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Comparative efficacy of microtubule inhibitors and ACCase inhibitors for weed suppression in chickpea

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Abstract

Weed competition is an important constraint to chickpea production, and herbicide efficacy depends on formulation, dose and the composition of the resident weed flora. A field experiment comprising six weed-management treatments with four replications was conducted to evaluate different formulations and doses of pendimethalin and clodinafop for weed suppression and grain yield of chickpea under mixed weed infestation. Weed density and weed biomass were recorded, and weed-control efficiency (WCE), relative density, relative frequency and importance value index (IVI) were determined to assess treatment effects on weed abundance and community composition. Mean total weed density ranged from 3.0 to 8.0 plants m⁻², whereas weed dry biomass was strongly affected by herbicide treatment ($P < 0.001$). Pendimethalin 38.7 CS at 0.33 kg ai ha⁻¹ recorded the lowest weed dry biomass (26.5 g m⁻²), highest WCE (66.5%) and highest chickpea yield (2.00 t ha⁻¹), compared with 79.0 g m⁻² weed dry biomass and 0.53 t ha⁻¹ grain yield in the weeded control. Pendimethalin 30 EC at 0.375 kg ai ha⁻¹ (34.1 g m⁻²; 56.8% WCE; 1.78 t ha⁻¹) and pendimethalin 38.7 CS at 0.17 kg ai ha⁻¹ (39.5 g m⁻²; 50.0% WCE; 1.67 t ha⁻¹) were the next most effective treatments. Clodinafop 15 WP at 0.03 kg ai ha⁻¹ provided comparatively weak suppression of the mixed weed flora (59.83 g m⁻²; 24.3% WCE) and recorded a grain yield of 0.73 t ha⁻¹. Species-wise IVI revealed treatment-dependent shifts in weed dominance, with *Cynodon dactylon*, *Chenopodium album* and *Argemone mexicana* showing marked variation in their relative ecological importance among herbicide treatments. Pre-emergence pendimethalin, particularly 38.7 CS at 0.33 kg ai ha⁻¹, provided the most effective suppression of mixed weeds and was associated with the highest chickpea yield under the experimental conditions. No phytotoxic injury was reported with tested herbicides.

Keywords: *Cicer arietinum*, herbicide efficacy, weed biomass, weed community, pre-emergence control, importance value index

Introduction

Chickpea (*Cicer arietinum* L.) is a major grain legume, but its relatively slow early growth and limited canopy closure make the crop particularly vulnerable to weed interference. Weeds compete with crops for light, water, nutrients and space, and the magnitude of interference is influenced by weed species, density, time of emergence, duration of competition and production environment. Studies across different cropping systems have demonstrated that crop spatial arrangement, weed emergence timing and competitive interactions can substantially influence weed growth and crop performance [1-4]. Manipulation of crop geometry and canopy development can improve interception of photosynthetically active radiation and enhance crop competitiveness against weeds [5-7]. Consequently, effective early-season weed management is an important component of maintaining crop productivity.

Chemical weed management is particularly important where timely hand or mechanical weeding is constrained. Pendimethalin has been widely investigated as a pre-emergence herbicide in chickpea and other field crops, whereas post-emergence grass-selective herbicides generally provide a narrower spectrum of activity. Veisi *et al.* [8], in a comprehensive review of weed management in chickpea, identified pendimethalin among the important herbicides evaluated for the crop and emphasized the need to adapt weed-management strategies to the prevailing weed flora. Recent research under Indian conditions has similarly demonstrated that appropriate herbicide selection is critical for managing diverse weed populations in chickpea [9]. Studies involving pre-emergence pendimethalin and other residual herbicides in different cropping

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systems have further demonstrated the importance of residual activity for suppressing early-emerging weeds and reducing subsequent weed competition^[10-12].

The efficacy of a herbicide programme is influenced by the active ingredient, formulation, application rate and timing, residual activity and composition of the weed flora. Residual pre-emergence herbicides can restrict weed establishment during the early stages of crop development, whereas narrow-spectrum treatments may leave non-target weed groups uncontrolled. Comparative studies of residual and post-emergence herbicide programmes have demonstrated that appropriately selected herbicide combinations can provide more effective and consistent weed suppression than reliance on a single herbicide tactic^[10-14]. Studies involving Palmer amaranth (*Amaranthus palmeri*) and other difficult-to-control weeds have also demonstrated substantial differences among herbicide programmes in weed control, residual activity and suppression of weed seed production^[12-15].

Herbicide performance, however, should not be assessed solely from total weed density. Weed biomass provides complementary information on the competitive burden imposed by surviving weeds because plants affected by herbicides may remain detectable in density counts while exhibiting substantial reductions in growth. Crop-weed competition is also strongly influenced by the timing of weed emergence and removal, crop spacing and the competitive ability of the surviving weed population^[3, 4, 16]. Changes in these factors can alter resource capture and the relative competitive contribution of individual weed species even when differences in total plant density are comparatively small.

Herbicide programmes can additionally modify weed-community structure by selectively suppressing susceptible species while allowing tolerant, persistent or later-emerging species to become proportionally more important. Studies on common waterhemp (*Amaranthus rudis*) and Palmer amaranth have demonstrated that the efficacy of residual and sequential herbicide programmes can vary substantially according to weed species and management system^[11, 17, 18]. Similarly, comparisons of weed-management systems involving glyphosate-, glufosinate- and conventional herbicide programmes have demonstrated that herbicide spectrum and cropping practices influence both weed suppression and the performance of the overall weed-management programme^[19-21]. Such responses indicate that treatment effects should be interpreted in terms of both overall weed suppression and changes in the composition of the residual weed flora.

Repeated dependence on a limited number of herbicide modes of action may also impose strong selection pressure on weed populations. The evolution and spread of herbicide-resistant weeds have increased reliance on additional herbicide applications, tillage, hand weeding and diversified weed-management practices in several cropping systems^[18, 22]. Integrated weed management combining effective herbicides with cultural, mechanical and other complementary practices is therefore increasingly important for maintaining long-term weed-control efficacy^[23]. Best-management recommendations for

herbicide-resistance mitigation similarly emphasize diversification of herbicide modes of action and integration of chemical and non-chemical tactics rather than repeated dependence on a single weed-control strategy^[18].

These considerations are particularly relevant to chickpea fields containing mixtures of grassy and broad-leaved weeds because a treatment effective against one weed group may provide inadequate suppression of another. Therefore, evaluation of herbicide efficacy should incorporate not only total weed density but also weed biomass, weed-control efficiency and species-level responses. Assessment of relative density, relative frequency and importance value index (IVI) can further help characterize treatment-associated changes in the ecological importance of individual weed species within the residual community. Such complementary measures provide a broader interpretation of herbicide performance than weed density alone.

Comparative information on different formulations and rates of pendimethalin, together with a grass-selective post-emergence standard, is therefore useful for identifying treatments capable of suppressing mixed weed communities in chickpea. The hypothesis of the present study was that pendimethalin efficacy in chickpea varies with formulation and dose and that a treatment providing broader early-season suppression would reduce weed biomass more effectively than clodinafop under mixed weed infestation. Therefore, the objective of this study was to compare pendimethalin 38.7 CS, pendimethalin 30 EC and clodinafop 15 WP for their effects on weed density, weed biomass, weed-control efficiency and weed-community composition in chickpea.

Materials and Methods

Experimental site and crop husbandry

The field experiment was conducted during *kharif* season of 2025 at dryland research farm of Punjab Agricultural University-Regional Research Station, Ballawal Saunkhri. The soil was sandy loam with pH 7.7, soil organic matter 8.02 g kg⁻¹, available N 218 kg ha⁻¹, available phosphorus 32 kg ha⁻¹ and available potassium 351 kg ha⁻¹. Chickpea cultivar [PDG 4] was sown on October 19, 2025 with pora method in rows 30 cm apart and at 12.5 cm depth by using a seed rate of 45 kg ha⁻¹. Nitrogen and phosphorus fertilization through urea and single super phosphate was applied at sowing at the rate of 15 and 20 kg ha⁻¹, respectively. Experiment was conducted under Dryland conditions, and no supplemental irrigation was applied to crop. For measurements at harvest, five plants were randomly selected from the net plot and thereafter average was computed. The crop were harvested manually with serrated sickle from the ground.

Experimental design and treatments

The experiment comprised six treatments arranged in a randomized complete block design with four replications. The individual plot size was 2.40 m × 4 m. Treatments application rate and timing were given in table 1. Herbicides were applied using knapsack sprayer with flat fan nozzle calibrated to deliver 140 L ha⁻¹ at 276 kPa at a constant speed of 4.8 km h⁻¹.

Table 1: Herbicides, application timing, rates, and products used for control of diverse weed flora in chickpea in field experiments conducted at Research farm, PAU-RRS, Ballawal Saunkhri in 2025

Herbicide program	Trade name	Application timing	Rate (kg ai ha ⁻¹)	Manufacture
Pendimethalin 38.7 CS	Active Extra	PRE	0.17	Krishi Crop Science
Pendimethalin 38.7 CS	Active Extra	PRE	0.33	Krishi Crop Science
Pendimethalin 30 EC	Anustorm	PRE	0.375	Anu proucts limited
Pendimethalin 30 EC	Anustorm	PRE	0.75	Anu proucts limited
Clodinafop propargyl 15 WP	Topik	POST	0.03	Syngenta
Unweeded control	-	No herbicide	-	-

^aAbbreviations: PRE, Pre-emergence herbicide application on the day of sowing; POST, Post-emergence herbicide application at 30 days after sowing

Weed observations

Weed observations were recorded at harvest. Species-wise weed density was determined from four quadrats of 0.5 m² quadrats placed at representative area within each plot and expressed as plants m⁻². Weeds were grouped as grasses, broadleaf weeds and sedges. Fresh weed biomass was measured immediately after sampling. Samples were subsequently dried at 65 °C to constant mass and dry biomass was expressed as g m⁻².

Weed-control and community indices

- Weed-control efficiency (WCE) based on dry biomass was calculated as

$$\text{WCE (\%)} = [(\text{DWC} - \text{DWT})/\text{DWC}] \times 100$$

where DWC is weed dry biomass in the unweeded control and DWT is weed dry biomass in a herbicide treatment.

- Relative density (%) was calculated as the density of 'a' species divided by the total density of all species $\times 100$.
- Relative frequency (%) was calculated as the frequency of 'a' species divided by the sum of frequencies of all species $\times 100$.
- Importance value index (IVI) was derived from the community metrics recorded in the field dataset.

Statistical analysis

Statistical analysis was performed in R software. Total weed density and weed dry biomass were analysed as a randomized complete block design with treatment as a fixed effect and replication (block) as a blocking factor. Treatment comparisons were made with Fisher's least significant difference (LSD) at $P \leq 0.05$. Weed density and biomass was subjected to square-root transformation for better presentation of data.

Results

Weed flora and total weed density

The experimental field supported a mixed weed flora comprising perennial and annual grasses and several broad-leaved weed species. The predominant weed species at the experimental site were *Cynodon dactylon* L., *Sorghum halepense* L., *Phalaris minor* Retz., *Chenopodium album* L., *Argemone mexicana* L., *Parthenium hysterophorus* L. and *Cannabis sativa* L. The occurrence and abundance of different weed species varied among replications, indicating spatial heterogeneity in the weed community. Variation in weed occurrence within agricultural fields may result from differences in weed emergence, competitive ability and responses to crop and weed-management practices [3, 4, 16].

Mean total weed density did not differ significantly among the herbicide treatments. However, total weed density alone may not

adequately characterize herbicide performance because surviving weeds can differ substantially in growth, biomass accumulation and competitive ability. Previous studies have demonstrated that weed emergence timing, crop competition and management practices can influence weed growth and competitive effects even when weed density differences are relatively small [1, 3, 4]. Therefore, weed biomass and species-wise weed responses were considered together with total weed density to provide a more reliable assessment of treatment performance.

Weed biomass and weed-control efficiency

Herbicide treatments markedly affected weed dry biomass (Table 2 and Figure 1). Pendimethalin 38.7 CS at 0.33 kg ha⁻¹ applied PRE recorded the lowest mean weed dry biomass (26.5 g m⁻²), corresponding to a weed-control efficiency (WCE) of 66.5% relative to the unweeded control. Pendimethalin 30 EC at 0.375 kg ha⁻¹ ranked second (34.1 g m⁻²; 56.8% WCE), followed by pendimethalin 38.7 CS at 0.17 kg ha⁻¹ (39.5 g m⁻²; 50.0% WCE). The superior biomass suppression obtained with the pre-emergence pendimethalin treatments is consistent with previous studies demonstrating the importance of pendimethalin and other residual pre-emergence herbicides for restricting early weed establishment and growth [8, 10-12]. Veisi *et al.* [8] identified pendimethalin as an important herbicide for weed management in chickpea, while Patel *et al.* [9] demonstrated the importance of appropriate chemical weed-management strategies for controlling diverse weed flora in chickpea.

Increasing the rate of pendimethalin 30 EC from 0.375 to 0.75 kg ha⁻¹ did not improve weed suppression under the conditions of the present experiment; the higher rate resulted in a mean weed dry biomass of 51.5 g m⁻² and 34.8% WCE. This response indicates that increasing herbicide dose does not necessarily result in proportionately greater weed suppression, because efficacy may also depend on weed species composition, susceptibility, emergence pattern and environmental conditions. Variation in weed response among herbicide programmes has similarly been reported in studies evaluating residual and sequential herbicide treatments against diverse and difficult-to-control weed populations [11-15, 17, 19].

Clodinafop 15 WP at 0.03 kg ha⁻¹ resulted in a mean weed dry biomass of 59.83 g m⁻² and only 24.3% WCE compared with 79.0 g m⁻² in the unweeded control. Its relatively low overall efficacy may be attributed to the mixed weed flora present in the experimental field, which included an appreciable broad-leaved component. Thus, suppression of susceptible grasses alone was insufficient to provide effective control of the entire weed community. This finding supports the broader principle that herbicide programmes should be selected according to the prevailing weed spectrum and that diversified or integrated weed-management approaches are preferable where multiple weed groups occur simultaneously [8, 9, 18, 23].

Table 2: Weed density, dry biomass and weed control efficiency as affected by herbicides programs for control of diverse weed flora in chickpea in field experiments conducted at Research farm, PAU-RRS, Ballawal Saunkhri in 2025

Herbicide program	Application timing	Weed density (plants m ⁻²)	Dry biomass (g m ⁻²)	Weed-control efficiency (%)	Chickpea yield (t/ha)
Pendimethalin 38.7 CS (0.17 kg ai ha ⁻¹)	PRE	3.00 $\pm$ 1.41	39.50 $\pm$ 0.00	50.0	1.67
Pendimethalin 38.7 CS (0.33 kg ai ha ⁻¹)	PRE	4.25 $\pm$ 2.36	26.50 $\pm$ 0.00	66.5	2.0
Pendimethalin 30 EC (0.375 kg ai ha ⁻¹)	PRE	4.25 $\pm$ 2.63	34.10 $\pm$ 0.00	56.8	1.78
Pendimethalin 30 EC (0.75 kg ai ha ⁻¹)	PRE	5.50 $\pm$ 2.52	51.50 $\pm$ 5.00	34.8	0.88
Clodinafop 15 WP (0.03 kg ai ha ⁻¹)	POST	5.50 $\pm$ 1.73	59.83 $\pm$ 0.00	24.3	0.73
Unweeded control	-	8.00 $\pm$ 2.45	79.00 $\pm$ 0.00	0.0	0.53

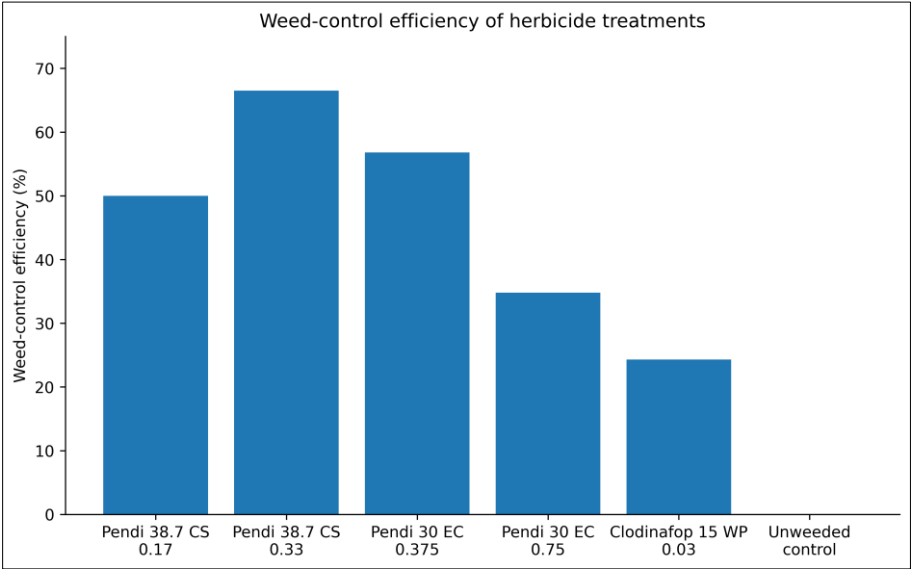


Fig 1: Weed-control efficiency (WCE) as affected by herbicides programs for control of diverse weed flora in chickpea in field experiments conducted at Research farm, PAU-RRS, Ballawal Saunkhri in 2025

Weed-community response

Species composition varied among treatments and blocks. *Chenopodium album* and *Argemone mexicana* were frequent broad-leaved components, while *Cynodon dactylon* and *Sorghum halepense* represented important grasses. The relative density, relative frequency and importance value index (IVI) indicated that herbicide treatments altered the relative contribution of individual weed species. Such shifts in weed-community composition can occur because herbicides differ in their spectrum of activity and selectively suppress susceptible species while allowing relatively tolerant or persistent species to constitute a greater proportion of the residual weed community (8, 18, 23). The species-wise IVI revealed marked variation in weed dominance among herbicide treatments in chickpea (Figs. 2 and 3). *Cynodon dactylon* remained an important grassy weed across all treatments, with IVI values ranging from 27.9 to 107.6. The highest IVI (107.6) was recorded with pendimethalin 38.7 CS at

0.33 kg ha⁻¹, whereas the lowest value (27.9) occurred with pendimethalin 30 EC at 0.75 kg ha⁻¹, compared with 28.8 in the unweeded control. The persistence and relative dominance of particular weed species following herbicide application may reflect differences in species susceptibility, emergence behaviour and competitive ability rather than simply differences in total weed density. Similar species-specific responses to herbicide programmes have been reported in studies evaluating residual and sequential weed-management strategies [11-15, 17, 19]. *Chenopodium album* was another dominant weed and occurred under all treatments. Its IVI ranged from 40.4 to 124.2, with the maximum value recorded under pendimethalin 30 EC at 0.75 kg ha⁻¹. *Argemone mexicana* also persisted across all treatments, although its IVI varied considerably, from 6.9 under pendimethalin 38.7 CS at 0.33 kg ha⁻¹ to 48.5 under clodinafop 15 WP at 0.03 kg ha⁻¹.

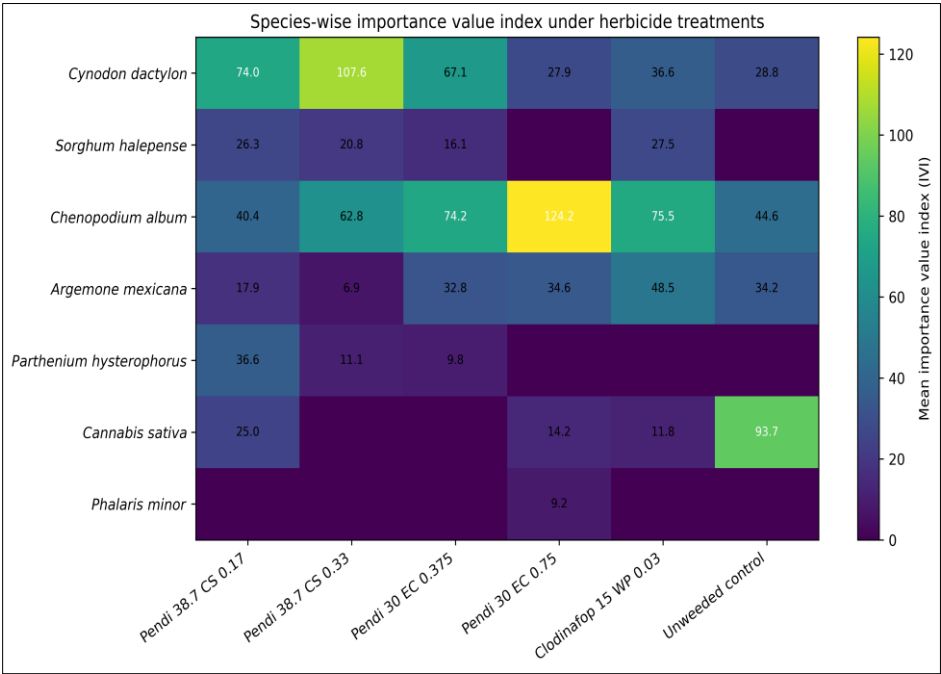


Fig 2: Species-wise importance value index (IVI) under herbicide treatments in chickpea. Values are means across four replications; a species not recorded in a replication was assigned IVI = 0 for calculation of the treatment mean

In contrast, *Sorghum halepense* showed greater treatment-specific suppression. Its IVI declined from 26.3 under pendimethalin 38.7 CS at 0.17 to 16.1 under pendimethalin 30 EC at 0.375. *Parthenium hysterophorus* L. recorded an IVI of 36.6 under

pendimethalin 38.7 CS at 0.17, which decreased to 11.1 and 9.8 under pendimethalin 38.7 CS at 0.33 and pendimethalin 30 EC at 0.375, respectively.

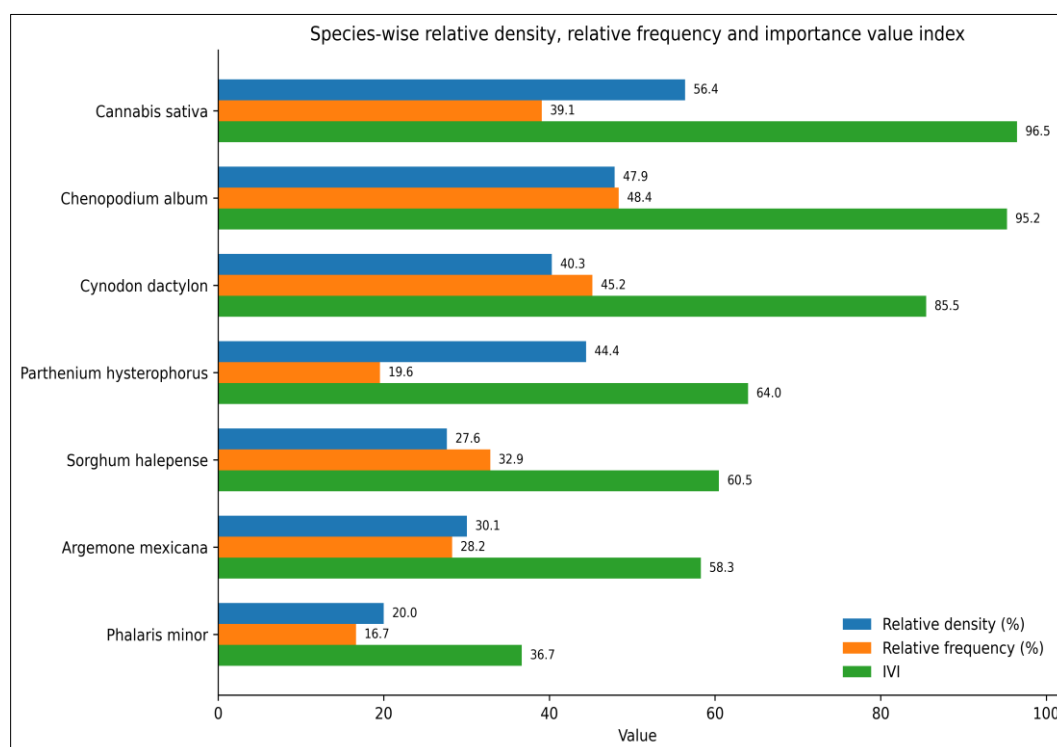


Fig 3: Species-wise mean relative density (RD), relative frequency (RF), and importance value index (IVI) for control of diverse weed flora in Chickpea

A pronounced treatment-dependent response was observed for *Cannabis sativa* L. It recorded a high IVI (93.7) in the unweeded control but substantially lower values under pendimethalin 38.7 CS at 0.17 (25.0), pendimethalin 30 EC at 0.75 (14.2), and clodinafop 15 WP at 0.03 (11.8). *Phalaris minor* was the least prominent species and was recorded only under pendimethalin 30 EC at 0.75, with an IVI of 9.2. Thus, the IVI analysis demonstrated that herbicide treatments substantially altered the relative composition and dominance of the weed flora in chickpea. No single treatment uniformly minimized the IVI of all weed species, indicating species-specific responses to the herbicides. pendimethalin 38.7 CS at 0.33 was associated with particularly low IVI of *Argemone mexicana* and *Parthenium hysterophorus* and absence of *Cannabis sativa*, although *Cynodon dactylon* remained highly dominant. Pendimethalin 30 EC at 0.75 markedly lowered the relative importance of *C. dactylon* and was associated with absence of *S. halepense* and *P. hysterophorus*, but *Chenopodium album* became highly dominant.

Chickpea yield

Herbicide treatments showed marked variation in chickpea yield (Table 2). The highest yield (2.00 t ha⁻¹) was recorded with pendimethalin 38.7 CS at 0.33 kg ai ha⁻¹ applied PRE, followed by pendimethalin 30 EC at 0.375 kg ai ha⁻¹ (1.78 t ha⁻¹) and pendimethalin 38.7 CS at 0.17 kg ai ha⁻¹ (1.67 t ha⁻¹). In contrast, pendimethalin 30 EC at 0.75 kg ai ha⁻¹ and clodinafop 15 WP at 0.03 kg ai ha⁻¹ recorded lower yields of 0.88 and 0.73 t ha⁻¹, respectively. The unweeded control produced the lowest grain yield (0.53 t ha⁻¹). The greater yield obtained with pendimethalin 38.7 CS at 0.33 kg ai ha⁻¹ coincided with the lowest weed dry

biomass and highest weed-control efficiency (66.5%), indicating that effective suppression of the mixed weed flora reduced weed competition and was associated with improved crop productivity.

Discussion

The present study demonstrated that the effects of herbicide treatments were expressed more distinctly in weed biomass than in total weed density, highlighting the importance of considering both parameters when assessing weed-control efficacy in chickpea. This distinction is biologically meaningful because herbicide injury does not necessarily result in immediate plant mortality. Treated weeds may survive in a stunted or physiologically suppressed state and therefore continue to contribute to weed density while producing relatively little biomass. Since crop-weed competition is strongly influenced by weed growth and resource capture, reduction in weed biomass may provide a more realistic indication of the reduction in competitive pressure than weed density alone. Similar distinctions between weed abundance, competitive growth and management response have been emphasized in crop-weed competition studies [1, 3, 4].

Among the treatments evaluated, pendimethalin 38.7 CS at 0.33 kg ha⁻¹ produced the greatest suppression of weed biomass and consequently the highest weed-control efficiency (WCE). The superior performance of pendimethalin can be attributed to its residual, early-season activity, which restricts weed establishment and growth during the critical period of crop-weed competition. Pendimethalin has been widely investigated for weed management in chickpea, particularly where early-emerging grassy and broad-leaved weeds occur together. Veisi *et al.* [8] identified pendimethalin among the important herbicides

evaluated in chickpea and emphasized that heterogeneous weed communities require management strategies with an adequate spectrum of activity. The present findings are consistent with this principle, as pendimethalin treatments generally provided better suppression of the mixed weed vegetation than the more selective post-emergence treatment [8-12].

In contrast, clodinafop 15 WP at 0.03 kg ha⁻¹ showed comparatively poorer suppression of total weed biomass. This response can be explained by its predominantly graminicidal activity, which provides effective control of susceptible grass weeds but limited control of broad-leaved species. The experimental weed flora contained an appreciable broad-leaved component, including *Chenopodium album*, *Argemone mexicana* L., *Parthenium hysterophorus* L. and *Cannabis sativa* L. Consequently, control of susceptible grasses alone was insufficient to achieve a comparable reduction in the overall weed burden. This finding illustrates an important practical limitation of narrow-spectrum post-emergence herbicides in fields where grasses and broad-leaved weeds occur simultaneously. Reports from Indian chickpea production systems have likewise indicated that weed-management programmes providing a broader spectrum of control can perform better than treatments directed primarily against grassy weeds when the weed flora is diverse. This interpretation agrees with the broader recommendation that herbicide spectrum should be matched to the resident weed flora and integrated with complementary management tactics [8, 9, 18, 23]. The species-wise importance value index (IVI) further clarified these treatment-induced changes in weed-community structure. However, IVI represents the relative ecological importance of a species rather than its absolute abundance. Therefore, a high IVI under a particular herbicide treatment should not necessarily be interpreted as herbicide-induced proliferation of that species. Instead, effective suppression of competing species can increase the proportional contribution—and hence IVI—of the weeds that survive. This phenomenon was evident in the present study, where herbicide treatments produced substantial shifts in the relative dominance of individual weed species. Species-specific responses and shifts in residual weed dominance following herbicide programmes have also been reported in other cropping systems [11-15, 17-19, 23].

For example, *Cynodon dactylon* remained an important component of the weed flora and attained a particularly high IVI (107.6) under pendimethalin 38.7 CS at 0.33 kg ha⁻¹, despite this treatment providing the greatest overall biomass suppression. This apparent contrast demonstrates why IVI and total weed biomass should be interpreted together. The high relative importance of *C. dactylon* does not imply failure of the treatment in overall weed suppression; rather, it suggests that this species constituted a greater proportion of the residual weed community after other susceptible weeds had been more effectively suppressed. Similarly, *Chenopodium album* reached its highest IVI (124.2) under pendimethalin 30 EC at 0.75 kg ha⁻¹, indicating a shift towards its relative dominance among the surviving weeds rather than necessarily an increase in its absolute population. The IVI pattern also revealed strong species-specific responses. *Parthenium hysterophorus* declined from an IVI of 36.6 under pendimethalin 38.7 CS at 0.17 kg ha⁻¹ to 11.1 and 9.8 at pendimethalin 38.7 CS at 0.33 kg ha⁻¹ and pendimethalin 30 EC at 0.375 kg ha⁻¹, respectively, and was not recorded under the remaining treatments. Likewise, *Cannabis sativa* had a high IVI (93.7) in the unweeded control but was absent under pendimethalin 38.7 CS at 0.33 kg ha⁻¹ and pendimethalin 30 EC at 0.375 kg ha⁻¹. Conversely, *Argemone mexicana* persisted across all treatments, although its relative importance varied

considerably. These contrasting responses demonstrate that herbicide application can restructure the weed community by selectively suppressing susceptible species while increasing the relative prominence of more persistent or less susceptible weeds. Taken together, the biomass, WCE and IVI results provide complementary evidence. Biomass and WCE demonstrate the overall magnitude of weed suppression and higher chickpea yield, whereas IVI reveals how that suppression modifies the composition and relative dominance of the residual weed flora. On this basis, pendimethalin 38.7 CS at 0.33 kg ha⁻¹ emerged as the most effective treatment for overall weed suppression, even though some surviving species retained high relative IVI values. The findings therefore emphasize that herbicide performance should not be judged from total weed density or species-wise IVI in isolation. Rather, weed density, biomass, WCE and species composition should be considered collectively. From a practical perspective, matching the herbicide spectrum to the prevailing weed flora and integrating chemical control with complementary weed-management practices would provide a more robust strategy for managing mixed grassy and broad-leaved weed populations in chickpea while reducing the potential for long-term shifts towards difficult-to-control species.

Conclusion

Pendimethalin 38.7 CS at 0.33 kg ha⁻¹ emerged as the most effective treatment, providing the greatest chickpea yield and suppression of weed dry biomass and achieving approximately 66.5% weed-control efficiency. Pendimethalin 30 EC at 0.375 kg ha⁻¹ and pendimethalin 38.7 CS at 0.17 kg ha⁻¹ were the next most effective treatments, whereas clodinafop 15 WP at 0.03 kg ha⁻¹ provided comparatively poor control of the mixed weed flora, indicating the limitations of a predominantly grass-selective herbicide where broad-leaved weeds constitute an important component of the weed community. The species-wise importance value index (IVI) further demonstrated that herbicide application not only reduced weed interference but also altered the relative composition and dominance of the residual weed flora. Because IVI reflects relative ecological importance rather than absolute weed abundance, a high IVI for a particular species following herbicide application should not necessarily be interpreted as an increase in its population. Instead, it may reflect greater suppression of competing species, thereby increasing the relative contribution of the surviving weed to the residual community. The superior biomass suppression obtained with pendimethalin 38.7 CS at 0.33 kg ha⁻¹, together with the observed treatment-induced shifts in weed dominance, emphasizes the importance of selecting herbicides according to the prevailing weed spectrum and higher chickpea yield. For mixed infestations comprising both grassy and broad-leaved weeds, integrated weed-management strategies with broad-spectrum activity are likely to provide more effective and sustainable weed suppression while minimizing undesirable shifts towards persistent or less susceptible weed species.

Author contributions

Ramandeep Kaur: Conceptualization; methodology; project administration; supervision; writing—original draft; writing—review and editing.

Amandeep Kaur: Data curation; formal analysis; investigation; methodology; writing—review and editing.

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Compliance with ethical standards

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical issues: None. This field study did not involve human participants or animals.

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