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Impact of Weed Management Options on Weed Dynamics and Yield of Chickpea (*Cicer arietinum* L.): A Review

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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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Review Article

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ABSTRACT

Chickpea (*Cicer arietinum*) belongs to *Fabaceae* family and a vital legume crop in India, serving as a primary source of protein in the Indian diet. It is essential to the nutrition of thousands of people in the developing world but at present its productivity is extremely low in India. There are various reasons for low productivity. Among the various factors that contribute to the low production losses resulting from weeds, one of the most significant one's accounts for 30–54% of the total loss. Understanding the weed populations in the field in full detail is necessary to determine when to manage weeds. Due to their slow development and growth rate, chickpea is a poor crop

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competition with weeds. Up to 60 days after sowing, it competes with chickpea weeds due to its few branches and little leaf area. Various management techniques, such as cultivar competition, spacing adjustments, *etc*., are helpful in increasing output. Pre-emergence herbicides like pendimethalin, quizalofop, *etc.*, are more effective in order to control the weeds right from the germination. Post-emergence herbicides like imazethapyr, imazamox and topramezone *etc.*, applications are becoming more important as the world enters the era of precision farming. Chickpea is highly susceptible to weed competition and the weeds causes 75% of yield losses. Considering the losses caused due to weeds, it is essential to manage the weeds within their critical crop-weed competition period. Combining two or more herbicides, either simultaneously or in a sequential 'double knockdown' approach, and integration of hand-weeding with pre-emergence herbicides, offers effective management of various weed species while minimizing the risks associated with post-emergence chemical weed control methods.

Keywords: Chickpea; weeds; weed density; herbicides; pre-emergence; post-emergence; weed index; yield.

1. INTRODUCTION

Pulses constitute one of the most important components of human diet and major source of protein particularly for the vegetarian population [1]. India is the largest producer (25% of the global production), consumer (27% of the world consumption) and importer of pulses (14%) in the world [2]. The net availability of food grains per capita increased day by day from 144.1 kg $year^{-1}$ in 1951 to 179.6 kg $year^{-1}$ in 2019 in spite of growth in population, however, the net availability of pulses has reduced from 25 kg $year^{-1}$ in 1961 to 17.5 kg $year^{-1}$ in 2019 [3]. Chickpea (*Cicer arietinum* L.) is the world's third most crucial pulse crop after French bean and field pea [4]. Chickpea commonly known as gram or Bengal gram is a legume of Asian origin [5]. It contains major source of dietary protein (18-22%), carbohydrates (52-70%), fat (4-10%), minerals (calcium, phosphorus and iron) and vitamins for predominantly vegetarian population of India [6]. Worldwide, the average grain yield of chickpea is 965.1 $kgha^{-1}$, while in Asia, it is 919.7 kg ha^{-1} and in Iran, it is 443.2 kg ha^{-1} [7]. The total area, production and productivity of chickpea in India during 2021-22 was 10.74 million hectares, 13.54 million tonnes and 1261 kg ha^{-1}, respectively [8].

Chickpea is short stature crop with slow initial growth and therefore, heavily infested with wide spectrum of weeds [9]. Poor weed management is one of the most important yield limiting factors in chickpea [10]. Crop yield losses due to weeds have been estimated to be 54.7% [11]. The critical period for crop-weed competition is defined as the number of weeks after crop emergence, during, which, a crop must be weed-free to prevent yield losses greater than 5% [12]. Thus, weeds are one of the major constraints to obtain high grain yield of improved crop cultivars if they are not controlled timely and properly [13]. The weed management in chickpea is an important component of plant protection and improving production potential of the crop [14].

2. CROP-WEED COMPETITION

2.1 Losses Caused by Weeds

About 68% of lower seed yield in chickpea was due to the presence of weeds throughout the crop season in Haryana [15].The yield reduction in chickpea was to the tune of 20 to 49.5% due to competition stress by weeds on clay loam soil in Maharashtra [16].The maximum yield to the extent of 81 to 97 per cent has also been reported by [17].Chickpea is not a competitive crop, especially whenweed competition occurs at early stages of crop growth [18].The magnitude of yield reduction depends upon many factors, such as composition of the weed species and their intensity, crop cultivars grown and agronomic practices of cultivation method [19]. The crop yield loss caused by the weeds is assumed greater than 20% in Ethiopia [20]. Weeds on an average reduced the chickpea crop yield by 40-87% if uncontrolled on loamy soil in Himachal Pradesh [21]. In chickpea, the weeds one of the major factors as their infestation caused an average yield reduction of 37.7% [22].

Critical period of weed interference: A period from 30 to 60 DAS is considered critical for crop-weed competition in chickpea [33]. One hand weeding was found inadequate for getting higher chickpea seed yield as weedy situation prevailing throughout the crop period caused

57% reduction in seed yield of chickpea [34]. In chickpea, a critical period for crop weed competition at 5% yield loss ranged from 50 to 69 days after sowing (DAS) on clay soil in Italy [35]. Similarly, presence of weeds throughout the crop season reduced the seed yield of chickpea up to 68% [36]. The critical period for weed control to prevent 10% yield and total dry matter loss was from 43 to 53 and 36-48 days after emergence (DAE) and 5% yield and total dry matter loss 36-60 and 26-71 DAE but the critical period for weed control to prevent 2.5% yield and total dry matter loss was wide spread than other levelsand was 31-66 and 19-81 DAE in chickpea on silt loam soil in Iran [37]. Though, the critical period of weed interference from 5 to 76 days after emergence, assuming an acceptable production loss of 5% [38].

Table 1. Losses caused by different weed flora infesting the chickpea crop

Sr. No.	Weed Flora	Place	Author	Estimated Yield Loss
1.	*Parthenium hysterophorus*, *Amaranthus viridis* L., *Physalis minima*, *Digera arvensis*, *Euphorbia hirta*, *Alternanthera philoxeroides*, *Echinochloacrusgalli* L., *Brachiriamutica*, *Cyperus rotundus* and *Cynodon dactylon* L.	Parbhani (Maharashtra)	[23]	40-90%
2.	*Chenopodium album*, *Chenopodium murale* and *Rumex dentatus*	Jodhpur (Rajasthan)	[24]	40-45%
3.	*Chenopodium album*, *Melilotus alba*, *Medicago hispida*, *Cynodon dactylon* and *Phalaris minor*.	Varanasi (Uttar Pardesh)	[25]	75%
4.	*Medicago polymorpha*, *Solanum nigrum*, *Galinsoga parviflora*, *Parthenium hysterophorus*, *Commelina benghalensis* and *Cyperus rotundus.*	Haramaya (Ethiopia)	[26]	20-50%
5.	*Celosia argentea*, *Euphorbia geniculata*, *Tridax procumbance*, *Anagallis arvensis Argemone mexicana*, *Parthenium hysterophorus*, *Chenopodium album*, *Ipomea carnea*, *Cyperus rotundus*, *cynodon dactylon*, *dinebra arabica*, *panicum spp. Cynodon dactylon*, *Digitaria sanguinalis*, *amaranthis viridis*, *Cyperus rotundus* and *Erogrostis.*	Akola (Maharastra)	[27]	60-67%
6.	*Medicago denticulata*, *Convolvulus arvensis*, *Chenopodium album*, *Melilotus indica* and *Brachiaria mutica*	Raipur (Chhattisgarh)	[28]	53-62%
7.	*Melilotus alba*, *Chenopodium album*, *Cynodon dactylon*, *Phalaris minor*, *Phylanthus niruri*, *Portulaca oleracea*, *Digera arvensis* and *Anagallis arvensis*	Fatehgargh (Punjab)	[29]	20-40%
8.	*Cynodon dactylon*, *Dactyloctenium aegyptium*, *Euphorbia hirta*, *Chenopodium album*, *Solanum nigrum*, *Amaranthus viridis*, *Vicia hirsuta*, *Vicia sativa*, *Polygonum plebeium*, *Anagallis arvensis*, *Argemone mexicana*, *Melilotus indicus*, *Fumaria parviflora* and *Coronopus didymus*	BAU, Bhagalpur (Bihar)	[30]	18-52 %
9.	*Cyperus rotundus*, *Panicum dichotomiflorum*, *Commelina benghalensis*, *Convolvulus arvensis*, *Euphorbia geniculate* and *Parthenium hysterophorus*	Dharwad (Karnataka)	[31]	15-63%
10.	*Cynodon dactylon*, *Launaea pinnatifida*, *Chenopodium album* and *Anagallis arvensis*	Madhya Pradesh	[32]	68%

2.2 Effect of Different Weed Management Approaches on

Tillage practices: The bulk density and porosity measures under four different tillage practices, namely zero tillage (ZT), minimum tillage (MT), conventional tillage (CT) and deep tillage (DT) result showed that tillage practices decrease the weed density of cereals [39]. Among tillage operations, zero-tillage registered significantly lower weed density and weed dry matter [40]. The bed planting of chickpea was significantly better than the conventional tillage due to better weed management, better root development and favorable soil environment [41].

Intercropping system: The grain biomass of chickpea (weed infested) in intercropping system (despite the less cultivated area) was not significantly different than pure cropping, thus indicating the superior performance of intercropping as compared to pure cropping [42]. According to a study, the cropping system cumin 50%- chickpea 50% had the minimum weed density, showing superiority over monoculture and other intercropping system [43]. Intercropping reduced the density and dry weight of weeds by increasing the competitive pressure caused by the presence of cumin and chickpea plants [44].

Allelopathy: Mulching with straw resulted in significantly higher grain yield and enhanced the water use efficiency in different chickpea cultivars [45]. Rye, sorghum, rice, sunflower, rape seed and wheat have been documented as important allelopathic crops, releasing allelochemicals, which not only suppress weeds but also promote underground microbial activities [46]. The better weed control by using *Eucalyptus* leaf mulch, crop or weed straw mulch, *Asphodelus tenuifolius* mulch and extract of *Cyperus rotundus* and *Sorghum halepense* in chickpea crop [47].

2.3 Chemical Weed Control

Effect of pre-emergence herbicides: The pre-emergence application of pendimethalin at the rate of 750-1500 g ha^{-1} and quizalofop-p-ethyl at the rate of 40-100 g ha^{-1} as post-emergence very effective for controlling weeds in chickpea crop [48]. Metachlor 83% and pendimethalin 13% 2.23 litre ha^{-1} showed promising results in controlling weeds [49]. The higher yield with pre-emergence application of pendimethalin at the rate of 600 g ha^{-1} + post-emergence imazethapyr at the rate of 60 g ha^{-1}at 20DAS, which was found at par with pre-emergence application of pendimethalin at the rate of 600 g ha^{-1} + post-emergence imazethapyr at the rate of 40 g ha^{-1} [50]. The application of pendimethalin at the rate of 1250 g ha^{-1} followed by quizalofop-ethyl at the rate of 150 g ha^{-1} resulted in poor crop-weed competition and lower weed index [51]. The maximum grain yield when pendimethalin herbicide was used at the rate of 750 g ha^{-1} as pre-emergence [52]. The crop chickpea gave maximum yield due to maximum nutrient uptake and minimum nutrient depletion by weeds with pre-emergence application of pendimethalin at the rate of 1000 g ha^{-1} [53]. Among herbicidal treatments, the minimum weed density was recorded with pendimethalin 1000 g ha^{-1} being at par with oxyfluorfen at the rate of 150 g ha^{-1} [54].

Effect of post emergence herbicides: The post-emergence application of imazethapyr at the rate of 30 g ha^{-1} at 10 days after germination (DAG) resulted in the maximum plant height and a greater number of branches per plant as compared to its other doses and time of application [55]. The minimum dry weight of weeds and weed index with pre-emergence application of oxyfluorfen at the rate of 180 g ha^{-1} followed by pre-mix of imazamox + imazethapyr at the rate of 30 g ha^{-1} as post-emergence at 40 DAS [56]. The toxic effect of post-emergence application of oxyfluorfen at the rate of 200 g ha^{-1} followed by clodinafop at the rate of 60 g ha^{-1} at 35 DAS on the formation of root nodules [57]. The maximum benefit to cost ratio with application of oxyflourfen at the rate of 150 gha^{-1}, which was closely followed by imazethapyr 10% at the rate of 50 g ha^{-1} [58]. Among herbicidal treatments, early post-emergence application of sodium acifluorfen 16.5% at the rate of 165 g ha^{-1} + clodinafop propargyl 8% at the rate of 80 g ha^{-1} significantly reduced density and dry weight of weeds and showed maximum weed control efficiency and closely followed by imazethapyr 3.75% at the rate of 50 g ha^{-1} + propaquizafop 2.5% at the rate of 75 g ha^{-1} at 20 DAS [59]. Among different herbicidal treatments, application of imazathapyr 450 g ha^{-1} followed by atrazine at the rate of 500 g ha^{-1} showed maximum weed control efficiency and minimum in case of metribuzin at the rate of 150 g ha^{-1} followed by oxyflorfen 50 g ha^{-1} [60].

2.4 Mechanical Weed Control

Hand weeding: The minimum weed population and weed dry weight in chickpea was observed under the treatment hand weeding at 20, 40 and 60 DAS [61]. Hand weeding twice at 20 and 40 DAS in chickpea resulted in minimum density and dry weight of weeds and maximum weed control efficiency on clay loam soil [62]. Among different weed management treatments, hand weeding twice at 30-35 DAS and 60-65 DAS showed maximum weed control efficiency in Bengal gram on clay loam soil [63].

Hand weeding twice at 20 and 30 DAS recorded maximum plant height, which was at par with two hand hoeing at 20 and 30 DAS in green gram on clayey soil [64]. Among different weed control methods, hand weeding at 20, 40 and 60 DAS recorded higher values for plant height, number of branches per plant and dry matter accumulation per plant in chickpea on clay soil [65]. Among different weed control methods, hand weeding at 20, 40 and 60 DAS recorded higher values for number of pods per plant, number of grains per pod and test weight in chickpea on clay soil [66]. Hand weeding twice at 20 and 30 DAS resulted in maximum number of pods per plant, which was at par with two hand hoeing at 20 and 30 DAS in green gram [67] and at 25 and 45 DAS in maximum seed yield in chickpea [68] on clayey soil. The maximum number of pods per plant, number of seeds per pod and test weight with two hand weeding at 20 and 40 DAS on clay loam soil [69].

Intercultural operations: The maximum weed control efficiency in soybean was noted with inter-cultivation followed by hand weeding at 20 and 40 DAS [70]. More plant height, number of branches per plant and dry matter per plant were recorded with inter-cultivation and hand weeding at 15 and 30 DAS over rest of the treatments in soybean on clayey soil [71]. Higher seed yield in chickpea was recorded with hand weeding + inter-cultivation at 30 and 45 DAS during *Rabi* season on loamy sand soil [72].

The mulching technique is very useful for protecting the plant roots from heat and cold, and it is used to cover soil surface around the plants to create congenial conditions for growth, which include temperature moderation, cutting back salinity and controlling weeds [73]. Chickpea crop gave significantly the maximum seed yield with two hoeing + two hand weeding, which was statistically at par with non-chemical treatments, *i.e.*, one hoeing + one hand weeding at 30 DAS with mulching of weed biomass and one hoeing + one hand weeding at 20 DAS in paired row planting + green gram with straw retained as surface mulch after harvest [74].

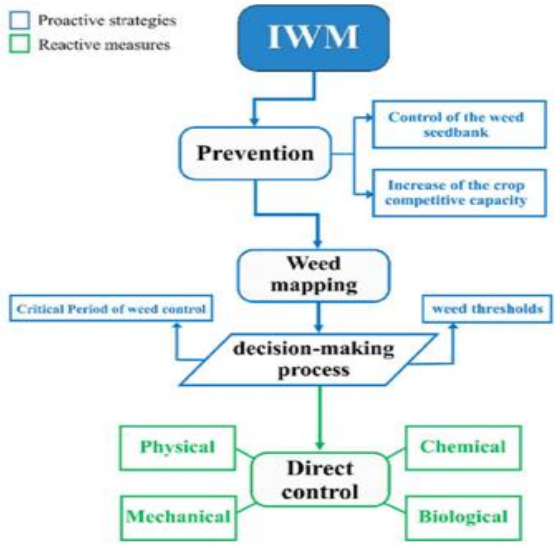

Fig. 1. Weed management strategies [80]

Integrated weed management: The minimum number of weeds m^{-2} was observed when imazethapyr was applied at the rate of 75 g ha^{-1} as post-emergence followed by hand weeding at 50 DAS [75]. Pendimethalin at the rate of 750 g ha^{-1} followed byonehand weeding at 45 days after sowing was found effective in controlling weeds [76]. The pre-emergence application of pendimethalin at the rate of 750 g ha^{-1} + hand weeding at 25-30 DAS was the best option for controlling weeds [77]. S-metolachlor at the rate of 1000 g ha^{-1} supplemented with hand weeding five weeks after emergence (WAE) resulted in minimum weeds followed by the weed free [78]. The integrated treatments performed significantly superior to alone pre-emergence application of pendimethalin 1000 g ha^{-1} followed by post-emergence application of imazethapyr 50 g ha^{-1} at 20 DAS closely followed by manual weeding at 40 DAS recorded maximum weed control efficiency and minimum weed index [79].

Studies on phytotoxicity: Pre-emergence application of pendimethalin at the rate of 1300 g ha^{-1}, S-metolachlor 960 g ha^{-1} and flumioxazin at the rate of 110 g ha^{-1} caused least phytotoxicity to common v*etc*h, lentil, chickpea or red pea [81]. The post-emergence application of quizalofop-p-ethyl at the rate of 60 g ha^{-1} showed higher dry matter accumulation as compared to application of single treatment, except some in, which crop phytotoxicity was noticed [82]. Topramezone at the rate of 40 and 60 g ha^{-1} showed phytotoxicity on crop, however, the crop growth was more vigorous after its recovery at 25 days after the application of herbicides with satisfactory toxicity on weeds [83].

2.5 Effect of Herbicides on

Weed population/ Weed density: The chickpea field treated with pendimethalin at the rate of 1250 g ha^{-1} as pre-emergence followed by one manual weeding at 40-45 DAS had minimum weed density [84]. The minimum weed density with the application of S-metolachlor at the rate of 1000 g ha^{-1} + hand weeding at five weeks after emergence [85]. The pre-emergence application of pendimethalin at the rate of 750 g ha^{-1} + one hand weeding reduced the weed density and dry weight to a minimum level [86]. The minimum weed density at harvest with hand weeding at 30 and 50 DAS as compared to chemical treatments [87]. Among weed control treatments, hand weeding twice at 30 and 50 DAS recorded significantly minimum weed density, whereas among herbicidal treatments, the minimum weed density was recorded with pendimethalin at the rate of 1000 g ha^{-1} being at par with oxyfluorfen 150 g ha^{-1} [88]. Pre-emergence application of pendimethalin at 800 g ha^{-1} followed by post-emergence (25 DAS) application of propaquizafop 2.5% + imazethapyr 3.75% (RM) at 125 g ha^{-1} was the most effective weed management practice for controlling complex weed flora of chickpea in term of reducing weed density, weed dry weight and weed index or having highest weed control efficiency [89].

Weed index: The combined pre- and post-emergence application of pendimethalin at the rate of 600 g $ha^{-1}$and imazethapyr at the rate of 60 g ha^{-1} at 20 DAS recorded significantly higher chickpea seed yield with higher weed control efficiency and weed index as compared to other weed management practices, which was at par with pre- and post-emergence application of pendimethalin at the rate of 600 g ha^{-1} + imazethapyr at the rate of 40 g ha^{-1}at 20 DAS [90]. The minimum weed index was observed in plots where oxyflourfen was applied at the rate of 150 g ha^{-1} as post-emergence 40 DAS [91].

Weed control efficiency: Pendimethalin at the rate of 1000 g ha^{-1}as pre-emergence in the chickpea + mustard intercropping system generated the maximum weed-control efficacy [92]. The pre-emergence application of pendimethalin 38% at the rate of 750 g ha^{-1}+ hand weeding at 30 to 35 DAS recorded the maximum weed control efficiency [93]. The weed control efficiency was recorded maximum next to the weed free (100%) treatment in treatment like pendimethalin at the rate of 1000 g ha^{-1} + one hand weeding at 45 DAS during the year experimentation [94]. Hand weeding at 25 DAS resulted in maximum weed control efficiency (100%) followed by oxyfluorfen at the rate of 180 g ha^{-1} as pre-emergence and pre-mix (imazamox + imazethaypr) at the rate of 30 g ha^{-1} [95]. Hand weeding twice between 30-35 and 60-65 DAS produced the maximum weed control effectiveness (WCE) in Bengal gram [96]. Among the weed management practices, weed free and the treatment pendimethalin as pre-emergence at the rate of 1000 g ha^{-1} + one hoeing 35 DAS were recorded minimum weed dry weight, weed index and maximum weed control efficiency [97].

Yield attributes and yield: The pre-emergence application of oxyfluorfen at the rate of 125 g ha^{-1} + metribuzin at the rate of 350 g ha^{-1} increase in the yield of chickpea notably over the control [98]. Pre-emergence application of herbicides, such as oxyflourfen, pendimethalin, *etc*. had positive impact on yield and yield attributes of chickpea due to the control of weeds at early stage of crop growth and they further observed minimum values of yield attributes, *viz*. number of pods per plant, number of seeds per pod and test weight under weedy check plot [99]. Among the treatments, hand weeding + inter-culture at 30 and 45 DAS established its superiority by recording significantly the maximum seed yield and the second-best treatment emerged out from the study was pendimethalin at the rate of 1000 g ha^{-1}as pre-emergence + two inter-culture at 30 and 45 DAS, which recorded seed yield, closely followed by pendimethalin at the rate of 750 g ha^{-1}as pre-emergence + two inter-culture at 30 and 45 DAS [100]. The weed free plot was recording higher grain yield but it was economically similar to the treatment pendimethalin at the rate of 1000 g ha^{-1}+ one hoeing 35 DAS [101]. The maximum seed, Stover and biological yield was obtained from the field treated with pre-emergence application of pendimethalin at the rate of 1000 g ha^{-1}+ quizalofop at the rate of 60 g ha^{-1} as post-emergence, which was at par with pendimethalin at the rate of 1000 g ha^{-1} + imazethapyr at the rate of 40 g ha^{-1} [102]. The maximum yield with post-emergence application of pyridate and pre-emergence application of oxyfluorfen at the rate of 125g ha^{-1}, which was similar to the weed free condition [103].

Economics: The pre-emergence application of pendimethalin at the rate of 1000 g ha^{-1} gave maximum weed-control efficiency, net returns and benefit to cost ratio in chickpea + mustard intercropping system [104]. The pre-emergence application of oxyfluorfen at the rate of 80 g ha^{-1} followed by hand weeding at 30 DAS recorded higher net returns with higher benefit to cost ratio [105]. The maximum net monetary returns and benefit to cost ratio was recorded under pre-emergence application of pendimethalin 30EC + imazethapyr 2 EC [106]. The maximum net monetary returns and benefit to cost ratio with two hand weeding followed by pendimethalin + hand weeding and pendimethalin + hand hoeing [107]. The higher net returns and benefit to cost ratio with post-emergence application of imazethapyr at the rate of 55 g ha^{-1}, followed by pre-emergence application of pendimethalin at the rate of 750 g ha^{-1} [108]. The maximum net profit, gross return and benefit to cost ratio was obtained under weed free treatment and the higher benefit to cost ratio may be attributed due to higher seed yield under the combination of lower cost chemical treatment [109]. Among the herbicide treatments, pre-emergence application of pendimethalin 38.7% 800 g ha^{-1}followed by propaquizafop 2.5% + imazethapyr 3.75% (RM) at the rate of 125 g ha^{-1}as post-emergence at 25 DAS was found to be the most effective weed management practice for controlling complex weeds in term of grain yield, net return and benefit to cost ratio [110].

3. CONCLUSION

One serious issue that can lower output in many pulse crops by 20-90% is weeds. Weeds reduce crop yields by competing with crops for resources like light, water, space, nutrition, etc. Pulses are a highly diversified agricultural resource that is heavily compressed by weed stress. Therefore, switching to the usage of more recent herbicides is essential for better weed control. It is impossible for a single pesticide to eradicate every kind of weed. Various pre- and post-emergence herbicides have been incorporated into the current setup, and the cultural technique is helpful for effective weed management. Pre-emergence herbicides like pendimethalin, quizalofop *etc*., and post-emergence herbicides like imazethapyr, imazamox and topramezone *etc*., incorporated with hand weeding at critical crop-weed competitionperiod is very effective to manage the weeds in chickpea crop.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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