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Weed management in millets: Retrospect and prospects

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ABSTRACT

Millets are important staple foods in semi-arid tropics of Asia and Africa. Low productivity and susceptibility to biotic and abiotic factors are the major reasons for declining area and productivity of millets in India. As the millets are grown predominantly in the hot and humid rainy season, weeds deprive these crops of vital nutrients and moisture and reduce the yield considerably. Because of wider row spacing and slow initial growth in millets, weeds are more problematic during initial crop growth period, and hence, early control is needed to optimize the yield. The objective of this paper is to review the research that has been conducted pertaining to various aspects of weed management in different millets while also identifying key knowledge gaps that should be addressed in future research. Literature suggests that satisfactory weed control can be achieved with integration of pre-emergence herbicides with one manual/mechanical weeding. Additionally, future research is needed to evaluate the post-emergence herbicides that are the best suited for different millets and millet-based intercropping systems to improve weed control and reduce environmental impacts, including herbicide residues.

Key words: Crop-weed competition, Herbicides, Losses, Millets, *Striga*, Weeds

Millets as a group of crops are represented by sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), barnyard millet (*Echinochloa frumentacea*), proso millet (*Panicum miliaceum*), kodo millet (*Paspalum scorbiculatum*) and little millet (*Panicum sumatrense*). They are the major crops of the semi-arid regions of the country, and have the potential to contribute substantially for food, fodder and nutritional security. Because of their drought tolerance, millets can be cultivated in areas that are often too hot and dry for other crops to be grown. Weeds are a major obstacle in increasing the productivity of millet crops especially during rainy season. Burnside and Wicks (1969) reported that weed competition had a greater effect on sorghum yield than crop row spacing or crop population. Millets grow slowly at first and are relatively poor competitor with weeds during the first few weeks of growth. Planting in wider rows to facilitate inter-row cultivation and/or ditch furrow irrigation worsen the problems. Because the crop canopy forms slowly and provides little shading of weeds between rows until mid season; by then, most weeds are well established. Weeds compete with millets for light, soil moisture and nutrients and reduce crop yields and quality. Therefore, appropriate weed management would help improve productivity and input use-efficiency of these crops. When improved agricultural technologies are adopted, efficient weed management becomes even more important, otherwise the weeds rather than the crops benefit from the costly inputs.

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Weed distribution

A mixed population of broad-leaved, grasses and cyperaceous weeds grows with millet crops under different agro-climatic conditions (Table 1).

Losses due to weeds

Weeds compete with crops for nutrients, soil moisture, sunlight and space when they are limiting, resulting in reduced yields, lower grain quality and increased production costs. The magnitude of losses depends on crop cultivars, nature and intensity of weeds, spacing, duration of weeds infestation, environmental conditions and management practices. Yield loss due to weeds in maize, sorghum and pearl millet are given (Table 2). In grain sorghum, uncontrolled weeds removed 29.94-51.05, 5.03-11.58 and 48.74-74.34 kg/ha NPK, respectively from soil (Satao and Nalamwar 1993).

Weeds also harbor insect-pests and diseases (Table 3). Weeds are an important plant resource for insects, although feeding by insects on weeds can have both positive and negative effects on crop productivity (Capinera 2005).

Table 1. Major weeds of millets in different states of India

States	Grasses	Broad-leaved	Sedges
Andhra Pradesh	*Cynodon dactylon, Echinochloa colona*	*Commelina benghalensis, Celosia argentea, Euphorbia geniculata, E. hirta, Digera arvensis, Corchorus olitorius*	*Cyperus rotundus*
Bihar	*Cynodon dactylon, Echinochloa colona, Dactyloctenium aegyptium*	*Canabis sativa, Ageratum conyzoides, Fumaria parviflora, Leucas aspera, Amaranthus viridis, Trianthema portulacastrum*	*Cyperus rotundus, Fimbristylis diphylla*
Gujarat	*Cynodon dactylon, Echinochloa colona, E. crus-galli*	*Chrozophora rottleri, Convolvulus arvensis, Digera arvensis, Corchorus aestuans*	*Cyperus rotundus, C. esculentus Eragrostis major*
Haryana	*Echinochloa colona, Dactyloctenium aegyptium, Paspalum paspaloides*	*Celosia argentea, Trianthema portulacastrum, Alhagi camelorum*	*Cyperus rotundus*
Himachal Pradesh	*Digitaria sanguinalis, Echinochloa colona, Panicum dichotomiflorum, Brachiaria ramosa*	*Ageratum conyzoides, Commelina benghalensis, Oxalis latiifolia, Ipomoea purpurea*	*Cyperus iria*
Karnataka	*Cynodon dactylon, Echinochloa colona, Digitaria marginata,*	*Amaranthus viridis, A. spinosus, Borreria articularis, Celosia argentea*	*Cyperus rotundus, C. esculentus*
Madhya Pradesh	*Cynodon dactylon, Echinochloa colona, E. crusgalli, Saccharum spontaneum*	*Amaranthus viridis, A. spinosus, Commelina benghalensis, Eclipta alba, Phyllanthus niruri, Leucas aspera*	*Cyperus rotundus*
Maharashtra	*Cynodon dactylon, Echinochloa colona, Brachiaria eruciformis*	*Celosia argentea, Striga asiatica, Commelina benghalensis, Sonchus arvensis, Striga asiatica.*	*Cyperus rotundus*
Odisha	*Echinochloa colona, Digitaria ciliaris, Paspalum scorbiculatum, Ischene despaire*	*Ageratum conyzoides, Cyanotis* spp., *Celosia argentea*	*Cyperus iria*
Punjab	*Digitaria ciliaris, Eleusine aegypticum, Sorghum halepense*	*Phyllanthus niruri, Celosia argentea, Cleome viscosa*	*Cyperus rotundus*
Rajasthan	*Echinochloa colona, Eleusine indica*	*Amaranthus viridis, A. spinosus, Commelina benghalensis, Digera arvensis,*	*Cyperus rotundus*
Tamil Nadu	*Echinochloa colona, Cynodon dactylon, Panicum repens*	*Amaranthus viridis, Tridax procumbens, Digera arvensis, Trianthema portulacastrum, Euphorbia hirta, Celosia argentea*	*Cyperus rotundus*
Uttar Pradesh	*Cynodon dactylon, Echinochloa colona, Brachiaria ramosa*	*Trianthema portulacastrum, Ageratum conyzoides, Phyllanthus niruri, Commelina benghalensis,*	*Cyperus rotundus*
West Bengal	*Digitaria sanguinalis, Cynodon dactylon*	*Commelina benghalensis, Celosia argentea, Croton bonplandianum*	*Cyperus rotundus*

Table 2. Losses due to weeds in millets

Crop	Reduction in grain yield (%)	Reference
Sorghum	15-83	Mishra (1997), Stahlman and Wicks (2000)
Pearlmillet	55	Banga *et al*. (2000)
	35-90	Umarani *et al*. (1980)
	31-46	Gautam and Kaushik (1984)
	16-94	Balyan *et al*. (1993)
	40	Sharma and Jain (2003)
Finger millet	55-61	Ramachandra Prasad *et al*. (1991)

Table 3. Weeds as alternate host for insect-pests and diseases

Weed species	Organism	Disease/insect-pests	Reference
Cynodon dactylon	*Sporisorium sorghi*	Sorghum covered smut	Marley (1995)
Sorghum halepense	*Colletotrichum graminicola*	Sorghum anthracnose	Frederiksen (1984)
	Stenodiplosis sorghicola	Sorghum midge	Monaghan (1978), Bilbro (2008)
	Claviceps africana	Sorghum ergot	Reed *et al*. (2000)
Brachiaria distachya, Panicum repens, Setaria intermedia, Cyperus rotundus		Sorghum shoot fly	Nwilene *et al*. (1998)

Critical period of crop-weed competition

In rainy season, weeds emerge in succession almost throughout the crop season. Removing weed competition any time during the growing season is not desired. Time of weed removal is as important as removal *per se*. 'Critical period' defines the maximum period weeds can be tolerated without affecting final crop yields (Zimdahl 1980). This provides information on the active duration when the presence of weeds make their deleterious effect on crops (Table 4). Millets are very susceptible to competition from weeds early in the life of the crop. Therefore efficient weed control at the pre- and early post-emergence stages is essential. Once the crop reaches approximately 0.5 m in height, weed control no longer affects yield. Millet-weed competition is largely influenced by moisture availability. Wiese *et al*. (1964) obtained a higher yield for irrigated sorghum in narrow rows without cultivation than in wide rows with cultivation, where as in dry-land, plants in wide rows were more able to compete for limited soil moisture.

Table 4. Critical period of crop-weed competiton in maize, sorghum and pearl millet

Crop	Critical periods (days after sowing)	Reference
Sorghum	28-42	Sundari and Kumar (2002)
Pearlmillet	28-42	Singh *et al.* (1986)
Fingermillet	25-42	Sundraesh *et al*. (1975)

Climate change and weed competition

Changes in temperature and carbon dioxide are likely to have significant influence on weed biology and vis-à-vis crop-weed interaction. Ziska (2003) studied the effect of elevated CO_2 on the interaction of dwarf sorghum (C_4) with and without presence of a C_3 weed (velvetleaf; *Abutilon theophrasti*) and a C_4 weed (redroot pigweed; *Amaranthus retroflexux*) and reported that in a weed-free environment, increased CO_2 significantly increased the leaf weight and leaf area of sorghum but no significant effect on seed yield or total above-ground biomass relative to the ambient CO_2 condition. Increase in velvet leaf biomass in response to increasing CO_2 reduced the yield and biomass of sorghum. Similarly, as CO_2 increased, significant losses in both seed yield and total biomass were observed for sorghum-redroot pigweed competition. Increased CO_2 was not associated with a significant increase in redroot pigweed biomass. These results indicate potentially greater loss in a widely grown C_4 crop from weedy competition as atmospheric CO_2 increases. In another experiment, Ziska (2001) observed that the vegetative growth, competition and potential yield of sorghum (C_4) could be reduced by co-occurring of common cocklebur (*Xanthium strumarium*: C_3) as the atmospheric CO_2 increases. Watling and Press (1997) investigated the effects of CO_2 concentrations (350 and 700 µmol/ml) in sorghum with and without *Striga* infestation. They observed that a high CO_2 concentration resulted in taller sorghum plants, and greater biomass, photosynthetic rates, water-use efficiencies and leaf areas. A high CO_2 concentration resulted in lower *Striga* biomass/host plant and a greater rate of photosynthesis. Parasite stomatal conductance was not responsive to CO_2 concentration. *Striga* emerged above ground and flowered earlier under the lower CO_2 concentration.

Control strategies

Mechanical and cultural options: Manual and mechanical weeding is by far the most widely followed method of weed control in millets. Hand weeding or inter-row cultivation provides reasonable weed control. But during rainy season, there are not many clear days and as a result, inter-culture operations have to be delayed and this help weeds to overtake the crops and cause severe reduction in yield. Also with rising labour wages and non-availability of adequate labour at times required, it is becoming a serious problem to control weeds manually on larger area at the proper tim**e.**

Growing of mungbean, groundnut, cowpea, soybean etc. as intercrops in sorghum/pearl millet could exert suppressing effect on weeds. Similarly narrow row spacing, use of higher seed rate, early application of nitrogen and its placement near to plants can help in increasing vigour of the crop and exert smothering effect on weeds. Narrow rows (<30 cm) are beneficial in reducing weed competition and increasing yield of foxtail and proso millets (Nelson 1977, Agdag 1995).

Herbicides: Use of herbicide saves labour and thus helps in diverting them to more important and productive activities. Depending upon the chemicals they may be applied either before planting of the crop (pre-planting e.g., fluchloralin), after planting but before emergence of the crop (pre-emergence e.g., atrazine, metolachlor, pendimethalin) or after emergence of the crop (post-emergence *e.g.* 2,4-D). In no-till conditions, herbicides are becoming a major component of weed management in maize and grain sorghum as they improve weed control and production efficiency (Brown *et al*. 2004). Foxtail millet lacks tolerance to saflufenacil, However, lower doses of saflufenacil (50 g/ha) may be safely applied as near as 7 days before planting proso or pearl millets. If situation demands, saflufenacil at 36 g/ha can also be applied as pre-emergence to either crop with risk of some crop injury (Reddy *et al.* 2014). Several herbicides have been evaluated for weed control **e**fficacy and crop safety in sorghum (Table 5), however in other millets, the herbicide recommendations are limited (Table 6). At present atrazine is the only herbicide most commonly used as pre-emergence for weed control in millets at various doses.

Table 5. Herbicides recommended for sorghum

Herbicide	Dose (kg/ha)	Time of application	Weeds controlled	Remarks
Atrazine	0.75-1.0	Pre-emergence/ early post-emergence	Broad-spectrum weed control. Some grasses are tolerant	For sole crop only. Did not control *Acrachne racemosa*, *Brachiaria reptans* and *Commelina benghalensis* (Walia *et al.* 2007)
Pendimethalin	0.75-1.0	Pre-emergence	Effective control of grasses	Suitable for intercropping, higher doses may cause phytotoxicity
Alachlor	1.5-2.0	Pre-emergence	Effective control of grasses	Suitable for intercropping
Metolachlor	1.0-1.5	Pre-emergence	Effective control of grasses	Suitable for intercropping
2,4-D	0.50-0.75	Post-emergence	Effective against broad-leaved weeds	For sole crop only. Apply at 4-6 weeks after planting. Good as sequential application to pre-emergence herbicides
Atrazine + pendimethalin	0.75+0.75	Pre-emergence	Broad-spectrum weed control	For sole crop only
Atrazine + alachlor	0.75+0.75	Pre-emergence	Broad-spectrum weed control	For sole crop only
Atrazine + metolachlor	0.75+0.50	Pre-emergence	Broad-spectrum weed control	For sole crop only

Table 6. Herbicides recommended for other millets

Millets	Herbicide	Dose (kg/ha)	Time of application	Weeds controlled	Remarks
Pearlmillet	Atrazine +	0.50	PE/early POE (10 DAS) 30 DAS	*Trianthema portulacastrum* and *E. colona*	For sole crop only (Banga *et al.* 2000).
	HW	1			Ramakrishna (1994)
	2,4-D	0.50-0.75	POE	Effective against broad-leaved weeds	For sole crop only. Apply between 4-6 WAS. Good as sequential application to pre-emergence herbicides
	Pendimethalin	1.0	PE	Broad-spectrum weed control	Each supplemented with one hand weeding at 45 DAS (Ram *et al.* 2005)
	Oxadiazone	1.0	PE		
Finger millet	Oxadiazone	1.0	PE	Broad-spectrum weed control	
	Isoproturon	0.50-0.75	PE		Ashok *et al.* (2003)
	Butachlor	0.75	PE		Prasad *et al.* (2010)
Kodomillet	Isoproturon	0.50	PE	Broad-spectrum weed control	Prajapati *et al.* (2007)
	+ intercultivation	1	20 DAS		
	+ HW	1	40 DAS		
Prosomillet	Atrazine	0.28-0.56	PE	Broad-spectrum weed control	Anderson and Greb (1987)
	Propazine	0.28-0.56	PE	Broad-spectrum weed control	

One supplementary weeding at 30 days after sowing following pre-emergence herbicides is required for broad-spectrum weed control and higher yields.

Herbicide mixtures: Most of the presently available herbicides provide only a narrow spectrum weed control. Herbicide mixtures may allow control of wider spectrum of weeds with less total active in gradient. In grain sorghum, Ramakrishna *et al.* (1991) reported that pre-emergence application of metolachlor at 1.0-1.25 kg/ha or combination of atrazine + metolachlor or sequential application of metolachlor and bentazon, atrazine at 0.75 kg/ha yielded as good as repeated weedings. Jadhav *et al.* (1988) found oxyfluorfen at 0.15 kg/ha and atrazine 0.75 kg/ha as pre-emergence as safe herbicides for post-rainy sorghum. Kalyansundaram and Kuppuswamy (1999) reported that tank mix application of butachlor at 0.75 kg/ha + atrazine 0.75 kg/ha followed by 1 HW at 45 DAS controlled the weeds effectively and produced the highest grain yield. Wu *et al.* (2004) reported that soil incorporation of atrazine mixed with metolachlor at sorghum planting provided effective seasonal control of barnyard grass (*E. colona*). Atrazine + pendimethalin or trifluralin applied late-post emergence (when weeds and sorghum were 10-15 cm tall) resulted in 99% control of tumble pigweed (*Amaranthus albus*) with less than 3% sorghum stunting (Grichar *et al.* 2005). Ishaya *et al.* (2007) observed that pretilachlor + dimethametryne at 2.5 kg/ha or cinosulfuron 0.05

kg/ha or piperophos + cinosulfuron 1.5 kg/ha effectively controlled weeds, increased crop vigour, plant height, reduced plant injury and produced higher grain yield of sorghum.

Intercropping

Growing of intercrops in widely spaced row not only reduces intensity of weeds but also gives additional yield. Although intercropping may reduce weed infestation and growth, there is still a need for some degree of weed management in most cases. While second weeding may be needed in sole crop, this is often not required in intercropping since the canopy coverage is almost complete and weed growth after first weeding is minimal.

Manual or mechanical weed control is the main method in intercropping systems. Most of the herbicides are crop specific and thus, can't be applied in inter cropping systems. Use of pendimethalin (0.75-1.0 kg/ha), metolachlor (1.0 kg/ha), butachlor (0.75-1.0 kg/ha) has been found safe and effective in intercropping systems. Metolachlor was however, not effective against *Celosia argentea*. Pendimethalin 1.0 kg/ha was toxic for sorghum germination (Ponnuswami *et al.* 2003).

Sequence cropping/ double cropping systems

Weed management in sequential cropping is a little different from those in intercropping systems. Continuous presence of crop cover, residual toxicity of herbicides applied to the previous crops on succeeding crops and changing weed flora with the season all need a different approach in weed management practices. Selective herbicides are available for sole crops but the residual effect of these herbicides have to be carefully evaluated before using them in crop sequence. Very little attempt has been made in this direction. In a three year study with a fixed three crop rotation, cotton-sorghum-*ragi*, raised under zero tillage conditions with chemical weed control, *Cynodon dactylon* became a major problem after the second year and was difficult to control (Palaniappan, 1988). In sorghum-cotton cropping sequence, pre-emergence application of atrazine 0.25 kg/ha in sorghum and pendimethalin 1.0 kg/ha in cotton was effective for control of broad-leaved weeds. Atrazine applied as pre-emergence at 0.50 kg/ha gave effective weed control in sorghum but the establishment of legumes such as greengram and groundnut which followed sorghum was poor. The following cotton was not affected (Palaniappan and Ramaswamy 1976). In sorghum-safflower sequence, Giri and Bhosle (1997) observed that pre-emergence application of atrazine at 0.75 kg/ha alone or atrazine at 0.50 kg/ha combined with weeding and hoeing 6 weeks after sowing were as effective as 2 weeding and hoeing at 3 and 6 weeks after sowing in controlling weeds without any phytotoxic effect on succeeding safflower.

Management of *Striga*

Striga is a major biotic constraint in the subsistence agriculture and causes considerable crop damage in millets in the semi-arid tropics. Adaptation of *Striga* to parasitism includes not only dependence upon a host plant for metabolic inputs such as water, minerals, and energy, but also for developmental signals. In this way, parasite and host development are highly integrated. The early host derived chemical signals *Striga* requires, for seed germination and for initiation of the haustorium by which it attaches to the host roots, are exuded from host roots into the soil. After *Striga* penetrates the host root, subsequent developmental signals are apparently exchanged directly, through vascular tissue. Germination stimulants for most *Striga* hosts have been identified as strigol-type compounds (strigolacetates).

There are no reliable global figures, based on rigorous sampling, for the total area affected by *Striga*, but an estimated 44 million ha were considered to be 'at risk' of *Striga* attack in the Africa, and the total loss of revenue from maize, pearl millet and sorghum 'could total' $US 2.9 billion. More recent figures suggest that 50 million ha and 300 million farmers are affected by *Striga* species in Africa, with losses of $US 7 billion (Ejeta 2007). In India, incidence of *Striga* alone caused 75% reduction in grain yield of sorghum (Nagur *et al.* 1962, Rao 1978). In sub-Saharan Africa, *S. hermonthica* caused 70-100% crop loss in sorghum and pearl millet (Emechebe *et al.* 2004).

Hand pulling is the most common control measure used by the small-scale farmers, but only effective when the *Striga* population is low. However, hand-pulling is no solution to a dense infestation but it should be encouraged to prevent new or light infestations getting worse, and as a part of integrated methods for control of moderate infestations. Plants which are pulled, within 2-3 weeks of the start of flowering, should be taken out of the field and burned so that seeds are not produced and shed from the drying plants. Cattle should not be fed the witch weed plants as the seeds pass through the cattle and are distributed in the manure.

Cultural practices such as stubble cleaning in sorghum fields after harvest, crop rotation with non hosts and with catch crops, mixed cropping without host crops, fertilizer management with high doses of nitrogen as top dressing, and use of resistant or tolerant varieties help in reducing *Striga* infestation. Whatever the methods, the ideal objective must be to prevent all *Striga* seed production - continuing control through and beyond harvest if necessary. Trap crops stimulate *Striga* germination but are not themselves attacked. Without supply of food from the plant root, the germinated *Striga* seeds die. It is therefore possible to rotate these crops with sorghum to induce suicidal germination. Crop rotation with trap/catch crops like soybean and cotton, intercropping with groundnut, soybean and cowpea and green manuring crops like sunhemp help in reducing the problem of parasitic weed *Striga*. Fertilizer, especially nitrogen, tends to reduce, or at least delay, *Striga* emergence and can be used to further reduce the numbers of parasite that need to be hand-pulled to prevent seeding.

In general, it has proved difficult to find good selective herbicide to control *Striga* in field crops. Since *Striga* is a broad-leaved plant, use of pre-plant/ pre-emergence herbicides such as atrazine, oxyfluorfen show some effect, though not efficient. Post-emergence application of 2,4-D is effective when sprayed on the *Striga* leaves. However, sorghum is vulnerable to stalk twisting and lodging if 2,4-D is sprayed into the leaf whorl, hence, proper precautions should be taken while spraying.

Herbicide resistance in grain sorghum

Acetolactate synthase (ALS)-inhibitor herbicides, *viz.* nicosulfuron and rimsulfuron are widely used to control broad-leaved and grassy weeds in corn (*Zea mays*), but the sorghum is susceptible to these herbicides. However, by transferring a major resistance gene from wild sorghum relative, researchers at Kansas State University (KSU), USA developed a grain sorghum that is resistant to several ALS-inhibiting herbicides as Steadfast (nicosul-furon), Accent (nicosulfuron), Resolve (rimsulfuron) and Ally (metsulfuron) (Tuinstra and Al-Khatib 2007, Tuinstra *et al.* 2009).

Sorghum roots exude a potent bio-herbicide known as 'sorgoleone', which is produced in living root hairs and is phytotoxic to broadleaved and grassy weeds at concentrations as low as 10 micro M (Yang *et al.* 2004). Herbicide tolerance through transgenic technology is not addressed worldwide because of the opinion of development of "Super Weed". It is understood that crops and related wild or weedy plants can and will exchange genes through pollen transfer, if provided with the opportunity, and have been doing so ever since there have been crops and weeds (Harlan 1982). Transfer of herbicide tolerant gene to johnsongrass from cultivated sorghum is considered a threat if hybrid develops due to their cross compatibility.

Future research needs

Millets have now been emphasized as nutri-cereals, and will play a major role in crop diversification, and food and nutritional security under changing climate scenario. As these crops are grown as subsistence crops mainly during rainy season by resource poor farmers on marginal lands with low inputs, efficient weed management is a major challenge. Most of the minor millets are the improved species of most troublesome grassy weeds. Hence, it is very difficult to identify weeds in early stages and control them. In general, weeds in millets are removed manually using hand tools and implements at the stage when they attain good amount of biomass and used as source of animal fodder. But the crop yield reduces drastically due to severe competition for nutrients and moisture. Therefore, the critical period of crop-weed competition, especially for the minor millets needs to be identified and weeds should be managed during that period. There is need to develop energy efficient small weeding tools for different agro-ecological regions. Herbicides though very effective for weed control in millets, are rarely used in millets except in sorghum and pearl millets. As these crops are also used as major fodder source for animals, farmers fear that use of herbicides may deteriorate the fodder quality and animal health. Hence, they should be educated and trained about the use of herbicides in millets. As the millets are grown in moisture stress conditions, the efficacy of pre-emergence herbicides like atrazine is reduced. Hence, there is a need for exploring potential post-emergence herbicides for safe and effective weed control. Millets are mainly grown as intercrop with pulses and oilseeds. Under such conditions, safe and effective broad-spectrum herbicides need to be developed and evaluated. Herbicide residues in soil and plant (grain and stover) need to be studied in different situations. More investigations are needed on integrated weed management, especially in minor millets.

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