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Influence of Different Herbicides on the Growth, Growth Attributes and Yield of Maize (*Zea mays* L.) under Central Plains Zone of Uttar Pradesh

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The field experiment was carried out at Agriculture Research Farm, Integral University, Lucknow, Uttar Pradesh, India during *Kharif*, 2021. The experiment was aimed at studying the effect of herbicides on the growth and yield of maize crop. The experiment was laid down in the Randomized Block Design (RBD) with 12 treatments and was replicated three times. The highest

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plant height was observed in weed free treatment due to weed free environment all over the maize growth period but among the herbicides, treatment(T_8) *Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS showed highest plant height of 115.2 cm, 173.63 cm and 226.29 cm at 40 DAS, 60 DAS and at harvest stage, respectively. The same treatment (T_8) also resulted in the highest number of leaves per plant. The highest cob weight per plant, grain weight per cob, number of seed per cob and test weight of 219.23 g, 144.1 g, 579.23 and 27.43 g, respectively was observed in the same treatment (T_8). The highest grain yield (5199 kg ha^{-1}) was observed in the weed free treatment but among the herbicidal treatment, the treatment T_8 obtained the highest grain yield of 4803 kg ha^{-1} and was at par with the treatment (T_7) *Atrazine* @ 0.5 kg a.i. ha^{-1} *fb* 2,4-D sodium salt @ 0.5 kg a.i. ha^{-1} PoE at 30 DAS bearing grain yield of 4723 kg ha^{-1}. Among the herbicidal treatments, the treatment (T_8) also resulted in the highest biological yield (12042 kg ha^{-1}) and Harvest index (39.89%) which was at par with the treatment *Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *2,4-D sodium salt* @ 0.8 kg a.i. ha^{-1} PoE at 30 DAS (T_7).

Keywords: Harvest index; biological yield, fb (followed by); PE (pre-emergence); PoE (Post emergence); active ingredients (a.i.).

1. INTRODUCTION

"Maize (*Zea mays* L.) stands as a pivotal cereal and versatile crop within the *Poaceae* family. Its significance spans diverse applications, encompassing human dietary needs, animal and poultry feed, and industrial utilization for the production of maize starch, dextrose, maize syrup, and maize flakes" [1]. Thriving in a broad spectrum of soil and climatic conditions, maize exhibits a remarkable capacity to extract more nutrients compared to other crops, including small-grain cereals and grain legumes. The cultivation of maize serves various purposes, including the production of animal and bird feed, both in the form of silage and grains, as well as meeting the dietary requirements of poultry through maize grains. Additionally, it contributes to pig feed by providing grains. Moreover, maize plays a pivotal role in human consumption, presenting itself in various forms such as grains, sweet maize, and grain maize.

Recognized as the "Queen of Cereals" for its prolific yield, maize, or corn, holds the esteemed position of being the third most extensively cultivated crop globally, trailing only wheat and rice. In terms of both area under cultivation and maize production, India secures the third position. Corn crops on a global scale play a vital role in sustaining food production for both human and animal consumption, as highlighted by Erenstein *et al.,* [2]. Maize stands out as a rich source of diverse nutrients, including carbohydrates, proteins, minerals, vitamins, iron, and more, offering notably high energy content at 365 Cal/100g.

Originating from central Mexico, maize has become one of the most extensively cultivated crops globally. Globally, around 1147.7 million metric tonnes of maize is produced from 193.7 million hectare with an average yield of 5.75 tonnes hectare^{-1} in 170 countries (Meena and Nirupma, 2021). "In India, it spans an impressive cultivation area of 9.63 million hectares, yielding an annual production of 25.90 million metric tons, with an average productivity of 2.69 metric tons per hectare. Its cultivation is widespread across diverse habitats throughout the country, with major production hubs situated in Karnataka, Andhra Pradesh, Telangana, Maharashtra, Bihar, Punjab, Rajasthan, and Haryana" as reported by Mallesh *et al*., [3].

Prakash and Venkataramana [4] reported that at present, 47 percent of the maize produced in India finds its primary utilization in the feed industry, with an additional 13 percent dedicated to animal feed. Maize holds a significant role in the starch industry, constituting approximately 14 percent of its consumption. Furthermore, various other industries rely on maize as a key raw material, encompassing starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceuticals, cosmetics, films, textiles, gums, packaging, and paper production, among others. Over the past decade, the direct consumption of maize as food has notably diminished, currently standing at around 13 percent. However, there is an upward trend in utilizing maize for processed food, contributing to approximately 7 percent of the annual maize consumption in the country. The emergence of specialty corns, such as sweet corn, baby corn, and popcorn, represents a recent development where maize cultivation intertwines with rural entrepreneurship and agro-business. Considering these multiple applications, maize stands out as the ideal crop

to support the government's objective of doubling farmer's income.

Crop success is primarily dependent on the weed management strategy's ability to effectively control weeds. Effective yet labor- and money-intensive is cultivation. An alternate approach to weed control is chemical weed control, which may be less expensive but carries more risk due to the possibility of herbicide resistance in weeds and unintended effects on soil microorganisms. It is necessary to create and improve improved weed control techniques, such as integrated cultivation and the use of chemical weed control with updated formulations and herbicide mixes. recently developed herbicide with a novel mode of action that works on both wide and narrow spectrum weeds in maize. In a similar vein, a mixture of herbicides may effectively manage weeds.

The increased need for labour during peak seasons, combined with its limited availability, underscores the necessity of resorting to herbicides as an efficient approach to weed management. Considering that chemical weed management demands less labour, it is advised as a means to overcome this constraint as reported by Sachan et al., [5].

2. MATERIALS AND METHODS

Experimental site: The experiment was carried out at Agriculture Research Farm, Integral University, Lucknow, Uttar Pradesh, India during Kharif, 2021. The city of Nawabs, Lucknow lies in the coordinates 26°51′N 80°57′E. Lucknow has a humid subtropical climate with hot, sunny summers from March to May. The city receives an average of 827.2 millimetres of rainfall from the southwest monsoon winds between June to October. Summers are very hot with temperatures rising to 40-45 °C (104-113 °F) range.

Edaphic condition: Soil samples were collected from different locations of the field at a depth of 0–20 cm before sowing and analysed for physio-chemical characteristics in the Agriculture Laboratory, Faculty of Agriculture, Integral University, Lucknow. The soil in the experimental field was clayey in texture and slightly alkaline with pH of 7.4. Organic carbon in the soil was 0.39% which was estimated by rapid titration method given by Walkley and Black (1934). The available Nitrogen in soil was 143 kg ha^{-1}, which was estimated by the Alkaline permanganate method given by Subbiah and Asija (1956). The available Phosphorus was 15.3 kg ha^{-1} estimated by Olsen's method given by Jackson (1967). The available K was 261.3 kg ha^{-1} which was estimated by the Flame photometer method given by Jackson (1967).

Experimental design and treatment details: The experiment was designed as Randomized block design (RBD) or Randomized Complete Block Design (RCBD) with 12 Treatments replicated thrice. The treatment was allocated randomly in each block. The details of the treatment are as follows: -

List 1. List of the Treatment Details

T_1	*Atrazine* @ 1.0 kg a.i. ha^{-1} PE (Pre-emergence)
T_2	*Pendimethalin* @ 1.0 kg a.i. ha^{-1} PE
T_3	Metribuzin @ 0.35 kg a.i. ha^{-1} PE
T_4	*Atrazine* @ 0.5 kg a.i. ha^{-1} + *Pendimethalin* @ 0.5 kg a.i. ha^{-1} PE
T_5	2,4-D sodium salt @ 0.8 kg a.i. ha^{-1} PoE (Post-emergence) at 30 DAS
T_6	*Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS
T_7	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *2,4-D sodium salt* @ 0.8 kg a.i. ha^{-1} PoE at 30 DAS
T_8	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS
T_9	*Topramezone* @ 0.0252 kg a.i. ha^{-1} PoE at 20 DAS
T_{10}	*Halosulfuron methyl* @ 0.05 kg a.i. ha^{-1} PoE at 20 DAS
T_{11}	Weed free
T_{12}	Weedy check.

Preparation of the experimental field and application of fertilizers: The initial ploughing involved using a Disc harrow drawn by a tractor, and the field was levelled using a tractor-drawn leveller. Subsequently, a seed bed was prepared by ploughing with a rotavator. The field was then manually laid out according to the plan, and *Pioneer 3396* Hybrid seeds were sown at a rate of 25 kg ha^{-1} with a spacing of 60 cm × 20 cm. Prior to the first irrigation, plants were thinned to one plant per hill. The first irrigation was administered within a week after seeding, followed by subsequent irrigations every two weeks throughout the growth season. Urea (46% N) was applied in split doses, while DAP (46% P_2O_5) and MOP (60% K_2O) were uniformly applied as a basal application across all treatments.

Application of chemical herbicides: The chemical herbicides were sprayed as per plan with the help of Knapsack sprayer with the regular flat-fan nozzle. Some herbicides were applied as pre-emergence and some as post-emergence. Pre-emergence (PE) herbicides were applied just day after sowing while post-emergence as per plan.

3. RESULTS AND DISCUSSION

Plant Height (cm) as influenced by weed management treatments: The periodical data on plant height (cm) of maize as influenced by different weed management treatments are presented in Table 1.

Plant height was gradually increased with advancement in crop age up to harvest stage. The rate of increase in plant height was rapid during early vegetative growth stage. The various weed control treatments significantly influenced plant height at all growth stages except stage of 20 DAS where the treatment differences were statistically not significant. The treatment *Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS (T8), were found highly superior over rest of the treatments, which was at par with the treatment *atrazine* followed by *2,4-D* and the lowest plant height was noticed in the preemergence application of *Pendimethalin* @ 1 kg a.i. ha^{-1} (T2) and Weedy check (T12) treatments.

"Significant reduction in plant height was noticed in un-weeded control treatment at all the growth stages of the crop. Decrease in plant height might be due to the fact that weeds suppressed the vegetative growth of plants by the competition between crop and weeds for soil moisture, plant nutrients, solar radiation and space during active growth period" [6-8].

Number of leaves per plant as influenced by different weed management treatments: Number of leaves of maize as influenced by different weed management treatments are presented in Table 2. The various weed control treatments significantly influenced leaves number at all growth stages except at 20 DAS where the treatment differences were statistically not significant. Treatment weed free (T_{11}) recorded maximum number of leaves in 20 DAS up to harvest. From rest of the herbicidal treatments, the treatment (T_8), were found highly superior over rest of the treatments, which was at par with the treatment (T_7). The minimum number of leaves was noticed in pre-emergence application of Pendimethalin (T_2) and Weedy check (T_{12}). Similar results were reported by Shinde et al., [9] and Birendra et al., [10].

Cob weight per plant(g): The data of cob weight per plant (g) is given in Table 3. Among all the weed management practices, maximum cob weight per plant was obtained with Weed free treatment (T_{11}) which was statistically at par with treatment T_8. However Weedy check (T_{12}) plot recorded significantly least cob weight per plant. The similar type of result with chemical and mechanical measures of weed control were also reported by Pandey et al., [11], Walia et al., [6] and Triveni et al., [8].

Grain weight per cob (g): The data of Grain weight per cob (g) is given in Table 3. Research data revealed that grain weight per cob recorded highest in treatment Weed free (T_{11}) and was statistically at par with treatment T_8. Weedy check (T_{12}) plot recorded significantly least grain weight per cob. Similar results were also obtained by Rao et al., [12] and Gantoli et al., [13].

Number of seed per cob: The data of Number of seed per cob is given in Table 3. Research data showed that number of seed per cob recorded maximum in treatment T_{11} followed by T_8. Treatment Weedy check (T_{12}) recorded minimum number of seed per cob. These results confirm with the findings of Pandey et al., [11], Walia et al., [6] and Triveni et al., [8].

Table 1. Plant height (cm) as influenced by different weed management treatments

Treatment		Plant height (cm)				
		20 DAS	40 DAS	60 DAS	80 DAS	At harvest
T_1	*Atrazine* @ 1.0 kg a.i. ha^{-1} PE (Pre-emergence)	28.43	112.67	168.20	184.37	220.34
T_2	*Pendimethalin* @ 1.0 kg a.i. ha^{-1} PE	25.47	93.31	139.20	154.52	197.45
T_3	Metribuzin @ 0.35 kg a.i. ha^{-1} PE	28.17	94.50	151.00	157.23	199.58
T_4	*Atrazine* @ 0.5 kg a.i. ha^{-1} + *Pendimethalin* @ 0.5 kg a.i. ha^{-1} PE	27.63	100.83	150.45	165.39	207.22
T_5	2,4-D *sodium salt* @ 0.8 kg a.i. ha^{-1} PoE (Post-emergence) at 30 DAS	26.47	98.03	147.96	162.97	204.96
T_6	*Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	26.73	101.48	153.47	167.81	211.74
T_7	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *2,4-D sodium salt* @ 0.8 kg a.i. ha^{-1} PoE at 30 DAS	27.13	114.17	170.73	187.89	223.51
T_8	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	**28.33**	**115.20**	**173.63**	**191.08**	**226.29**
T_9	*Topramezone* @ 0.0252 kg a.i. ha^{-1} PoE at 20 DAS	25.93	103.93	155.80	170.61	215.21
T_{10}	*Halosulfuron methyl* @ 0.05 kg a.i. ha^{-1} PoE at 20 DAS	26.10	95.93	144.29	159.83	202.96
T_{11}	Weed free	29.87	117.27	175.44	193.06	228.64
T_{12}	Weedy check.	24.77	82.33	132.47	145.78	169.97
SE (M)±		0.99	2.20	3.08	3.22	2.61
C. D. at 5 %		**NS***	6.46	9.01	9.44	7.66
GM		27.09	102.47	155.22	170.05	208.99

Fig. 1. Influence of treatments on plant height (cm) at 60 days after sowing and at harvest stage during experimental year, 2021

Table 2. Number of leaves per plant as influenced by different weed management treatments

Treatment		Number of leaves per plant				
		20 DAS	40 DAS	60 DAS	80 DAS	At harvest
T_1	*Atrazine* @ 1.0 kg a.i. ha^{-1} PE (Pre-emergence)	7.53	11.20	12.60	13.05	12.85
T_2	*Pendimethalin* @ 1.0 kg a.i. ha^{-1} PE	7.40	9.67	10.07	10.24	10.19
T_3	Metribuzin @ 0.35 kg a.i. ha^{-1} PE	7.05	10.27	11.00	11.31	11.23
T_4	*Atrazine* @ 0.5 kg a.i. ha^{-1} + *Pendimethalin* @ 0.5 kg a.i. ha^{-1} PE	7.47	10.80	12.33	12.57	12.47
T_5	2,4-D sodium salt @ 0.8 kg a.i. ha^{-1} PoE (Post-emergence) at 30 DAS	6.27	10.00	10.40	10.67	10.53
T_6	*Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	7.13	10.40	11.40	11.69	11.59
T_7	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *2,4-D sodium salt* @ 0.8 kg a.i. ha^{-1} PoE at 30 DAS	8.13	11.33	12.93	13.12	13.02
T_8	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	**8.27**	**11.87**	**13.07**	**13.40**	**12.64**
T_9	*Topramezone* @ 0.0252 kg a.i. ha^{-1} PoE at 20 DAS	6.00	10.60	11.93	12.19	12.11
T_{10}	*Halosulfuron methyl* @ 0.05 kg a.i. ha^{-1} PoE at 20 DAS	6.40	10.20	10.67	10.89	10.74
T_{11}	Weed free	8.33	12.47	13.40	13.81	13.63
T_{12}	Weedy check.	5.60	8.87	9.73	9.93	9.09
SE (M)±		0.36	0.62	0.74	0.31	0.27
C. D. at 5 %		**NS***	1.82	2.18	0.91	0.81
GM		7.13	10.64	11.63	11.91	11.67

Table 3. Cob weight per plant(g), Grain weight per cob (g), Number of seed per cob and Test weight (g) as influenced by different weed management treatments

Treatment		Cob weight per plant (g)	Grain weight per cob (g)	Number of seed per cob	Test weight (g)
T_1	*Atrazine* @ 1.0 kg a.i. ha^{-1} PE (Pre-emergence)	214.41	140.47	572.17	27.13
T_2	*Pendimethalin* @ 1.0 kg a.i. ha^{-1} PE	185.71	113.6	547.3	25.89
T_3	Metribuzin @ 0.35 kg a.i. ha^{-1} PE	197.59	131.73	560.18	26.59
T_4	*Atrazine* @ 0.5 kg a.i. ha^{-1} + *Pendimethalin* @ 0.5 kg a.i. ha^{-1} PE	200.5	132.13	561.67	26.97
T_5	2,4-D sodium salt @ 0.8 kg a.i. ha^{-1} PoE (Post-emergence) at 30 DAS	187.67	127.97	544.9	26.19
T_6	*Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	195.06	130.1	555.13	26.34
T_7	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *2,4-D sodium salt* @ 0.8 kg a.i. ha^{-1} PoE at 30 DAS	216.15	141.13	577.33	27.27
T_8	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	**219.23**	**144.1**	**579.23**	**27.43**
T_9	*Topramezone* @ 0.0252 kg a.i. ha^{-1} PoE at 20 DAS	199	130.6	559.08	26.73
T_{10}	*Halosulfuron methyl* @ 0.05 kg a.i. ha^{-1} PoE at 20 DAS	179.28	115.7	552.6	26.07
T_{11}	Weed free	***225.83***	***147.83***	***581.9***	***27.96***
T_{12}	Weedy check.	132.35	78.3	438.27	22.67
SE (M)±		4.01	2.64	6.64	0.29
C. D. at 5 %		11.74	7.72	19.43	0.87
GM		196.06	127.81	552.48	26.44

Table 4. Grain yield (kg ha^{-1}), Biological Yield (kg ha^{-1}), Harvest Index (%) as influenced by different weed management treatments

Treatment		Grain yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
T_1	*Atrazine* @ 1.0 kg a.i. ha^{-1} PE (Pre-emergence)	4596	11684	39.34
T_2	*Pendimethalin* @ 1.0 kg a.i. ha^{-1} PE	3574	10096	35.4
T_3	Metribuzin @ 0.35 kg a.i. ha^{-1} PE	4115	11028	37.31
T_4	*Atrazine* @ 0.5 kg a.i. ha^{-1} + *Pendimethalin* @ 0.5 kg a.i. ha^{-1} PE	4223	11235	37.59
T_5	2,4-D sodium salt @ 0.8 kg a.i. ha^{-1} PoE (Post-emergence) at 30 DAS	3872	10681	36.25
T_6	*Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	3984	10862	36.68
T_7	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *2,4-D sodium salt* @ 0.8 kg a.i. ha^{-1} PoE at 30 DAS	4723	11862	39.81
T_8	*Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS	**4803**	**12042**	**39.89**
T_9	*Topramezone* @ 0.0252 kg a.i. ha^{-1} PoE at 20 DAS	4105	11100	36.98
T_{10}	*Halosulfuron methyl* @ 0.05 kg a.i. ha^{-1} PoE at 20 DAS	3746	10445	35.86
T_{11}	Weed free	5199	12761	40.76
T_{12}	Weedy check.	2345	8110	28.91
SE (M)±		206	487	37.06
C. D. at 5 %		605	1426	--
GM		4107	10992	--

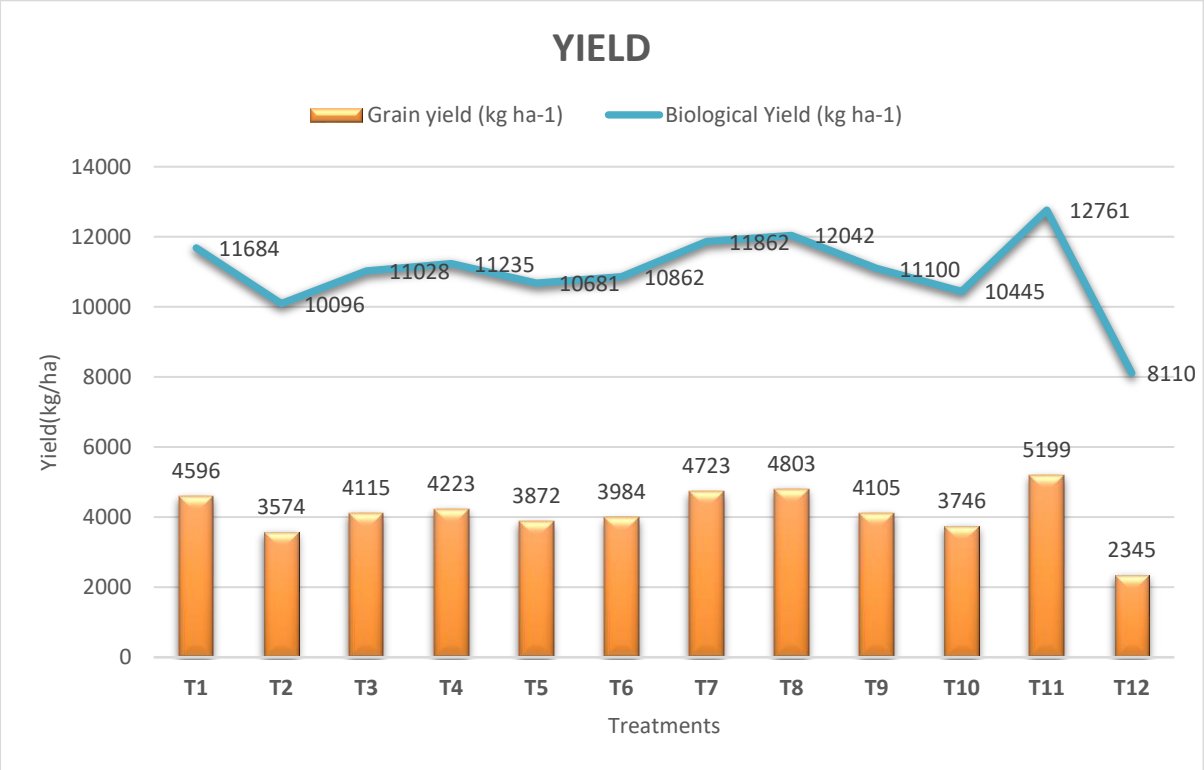

Fig. 2. Yield of maize in the experimental year, 2021

Test weight (g): The data of test weight (g) is given in Table 3. Among the herbicidal treatments the highest test weight (27.43 g) was observed in the treatment $T_{8.}$

Grain yield, Biological Yield and Harvest Index: The data of Grain yield (kg ha^{-1}), Biological Yield (kg ha^{-1}) and Harvest Index (%) is given in Table 4. Among the weed control treatments, sequential application of *Atrazine* @ 0.5 kg a.i.ha^{-1} PE followed by *Tembotrione* @ 0.120 kg a.i. ha^{-1} PoE at 20 DAS (T_8) and *Atrazine* @ 0.5 kg a.i. ha^{-1} PE followed by *2,4-D sodium salt* @ 0.8 kg a.i. ha^{-1} PoE at 30 DAS (T7) the higher grain yield in this treatment could be attributed to improved yield components such as higher cob weight at harvest (g), grain weight per cob, number of seed per cob, and test weight (g). This could be attributed to the effective control of weeds during the germination phase through the pre-emergence application of herbicides. Substantial reduction in later growth stages occurred as late germinating weeds were managed by *Tembotrione* and 2,4-D, leading to a diminished competition with the crop for essential growth factors like light, space, and nutrients. This, in turn, facilitated efficient photosynthetic activity, upon which cob weight, grain weight, test weight, and the number of grains depend. These results confirm with the findings of Kamble *et al.,* [14] and Tesfay *et al.,* [15][16].

4. CONCLUSION

Hence, it is recommended and concluded that farmers in the Central plains zone of Uttar Pradesh consider applying *Atrazine* at a rate of 0.5 kg a.i. ha^{-1} as a pre-emergence herbicide, followed by *Tembotrione* at the rate 0.120 kg a.i. ha^{-1} as a post-emergence herbicide. The utilization of *Atrazine* and *Tembotrione* herbicides has proven to be highly effective in weed control within maize fields, contributing to increased crop yields by mitigating crop-weed competition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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