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Response of chickpea cultivars to post-emergence herbicides: Growth, yield and economic performance

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Abstract
Chickpea (*Cicer arietinum* L.) is a vital pulse crop in India, but its productivity is often limited by weed competition, necessitating effective herbicide use. This study evaluated the response of four chickpea cultivars (NBeG-452, JG-11, Jaki-9218 and KAK-2) to four post-emergence herbicides (Topramezone, Imazethapyr, Sodium Acifluorfen + Clodinafop Propargyl and Fomesafen + Fluazifop-p-butyl) applied at 25 days after sowing during the *rabi* season of 2024-25 at RARS, Lam Farm, Guntur, Andhra Pradesh. Cultivars NBeG-452 and Jaki-9218 exhibited superior growth parameters, including higher plant height (39.5 and 38.2 cm at 45 DAS), drymatter production (1915 and 1865 kg ha^{-1} at 60 DAS) and number of pods per plant (27.0 and 24.6), resulting in higher seed yields (1759 and 1693 kg ha^{-1}) respectively compared to KAK-2 (1349 kg ha^{-1}). Topramezone (15 g ha^{-1}) and Sodium Acifluorfen + Clodinafop Propargyl (122.5 g ha^{-1}) recorded the highest seed yields (1910 and 1823 kg ha^{-1}) with minimal phytotoxicity and higher net returns (Rs 70141 and Rs 67683 ha^{-1}), benefit-cost ratios (2.0 and 1.9). These findings highlight the efficacy of Topramezone and Sodium Acifluorfen + Clodinafop Propargyl with NBeG-452 and Jaki-9218 for optimizing chickpea productivity and economic returns.

Keywords: Chickpea, post-emergence herbicides, cultivar, yield, economics

Introduction

Chickpea cultivation in Andhra Pradesh is predominantly situated in regions characterized by semi-arid climatic conditions. In parts of coastal Andhra Pradesh, the land is often left uncultivated during the *kharif* season and maintained in a relatively weed-free state through timely tillage practices. With the retreat of the southwest monsoon, chickpea is typically planted using the available residual soil moisture, minimizing the need for irrigation inputs (Medida, 2018) [8]. Weed species composition and dominance in these fields differ notably from other chickpea producing zones, influenced by prior land management, climatic variability and soil moisture dynamics. During the first 30-45 days after sowing, chickpea's slow vegetative development, limited ground cover and compact stature make it highly vulnerable to weed infestation, potentially causing yield losses ranging from 24% to 80%, depending on weed pressure and local conditions (Singh *et al.*, 2020 and Kumar *et al.*, 2023) [18]. Conventional weed management strategies, notably pre-emergence herbicides such as Pendimethalin, Oxadiazon and Pyroxasulfone and inter-cultivation are frequently employed, yet both methods exhibit substantial limitations under typical field conditions. Pre-emergence herbicides depend on adequate soil moisture to activate, a requirement often unmet in rainfed and semi-arid regions, leading to suboptimal weed control and increased risk of crop damage, especially in soils with high organic matter or poor structure (Kumar and Sharma, 2022) [6]. These herbicides may also be ineffective against later-emerging weed species and must be applied shortly after sowing often a challenge for smallholder farmers lacking timely access to labour or equipment. Meanwhile, inter-cultivation requires intensive labour, poses physical risks to young seedlings and is sensitive to soil moisture conditions and weather variability. In light of these challenges, the use of post-emergence herbicides has gained attention as a feasible alternative. Herbicides such as imazethapyr (Sethi *et al.*, 2021) [17], topramezone (Nath *et al.*, 2021) [10], Sodium Acifluorfen + Clodinafop Propargyl (Rao and Kumar. 2025) [14] and Fomesafen

+ Fluazifop-p- butyl (Vyshnavi *et al*., 2022) [20] have demonstrated promising results in controlling a wide spectrum of weed species, particularly when applied during the 15-30 DAS period. However, their effectiveness is influenced by application timing, environmental conditions and varietal sensitivity, with concerns related to phytotoxicity and chemical residues in subsequent cropping seasons. This study investigates the growth, yield and economic responses of four chickpea cultivars to various post-emergence herbicides to identify optimal combinations for enhancing productivity and profitability.

Materials and Methods

The experiment was conducted during the *rabi* season of 2024-25 at the Regional Agricultural Research Station, Lam Farm, Guntur, Andhra Pradesh, India (16.36° N, 80.43° E, 33 m above mean sea level). The soil was clay textured, neutral (pH 7.6), low in organic carbon (0.32%), available nitrogen (242 kg ha^{-1}, medium in available phosphorus (28 kg ha^{-1}), and high in available potassium (328 kg ha^{-1}). A split-plot design with three replications was used, with four main plot treatments (chickpea cultivars: M_1: NBeG452, M_2: JG-11, M_3: Jaki-9218, M_4: KAK-2) and five subplot treatments (post-emergence herbicides: S_1: Topramezone @ 15 g ha^{-1}, S_2: Imazethapyr @ 40 g ha^{-1}, S_3: Sodium Acifluorfen + Clodinafop Propargyl @ 122.5 g ha^{-1}, S_4: Fomesafen + Fluazifop-p-butyl @ 40 g ha^{-1}, S_5: Unweeded check), applied at 25 DAS. The field was ploughed twice with a tractor-drawn cultivator, followed by a rotavator for fine tilth, and leveled manually. Chickpea seeds were treated with carbendazim + mancozeb (2.5 g kg^{-1} seed), acephate (1 g kg^{-1} seed), and Trichoderma viride (10 g kg^{-1} seed) and sown on 12 November 2024 at a depth of 4-5 cm with 30 cm row spacing and 10 cm plant spacing. A basal fertilizer dose of 20 kg N and50 kg P_2O_5 ha^{-1} was applied as urea and single super phosphate. One irrigation (20 mm) was provided post-sowing using sprinklers. Root rot was managed with carbendazim + mancozeb drenching, and pod borer was controlled with chlorantraniliprole 18.5% SC (60 mlacre^{-1}). Desi cultivars (NBeG-452, JG-11, Jaki-9218) were harvested on 18 February 2025, and KAK-2 (kabuli) on 12 March 2025 at physiological maturity, followed by sun- drying, threshing and seed weighing.

Results and Discussion

Plant population

Data on plant population at 30, 60DAS and at harvest is presented in Table-1. Plant population at 30, 60 DAS and at harvest were not significantly influenced with chickpea cultivars and post-emergence herbicides. However, slight phytotoxic symptoms were observed in certain herbicide treatments. In particular, the application of Topramezone @ 15 g ha^{-1} (S_1) caused slight early-stage phytotoxicity, which did not affect the final plant population**.** Similarly, Sodium Acifluorfen + ClodinafopPropargyl @ 122.5 g ha^{-1} (S_3) resulted in mild phytotoxicity symptoms such as leaf chlorosis and marginal necrosis, which were temporary and subsided within 14 days of application, with no significant reduction in plant stand. In contrast, Imazethapyr @ 40 g ha^{-1} (S_2) induced more pronounced phytotoxicity, including necrosis of terminal leaves, with slower recovery. No phytotoxic effects were observed with Fomesafen + Fluazifop-p-butyl @ 40 g ha^{-1} (S_4)**,** indicating good crop safety as the dosage is low. These findings highlight that, while initial phytotoxic responses may occur with certain herbicides, final plant population remains unaffected when recovery occurs promptly. The choice of herbicide formulation and dosage plays a crucial role in ensuring crop safety during early vegetative stages.

Table 1: Plant population (No. m^{-2}) in chickpea as influenced by cultivars and post-emergence herbicides

Treatments	30 DAS	60 DAS	At harvest
Chickpea cultivars			
M_1: NBeG-452	32.3	31.5	30.4
M_2: JG-11	30.0	28.0	28.9
M_3: Jaki-9218	32.1	30.7	29.9
M_4: KAK-2	30.0	30.0	29.4
S.Em(±)	0.76	0.90	0.78
CD (P=0.05%)	NS	NS	NS
CV (%)	9.5	11.6	10.2
Post-emergence herbicides			
S_1: Topramezone@15g ha^{-1} at 25 DAS	33.0	31.0	31.2
S_2: Imazethapyr@40 g ha^{-1} at 25 DAS	32.0	30.5	29.3
S_3: Sodium acifluorfen +Clodinafop propargyl@122.5 g ha^{-1} (RM) at 25 DAS	30.6	29.4	31.0
S_4: Fomesafen+Fluazifop-p-butyl @ 40 g ha^{-1} (RM)at 25 DAS	30.4	30.4	29.3
S_5: Un weeded check	29.6	28.9	27.6
S.Em(±)	1.05	0.84	0.93
CD (P=0.05%)	NS	NS	NS
CV (%)	11.7	9.7	11.0
Interaction			
M x S	NS	NS	NS
S x M	NS	NS	NS

Plant height

Plant height recorded at 15, 30, 45, 60 DAS and at harvest were statistically analysed for different chickpea cultivars and post-emergence herbicides. Plant height was gradually increased with advancement in crop age up to harvest. The rate of increase in plant height was maximum up to 60DAS and later it declined. Plant height was significantly influenced by chickpea cultivars and post-emergence herbicides. Experimental data revealed that plant height at 15DAS was significantly influenced with chickpea cultivars but not with post-emergence herbicides as these herbicides were applied at 25 DAS. KAK-2 (M_4) recorded significantly highest plant height (16.1cm) at 15 DAS and it was on par with NBeG-452, (M_1) (15.2 cm) and these two cultivars are superior over Jaki-9218(M_3) (13.8 cm) and significantly lowest plant height was recorded with JG-11(M_2) (12.5 cm). Similar observations were recorded at 30,45,60 DAS and at harvest.

At 30DAS among the post-emergence herbicides significantly higher plant height (29.1cm) was recorded in unweeded check (S_5) due to no phytotoxicity and it was on par with the application of topramezone@15g ha^{-1} (27.0 cm) (S_1), due to slight Phytotoxicity, lowest plant height was recorded with the application of Imazethapyr@40 g ha^{-1} (24.3 cm) (S_2) as the top leaves were having necrosis effect on crop and arrested the plant growth. There is no phytotoxic effect of Fomesafen+Fluazifop-p-butyl@ 40 g ha^{-1}(S_4) as the dosage is low, whereas Sodium Acifluorfen + ClodinafopPropargyl @ 122.5 g ha^{-1} (S_3).at 25 DAS shows phytotoxicity to the crop. These results revealed the importance of selecting crop-safe herbicides and using proper dosages**.** While unweeded check may show taller plants due to absence of herbicide stress. On the other hand, herbicides like Topramezone offer a balance between weed control and crop safety, while Imazethapyr at higher doses may cause significant Phytotoxicity, affecting chickpea growth. There is no significant interaction effect on plant height at 30DAS with chickpea cultivars and post-emergence herbicides.

Plant height at 45DAS was significantly influenced with chickpea cultivars and post-emergence herbicides. At 45DAS (Table 4.13) KAK-2 variety (42.5 cm) (M_4), recorded significantly the highest plant height and it was found to be on par with NBeG-452 variety (39.5cm) (M_1). Significantly the lowest plant height was recorded with JG-11 variety (35.1cm) (M_2).

Among the post-emergence herbicides significantly higher plant height at 45 DAS was recorded with the application of topramezone@15g ha^{-1} (41.6cm)(S_1), which was on par with Sodium Acifluorfen + Clodinafoppropargyl @122.5 g ha^{-1}(S_3) (40.8 cm)and these two treatments recorded higher plant height over Imazethapyr @40 g ha^{-1} (S_2) and Fomesafen+Fluazifop-p-butyal@40 g ha^{-1}(S_4),whereas lowest plant height was recorded in unweeded check (S_5) (35.3cm).The higher plant height at 45 DAS with Topramezone @ 15 g ha^{-1} (41.6 cm) (S_1)comparable to Sodium Acifluorfen + ClodinafopPropargyl @ 122.5 g ha^{-1}, (S_3) (40.8 cm), can be attributed to their effective weed control, which minimized competition for essential resources like light, nutrients and water, promoting optimal chickpea growth. This recovery facilitated enhanced vegetative growth, as evidenced by increased plant height compared to other treatments. These results underscore the role of these post-emergence herbicides in fostering robust crop development by reducing weed interference in chickpea cultivation.

There is no significant interaction effect among the chickpea cultivars and post-emergence herbicides on plant height at 45 DAS. At 60DAS and at harvest similar trend was recorded as in 45 DAS. These findings are in agreement with the earlier reports of Chitale *et al*. (2024) [2] and Sanketh *et al*. (2021) [15].

Table 2: Plant height (cm) at different growth stages of chickpea as influenced by cultivars and post-emergence herbicides

Treatments	Plant height(cm)				
	15 DAS	30 DAS	45 DAS	60 DAS	At harvest
Chickpea cultivars					
M_1: NBeG-452	15.2	27.4	39.5	47.3	51.0
M_2: JG-11	12.5	23.3	35.1	43.6	47.6
M_3: Jaki-9218	13.8	25.6	37.3	44.1	49.4
M_4: KAK-2	16.1	29.7	42.5	48.8	53.5
S.Em(±)	0.35	0.82	1.14	1.03	1.13
CD (P=0.05%)	1.2	2.8	3.9	3.6	3.9
CV (%)	9.3	11.9	11.4	8.7	8.7
Post-emergence herbicides					
S_1: Topramezone@15g ha^{-1} at 25 DAS	14.3	27.0	41.6	51.0	57.4
S_2: Imazethapyr@40 g ha^{-1} at 25 DAS	13.9	24.3	37.8	44.1	52.0
S_3: Sodium acifluorfen +clodinafop propargyl@122.5 g ha^{-1} (RM) at 25 DAS	14.3	26.8	40.8	49.8	54.8
S_4: Fomesafen+Fluazifop-p-butyl@ 40 g ha^{-1} (RM) at 25 DAS	13.8	25.6	37.7	43.6	46.6
S_5: Unweeded check	15.5	29.1	35.3	41.3	41.1
S.Em(±)	0.50	0.81	1.00	1.31	1.35
CD (P=0.05%)	NS	2.3	2.9	3.8	3.9
CV (%)	12.0	10.6	9.0	9.9	9.3
Interaction					
M x S	NS	NS	NS	NS	NS
S x M	NS	NS	NS	NS	NS

Drymatter production (kg ha^{-1})

Drymatter production is a direct measure of vegetative growth and a strong indicator of crop performance. The data recorded at 30**,** 60 DAS and at harvest are presented in Table. Statistical analysis revealed that chickpea cultivars and post-emergence herbicides significantly influenced drymatter production at all stages of observation. At 30 DAS, the cultivar NBeG-452 (M_1) recorded the highest drymatter production (662 kg ha^{-1}), statistically on par with Jaki 9218 (M_3) (623 kg ha^{-1}), while KAK-2 (M_4) recorded the lowest drymatter (606 kg ha^{-1}). Among herbicide treatments, the unweeded check **(S_5)** produced the highest drymatter (664 kg ha^{-1}), followed by Fomesafen + Fluazifop-p-butyl **(S_4)** (633 kg ha^{-1}). The lowest value was observed in Imazethapyr-treated plots (S_2) (582 kg ha^{-1}) attributed to observed phytotoxicity.

At 60 DAS**,** NBeG-452 (M_1) continued to show significantly higher drymatter production (1915 kg ha^{-1}), on par with Jaki 9218 (M_3) (1865 kg ha^{-1}), while KAK-2 (M_4) remained the lowest (1620 kg ha^{-1}). For herbicide treatments, Topramezone @ 15 g ha^{-1} **(S_1)** recorded the highest drymatter production (2219 kg ha^{-1}), followed by Sodium Acifluorfen + Clodinafop-Propargyl@122.5 g ha^{-1}**(S_3)** (2044 kg ha^{-1}). The unweeded check (S_5) (1275 kg ha^{-1}) recorded the lowest drymatter at this stage. At harvest, the same pattern persisted as that observed at 60 DAS.No significant interaction was found between chickpea cultivars and post-emergence herbicide treatments at any stage. The superior drymatter accumulation in NBeG-452(M_1**)** and Jaki 9218(M_2**)** at all stages can be attributed to their vigorous early growth, higher branching ability, larger leaf area and more efficient photosynthetic activity, all of which contribute to better biomass partitioning. Conversely, KAK-2 (M_4**)** produced the lowest drymatter, likely due to reduced Branching ability and limited canopy development during early stages. Among herbicide treatments, the unweeded check (M_4) recorded the highest drymatter at 30 DAS due to absence of herbicide-induced stress. However, this early advantage diminished by 60 DAS and harvest, where weed competition likely suppressed further crop development.

Imazethapyr-treated plots consistently recorded the lowest drymatter, which may be attributed to its phytotoxic effect on chickpea. As an ALS-inhibiting herbicide, Imazethapyr disrupts synthesis of essential branched-chain amino acids, leading to impaired protein synthesis and cellular growth (Patel *et al*., 2024) [11]. Symptoms like necrosis, chlorosis and stunted growth were observed, confirming crop stress and reduced biomass accumulation. In contrast, Topramezone @ 15 g ha^{-1} and Sodium Acifluorfen + Clodinafop-Propargyl@122.5g ha^{-1} promoted high drymatter due to broad-spectrum weed control with minimal crop injury, enhancing crop resource use and growth potential. These findings support the importance of herbicide selectivity, timing of application and compatibility with the crop for maximizing biomass and ensuring sustained growth. Similar results were reported by Patel *et al*. (2024) [11]**,** emphasizing the benefits of early post-emergence herbicide application for drymatter enhancement.

Table 3: Drymatter production (kg ha^{-1}) of chickpea as influenced by cultivars and post-emergence herbicides

Treatments	30DAS	60 DAS	At Harvest
Chickpea cultivars			
M_1: NBeG-452	662	1915	4655
M_2: JG-11	599	1743	4292
M_3: Jaki-9218	623	1865	4525
M_4: KAK-2	606	1620	4226
S.Em(±)	12.8	42.0	86.5
CD (P=0.05%)	44	145	299
CV (%)	8	9	8
Post-emergence herbicides			
S_1: Topramezone@15g ha^{-1} at 25 DAS	632	2219	4925
S_2: Imazethapyr@40 g ha^{-1} at 25 DAS	582	1887	4378
S_3: Sodium Acifluorfen +clodinafop propargyl@122.5 g ha^{-1} (RM) at 25 DAS	602	2044	4636
S_4: Fomesafen+Fluazifop-p-butyl@ 40 g ha^{-1} (RM)at 25 DAS	633	1505	4229
S_5: Un weeded check	664	1275	3954
S.Em(±)	18.9	63.1	149.1
CD (P=0.05%)	54	182	429
CV (%)	11	12	12
Interaction			
M x S	NS	NS	NS
S x M	NS	NS	NS

Phytotoxicity score

The phytotoxicity ratings of various post-emergence herbicides applied to chickpea were recorded at **7** and 14 days after herbicide application (DAA) and are presented in Table-4. The data indicated differential responses among treatments in terms of crop safety. Topramezone @ 15 g ha^{-1} (S_1) exhibited a low phytotoxicity rating of 2 at 7 DAA, which reduced to 1 by 14 DAA, suggesting minimal and transient crop injury. Similarly, Sodium Acifluorfen + ClodinafopPropargyl @ 122.5 g ha^{-1} **(**S_3) showed a slightly higher rating of 3 at 7 DAA, which also decreased to 1 by 14 DAA, indicating moderate initial effects followed by complete recovery. In contrast, Imazethapyr @ 40 g ha^{-1} (S_2) showed relatively higher phytotoxicity symptoms, including visible necrosis and leaf distortion. Meanwhile, Fomesafen + Fluazifop-p-butyl @ 40 g ha^{-1} (S_4) recorded no visible phytotoxic effects, indicating good crop safety. On a standard 0-10 rating scale (0=no phytotoxicity, 10=complete crop destruction), most treatments fell within the safe threshold, though the degree of initial stress varied.

The observed differences in phytotoxicity levels among herbicide treatments are primarily linked to the mode of action and crop selectivity of each active ingredient. The low and declining phytotoxicity ratings in Topramezone confirm the crop's ability to recover rapidly, with only minor symptoms such as transient chlorosis and slight stunting**.** Sodium Acifluorfen + ClodinafopPropargyl, a combination of PPO and ACCase inhibitors, induced slightly higher phytotoxicity initially but was still within acceptable crop safety limits, with symptoms subsiding by 14 DAA. The temporary effects may result from the contact and systemic action of the herbicide on sensitive tissues, which the crop overcame through recovery processes. Imazethapyr**,** however, exhibited the most pronounced phytotoxic effects, which aligns with its known ALS-inhibiting mechanism, disrupting essential amino acid synthesis and affecting early vegetative development. This treatment, although effective in weed suppression, poses higher risks of crop injury in chickpea. The absence of phytotoxicity in Fomesafen + Fluazifop-p-butyl may be attributed to its low application rate and selective activity, ensuring safe integration into chickpea weed management programs.

These findings underscore the need for careful herbicide selection and dosage calibration in chickpea cultivation to avoid growth suppression while ensuring effective weed control. Similar observations were reported by Nath *et al.* (2018) [9] and Manasa *et al.* (2022) [7], who documented crop tolerance patterns consistent with the present study.

Table 4: Phytotoxic score of different herbicide treatments in chickpea as influenced by cultivars and post-emergence herbicides

Treatments	Phytotoxic score	
	7 DAA	14 DAA
Chickpea cultivars		
M_1: NBeG-452	-	-
M_2: JG-11	-	-
M_3: Jaki-9218	-	-
M_4: KAK-2	-	-
Post-emergence herbicides		
S_1: Topramezone@15g ha^{-1} at 25 DAS	2	0
S_2: Imazethapyr@40 g ha^{-1} at 25 DAS	3	1
S_3: Sodium Acifluorfen +clodinafop propargyl@122.5 g ha^{-1} (RM) at 25 DAS	2	1
S_4: Fomesafen+Fluazifop-p-butyl@ 40 g ha^{-1} (RM)at 25 DAS	0	0
S_5: Un weeded check	0	0

SPAD Chlorophyll meter reading

The SPAD chlorophyll meter readings taken at 7 and 14 days after herbicide application (DAS) Table-5 indicate the impact of post-emergence herbicides on chickpea cultivars photosynthetic capacity. At 7 DAA, the lower SPAD value (38.5) across cultivars reflects temporary phytotoxicity, likely due to herbicide induced stress affecting chlorophyll synthesis or leaf tissue integrity. By 14 DAA, the recovery to higher SPAD values (42) in all cultivars suggests effective plant recovery, possibly due to the selective nature of the herbicides allowing chickpeas to resume normal photosynthetic activity. Among the herbicides, Topramezone @ 15 g ha^{-1}(S_1) recorded the highest chlorophyll meter values, followed by Sodium Acifluorfen + ClodinafopPropargyl @ 122.5 g ha^{-1}, (S_3) likely owing to their minimal phytotoxic and phytotoxicity ratings of 2 and 3 at 7 DAA, reducing to 1 at 14 DAA). While Imazethapyr has lower values of SPAD chlorophyll meter values Topramezone's HPPD-inhibiting mechanism and the combined PPO and ACCase inhibition by Sodium Acifluorfen + ClodinafopPropargyl likely caused less disruption to chlorophyll content, supporting better photosynthetic recovery.

Table 5: SPAD chlorophyll meter readings in chickpea as influenced by cultivars and post-emergence herbicides

Treatments	NBeG-452		JG-11		Jaki-9218		KAK-2	
Days after spraying (DAS)	7 DAS	14 DAS	7 DAS	14 DAS	7 DAS	14 DAS	7 DAS	14 DAS
S_1: Topramezone@15 g ha^{-1}	38.5	42.0	39.0	43.0	36.5	41.0	37.0	43.0
S_2: Imazethapyr @ 40 gha^{-1}	35.0	39.5	34.0	41.0	33.0	39.5	32.0	39.0
S_3: Sodium Acifluorfen + ClodinafopPropargyl @122.5 g ha^{-1}	37.8	41.5	37.0	43.0	35.0	41.0	35.0	41.0
S_4: Fomesafen+ Fluazifop - p - butyl @40 g ha^{-1}	34.5	38.0	32.0	38.5	32.0	38.0	33.0	36.0
S_5: Un weeded check	40.0	39.0	39.5	38.8	39.0	38.5	40.0	38.8

Number of Branches

Data pertaining to number of branchesper plant in chickpea presented in Table-6 revealed that the chickpea cultivars and post-emergence herbicides could significantly influence the number of branches, but interaction was non-significant. Significantly the higher number of branches per plant were recorded with NBeG-452 (14.1) (M_1), which was on par with Jaki-9218 (12.3) (M_3) and showed significant effect with JG-11 (11.3) (M_2) and KAK-2 (9.7) (M_4). The higher number of branches per plant in NBeG-452 (M_1) and Jaki-9218 (M_3) due to their superior genetic potential, vigorous early growth and efficient assimilate partitioning towards axillary bud development. These varieties are known for their prolific branching habit, contributing to better canopy structure and productivity. In contrast, KAK-2 (M_4) and JG-11 (M_4) exhibited fewer branches due to their comparatively determinate or less-branching growth habit.

Among the post-emergence herbicides applied at 25 DAS, significantly highest number of branches per plant were recorded with Topramezone15gha^{-1} (16.6) (S_1) followed by the application of Sodium Acifluorfen + ClodinafopPropargyl 122.5 g ha^{-1}(S_3) (14.3) and these two treatments are having more number of branches than Imazethapyr @ 40 g ha^{-1} (S_2) and Fomesafen + Fluazifop-p-butyl (S_4) as these herbicides are having higher values of weed density and dry weight. Significantly lowest number of branches $plant^{-1}$were reported under unweeded check (6.0) (S_5). Significantly higher number of branches $plant^{-1}$ with Topramezone 15 g ha^{-1} (S_1) and Sodium Acifluorfen + ClodinafopPropargyl 122.5 g ha^{-1} (S_3) is due to their effective post-emergence weed control, which reduces crop weed competition for light, nutrients and moisture, thereby promoting better axillary bud development and branching. In contrast, the unweeded check faced intense competition, which suppressed growth and branching due to resource limitation. Similar findings were reported by Chitale *et al.* (2024) [2], who documented improved crop architecture under effective weed management regimes. The interaction effect was found to be non-significant among the chickpea cultivars and post-emergence herbicides.

No. of Pods Plant^{-1}

Data pertaining to number of pods plant^{-1} was presented in Table-6. An examination of the data indicated that different chickpea cultivars and post-emergence herbicides have conspicuous influence on number of pods plant^{-1}. Chickpea variety NBeG-452 (M_1) recorded highest number of pods plant^{-1} (27.0), which was on par with Jaki-9218 (24.6) (M_3) and significantly higher than the number of pods observed with JG-11(M_2) and KAK-2 varieties (14.7) (M_2). More number of pods plant^{-1} in NBeG-452 (M_1) due to higher and profused branches, which have facilitated plants for better utilization of resources such as nutrients, moisture and light. More availability of these natural resources which encouraged the growth and development of the plant expressed in a greater number of pods per plant.

Among the post-emergence herbicides applied at 25DAS, significantly the highest number of pods plant^{-1} were recorded with the Topramezone 15g ha^{-1} at 25 DAS (26.7) (S_1) followed by the application of Sodium Acifluorfen+ClodinafopPropargyl 122.5 g ha^{-1} (26.0) (S_3) and were found to be superior to Imazethapyr@15 g ha^{-1} (S_2) and Fomesafen+ Fluazifop-p-butyl @ 40 g ha^{-1} (S_4). This is due to effective and broad-spectrum control of weeds as well as less weed competition during crop growth and development which increased nutrient availability to the crop. Which in turn increased the no of pods plant^{-1}, whereas significantly lowest no of pods plant^{-1} was recorded with weedy check (18.7) (S_5) due to heavy weed competition which effected plant height and drymatter production resulting in lower pods plant^{-1}. The overall results suggest that timely post-emergence weed control is critical for maximizing reproductive success in chickpea. The effectiveness and crop safety of Topramezone (S_1) were clearly reflected in enhanced pod-setting ability. These observations are supported by studies conducted by Bhosale *et al.* (2023) [1] and Sanketh *et al.* (2023) [16], which emphasized the importance of timely and effective post-emergence weed control in enhancing reproductive success in chickpea. There is no significant interaction among the chickpea cultivars and post-emergence herbicides on number of pods plant^{-1}.

Table 6: No. of Branches palnt^{-1}, no. of pods plant^{-1} and test weight of chickpea as influenced by cultivars and post-emergence herbicides

Treatments	No of branches plant^{-1}	No of pods plant^{-1}	Test weight (g/100)
Chickpea cultivars			
M_1:NBeG-452	14.1	27.0	22.4
M_2:JG-11	11.3	21.0	21.1
M_3:Jaki-9218	12.3	24.6	21.3
M_4:KAK-2	9.7	14.7	36.0
S.Em(±)	0.71	0.72	0.56
CD (P=0.05%)	2.2	2.4	1.9
CV (%)	9.1	10.0	8.6
Post-emergence herbicides			
S_1: Topramezone@15g ha^{-1} at 25 DAS	16.6	26.7	25.8
S_2: Imazethapyr@40 g ha^{-1} at 25 DAS	11.5	23.1	24.7
S_3: Sodium acifluorfen +Clodinafop propargyl@122.5 g ha^{-1} (RM) at 25 DAS	14.3	26.0	25.2
S_4: Fomesafen+Fluazifop-p-butyl@ 40 g ha^{-1} (RM)at 25 DAS	8.0	21.5	25.0
S_5: Un weeded check	6.0	18.7	25.5
S.Em(±)	0.79	0.76	0.67
CD (P=0.05%)	2.3	2.2	NS
CV (%)	9.1	9.2	9.2
Interaction			
M x S	NS	NS	NS
S x M	NS	NS	NS

Test weight (100 seeds)

The data presented in Table-7 show that test weight was significantly influenced by chickpea cultivars, whereas the effect of post-emergence herbicides and their interaction with cultivars was statistically non-significant. Among the chickpea cultivars, KAK-2 (M_4) recorded the highest test weight of 36.0 g**,** which was significantly superior to all other varieties. NBeG-452 (M_1)**,** JG-11 (M_2) and Jaki-9218 (M_3) recorded statistically lower test weights of 22.4g, 21.1 g and 21.3 g**,** respectively. In contrast, the influence of herbicide treatments on test weight was not significant. However, numerically, Topramezone (S_1) recorded the highest value (25.8 g), followed by Sodium Acifluorfen + ClodinafopPropargyl (S_3) **(**25.2 g**),** Fomesafen + Fluazifop-p-butyl @ 40 g ha^{-1} (S_4) (25.0) and Imazethapyr (S_2) **(**24.7 g**).** The unweeded check (S_5) showed a comparable value (25.5 g), indicating minimal variation among herbicide treatments. Interaction effects between cultivars and herbicides were found to be non-significant**.**

The significant variation in test weight among cultivars is primarily attributed to genetic differences in seed size and seed filling efficiency. KAK-2 (M_4)**,** known for its bold seed type, maintained its genetic potential under the given environmental conditions, resulting in the highest seed weight. In contrast, NBeG-452**,** JG-11 and Jaki-9218 are medium to bold seeded genotypes, which explains their relatively lower test weights. These findings corroborate earlier reports where seed weight was considered a genotype-specific trait with limited plasticity under variable management conditions.

Although the effect of post-emergence herbicides on test weight was not statistically significant, the numerical consistency across treatments suggests that herbicide application did not adversely affect seed filling. This may be due to the timely application at 25 DAS, which mitigated weed competition during the critical reproductive phase, thereby enabling sufficient resource allocation for seed development. Furthermore, the non-significant interaction between varieties and herbicides implies that herbicide safety and efficacy were consistent across all genotypes with respect to seed weight.These results align with the findings of Sanketh *et al*. (2023) [16] and Chitale *et al*. (2024) [2]**,** who reported that while test weight is largely governed by varietal characteristics, effective weed management supports the physiological processes necessary for optimum seed development.

Seed Yield

On appraisal of data pertaining seed yield was presented in Table-7 revealed that chickpea cultivars and post emergence herbicides has significant effect but their interaction was not effective.

The data reveals that, NBeG-452 variety (1759 kg ha^{-1}) (M_1) recorded significantly the highest seed yield which was on par with Jaki-9218 variety (1693 kg ha^{-1}) (M_3) and these two cultivars are having higher seed yield over JG-11(M_2), while significantly lower seed yield was recorded with KAK-2 variety (1349 kg ha^{-1}) (M_4). Experimental data reveals that various post-emergence herbicides application had a significant impact on seed yield. Significantly maximum seed yield was recorded with the application of Topramezone 15g ha^{-1}at 25 DAS (1910 kg ha^{-1}) (S_1) which was found to be on par with Sodium Acifluorfen+ClodinafopPropargyl 122.5g ha^{-1} at (1823 kg ha^{-1}) (S_3) and superior to Imazethapyr (S_2) and Fomesafen+Fluazifop-p-butyl (S_4). The higher seed yield with the post-emergence application of Topramezone due to increasing number of branches $palnt^{-1}$, no. of pods $plant^{-1}$.

The superior seed yields in cultivars NBeG-452 and Jaki-9218 may be attributed to their enhanced morphological traits, such as higher number of branches and pods per plant, which translated into better sink capacity and reproductive success. These genotypes likely utilized available resources more efficiently under weed-free conditions. Topramezone and Sodium Acifluorfen + ClodinafopPropargyl outperformed other herbicide treatments due to their effective weed control, which minimized competition and enhanced resource availability for chickpea plants. The unweeded check recorded the lowest seed yield (1105 kg ha^{-1}) due to severe competition from weeds.

The yield improvement under these treatments is mainly due to effective weed control, leading to reduced competition and better resource availability. Meanwhile, the weedy check plots recorded the lowest yield due to continuous crop-weed competition. These results highlight the importance of appropriate herbicide selection and varietal choice for achieving optimum yield in chickpea under post-emergence weed management systems. The superior performance of Topramezone may be attributed to enhanced weed suppression, leading to increased number of branches and pods per plant, thereby improving assimilate allocation to reproductive sinks (Nath *et al*., 2021 and Sethi *et al*., 2021) [10, 17]. These results are in accordance with Gairola *et al*. (2024) [4] who also reported significant gains in chickpea productivity following effective post-emergent weed management. There is no significant interaction among the chickpea cultivars and post- emergence herbicides on seed yield.

Haulm yield

Haulm yield of chickpea was significantly influenced by chickpea cultivars and post emergence herbicides (Table-7).

Among the chickpea cultivars significantly highest haulm yield (2506 kg ha^{-1}) was recorded in NBeG-452 (M_1), which is statistically on par with Jaki-9218 (2446 kg ha^{-1}) (M_3) and superior over JG-11(M_1) and the lowest haulm yield was recorded in KAK-2 (1921kg ha^{-1}). The higher haulm yields associated with NBeG-452 and Jaki-9218 are likely a result of their greater vegetative vigour and better drymatter accumulation. The enhanced vegetative growth in these cultivars may be due to increased plant height, branching and drymatter accumulation (Vyshnavi *et al*., 2022) [20].

Significantly the highest haulm yield of chickpea was recorded with the post-emergence herbicide application of Topramezone 15g ha^{-1} at 25 DAS (2729 kg ha^{-1}) (S_1), which was found to be on par with Sodium Acifluorfen+ClodinafopPropargyl 122.5g ha^{-1} (S_3) (2565 kg ha^{-1}) and found to be superior over Imazethapyr @ 40 g ha^{-1} (S_2) and Fomesafen+Fluazifop-p-butyl @ 40 g ha^{-1} (S_4).The highest haulm yield of chickpea with Topramezone 15 g ha^{-1} (S_1) comparable to Sodium Acifluorfen + ClodinafopPropargyl 122.5 g ha^{-1}(S_3) can be attributed to effective weed control, reducing competition for nutrients, water and light.

The effectiveness of Topramezone and Sodium Acifluorfen + ClodinafopPropargyl in controlling a wide spectrum of weeds led to reduced competition and improved uptake of nutrients and moisture, enhancing biomass accumulation. The reduced haulm yield in the unweeded check underscores the negative impact of unchecked weed growth on crop productivity. This suggests that superior weed control improved plant resource acquisition and photosynthetic efficiency, facilitating higher biomass accumulation (Deva, 2018; Sanketh *et al*. 2021) [3, 15]. These findings also corroborate those of Nath *et al*. (2018) [9], who reported that efficient weed control positively influences haulm production in pulses. There is no significant interaction between chickpea cultivars and post-emergence herbicides on haulm yield of chickpea.

Harvest Index (%)

The data pertaining to harvest index was presented in the table and it shows that harvest index was not significantly influenced by both chickpea cultivars and post-emergence herbicides. This indicates that although there were differences in both seed and haulm yields among treatments, the proportion of economic yield to total biomass remained consistent across treatments. The lack of significant variation in harvest index suggests uniformity in biomass partitioning among the cultivars and herbicide strategies tested. These findings are consistent with those reported by Raju, (2021) [12], who also found minimal variation in HI across diverse weed management practices.

Table 7: Seed yield (kg ha^{-1}), Haulm yield (kg ha^{-1}) and Harvest index (%) in chickpea as influenced by cultivars and post-emergence herbicides

Treatments	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Harvest index (%)
Chickpea cultivars			
M_1:NBeG-452	1759	2506	41.1
M_2:JG-11	1478	2289	38.9
M_3:Jaki-9218	1693	2446	41.2
M_4:KAK-2	1349	1921	41.5
S.Em(±)	38.4	59.2	1.01
CD (P=0.05%)	133	205	NS
CV (%)	9	10	9.6
Post-emergence herbicides			
S_1: Topramezone @15g ha^{-1} at 25 DAS	1910	2729	41.4
S_2: Imazethapyr @ 40 g ha^{-1} at 25 DAS	1587	2255	41.3
S_3: Sodium acifluorfen +Clodinafop propargyl @122.5 g ha^{-1} (RM) at 25 DAS	1823	2565	41.8
S_4: Fomesafen+Fluazifop-p-butyl @ 40 g ha^{-1} (RM)at 25 DAS	1423	2045	41.1
S_5: Un weeded check	1105	1857	37.7
S.Em(±)	34.4	88.3	1.23
CD (P=0.05%)	99	254	NS
CV (%)	8	13	10.5
Interaction			
M x S	NS	NS	NS
S x M	NS	NS	NS

Gross Returns

The gross returns of chickpea were significantly influenced by both chickpea cultivars and post-emergence herbicides. Among the chickpea cultivars, NBeG-452 (M_1) recorded significantly higher gross returns (Rs 96723 ha^{-1}) which was on par with Jaki-9218(Rs. 94934 ha^{-1}) (M_3) and these two cultivars are superior to JG-11(M_2). The lowest gross return was observed with KAK-2 (Rs 74195 ha^{-1}) (M_4). The highest gross returns with the chickpea cultivar NBeG-452 (Rs 96723 ha^{-1}) (M_1), comparable to Jaki-9218 (Rs94934 ha^{-1}) (M_3), can be attributed to its superior yield potential and adaptability. Among post-emergence herbicides Topramezone @15 g ha^{-1} (S_1) recorded significantly higher gross returns (Rs 105064 ha^{-1}) and it is on par with Sodium Acifluorfen + ClodinafopPropargyl @ 122.5 g ha^{-1} (S_3) (Rs 102575 ha^{-1}) and these two herbicides are significantly superior to Imazethapyr @ 40 g ha^{-1}(S_2) and Fomesafen + Fluazifop-p-butyl@122.5 g ha^{-1}this might be due to less weed density and dry weight, a greater number of pods and higher seed yield. Significantly lowest gross returns (Rs 60798 ha^{-1}) were realized with the unweeded check due to reduced seed yield as a result of heavy weed competition.

The lowest gross returns were recorded in the unweeded check (Rs 60798 ha^{-1}), which is consistent with research showing that unchecked weed competition can reduce legume yields by up to 80% depending on weed flora and density (Ramesh *et al.*, 2017) [13].

Net Returns

Chickpea cultivars and post-emergence herbicides were significantly influenced the net returns of chickpea (Table-8) and illustrated graphically in Fig. Among the chickpea cultivars NBeG-452 (M_1) produced markedly higher net returns (Rs. 61985 ha^{-1}) than other cultivars and it was on par with Jaki-9218 (Rs. 60195 ha^{-1}) and superior to JG-Q11(M_2) Significantly lowest net returns were recorded in KAK-2 (M_4) (Rs 39457 ha^{-1}). Among the post-emergence herbicides higher net returns was obtained with the application ofTopramezone@15 g ha^{-1}(Rs70141 ha^{-1}) and it was on par with Sodium acifluorfen +Clodinafoppropargyl@122.5 (Rs67683 ha^{-1}). The next best treatment was Imazethapyr @40 ga^{-1} (Rs 52535 ha^{-1}). Unweeded check (W_{12}) resulted in lesser net returns (Rs 26648 ha^{-1}), than rest of the weed management practices due to reduced economic yield as a result of heavy weed competition offered by weeds. These findings are consistent with the observations of Manasa *et al.* (2022) [7] and patel *et al.* (2024) [11] who reported that weed infestation beyond critical periods significantly reduces economic returns in legumes due to competition during early growth stages.

Benefit Cost Ratio

The benefit cost ratio was influenced by chickpea cultivars and post-emergence herbicides (Table-8). Among the chickpea cultivars the highest benefit cost ratio was observed with NBeG-452 (M_1) (1.8) and it is on par with Jaki-9218 (M_3) (1.7) and superior to JG-11(JG-11) this might be due to more net returns obtained with higher economic yield of NBeG-452, whereas lower Net returns were obtained with KAK-2 (M_4) cultivar. The highest benefit cost ratio observed with post-emergence application of Topramezone @ 15 g ha^{-1} (S_1) (2.0) and it is on par with Sodium Acifluorfen+ Clodinafoppropargyl @122.5 g ha^{-1} (S_3) (1.9). Significantly the highest B:C ratio of Topramezone @ 15 g ha^{-1} can be attributed to its effective control of a broad spectrum of weeds minimizing crop-weed competition and enhancing yield. These results highlight Topramezone's potential as a cost-effective and efficient weed management option in post-emergence applications. These results are in accordance with those of Manasa *et al.* (2022) [7] and Bhosale *et al.* (2023) [1] who highlighted that while high-efficacy herbicides improve productivity, cost-effective combinations can often yield better economic returns. Similar conclusions were drawn by Singh *et al.* (2015) and Kumar and Sharma (2018) [19, 6].

Table 8: Economics of chickpea as influenced by chickpea cultivars and post- emergence herbicides

Treatments	Gross Returns (Rs ha^{-1})	Net Returns (Rs ha^{-1})	B:Cratio
Chickpea cultivars			
M_1: NBeG-452	96723	61985	1.8
M_2: JG-11	81316	46577	1.3
M_3: Jaki-9218	94934	60195	1.7
M_4: KAK-2	74195	39457	1.1
S.Em(±)	1763.6	1763.6	0.05
CD (P=0.05%)	6103	6103	0.2
CV (%)	8.0	13.1	13.1
Post-emergence herbicides			
S_1: Topramezone @1 5g ha^{-1}at 25 DAS	105064	70141	2.0
S_2: Imazethapyr @ 40 g ha^{-1}at 25 DAS	87285	52535	1.5
S_3: Sodium Acifluorfen + Clodinafop Propargyl @ 122.5g ha^{-1} (RM) at 25 DAS	102575	67683	1.9
S_4: Fomesafen+Fluazifop-p- butyl @ 40g ha^{-1} (RM) at 25 DAS	78238	43261	1.2
S_5:Unweeded check	60798	26648	0.8
S.Em (±)	2529.0	2529.0	0.07
CD (P=0.05)	7285	7285	0.2
CV (%)	10.1	16.8	16.9
Interaction			
M xS	NS	NS	NS
S xM	NS	NS	NS

Conclusion

NBeG-452 and Jaki-9218, combined with Topramezone or Sodium Acifluorfen + Clodinafop Propargyl, exhibited superior growth, yield and economic performance, with seed yields of 1910 and 1823 kg ha^{-1}, net returns of Rs 70141 and Rs 67683 ha^{-1}and benefit-cost ratios of 2.0 and 1.9, respectively. These combinations offer a sustainable approach to chickpea weed management, enhancing productivity and profitability.

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