Growth Promoters enhance nutrient uptake, especially nitrogen, phosphorus, and potassium, essential for maize growth. They also improve stress tolerance, helping maize withstand drought, salinity, and extreme temperatures. Furthermore, they stimulate root development and promote soil health, boosting nutrient availability and maize productivity (Iqbal *et al.* 2023). In plants, cytokinin have a role in the transport of amino acids as well as cell division, cell growth, and senescence. In recent years, the use of plant growth promoters in sustainable agriculture has been growing so; using the plant growth promoters to promote plant growth has recently acquired expanding attention worldwide (Ertani *et al.* 2013). Overall, the use of PGPs in maize cultivation represents a promising approach to boost productivity, improve resilience, and promote sustainable agricultural practices in maize production systems.

A wide-spaced crop has high weed infestation as a result of its initial slow development, especially during the *Kharif* season. The soil loses 30–40% of the provided nutrients due to weed growth. Because weeds consume a sizable percentage of the fertilizer applied to the soil, they hinder the efficiency with which crops plants use fertilizer. However, the growth and productivity of maize are often hindered by weed infestations, leading to substantial yield losses if left uncontrolled. Herbicides play a significant role because manual weeding is more expensive and requires labour that is not always available in sufficient quantities and at the right times (Clay *et al.* 2021). Herbicides used pre- and post-emergence in sequence with temporal variation may aid in preventing the problem of weeds at all phases of growth. Through careful selection and application, herbicides can significantly suppress weed growth while minimizing adverse effects on maize plants. However, it is essential to consider factors such as herbicide resistance, environmental impact, and application techniques to ensure sustainable weed control practices (Schutte *et al.,* 2017).

Materials and Methods

The field experiment was carried out during *kharif* seasons of 2022 and 2023 at Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, (U.P.) - 208002 India, which is situated 26.4148^0 North latitude, 80.2321^0 East longitude and at the 125.9 meters above sea level in the alluvial tract of Indo - Gangetic Plain zone of central part of Uttar Pradesh. The irrigation facilities are sufficiently available on this farm. The experiment was laid out in Split Plot Design and allocated plant growth promoters in main plots and herbicides in sub plots with eighteen treatment combinations were replicated three times. The experimental setup included three plant growth promoters *viz,* Gibberellic acid (P_1), Cytokinin + Enzymes (P_2) and Amino acid + Humic acid + Sea weed extract (P_3) along with six herbicides *viz,* Weedy check (W_1), Tembotrione 42%SC @ 120g a.i./ha (W_2), Halosulfuron methyl 75% WG @ 72g a.i./ha (W_3), Topramezone 33.6 SC @ 25.2g a.i./ha (W_4), Atrazine 50%WP @ 1kg a.i./ha (W_5) and Mesotrione 2.27%W + Atrazine 22.7%SC @ 750 ml a.i./ha (W_6). The seeds of maize variety DKC-9144 was sown 5 cm depth @ 25 kg ha^{-1} at 50 cm × 20 cm spacing by seed drill. The crop was sown on 7th July during 2022 and 17th July during 2023. The mean weekly maximum and minimum temperature during the crop growth period ranged from 29.3 °C to 37.7°C and 16.0°C to 28.5 °C, during 2022 and 31.4 °C to 35.6°C and 14.5°C to 28.9 °C during 2023, respectively. The crop availed maximum relative humidity 94%, 93% against minimum 42% and 37% during 2022 and 2023, respectively. Total rainfall of 984.90 mm and 424.4 mm was received during crop period 2022 and 2023, respectively. During the crop growing period, the mean weekly highest and lowest total rainfall recorded ranging from 0.0 mm to 159 mm and 0.0 mm to 128 mm and evaporation ranged from 2.60 to 7.94 mm day^{-1} and 2.01 to 4.86 mm day^{-1} during 2022 and 2023, respectively. Soil of the experimental field was silty loam in texture having 0.37 and 0.34% organic carbon, 179.5 and 152.20 kg ha^{-1} available N, 12.5 and 13 kg ha^{-1} available P_2O_5, 142.0 and 139.0 kg ha^{-1} available K_2O and soil pH 7.7 and 7.7 in 2022 and 2023, respectively. The crop was harvested at the fully ripe stage on October 25th in 2022 and November 2nd in 2023. The plant height of these selected plants was measured with the help of meter scale from ground level to the tip of the newly emerged leaf before tasseling while after tasseling it was measured from ground level up to the ligule of the upper most fully opened leaf. Average plant height was worked out in cm. For dry weight the samples were dried in sun for few days and then in electric oven for constant drying at 65 ^{0}C temperature for 24-48 hours. After drying weight of this sample was done on physical balance and figures obtained were used for computing dry weight per plant.

Leaf area index was computed taking into account, the area occupied by each plant as per the following formula (Watson, 1952).

$$\text{LAI} = \frac{\text{Total leaf area of plant}}{\text{Ground area}}$$

After emergence of first tassel bearing plant, periodic counts on the number of plants bearing tassel were made. The date by which 50 percent of the plants bear tassel was recorded as date of 50 percent tasseling.

Harvest index was calculated by the formula (Donald and Hamblin, 1976).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

where,

Economic yield = seed yield (kg ha^{-1})

Biological yield = seed yield + straw yield (kg ha^{-1})

Nitrogen content was estimated by Bremner and Mulvaney (1982) suggested Modified kjeldhal method.

Protein content was determined from this nitrogen content utilizing the formula below:

Protein content = Nitrogen content (%) x 6.25

Weed control efficiency (WCE) is usually determined by calculating weed dry biomass recorded from each treatment by utilizing the formula.

$$\text{W.C.E.}(\%) = \frac{W_0 - W_t}{W_0} \times 100$$

where,

W_0 = weed dry weight of weedy check plot (g m^{-2})

W_t = weed dry weight of treated plot (g m^{-2})

Gross return = Total income from grain and straw yields.

Net return was calculated by subtracting the cost of cultivation from the gross return of the individual treatment combination.

Net return = Gross return - Cost of cultivation

Benefit: Cost ratio (B: C) was calculated using the formula as given

$$\text{Benefit Cost Ratio (B : C)} = \frac{\text{Gross Return}\left(\text{ha}^{-1}\right)}{\text{Cost of Cultivation}\left(\text{ha}^{-1}\right)}$$

Recorded data was analyzed using appropriate method of 'Analysis of Variance (ANOVA)' given by Gomez and Gomez (1984). Pooled analysis data of two consecutive *kharif* seasons 2022 and 2023 has been given in table.1,2 and 3.

Results and Discussion

Effect of plant growth promoters on growth characters of *kharif* maize

The pooled data results from Table. 1 clearly demonstrate the significant impact of various plant growth promoters and herbicides on the growth characteristics of the maize plant. Application of various plant growth promoters, Amino acid + Humic acid + Sea weed extract was recorded maximum plant height (208.22cm), dry weight (306.85g) at harvest stage and leaf area index (1.27, 4.58 and 5.06) at 30, 60 and 90 DAS, respectively, however, early days to 50% tesseling (60.95days) recorded under Gibberellic acid treatment. Amino acids facilitate nutrient uptake by acting as chelators, making nutrients more accessible to plants. Humic acid increases microbial activity, which helps break down organic matter and releases essential nutrients for plant uptake. They also help reduce transpiration and improve stomatal conductance, ultimately promoting increased plant growth. These findings earlier reported by Wang *et al.* (2021), Salah *et al.* (2019) and Muthukumar *et al.* (2005).

In herbicidal treatments, the application of Tembotrione 42%SC @ 120g a.i./ha in *kharif* maize was recorded significantly maximum plant height 216.59cm, dry weight 317.78g at harvest stage, leaf area index 4.78 and 5.23 at 60 and 90 DAS, respectively, and early days to 50% tesseling (57.98days) recorded under weedy check treatment. Tembotrione, a selective post-emergence herbicide, targets broadleaf weeds (*Trianthema portulacastrum* L., *Digera muricata* L., *Commelina benghalensis* L., *Cucumis melo* L., *Phyllanthus niruri* L. and *Convolvulus arvensis* L.) and grassy weeds (*Echinochloa colona* L., *Digitaria sanguinalis* L., *Dactyloctenium aegyptium* L. and *Eleusine indica* L.) which compete with maize for essential nutrients, water, and sunlight. This reduction in crop-weed competition creates more favourable conditions for crop growth, leading to an increased growth character. Similar result has been also reported by Sachan *et al.* (2024) and Sandeep *et al.* (2018).

Effect of treatments on yield of *kharif* maize

The application of various plant growth promoters in *kharif* maize, Amino acid + Humic acid + Sea weed extract recorded highest grain yield 5.28%, stover yield 3.94% and harvest index 0.91% compared to Gibberellic acid (Table. 2). The yield of a crop depends on the harmonious interaction between environmental conditions, such as temperature and rainfall, and the plant's internal metabolic processes, including nutrient assimilation and photosynthesis. Plant growth promoters enhance the source-sink relationship and the translocation of photo assimilates, improving plant's photosynthetic ability, which significantly improved in growth and yield attributing characters were ultimately reflected in higher yield. Similar result had been also reported by Aalipour *et al.* (2023) and Eryigit, and Husamalddin (2023).

Among herbicidal treatments, the application of Tembotrione 42%SC @ 120g a.i./ha recorded increment in grain yield which varied to the tune of 86.96%, stover yield 53.34% and harvest index 14.14% compared to Weedy check. However, application of Mesotrione 2.27%W + Atrazine 22.7%SC @ 750 ml a.i./ha was also enhanced to the tune of 84.08, 52.64 and 13.33% grain yield, stover yield and harvest index, respectively, Topramezone 33.6 SC @ 25.2g a.i./ha 82.34, 51.72 and 13.07% grain yield, stover yield and harvest index, respectively, and Atrazine 50%WP @ 1kg a.i./ha 80.63, 51.03 and 12.69% grain yield, stover yield and harvest index, respectively, over Weedy check treatments and found at par with Tembotrione 42%SC @ 120g a.i./ha. Applied Tembotrione during the early post-emergence stage, when weeds are actively growing but not yet established, maximizes its effectiveness by reducing competition for nutrients, water, and light, promoting stronger maize growth and improving overall crop health and yield potential. This strategy helps in minimizing competition and maximizing the maize crop yield potential. Similar findings were also reported by Sahoo *et al.* (2024) and Kaur *et al.* (2018).

Effect of treatments on weed control efficiency

The pooled data revealed that plant growth promoters did not significantly enhance weed control efficiency.

Tembotrione 42% SC @120 g a.i./ha recorded significantly higher weed control efficiency 85.92% at 90 DAS. However, Halosulfuron methyl 75% WG @ 72 g a.i./ha achieved only 28.94% weed control efficiency at 90 DAS (Table. 2). The application of Tembotrione 42% SC @120 g a.i./ha has proven effective in managed weed populations, significantly reducing their density and biomass, resulted in ultimate increased weed control efficiency. Similar findings were also supported by Janaki *et al.* (2024) and Jaysawal *et al*. (2018).

Effect of treatments on quality parameters of *kharif* maize

Among plant growth promoters, Amino acid + Humic acid + Sea weed extract was evaluated maximum nitrogen content in grain (1.65%) and protein content in grain (10.31%) as compared to Gibberellic acid (Table.3). Amino acids enhance protein synthesis and improve stress resistance. Application of amino acid-based PGRs enhanced crop growth, leading to better nitrogen utilization and increased protein content in grains. Equivalent outcomes were also noted by Abdel-Ati *et al.* (2023) and Jadhav *et al.* (2020).

Application of various herbicide in *kharif* maize, Tembotrione 42%SC @ 120g a.i./ha was recorded maximum nitrogen content in grain (1.75%) and protein content in grain (10.95%) while minimum nitrogen content in grain (1.34%) and protein content in grain (8.38%) were recorded under Weedy check treatment in *kharif* maize. The role of nitrogen, being a crucial component of enzymes, proteins, and chlorophyll, is vital in supporting various biochemical pathways involved in carbohydrate, protein, and fat metabolism within the plant system. These conclusions have been supported by Aslam *et al.* (2024) and Kumawat *et al.* (2021).

Effect of treatments on economics of *kharif* maize

Application of various plant growth promoters, the combination of Amino Acid + Humic Acid + Sea weed extract were recorded significantly maximum gross return (151356 ha^{-1}), net return (103362 ha^{-1}) and B:C ratio (3.14) compared to Gibberellic acid and the increment recorded upto gross return (5.09%), net return (8.18%) and B:C ratio (6.08%). The gross return, net return, and benefit-cost ratio were higher due to the increased grain yield of the *kharif* maize crop (Table.3). Similar findings also reported by Singh *et al.* (2018) and Pal *et al.* (2015).

Among herbicidal treatments, Tembotrione 42%SC @ 120g a.i./ha recorded increment in gross return to the tune of 84.49%, net return 160.17% and B:C ratio 70% as compared to Weedy check treatment in *kharif* maize crop. Similar, the gross return, net return, and benefit-cost ratio were higher due to the increased grain yield through application of Tembotrione 42%SC @ 120g a.i./ha. The effect of herbicide on economics of maize crop has been also described by Jaybhaye *et al.* (2020) and Sundari *et al.* (2019).

The interaction effect of plant growth promoters and herbicides were not showed any significant effect on all parameters of *kharif* maize.

Conclusion

The current study concluded that, the application of Amino acid + Humic acid + Sea weed extract was recorded significantly enhanced growth characters, quality, grain yield (6835.95 kg ha^{-1}), net return and B:C ratio (3.14). Among herbicides, maximum weed control efficiency (85.92% at 90 DAS), growth, quality, grain yield (7600.45 kg ha^{-1}), net return and B:C ratio (3.40) were observed under Tembotrione 42%SC @ 120g a.i./ha treatment in *kharif* maize

Table 1: Effect of treatments on growth parameters of *kharif* maize

Treatments	Plant height at harvest (cm)	Dry weight of plant at harvest (g)	Leaf area index			Days to 50 % tasseling
			30 DAS	60 DAS	90 DAS	
A. Plant Growth Promoters						
Gibberellic acid (P_1)	200.36	291.68	1.22	4.42	4.90	60.95
Cytokinin + Enzymes (P_2)	204.96	298.86	1.25	4.51	5.01	61.68
Amino acid + Humic acid + Sea weed extract (P_3)	208.22	306.85	1.27	4.58	5.06	61.80
SE(d) ±	1.49	3.72	0.02	0.05	0.05	0.26
C.D at 5%	4.24	10.59	NS	NS	NS	NS
B. Herbicide						
Weedy check (W_1)	174.80	266.25	1.24	4.02	4.51	57.98
Tembotrione 42%SC @ 120g a.i./ha (W_2)	216.59	317.78	1.28	4.78	5.23	63.48
Halosulfuron methyl 75% WG @ 72g a.i./ha (W_3)	198.27	288.30	1.25	4.41	4.91	59.49
Topramezone 33.6 SC @ 25.2g a.i./ha (W_4)	212.56	306.73	1.24	4.61	5.10	62.59
Atrazine 50%WP @ 1kg a.i./ha (W_5)	210.32	302.77	1.23	4.52	5.04	62.29
Mesotrione 2.27%W + Atrazine 22.7%SC @ 750 ml a.i./ha (W_6)	214.52	312.95	1.25	4.69	5.16	63.01
SE(d) ±	3.48	7.99	0.03	0.14	0.14	0.75
C.D at 5%	7.14	16.41	NS	0.28	0.28	1.54
Interaction						
A × B						
SE(d) ±	5.07	13.18	0.06	0.22	0.22	1.21
C.D at 5%	NS	NS	NS	NS	NS	NS
B × A						
SE(d) ±	6.03	13.85	0.06	0.24	0.24	1.30
C.D at 5%	NS	NS	NS	NS	NS	NS

Table 2: Effect of treatments on yield and weed control efficiency in *kharif* maize

Treatments	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)	Weed control efficiency at 90 DAS
A. Plant Growth Promoters				
Gibberellic acid (P_1)	6492.88	12501.74	33.95	58.18
Cytokinin + Enzymes (P_2)	6679.87	12727.14	34.20	57.26
Amino acid + Humic acid + Sea weed extract (P_3)	6835.95	12994.66	34.26	58.28
SE(d) ±	58.56	148.58	0.36	1.96
C.D at 5%	166.93	NS	NS	NS
B. Herbicide				
Weedy check (W_1)	4065.14	9102.89	30.90	0.00
Tembotrione 42%SC @ 120g a.i./ha (W_2)	7600.45	13958.57	35.27	85.92
Halosulfuron methyl 75% WG @ 72g a.i./ha (W_3)	6113.37	11931.38	33.86	28.94
Topramezone 33.6 SC @ 25.2g a.i./ha (W_4)	7412.02	13811.42	34.94	78.73
Atrazine 50%WP @ 1kg a.i./ha (W_5)	7343.22	13747.58	34.82	72.01
Mesotrione 2.27%W + Atrazine 22.7%SC @ 750 ml a.i./ha (W_6)	7483.22	13895.24	35.02	81.83
SE(d) ±	127.82	320.25	0.45	1.29
C.D at 5%	262.30	657.20	0.93	2.64
Interaction				
A × B				
SE(d) ±	210.41	527.71	0.80	2.82
C.D at 5%	NS	NS	NS	NS
B × A				
SE(d) ±	221.39	554.69	0.79	2.23
C.D at 5%	NS	NS	NS	NS

Table 3: Effect of treatments on quality parameters and economics of *kharif* maize

Treatments	Nitrogen content in grain (%)	Protein content in grain (%)	Gross Return (ha^{-1})	Net Return (ha^{-1})	B:C Ratio
A. Plant Growth Promoters					
Gibberellic acid (P_1)	1.57	9.81	144017	95548	2.96
Cytokinin + Enzymes (P_2)	1.61	10.07	147623	98155	2.97
Amino acid + Humic acid + Sea weed extract (P_3)	1.65	10.31	151356	103362	3.14
SE(d) ±	0.02	0.10	932	932	0.02
C.D at 5%	0.04	0.27	2657	2657	0.05
B. Herbicide					
Weedy check (W_1)	1.34	8.38	90951	45553	2.00
Tembotrione 42%SC @ 120g a.i./ha (W_2)	1.75	10.95	167803	118518	3.40
Halosulfuron methyl 75% WG @ 72g a.i./ha (W_3)	1.48	9.24	134914	85220	2.71
Topramezone 33.6 SC @ 25.2g a.i./ha (W_4)	1.70	10.60	163544	113988	3.30
Atrazine 50%WP @ 1kg a.i./ha (W_5)	1.68	10.49	162946	114740	3.38
Mesotrione 2.27%W + Atrazine 22.7%SC @ 750 ml a.i./ha (W_6)	1.72	10.72	165834	116111	3.33
SE(d) ±	0.05	0.29	2308	2308	0.05
C.D at 5%	0.10	0.60	4737	4737	0.10
Interaction					
A × B					
SE(d) ±	0.08	0.47	3767	3767	0.08
C.D at 5%	NS	NS	NS	NS	NS
B × A					
SE(d) ±	0.08	0.51	3998	3998	0.08
C.D at 5%	NS	NS	NS	NS	NS

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