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RESEARCH ARTICLE

Optimizing spacing, varietal selection and weed management for enhanced growth and yield of finger millet crop

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Abstract

An experimental trial was conducted during *Kharif* 2023 and 2024 at the research farm of the Advanced Centre for Rainfed Agriculture, Dhiansar, SKUAST-Jammu, to evaluate the impact of spacing, varieties and weed management practices on the productivity of finger millet. Among the tested spacings, 20 cm × 5 cm recorded the lowest total weed density and dry weight of weeds compared to 30 cm × 10 cm spacing. This closer spacing also resulted in higher crop growth and yield parameters, suggesting its suitability for enhancing productivity. However, while 20 cm × 5 cm spacing improved plant density and yield per unit area, it may also lead to increased competition for nutrients and moisture, necessitating balanced nutrient and water management for sustainable cultivation. Among the varieties tested, VL Mandua 379 exhibited significantly superior growth and yield performance. In terms of weed management, the application of Oxyfluorfen @ 80 g ha^{-1} as a pre-emergence herbicide followed by Bispyribac sodium @ 20 g ha^{-1} as a post-emergence herbicide effectively suppressed weed density and biomass, leading to significantly higher growth and yield. This treatment also recorded the maximum weed control efficiency and lowest weed index, highlighting its effectiveness in reducing weed competition. These findings emphasize the importance of optimized spacing, variety selection and integrated weed management in improving finger millet productivity under rainfed conditions in the Jammu region.

Keywords

finger millet; growth; spacing; varieties; weed management; yield

Introduction

The Green Revolution in India emphasized the large-scale production of staple cereal crops such as wheat and rice, leading to a decline in millet cultivation and consumption (1). However, millets, including finger millet (*Eleusine coracana*), are nutritionally superior to many cereals, being rich in iron, zinc and calcium. They are also gluten-free and have a low glycemic index, making them a valuable alternative for food security and improved nutrition (2). With increasing concerns over climate change, soil degradation and resource-intensive agricultural practices, there is an urgent need to promote sustainable crop alternatives that require minimal inputs while maintaining high nutritional value.

Recognizing these challenges, the Government of India has prioritized sustainable agriculture as a key strategy for ensuring food security and environmental resilience. Finger millet stands out due to its drought tolerance, ability to thrive in marginal soils and lower dependence on chemical inputs (3). These attributes make it an ideal crop for rainfed regions. However, despite its agronomic and nutritional advantages, finger millet cultivation remains limited due to challenges such as weed competition, suboptimal plant spacing and a lack of high-yielding varieties suited for rainfed conditions. Addressing these constraints is crucial for enhancing yield potential and promoting the wider adoption of finger millet, particularly in the rainfed regions of Jammu.

Among these challenges, weed infestation is a major limiting factor in finger millet production. The crop has a slow initial growth, making it highly vulnerable to weed competition during early developmental stages (4). Weeds compete for water, nutrients, space and sunlight, leading to yield reductions of up to 20-50 % (5). Additionally, high weed density reduces plant population, biomass accumulation and nutrient uptake efficiency (6). Traditionally, manual weeding has been the primary method of weed control, but it is labor-intensive, time-consuming and often ineffective during the rainy season, when peak weeding coincides with critical crop growth stages. Furthermore, labor shortages during these periods further limit effective weed management (7). Thus, adopting improved weed management strategies is essential to enhance productivity while reducing labor dependency and production costs.

Crop spacing is another critical factor that influences finger millet growth, resource efficiency and yield potential. Proper spacing not only enhances light interception, nutrient uptake and moisture availability but also suppresses weed competition by reducing open spaces for weed emergence (8). Likewise, the choice of variety plays a crucial role in determining yield outcomes, as different cultivars exhibit varied responses to environmental conditions, soil fertility and management practices (9). Despite these well-documented influences of spacing and variety selection, limited research has explored their combined effects with weed management strategies under rainfed conditions in the Jammu region. This study aims to fill this gap by evaluating optimal plant spacing, identifying the most suitable variety and determining the most effective weed management strategies to enhance finger millet productivity in this region.

Research objectives

Considering the agronomic significance of finger millet and the challenges associated with its cultivation, this study aims to:

1. Evaluate the effect of different plant spacing configurations on growth and yield performance under rainfed conditions.
2. Assess the impact of various weed management strategies on weed suppression, crop health and productivity.
3. Identify the most suitable finger millet variety that exhibits high yield potential and stress tolerance in rainfed conditions of Jammu.

Materials and Methods

A field experiment was conducted during *kharif* 2023 and 2024 at the research farm of Advance Centre for Rainfed Agriculture, Dhiansar, SKUAST-Jammu. The soil was sandy loam in texture, slightly acidic to neutral in reaction (*p*H 6.64) with electrical conductivity of 0.25 dS/m, low in organic carbon (2.53 g/kg), available nitrogen (165.68 kg/ha) and potassium (99.80 kg/ha) but medium in available phosphorus (14.62 kg/ha) which influences both crop performance and weed growth. The experiment was laid out in factorial randomized block design with three replications. The treatments consisted of two spacings, *viz*., 30 cm x 10 cm and 20 cm x 5 cm, two varieties VL Mandua 382 and VL Mandua 379 and five weed management practices Weedy check, weed free, Oxyflourfen (80 g ha^{-1}) pre-emergence, Bispyribac sodium (20 g ha^{-1}) post-emergence and pre-emergence followed by post emergence. The crop was fertilized with 60:30:30 kg of $N:P_2O_5:K_2O$/ha. Full doses of phosphorus and potassium along with half dose of nitrogen were applied as basal dose at the time of sowing. Remaining half dose of nitrogen was applied at 30 days after sowing. Pre-emergence herbicide was applied on the same day of sowing while post-emergence herbicide was applied within 20-25 days after sowing with the help of knapsack sprayer. Weedy check plots remained infested with native population of weeds till harvest.

Data collected on various growth, yield and weed-related parameters were subjected to statistical analysis using Analysis of Variance (ANOVA) to determine the significance of treatment effects. Differences among treatment means were further analyzed using Least Significant Difference (LSD) test at a 5 % level of significance ($p < 0.05$). Statistical analysis was performed using OPSTAT to ensure accurate interpretation of results.

The weed count and weed dry matter accumulation were recorded using quadrate of 1 m^2 size using a randomly placed quadrat method. The quadrat placed randomly in plots for each observation to capture spatial variation in weed distribution. The weeds were dried in oven till a constant weight was observed and then transformed into g/m^2 by using the appropriate formula. The data on weed count and weed dry weight were subjected to square root transformation ($\sqrt{x+1}$) to normalize their distribution (10). Weed control efficiency (WCE), Weed index (WI) were worked out by the formula given (11). Plant height was recorded by measuring the height from ground surface to the tip of the plant with the help of wooden scale and for dry matter accumulation 1m row length was cut with the help of sickle from above ground surface and oven dried at 60 °C till their constant weight. The crop was harvested from the net plot with the help of sickle after 107 days. Due to difference in maturity of all panicles, the early matured panicles were harvested first and then remaining panicles were harvested after 5-7 days to prevent the loss of panicles from birds' attack or scattering of grain due to over mature. After that, the straw was harvested alone with sickle and both grain yield and straw yield were recorded.

Mechanism of herbicides

1. *Oxyflourfen*:

Uses: Oxyfluorfen used to control broad leaf and grassy weeds. It is also used for residential weed control.

Mode of action: It is a contact herbicide. It forms a barrier on the surface of the targeted weed, inhibiting its ability to photosynthesize. Herbicide disrupts the electron transport chain in chloroplasts, leading to the accumulation of free radicals and ultimately causing cell membrane damage in the weed's foliage.

2. Bispyribac sodium

Uses: It is a broad-spectrum herbicide used to control grass, sedges and broad leaf weeds. It is systemic in nature and applied as a post emergence. It is broadly used in rice crops to control the weeds.

Mode of action: It is inhibition of acetolactate synthase or acetohydroxyacid synthase (AHAS). Plants and microorganisms both have acetolactate synthase enzyme that facilitate synthesis of branched chain amino acid. Thus, this herbicide hinders the regular protein synthesis of weeds and finally kills them.

Potential resistance risks

Bispyribac-sodium is classified as a Group 2 herbicide by the Weed Science Society of America (WSSA), targeting the acetolactate synthase (ALS) enzyme. Repeated application of ALS-inhibiting herbicides can lead to the selection of resistant weed populations. For instance, resistance to ALS inhibitors has been confirmed in terrestrial species, highlighting the importance of rotating herbicides with different modes of action to mitigate resistance development.

Similarly, continuous use of oxyfluorfen, a protoporphyrinogen oxidase (PPO) inhibitor, may also contribute to resistance if not managed properly. Although specific cases of oxyfluorfen resistance are less documented, relying solely on a single herbicide increases the risk over time.

Results and Discussion

Weed parameters

Weed flora, Weed density (m^{-2}) and Weed dry weight (g m^{-2}): The data presented in Table 1 represents the weed flora associated with finger millet crop. Total ten weed species were observed in the experimental field out of them three were broad leaved weeds, two were sedges and five were grasses. Broadleaf weed species predominated throughout the crop's growing period. The results are proximity to the previous findings (12-14).

The data presented in Table 2 showed that experimental field was predominantly infested with grasses followed by broad leaved weed and sedges. Narrow spacing (20 cm × 5 cm) recorded significantly lowest weed density (8.89 and 10.18), weed dry weight at harvest (10.62 gm^{-2} and 11.90 gm^{-2}) and low weed index (19.95 and 21.71) over wider spacing (30 cm × 10 cm). This could be due to the narrow spacing, which enhances light interception by the plants, reducing sunlight availability for weed growth beneath the crop canopy and boosting the crop's ability to suppress weeds. These findings align with earlier observations (15, 16). Comparing varieties the results were non-significant during both years while among weed management practices, significant difference existed among the treatments. Weed free treatment exhibited the lowest weed density, weed dry weight and weed index, along with the highest weed control efficiency, outperforming all other treatments. Among the herbicidal practices, the pre-emergence application of Oxyflourfen @ 80 g ha^{-1} followed by post-emergence application of Bispyribac sodium @ 20 g ha^{-1} demonstrated superior performance with the lowest weed density (5.14 and 7.56), weed dry weight (9.96 and 11.07), weed index (11.19 and 10.40) and the highest weed control efficiency (62.01 and 56.46) during both years of experimentation, shown in Table 2. Similar findings were previously reported (17, 18).

Interaction effect on weed density and dry matter of weeds **:** The interaction effect of spacing and weed management practices significantly influenced the weed density and dry weight of weeds. The lowest weed density and weed dry weight was found in finger millet sown at spacing of 20 cm × 5 cm with the application of Oxyflourfen @ 80 g ha^{-1} followed by post-emergence application of Bispyribac sodium @ 20 g ha^{-1}. The finding clearly indicated that density of crop population with appropriate weed management strategy suppress the weed dynamics. The interaction between spacing and weed management was in correlation with prior reports (19, 20).

Growth parameters

Plant height (cm) and Dry weight (g m^{-2}) : The results presented in Table 3 and Fig. 1 revealed that the highest growth parameters *viz*., plant height (73.61 cm and 65.98 cm) and dry matter (450.12 and 439.32) during both years were observed under the 20 cm × 5 cm spacing during both years. This is

Table 1. Major weed flora found in experimental field area

S. N.	Scientific Name	Common/Local Name	English Name	Family	Habitat
1.	**Broad Leaved**				
	i. *Commelina benghalensis*	Kanshira, Wandering Jew	Day Flower, Tropical Spiderwort	Commelinaceae	Perennial
	ii. *Physalis angulata*	Wild tomato, Gooseberry	Balloon cherry	Solanaceae	Annual
	iii. *Ipomoea pes-tigridis*	Tiger's footprint	Bindweed, Morning glory	Convolvulaceae	Annual
2.	**Sedges**				
	i. *Cyperus rotundus*	Motha	Purple Nutsedge, Nutgrass	Cyperaceae	Perennial
	ii. *Cyperus esculentus*	Tiger nut, Chichada	Earth almond, Rush nut	Cyperaceae	Annual
3.	**Grasses**				
	i. *Cynodon dactylon*	Durva grass, Dhoob	Bermuda grass, Couch grass	Poaceae	Perennial
	ii. *Echinochloa colona*	Jungle rice, Wild rice	Awnless barnyard grass	Poaceae	Annual
	iii.*Eleusine indica*	Crab grass, crowfoot grass	Indian goosegrass	Poaceae	Annual
	iv.*Bracharia ramosa*	Browntop millet	Signal grass	Poaceae	Annual
	v. *Paspalum distichum*	Knot grass, Water-finger grass	Ginger grass, Thompson grass	Poaceae	Perennial

Table 2. Effect of spacing, varieties and weed management practices on weed density (m^{-2}), weed dry weight ($g\ m^{-2}$), weed control efficiency (%) and weed index

Treatments	Weed density (m^{-2})		Weed dry weight ($g\ m^{-2}$)		Weed control efficiency (%)		Weed Index	
	2023	2024	2023	2024	2023	2024	2023	2024
Spacing (S)								
30 x 10 cm	11.25 (125.99)	12.79 (162.61)	12.36 (151.67)	12.70 (160.19)	45.47	48.36	24.30	26.53
20 x 5 cm	8.89 (78.04)	10.18 (102.59)	10.62 (111.87)	11.90 (140.68)	50.72	44.88	19.95	21.71
SEm±	1.79	2.37	2.57	2.85	--	--	--	--
CD at (5%)	5.14	6.78	7.35	8.16	--	--	--	--
Varieties (V)								
VL Mandua 382	10.14 (101.85)	11.56 (132.55)	11.52 (131.62)	12.30 (150.40)	48.21	46.61	18.21	22.07
VL Mandua 379	10.14 (102.18)	11.56 (132.65)	11.53 (131.92)	12.31 (150.48)	47.98	46.63	26.04	26.17
SEm±	1.79	2.37	2.57	2.85	--	--	--	--
CD at (5%)	NS	NS	NS	NS	--	--	--	--
Weed management (W)								
Weedy check	16.99 (288.41)	18.03 (324.06)	15.96 (253.71)	16.88 (283.84)	0.00	0.00	42.66	49.07
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	100.00	100.00	0.00	0.00
PE	11.12 (122.66)	12.83 (163.49)	12.78 (162.42)	13.71 (186.85)	35.95	33.78	32.79	36.28
PoE	8.64 (73.63)	10.97 (119.36)	12.06 (144.56)	12.68 (159.90)	42.52	42.85	23.98	24.85
W_3 *fb* W_4	5.14 (25.39)	7.56 (56.10)	9.96 (98.17)	11.07 (121.59)	62.01	56.46	11.19	10.40
SEm±	2.84	3.75	4.06	4.51	--	--	--	--
CD at (5%)	8.12	10.72	11.62	12.91	--	--	--	--
Interaction								
S × V	NS	NS	NS	NS	--	--	--	--
S × W	11.48	15.17	16.43	18.26	--	--	--	--
V × W	NS	NS	NS	NS	--	--	--	--
S × V × W	NS	NS	NS	NS	--	--	--	--

Note: Values are subjected to square root transformation (√x+1), original data given in parenthesis. PE: Pre emergence application of Oxyflourfen @ 80 g ha^{-1} and PoE: Post emergence application of Bispyribac sodium @ 20 g ha^{-1}

Table 3. Effect of spacing, varieties and weed management practices on plant height (cm), dry weight ($g\ m^{-2}$) at harvest, grain yield ($kg\ ha^{-1}$) and straw yield ($kg\ ha^{-1}$) of finger millet

Treatments	Plant height (cm)		Dry weight ($g\ m^{-2}$)		Grain yield ($kg\ ha^{-1}$)		Straw yield ($kg\ ha^{-1}$)	
	2023	2024	2023	2024	2023	2024	2023	2024
Spacing (S)								
30 x 10 cm	65.97	53.90	403.16	390.27	1503.27	1365.57	3354.60	3094.89
20 x 5 cm	73.61	65.98	450.12	439.32	1658.12	1540.98	3540.11	3296.33
SEm±	1.11	0.84	6.20	6.17	23.31	21.19	51.52	57.52
CD at (5%)	3.19	2.39	17.75	17.67	66.74	60.65	147.50	164.67
Varieties (V)								
VL Mandua 382	71.44	61.56	413.11	396.34	984.65	891.06	1715.08	1515.17
VL Mandua 379	68.14	58.32	440.16	433.26	2176.74	2015.49	5179.63	4876.05
SEm±	1.11	0.84	6.20	6.17	23.31	21.19	51.52	57.52
CD at (5%)	3.19	2.39	17.75	17.67	66.74	60.65	147.50	164.67
Weed management (W)								
Weedy check	55.41	44.37	276.14	268.53	1108.56	948.49	2926.29	2671.60
Weed free	84.32	72.30	540.11	528.39	2076.76	1941.75	3875.99	3617.55
PE	61.74	52.86	339.16	331.15	1324.56	1199.15	3326.84	3055.11
PoE	69.99	61.70	472.50	462.27	1549.93	1446.29	3418.22	3177.97
W_3 *fb* W_4	77.49	68.48	505.27	483.64	1843.67	1730.69	3689.44	3455.84
SEm±	1.76	1.32	9.80	9.76	36.86	33.50	81.46	90.94
CD at (5%)	5.05	3.78	28.07	27.93	105.52	95.90	233.22	260.37
Interaction								
S × V	NS	NS	25.11	24.99	NS	NS	NS	NS
S × W	7.14	5.35	NS	NS	NS	NS	NS	NS
V × W	NS	NS	NS	NS	149.23	135.63	NS	NS
S × V × W	NS	NS	NS	NS	NS	NS	NS	NS

because a higher plant density significantly reduces light availability for individual plants, particularly for the lower leaves due to increased shading. As mutual shading intensifies at higher densities, plants tend to grow taller. Similar observations were previously reported (21, 22). Additionally, a higher plant population resulting from closer spacing promotes tiller formation, ultimately leading to greater dry matter production, which aligns with previous findings (21-24). Variety VL Mandua 379 exhibited better performance than VL Mandua 382, likely due to its superior genetic makeup, which contributes to enhanced growth parameters (14, 25, 26). Among weed management practices application of Oxyflourfen @ 80 g ha^{-1} followed by post-emergence application of Bispyribac sodium @ 20 g ha^{-1} (W_5) demonstrated superior performance, in terms of growth parameters with the highest plant height (77.49 cm and 68.48 cm) and dry matter (505.27 and 483.64), during both years of experimentation. Similar findings were already reported (4, 13, 22).

Interaction effect on plant height of crop at harvest **:** The interaction effect of spacing and weed management practices was significantly influenced by the plant height of crop at harvest. The maximum plant height was found in finger millet sown at spacing of 20 cm × 5 cm under weed free conditions. But among herbicidal treatments the maximum height was found at spacing 20 cm × 5 cm with the pre-emergence application of Oxyflourfen @ 80 g ha^{-1} followed by post-

Fig. 1. Growth parameters: **a.** Plant height **b.** Dry matter.

emergence application of Bispyribac sodium @ 20 g ha^{-1}. The finding clearly indicated that density of crop population with appropriate weed management strategy increases the plant height (27).

Interaction effect on crop dry matter : The interaction effect of spacing and variety were significantly influenced the dry matter production of crop at harvest. The maximum dry matter production of finger millet crop at harvest was found in finger millet variety VL Mandua 382 sown at spacing of 20 cm × 5 cm. This might be due to the genetic potential of that variety which outperforms under increased plant population due to closer spacing which increased the number of tillers and eventually plant dry matter accumulation. Improvement of leaves might have increased the phorosynthetic efficiency of finger millet and have induced to produce plant dry matter production. This was accordance with the earlier findings (27).

Yield parameters

Grain yield (kg ha^{-1}) and Straw yield (kg ha^{-1}) : The data presented in Table 3 and Fig. 2 shows that the grain yield (1658.12 and 1540.98 kg ha^{-1}) and straw yield (3540.11 and 3296.33 kg ha^{-1}) were significantly highest with sowing of finger millet at 20 cm x 5 cm spacing during both years. This could be attributed to higher plant population per unit area, reduced competition from weeds due to closer spacing. Optimum plant spacing ensures adequate light penetration, reducing competition among plants. Proper spacing has been associated with higher grain and straw yield, as it facilitates better resource utilization and reduces intra-specific competition. Similar findings were reported by Shinggu and Gani 2012 (28). The differences in yield parameters can be attributed to spacing, which created optimal conditions for better growth. A higher plant population resulting from closer spacing may have led to increased dry matter production, ultimately enhancing straw yield. Similar findings were reported (24). Comparing varieties, VL Mandua 379 recorded significantly highest grain yield (2176.74 and 2015.49) and straw yield (5179.63 and 4876.05) as compared to variety VL Mandua 382, this is due to the ability of varieties to utilize the available nutrients as well as partitioning of photo-assimilates resulted in higher yields (14, 26). Among weed management practices, significantly higher grain yield (1843.67 and 1730.69) and straw yield (3689.44 and 3455.84) was recorded in Oxyflourfen @ 80 g ha^{-1} followed by post-emergence application of Bispyribac sodium @ 20 g ha^{-1} (W_5) treatment. This might be due to the effective weed control which results in lower weed population and weed biomass and created favourable conditions for crop to produce growth characters and high chlorophyll content to higher dry matter accumulation and finally higher yield. The results are in accordance with the results of previous research (29, 18). Fig. 3 depicts the general view of experimental field.

Interaction effect on grain yield : The interaction effect of variety and weed management practices were significantly influenced by the grain yield of crop at harvest. The maximum

Fig. 2. a. Grain yield and **b.** Straw yield.

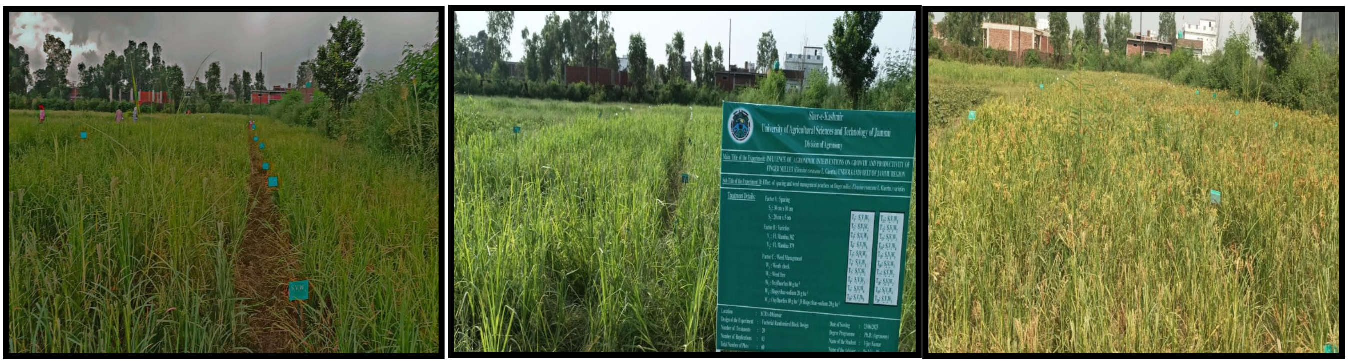

Fig. 3. Experimental field.

grain yield was found in finger millet variety VL Mandua 379 sown with weed free conditions. But among herbicidal treatments the maximum grain yield was found in sowing of variety VL Mandua 379 alongwith the application of Oxyflourfen @ 80 g ha^{-1} followed by post-emergence application of Bispyribac sodium @ 20 g ha^{-1}. The finding clearly indicated that selection of appropriate variety with appropriate weed management strategy increases the grain yield. This might be due to the better control of weeds resulting in minimum competition of weeds with finger millet for resources dueing crop growth period and helped in better utilization of nutrients, moisture, space and light by the crop and genetic potential of variety to yield more under such conditions. Similar findings were already reported (30).

Conclusion

Sowing of finger millet variety VL Mandua 379 at spacing 20 cm × 5 cm with the pre-emergence application of Oxyflourfen @ 80 g ha^{-1} followed by post-emergence application of Bispyribac sodium @ 20 g ha^{-1}, can be helpful in better weed control and improving grain yield. The farmers mainly *kandi* farmers of Jammu region can use these combinations for better crop production and to gain more profits as they do not require any special implementation or skill.

Over-reliance on specific herbicides can lead to resistance development in weed populations, diminishing the efficacy of these chemicals over time. To mitigate such risks and promote sustainable agriculture, integrating additional strategies is advisable:

***Alternative Integrated Weed Management Approaches* :** To reduce the risk of herbicide resistance and promote sustainable weed control in finger millet cultivation, consider the following IWM strategies:

1. ***Herbicide rotation*:** Alternate herbicides with different modes of action to prevent the selection of resistant weed biotypes. For example, integrating herbicides from different WSSA groups can disrupt weed adaptation.
2. ***Cultural practices*:** Implement agronomic techniques such as crop rotation, intercropping and adjusting planting dates to suppress weed growth. These practices enhance crop competitiveness and reduce weed pressure.
3. ***Mechanical control*:** Employ physical methods like hand weeding, hoeing and mechanical cultivation during the critical period of crop-weed competition (initial five weeks after sowing) to effectively manage weeds.
4. ***Biological control*:** Explore the use of natural enemies or competitive cover crops to suppress weed populations, thereby reducing reliance on chemical herbicides.
5. ***Monitoring and early detection*:** Regularly scout fields to identify weed species and assess the effectiveness of current management practices. Early detection of potential resistance allows for timely intervention.

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Authors' contributions

VK carried out the field experiment, collection and analysis of data, participated in the sequence alignment and drafted the manuscript. VB participated in the design of the study, supervised the whole research and helped in compiling the manuscript. AK also participated in the design of the study and helped in compiling the manuscript. VS and BK participated in finalization and compiling manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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