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KV Hirapara
Ph.D. Scholar, Department of Agronomy, Junagadh Agricultural University, Junagadh, Gujarat, India

PK Chovatia
Associate Professor, Department of Agronomy, College of Agriculture, JAU, Junagadh, Gujarat, India

JB Gajera
Ph.D. Scholar, Department of Agronomy, Junagadh Agricultural University, Junagadh, Gujarat, India

Corresponding Author:
KV Hirapara
Ph.D. Scholar, Department of Agronomy, Junagadh Agricultural University, Junagadh, Gujarat, India

Enhancing productivity of pigeon pea (*Cajanus cajan* L.) by weed management under climate crisis condition

KV Hirapara, PK Chovatia and JB Gajera

Abstract
On calcareous clayey medium black soil in Junagadh (Gujarat, India), a field investigation was conducted throughout the seasons of *kharif* and *rabi*, 2021–22 and 2022–23 to investigate the effects of various pre and post–emergence herbicides on pigeon pea and their combination with hand weeding. Pre-emergence application of pendimethalin 1000 g/ha *fb* IC & HW at 30 and 60 DAS was found to be equally effective as weed free in controlling weeds and improving growth, yield attributes, yield and quality parameter *viz*., plant height, branches/plant, number of pods/plant, seed and stalk yields and protein content in seed, subsequently oxyfluorfen 180 g/ha as pre-emergence(PE) *fb* IC & Hand weeding at 30 and 60 DAS and IC & Hand weeding at 20 & 45 DAS *fb* glyphosate 900 g/ha or glufosinate ammonium 400 g/ha as post-emergence(PoE) at 75 DAS. Whereas, highest net economic return (Rs. 136215/ha) and B:C (3.38) was noted in with application of pendimethalin 1000 g/ha as pre-emergence *fb* IC and HW at 30 and 60 DAS.

Keywords: Pigeon pea, herbicides, yield and economics

Introduction
In underdeveloped nations like India, where it enhances cereal-based diets by enhancing their nutritional value, pigeon pea [*Cajanus cajan* (L.) Millsp.] is essential to human nutrition. The primary source of nutritional protein, it is crucial to Indian agriculture. Since it is suited to tropical and subtropical climates, pigeon pea thrives in areas with poor soils, little fertilizer application and inconsistent or insufficient moisture supply, even in drought-prone areas. Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, Bihar and Gujarat are the top-grower states make up the 4.72 million ha that India occupies, with an output of 4.31 million tonnes(Mt) and 914 kg/ha of productivity (Anon., 2021a) [1]. Gujarat has a 2.41 lakh ha pigeon pea cultivation area, producing 2.85 lakh tonnes at an usual output of 1185 kg/ha (Anon., 2021b) [2].
Weed is the most important out of the several biotic variables that are restricting the productivity and output of pigeon peas. In India, weeds generally lower agricultural production by 37% to 45%. According to Tomar *et al*. (2003) [13], the first 55 DAS are the utmost important for crop-weed antagonism in pigeon pea. The longer the weed interference lasts, the more of a depressing effect it has on the plant's height, integer of branches, and total of leaves. In addition, weeds serve as the primary host for a number of insect pests and the carriers of several significant pathogens that affect pigeon pea. Therefore, the most important productivity component in the cultivation of pigeon pea is weed control. Due to prolonged rain and a lack of labour throughout the crucial time of crop-weed competition period (CWCP), manual & mechanical weeding is challenging.
In recent years, the intense use of herbicides in agriculture has gained appeal because to its cheaper cost, quick and simple application, and efficiency in weed control. Climate change-related changes to the growing environment will have an impact on the distribution and dominance of plant species as well as biodiversity. It is probable that with an altered environment, weed populations will also become more variable and so more competitively suited versus agricultural plants. It's conceivable that the indirect effects of climate change will often outweigh the direct effects in many situations. In order to increase pigeon pea produce in the face of climate change, effective weed management strategies must be evaluated.

Materials and Methods
The above field research was carried out at the main campus of SAU-Junagadh Agricultural University, Junagadh (Gujarat state of India) during *kharif* season of 2021-22 and 2022-23. Geographically, Junagadh is situated in 21.50° North latitude and 70.50° East longitude, and it is 60 m above mean sea level.

The investigational soil had a pH of 8.18, an EC of 0.48 dS/m, was somewhat alkaline, had low available nitrogen content of 248 kg/ha, a medium available phosphorus content of 39 kg/ha, and a high available potash content of 270 kg/ha. During the crop season, the mean maximum and minimum temperatures varied from 25.7 to 36.5 °C and 09.4 to 26.6 °C, respectively. The relative humidity extended between 57 & 95% during the crop season. Hours of direct sunlight, wind speed, and daily evaporation ranged from 0.0 to 10.1, 2.2 to 8.9, and 1.2 to 06.3 mm/day, respectively. Ten treatments were used in the experiment *viz*., T_1: Pendimethalin 1000 gram/ha as pre-emergence (PE) *fb* IC and Hand weeding at 30 and 60 DAS, T_2: Oxyfluorfen 180 gram/ha as pre-emergence *fb* IC and Hand weeding at 30 & 60 DAS, T_3: IC and Hand weeding at 20 DAS *fb* quizalofop-ethyl 40 gram/ha as post-emergence (PoE) at 50 days after sowing, T_4: IC & Hand weeding at 20 DAS *fb* imazethapyr 75 gram/ha as post-emergence at 50 days after sowing, T_5: IC & Hand weeding at 20 days after sowing *fb* propaquizafop 75 gram/ha as post-emergence at 50 days after sowing, T_6: IC & Hand weeding at 20 and 45 days after sowing *fb* paraquat 300 gram/ha as post-emergence at 75 days after sowing (directed spray), T_7: IC & Hand weeding at 20 and 45 days after sowing *fb* glyphosate 900 gram/ha as post-emergence at 75 days after sowing (directed spray), T_8: IC & Hand weeding at 20 and 45 days after sowing *fb* glufosinate ammonium 400 gram/ha as post-emergence at 75 days after sowing (directed spray), T_9: Weed-free check and T_{10}: Unweeded control, was outlay in randomized block design (RBD) by 3 replications. Pigeon pea cultivar "GJP-1" was seeded with a seed requirement of 12 kg/ha at 90 cm x 20 cm spacing. Using urea and a single superphosphate, the required fertilizer dosage of 25 kg nitrogen/ha, 50 kg phosphorus/ha, and 0 kilogram potash/ha was applied during sowing. In the experimental site, monocot weeds made up the majority of the weed flora *viz*., *Brachiaria ramosa* (L.) Stapf, *Eluropus villosus* Hook. f, *Dactyloctenium aegyptium* L. and *Echinochloa colona* L.; dicot weeds *viz*., *Digera arvensis* F., *Indigofera glendulosa* L., *Leucas aspera* Link., *Euphorbiya hirta* L., *Phyllanthus niruri* L., *Commelina nudiflora* L. and *Tridax procumbens* L.; plus sedge *viz*., *Cyperus rotuendus* L.

Results and Discussion

Effect on growth parameters

Other than the weed-free check (T_9), higher growth parameters, such as plant height at 60 DAS (73.94 cm), 90 DAS (135.67 cm), at harvest (196.90 cm), & integer of branches/plant at harvest (16.88), were perceived under pendimethalin 1000 gram/ha as pre-emergence *fb* IC & Hand weeding at 30 and 60 days after sowing (T_1), being at par with oxyfluorfen 180 gram/ha as pre-emergence *fb* IC & Hand weeding at 30 and 60 DAS (T_2), IC and Hand weeding at 20 and 45 DAS *fb* glyphosate 900 gram/ha as post-emergence at 75 DAS (T_7) and IC & HW at 20 and 45 DAS *fb* glufosinate ammonium 400 gram/ha as post-emergence at 75 days after sowing (T_8). However, in the unweeded control (T_{10}), the considerably lowest values of these growth metrics were recorded. Less crop-weed competition throughout the crop's development phase is evidence that the use of herbicides in combination with manual weeding in these treatments improved weed control from the outset. Enhanced cell division, multiplication, and elongation as a result of enhanced water and nutrient intake led to a rise in growth character. This increase in growth character may have been caused by accelerated photosynthetic rate, which would have boosted the supply of carbohydrates. The results corroborate the findings of Kaur *et al.* (2015) [4], Nambi (2017) [6] and Keer *et al.* (2020) [5].

Effect on yield attributes and yield

An analysis of the figures (Table 1) showed that the weed-free check (T_9) was considerably associated with a higher average number of pods per plant (262.52), which remained statistically comparable to pendimethalin 1000 gram/ha as pre-emergence (PE) *fb* IC & Hand weeding at 30 and 60 days after sowing (T_1), oxyfluorfen 180 gram/ha as pre-emergence *fb* IC & Hand weeding at 30 and 60 days after sowing (T_2), IC & HW at 20 and 45 DAS *fb* glyphosate 900 gram/ha as post-emergence at 75 days after sowing (T_7) and IC & HW at 20 and 45 DAS *fb* glufosinate ammonium 400 gram/ha as post-emergence at 75 days after sowing (T_8) in collective results. But, different treatments of weed management did not influence integer of seeds per pod and 100-seed weight. However, numerically highest number of seeds per pod and 100-seed weight were found with the weed free check (T_9), followed by pendimethalin 1000 gram/ha as pre-emergence *fb* IC & Hand weeding at 30 and 60 days after sowing (T_1).

A closer look at the statistics (Table 1) also showed that the weed-free treatment (T_9) demonstrated its dominance by the maximum pigeon pea seed yield (3153 kg/ha), though it was found statistically equivalent with the pendimethalin 1000 g/ha as pre-emergence *fb* IC & HW at 30 and 60 days after sowing (T_1), oxyfluorfen 180 gram/ha as pre-emergence (PE) *fb* IC & Hand weeding at 30 and 60 days after sowing (T_2) and IC & Hand weeding at 20 and 45 days after sowing *fb* glyphosate 900 g/ha as post-emergence at 75 days after sowing (T_7). In contrast, the aggregated findings showed that the unweeded control (T_{10}) had considerably less pods per plant (216.12) and a lower pigeon pea seed yield (1911 kg/ha). The extent of escalation in pigeon pea seed yield with treatments T_9, T_1, T_2 and T_7 was 65.00, 61.69, 59.18 and 54.09 per cent, respectively over the treatment T_{10} (Unweeded control).

It's noteworthy that the weed-free check (T_9) yielded the highest pigeon pea stalk production (7813 kg/ha), and it was originate statistically related to the treatments comprising pendimethalin 1000 gram/ha as pre-emergence (PE) *fb* IC & Hand weeding at 30 and 60 days after sowing (T_1), oxyfluorfen 180 gram/ha as pre-emergence *fb* IC & Hand weeding at 30 and 60 DAS (T_2), IC & Hand weeding at 20 and 45 DAS *fb* glyphosate 900 g/ha as post-emergence at 75 days after sowing (T_7) and IC & HW at 20 and 45 days after sowing *fb* glufosinate ammonium 400 gram/ha as post-emergence at 75 days after sowing (T_8). The range of surge in stalk yield with the treatments T_9, T_1, T_2, T_7 and T_8 was 32.26, 27.18, 24.13, 22.03 and 20.11 per cent, respectively over the unweeded control (T_{10}).

The increased yields under these treatments may have contributed to a decrease in crop-weed competition and a reduction in the stress that plants experience from nutrition, moisture, light, and space shortages. These assisted the plant in setting ideal development conditions. Additionally, it may have boosted photosynthetic activity and assimilate partitioning, resulting in better yield qualities that were positively connected with seed production and clearly led to greater seed output under the aforementioned treatments. The

unweeded control (T_{10}) had significantly lower seed and stalk yields than other scenarios. Poor yields might have been caused by a crop under unweeded management experiencing stunted growth and development as a result of intense resource competition between the crop and weeds. The existent results are within the close locality of those described by Rathod *et al.* (2016) [9], Reddy *et al*. (2016) [10] and Yende *et al.* (2019) [14].

Table 1: Effect of different treatments on growth and yield parameters of pigeon pea (Pooled over two years)

Treatments	Plant height (cm)			Branches/ plant	Pods/ plant	Seeds/ pod	100-seed weight (g)
	60 DAS	90 DAS	Harvest				
T_1: Pendimethalin 1000 gram/ha as PE *fb* IC & HW at 30 and 60 DAS	73.94	135.67	196.90	16.88	259.38	3.87	11.77
T_2: Oxyfluorofen 180 gram/ha as PE *fb* IC & HW at 30 and 60 DAS	71.79	133.27	194.52	15.90	254.74	3.85	11.72
T_3: IC & HW at 20 DAS *fb* Quizalofop-ethyl 40 gram/ha as PoE at 50 DAS	64.47	117.57	170.98	12.20	222.75	3.60	11.30
T_4: IC & HW at 20 DAS *fb* Imazethapyr 75 gram/ha as PoE at 50 DAS	66.20	118.47	176.74	13.00	232.10	3.66	11.42
T_5: IC & HW at 20 DAS *fb* Propaquizafop 75 gram/ha as PoE at 50 DAS	65.90	118.19	173.01	12.67	226.89	3.63	11.35
T_6: IC & HW at 20 and 45 DAS *fb* Paraquat 300 gram/ha as PoE at 75 DAS (directed spray)	67.50	119.64	179.31	13.32	233.32	3.69	11.50
T_7: IC & HW at 20 and 45 DAS *fb* Glyphosate 900 gram/ha as PoE at 75 DAS (directed spray)	69.95	130.60	191.76	15.38	247.43	3.80	11.64
T_8: IC & HW at 20 and 45 DAS *fb* Glufosinate ammonium 400 gram/ha as PoE at 75 DAS (directed spray)	70.17	124.47	184.88	13.78	243.33	3.77	11.54
T_9: Weed free check	74.98	139.29	199.34	17.65	262.52	3.91	11.91
T_{10} : Unweeded control	61.67	115.94	164.79	11.29	216.12	3.50	10.82
S.Em.±	1.85	3.88	5.18	0.63	6.80	0.14	0.44
C.D. at 5%	5.30	11.13	14.87	1.79	19.51	NS	NS
C.V.%	6.59	7.58	6.93	10.79	6.95	8.90	9.41

PE: Pre-emergence, PoE: post-emergence, HW: Hand weeding, IC: Interculturing and DAS: Days after sowing

Effect on quality parameter

Different weed control techniques have a substantial impact on the protein content of seeds. Weed-free check (T_9) resulted in noticeably greater protein content in seed, which stayed statistically analogous with pendimethalin 1000 gram/ha as pre-emergence (PE) *fb* IC & Hand weeding at 30 and 60 days after sowing (T_1) & oxyfluorfen 180 gram/ha as pre-emergence(PE) *fb* IC & Hand weeding at 30 and 60 days after sowing (T_2) in pooled outcomes. The unweeded control (T_{10}), however, had the lowest protein content (17.86%) by a substantial margin. This can be attributed to more effective weed management using hand weeding and herbicides as opposed to the un-weeded situation, which may have boosted crop uptake of nitrogen and water and decreased weed uptake,, which in turn increased amino acid synthesis and seed protein content. These results are in orthodoxy with those testified by Pradhan *et al.* (2010) [8] and Singh and Sandya, (2016) [11].

Effect on economics

The maximum net realization (₹136215/ha) and BCR (3.38) were achieved with pendimethalin 1000 gram/ha as Pre-emergence (PE) *fb* IC & Hand weeding at 30 and 60 days after sowing (T_1), closely afterward with oxyfluorfen 180 gram/ha as pre-emergence (PE) *fb* IC & Hand weeding at 30 and 60 days after sowing (T_2) and IC & Hand weeding at 20 and 45 days after sowing *fb* glyphosate 900 gram/ha as Post-emergence (PoE) at 75 DAS (T_7). This might be as a result of weeds being effectively and efficiently controlled by combining manual weeding with pre-&post-emergence herbicides. The fact that these treatments were more cost-effective than hand weeding was another factor in the greater advantages that were attained. In contrast, the unweeded control (T_{10}) recorded the lowest net returns and BCR, This may be caused by exceptionally low seed and stalk yields driven on by a weed infestation. The outcomes are on line by those of Suman *et al*. (2017) [12], Pagar *et al*. (2019) [7] and Singh *et al*. (2020).

Effect on Weed Control Efficiency

The average weed control effectiveness (WCE) data shown in Table 2 revealed that, beside the weed-free check (T_9), higher WCE (89.06%) noticed in pendimethalin 1000 gram/ha as pre-emergence *fb* IC & Hand weeding at 30 and 60 days after sowing (T_1), charted by treatments *viz*., oxyfluorfen 180 gram/ha as pre-emergence *fb* IC & Hand weeding at 30 and 60 days after sowing (T_2) and IC & Hand weeding at 20 and 45 days after sowing *fb* glyphosate 900 gram/ha as post-emergence at 75 days after sowing (T_7) by recording WCE of 87.08 and 82.27%, respectively. Dhonde *et al*. (2009) [3] also reported analogous results.

Table 2: Effect of different treatments on yields, quality and economics of pigeon pea (Pooled over two years)

Treatments	Yield (kg/ha)		Protein content (%)	Net returns (₹/hectare)	BCR	WCE (%)
	Seed	Stalk				
T_1: Pendimethalin 1000 gram/ha as PE *fb* IC & HW at 30 and 60 DAS	3090	7513	22.94	136215	3.38	89.06
T_2: Oxyfluorofen 180 gram/ha as PE *fb* IC & HW at 30 and 60 DAS	3042	7333	22.02	133094	3.33	87.08
T_3: IC & HW at 20 DAS *fb* Quizalofop-ethyl 40 gram/ha as PoE at 50 DAS	2219	6011	18.08	90575	2.82	47.45
T_4: IC & HW at 20 DAS *fb* Imazethapyr 75 gram/ha as PoE at 50 DAS	2471	6330	18.97	105764	3.13	61.47
T_5: IC & HW at 20 DAS *fb* Propaquizafop 75 gram/ha as PoE at 50 DAS	2370	6094	18.22	99468	3.00	50.49
T_6: IC & HW at 20 and 45 DAS *fb* Paraquat 300 gram/ha as PoE at 75 DAS (directed spray)	2599	6640	19.20	108083	2.95	69.82
T_7: IC & HW at 20 and 45 DAS *fb* Glyphosate 900 gram/ha as PoE at 75 DAS (directed spray)	2944	7209	21.58	128117	3.28	82.27
T_8: IC & HW at 20 and 45 DAS *fb* Glufosinate ammonium 400 gram/ha as PoE at 75 DAS (directed spray)	2758	7096	19.63	116098	3.02	74.56
T_9: Weed free check	3153	7813	23.26	132592	3.04	99.21
T_{10}: Unweeded control	1911	5907	17.86	80868	2.93	0
S.Em.±	118	294	0.43	-	-	-
C.D. at 5%	340	843	1.25	-	-	-
C.V.%	10.92	10.60	5.28	-	-	-

PE: Pre-emergence, PoE: post-emergence, HW: Hand weeding, IC: Interculturing and DAS: Days after sowing

Conclusion

Built on the combined findings of a two-year field trial, it has been determined that, greater yield and economical production in *kharif* pigeon pea in South Saurshtra Agro_climatic Zone can be achieved through either use of the pendimethalin 1000 gram/ha as pre emergence (PE) *fb* IC *&* Hand weeding at 30 and 60 days after sowing or oxyfluorfen 180 gram/ha as pre emergence (PE) *fb* IC & Hand weeding at 30 and 60 days after sowing according to availability of labourers.

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