

Review Article

INTEGRATED WEED MANAGEMENT IN MINOR MILLETS - A REVIEW

ABSTRACT

Presently, agriculture is facing tremendous problem due to climate change and global warming. To ensure food and nutritional security at national level, there is an immediate need to promote the cultivation of millets as millets are considered climate smart and nature friendly crops because of high nutritive value and can withstand under warm and drought conditions with short life, low external inputs requirement, tolerance to water and temperatures stress. Ten millet crops have been declared as 'Nutri Cereals' which include three major millets i.e., pearl millet, sorghum and finger millet; five minor millets i.e. foxtail millet, proso millet, kodo millet, barnyard millet, little millet; and two pseudo millets i.e. kuttu (buckwheat) and amaranthus. Due to sluggish growth in initial phases of life, millets proved relatively poor competitors against weeds. Manual weeding is the most commonly adopted for weed control in millets. But the non-availability of labour and ever increasing labour wages have compelled the farmers to seek alternate method of weed management. Herbicide use is the most viable method of weed control but their continuous and excessive use is not advisable due to its ill effects on environment and development of herbicide resistance in weeds. Very limited options are available in literature for weed control in minor millets. Thus, integrated weed management practices should be followed on site and time specific basis for effective and efficient weed management in minor millets. For integrated weed management in minor millets, 2-3 times inter-cultivation and 1-2 time hand weeding during initial 25 days after sowing in addition to pre-emergence spray with Isoproturon @ 0.5 -1.0 kg a.i./ha and post emergence spray of 2, 4-D sodium salt @ 0.75-1.0 kg a.i./ha at 20-25 days after sowing should be done for effective weed control.

Key words: Minor millet, weed, integrated weed management, herbicide

Introduction

In India, after green revolution main focus was given on production of fine cereals, namely, rice and wheat and millets became neglected grains. Further, urbanization, increase of income and change of food habit also made millets as poor-man's food. But during recent time, millets have regained their lost pride due to re-evaluation of nutritional qualities (Maitra, 2020). Due to climate change, there is a decline in yield leading to food insecurity, more attacks of pests and diseases, soil degradation, change in crop schedules, and desertification. Considering, millets as an alternative crop is a better choice and we can say it is the future crop. There is an immediate need to promote the cultivation of millets to ensure food and nutritional security at national level. Presently, agriculture is facing tremendous problem due to climate change and global warming. The main effects of climate change are increase in temperature, uncertainties in rainfall and enhancement of greenhouse gasses emission (mainly carbon-dioxide). As C4 plants, millets can use enhanced atmospheric CO₂ and convert into biomass (Brahmachari *et al.* 2018). Millets are considered climate smart and nature friendly crops because of high nutritive value and can withstand under warm and drought conditions with short life, low external inputs requirement. tolerance to water and

temperatures stress, (Yadav *et al.*, 2012; Gupta *et al.*, 2017; De Vries *et al.*, 2020). Ten millet crops have been declared as ‘Nutri Cereals’ which include three major millets i.e., pearl millet, sorghum and finger millet; five minor millets i.e. foxtail millet, proso millet, kodo millet, barnyard millet, little millet; and two pseudo millets i.e. kuttu (buckwheat) and amaranthus (NAAS, 2022). Considering the importance of millets in food and nutritional security, the year 2018 as ‘National Year of Millets’ at national level and the year 2023 as ‘International Year of Millets’ was celebrated at global level. Millets are currently grown in 131 countries in over 78 million ha (FAO, 2022) with sorghum and pearl millet accounting for over 90 per cent share at global level. India is the largest grower (with 19% contribution) and producer (20% production) of millets in the world. Share of India in Asia stands at 85% in area and 80% in production of millets. In India, minor millets share an area of 0.44 million ha with a production of 0.35 million tones having productivity of 781 kg/ha and among the minor millets, finger millet occupies larger area under cultivation (Dubey *et al.*, 2023). At national level maximum area (89000 hectares) and production (76000 tonnes) of minor millets was reported from Madhya Pradesh. Top seven countries in the world for pearl millet cultivation are India, Niger, Sudan, Nigeria, Mali, Burkina Faso and Chad. Thus, among the major millets India ranks first in the world with respect to pearl millet cultivation and third in sorghum cultivation. The major millets are Sorghum, Pearl Millet, and Finger Millet covering 95% of the total millet growing area in India and the rest 5% are Little Millet, Foxtail Millet, Barnyard Millet, Proso Millet, Kodo Millet, and Browntop Millet. The most important states for pearl millet cultivation are Rajasthan, Uttar Pradesh and Maharashtra having a total share of 78 per cent. Karnataka alone accounts for more than 2/3rd acreage of finger millet. Chhattisgarh and Madhya Pradesh grow more than 60per cent of small millets.

Weeds are unwanted plants and in India the loss caused by weeds, insects, diseases and others accounts for 37, 29, 22 and 12 per cent, respectively (Yaduraju, 2006). The magnitude of losses depends on crop cultivars, nature and intensity of weeds, spacing, duration of weed infestation, edaphic and climatic factors and management practices followed. Weeds compete with crops for nutrients, soil moisture, sunlight and space when they are limiting, resulting in reduced yield and quality and increased cost of production. Weeds acts as alternate host for insect pest and thus affect the crop production adversely. Due to sluggish growth in initial phases of life, millets proved relatively poor competitors against weeds (Mishra, 2015). Further more wider row planting in millets to facilitate intercultural operations and input application worsens the problems providing more space to weeds to grow. Millets are mostly grown in the dryland, where availability of water is scanty and uncertain. Under moisture stress condition, weeds alone can cause 50 per cent reduction in yield due to competition for moisture (Abouziena *et al.*, 2014). Depletion of soil-water by weeds, however, may create severe moisture stress conditions for the millets to grow. 5-73 percent reduction in grain yield of Finger millet ((Kujur *et al.* (2019), Sharma and Jain (2003), Ramachandra Prasad *et al.* (1991), Shubhashree and Sowmyalatha (2019), Rao *et al.* (2015), Asargew and Shibabawu (2014), Dubey and Mishra (2023), Mishra *et al.* 2016, Rama Devi *et al.* 2021)), 55-67.3 percent reduction in Kodo millet (Lekehana *et al.* (2021), Prajapathi *et al.* (2007), Jawahar *et al.* (2019), Vinothini *et al.* (2017), ICAR-DWR 2021), 30- 63.5 percent reduction in grain yield of Barnyard millet (Kumar *et al.* (2019), Shamina *et al.* (2019), ICAR-DWR 2021) and 59.6 percent yield reduction in little millet (ICAR-DWR 2021) were reported. Manual weeding is the most commonly adopted for weed control in millet. But the non-availability of labour and ever increasing labour wages have made the farmers to seek alternate method of weed management. Chemical method is the most viable method of weed

control in crops. However, rely on chemicals alone for weed management is not advisable due to its ill effects on environment and development of herbicide resistance in weeds (Sneha and Sheeja, 2022). Now, to meet out this challenge, the reliance on one or two specific weed control mechanisms is to be reduced. The best solution may be the integration of all preventive, physical, mechanical, agronomic, cultural, biological and chemical weed management practices in to a comprehensive system which is environmentally viable and maintain weed densities below their economic thresholds, along with simultaneously maximize millet yield and profits. Thus, integrated weed management practices should be decided on site and time specific basis and should design the weed control management strategy on long term basis by considering the weeds in a broader ecological and management context. In an Integrated approach the best options and tools are combined in such a way that the cropping system becomes unfavorable for weeds (Singh *et al*, 2013)

Critical period of crop weed competition: Every crop has its critical period of crop weed competition during which weeding results in maximum economic returns. The “critical period” of crop–weed competition defines the maximum period the weeds can be tolerated without affecting final crop yields (Zimdahl, 1980). It is the active crop growth duration when the presence of weeds make their deleterious effect on the crops. Due to slow initial growth, millets are very susceptible to competition from weeds early in early phase of life. Therefore, efficient weed control at the pre- and early postemergence stages is essential. Weed control no longer affects the yields after attainment of approximately 0.5 m height in millets. Therefore, the timing of weed removal is as important as removal *per se* to keep crop–weed competition at bare minimum. Critical period of weed competition of millet crops are given in following Table.

Table 1. Critical period of crop weed competition

Crops	Critical periods (DAS)	References
Finger millet	20-30	Pradhan and Patil (2010)
	20-25	Chapke <i>et al</i> (2020)
Barnyard millet	25-30	TNAU (2021)
	20-25	Chapke <i>et al</i> (2020)
Foxtail millet	20-35	TNAU (2016)
	20-25	Chapke <i>et al</i> (2020)
Proso millet	Up to 35	TNAU (2021)
Little millet	20-25	Chapke <i>et al</i> (2020)
Kodo millet	20-25	Chapke <i>et al</i> (2020)

Weed flora in millets: Several species of grasses, broad-leaved weeds and sedges were found in association with millets. As per Dubey *et al* (2023), Mahapatra *et al* (2023), Lekhana *et al*. (2021), Rao (2021), Chapke *et al* (2020), Vinothini and Arthanari (2017), Prabhakar *et al*. (2017), Mishra *et al* (2018), Mishra (2015), Atera *et al*. (2012), Parker (2012). Major weeds found in association with millets are as follows :

Grassy weeds: *Brachiaria ramosa* (Brown top millet), *Echinochloa colona* (Jungli rice), *Echinochloa crusgulli* (Sawan), *Dinebra retroflexa* (Viper grass), *Chloris barbata* (Peacock plume grass) *Digitaria sanguinalis* (Crab grass), *Dactyloctenium aegypticum* (makra/

Crowfoot grass), *Elusine indica* (Goose grass), *Paspalum paspaloides* (Hilo grass/Sour grass), *Setaria glauca* (bajra/ Yellow foxtail)), *Cynodon dactylon* (Doob/Bermuda grass), *Phragmites karka* (narkul), *Sorghum halepense* (banchari/Johnson grass), *Setaria viridis* (Green Foxtail), *Digitaria ciliaris* (Southern crabgrass/Tropical crab grass), *Eragrostis pilosa* (Indian Love grass), *Acrachne racemosa* (Chinkhe/Jaura), *Chloris barbata* (Swollen finger grass/ Purple Top Chloris) and *Panicum repens* (Tarpedo grass) are common.

Broad-leaved weeds: *Ageratum conyzoides* (Bill goat weed), *Convolvulus arvensis* (Field bind weed), *Acanthospermum hispidum* (Bristly starbur), *Achyranthes aspera* (Prickly chaff flower), *Celosia argentea* (chilimil/ White cock's comb), *Boerhaavia diffusa* (Hog weed) *Commelina benghalensis* (kankoua/ Tropical spider wort), *Phyllanthus niruri* (hulhul), *Solanum nigrum* (makoi), *Cleome viscosa* (Cleome), *Amaranthus palmeri* (Palmar amaranth), *Digera arvensis* (False amaranth), *Euphorbia hirta* (Pill pod spurge), *Corchorus acutangulus* (Jew's mellow), *Tridax procumbens* (Coat buttons), *Amaranthus viridis* (chulai/Pig weed), *Amaranthus retroflexus* (Redroot pigweed), *Portulaca oleracea* (Common purslane), *Eclipta alba* (False daisy), *Ipomoea hederacea* (Morning glory), *Trianthema portulacastrum* (Horse purslane), *Tribulus terrestris* (Puncture vine) and *Xanthium strumarium* (Common Cocklebur), *Leucas aspera* (Common Leucas/Thumba/Gopha), *Canabis sativa* (Bhang/Gallow grass), *Fumaria parviflora* (Indian fumitory/Pitpapra), *Oxalis latifolia* (Garden Pink sorrel/Broad leaf wood sorrel), *Ipomoea purpurea* (Common Morning Glory), *Syndrella nodiflora* (Cinderella weed), *Borreria articularis* (Jointed Button weed), *Alternanthera sessilis* (Sissoo spinach/ Brazilian spinach/Stakless Joyweed), *Amaranthus spinosus* (Spiny Pigweed/ Thorny amaranth), *Sonchus arvensis* (Field milk thistle/ Perennial saw thistle/ Gutweed), *Bergia capensis* (White water fire), *Galinsoga parviflora* (Gallant Soldier/ Quick weed/Potato weed), *Persicaria capitatum* (Pink Knotweed/ Japanese Knotweed), *Croton bonplandianum* (Ban Tulsi/Kala Bhangra), *Spilanthes acmella* (Toothache plant), *Parthenium hysterophorus* (Congress grass/Carrot grass/Gajar Ghas) and *Ocimum canum Sims* (Nai Tulasi)

Sedges: *Cyperus rotundus* (Purple nut sedge) and *Cyperus iria* (Rice flat sedge/Umbrella sedge), *Fimbristylis diphyllo* (Forked fimbry/Eight day grass), *Cyperus esculentus* (Yellow nut sedge) and *Cyperus defformis* (Smallflower umbrella sedge)

Parasitic weed: *Striga asiatica* (Witch weed) is a root hemi parasitic plant which may reduce millet yield from 75 per cent yield loss to complete crop failure (Walia, 2006).

Integrated weed management: The principal strategies which we can consider under an integrated weed management approach are preventive, agronomic and cultural and chemical strategies. Conceptually integrated weed management is a systematic weed management approach combining monitoring, prevention and control and not based on the complete eradication of weeds, but rather on their control below thresholds that are agronomically, environmentally and economically acceptable.

(A) **Preventive methods:**

As we know that "Prevention is better than cure," so it is better to prevent the weed species to spread in the croplands and infest the crop. Prevention is least cost strategy but often least used control strategy. Preventive methods, often referred to as cultural methods, include those strategies or agronomic choices, which are aimed at preventing weed germination, emergence, growth, diffusion and dispersal (Bond and Grundy, 2001). These goals could be reached by reducing the soil weed seed bank and increasing the crop

competitive capacity. Soil weed seed bank may be controlled through crop rotation, Stale seedbed, Soil solarization, Good agronomic practices, ploughing, cover cropping, mulching, intercropping and green manuring, while increase in crop competitive ability may be obtained by selecting good cultivars (having better root development, fast early vigour, high leaf area development), higher crop density and proper spatial planting patterns to smothering weeds and Changing the crop calendar in accordance with prevailing climatic conditions to ensure better crop germination and establishment before weed emergence (Scavo and Mauromicale (2020). So, to prevent the introduction of weeds to fields, always use certified, clean and weed free crop seeds only. Millet seed contaminated with weed seed has been a major source of its short and long distance spread (Singh, 2007). Use clean farm equipment and machines. Pull out weeds before seed setting. Control the weeds in animal feed and fodder and bedding ground because some weeds seeds remain viable and active even after passing through animal digestive tract. Use only well rotted manure (minimum of 4-5 months old material) because through unrotted or half rotted manures viable weed seeds enter the fields and spread. Some organic manure like FYM and vermi-compost are important source of crop nutrition but demerits that these may carry weed seeds which increase weed infestation and introduction of new weeds to fields. Maintenance of farm hygiene is must that prevents the every year production of seeds, tubers, and rhizomes of already present weed species on the farm. (Mahapatra *et al* ,2023; Singh and Singh, 2005; Badiyal *et al.*, 1991).

(B) Mechanical methods:

Removal of weeds by various means of tools and implements, hand weeding and pulling comes under mechanical and physical practices of weed control, respectively. The mechanical method of weed control helps in weed seed burial as well as the removal of weed plant and vegetative propagules from the soil of the cultivated field which reduces the weed thrust in the field eventually reducing the crop-weed competition and enhancing the crop yield. Hoeing as inter-row cultivation and hand weeding are most widely followed methods of weed control in millets, which stirs the soil and makes the soil more loosened. Though effective it is time consuming, labour intensive and often costlier than chemical method of weed control. It effectively controls annual weeds, but not perennial weeds. Line sowing was a prerequisite for hoeing. Among the weed management practices, significantly lower density, dry matter of weeds, higher weed control efficiency and lower weed index were noticed in hoeing twice by wheel hoe between the rows in finger millet (Kujur *et al.*, 2018). For all millets except Browntop millet, it is essential to control weeds in the initial stage of plant growth and development. For Finger millet and Barnyard millet one weeding should be done with hand hoe at 25 DAS. In line sown crop 2-3 times inter-cultivation and one time hand weeding, while for broadcasted crop two effective hand weeding are suggested to control weeds. For Foxtail and Little millet two inter-cultivation in addition to one hand weeding in line sown crop and two hand weeding in broadcast crop are necessary for effective weed control. In Proso and Kodo millets it is essential to control weeds in the initial stages of plant growth. Generally, two weeding with hand hoe or wheel hoe at an interval of 15 days are sufficient. To control weeds in Browntop Millet, it is best to plant in a well-tillage field, weed-free bed with narrow row spacing (Chapke *et al*, 2020). Ravali *et al* (2021) revealed that hand weeding twice at 15 and 30 DAS produced significantly higher growth parameters, yield attributes and yield for foxtail millet. Two time hand weeding at hand

weeding twice at 20 and 40 days after transplanting in Kodo millets resulted with significantly higher weed control efficiency. (Jawahar *et al.*, 2020 and Yendrembam *et al.* (2018). The conventional tillage (ploughing twice + harrowing once + inter-cultivation twice at 25 and 50 days after sowing (DAS) in Alfisols) compared to minimum and zero tillage practices was found more effective and economical in Finger millet (Hatti *et al.* 2018). For effective weed control in Finger millet three hand weeding at 20, 40 and 60 DAS were recommended by Naik *et al.* 2001 and 2005. One hoeing at 15 DAS followed by hand weeding thrice at 25,40, 60 DAS were recommended by Tosh and Nanda, 1983. Hoeing once (30 DAS) fb Hand weeding once at 30 DAS was resulted in better weed control in finger millet (Reddy *et al.* 1990). Inter-cultivation twice at 20 and 40 DAS fb hand weeding once at 35 DAS resulted with significantly higher yield of finger millet (Singh and Arya 1999, Ramamoorthy *et al.* 2002). Similarly, Inter-cultivation once fb hand weeding twice at 30 and 45 DAS has also resulted in better weed control in finger millet (Ramamoorthy *et al.* 2010). Lower weed density and weed dry weight in two hand weeding at 20 and 40 DAS plot was observed by Thambi *et al.*, 2021. Among the weed management treatments, one inter-culture at 20 DAS and one hand weeding at 40DAS registered significantly lower population and dry biomass of weeds in comparison to other treatments for barnyard millet (Kumar *et al.*, 2019). Millets are mainly grown in semiarid areas where intercultivation helps in the conservation of soil moisture. Vijaymahantesh *et al.*(2013) reported that tillage and soil depth had significant effects on weed dynamics and weed seed bank in finger millet crop and suggested that by intensive tillage practices could make considerable weed seed bank reduction in the soil. Sidar and Thankur (2017) found that summer tillage recorded lower weed population and dry matter leading to yield in finger millet. Hand weeding twice at 20 and 40 DAS and narrow spacing had strong and negative effects on weed biomass and positive effects on barnyard millet biomass and yield (Shamina *et al.* (2019). Usually the inter-cultivation operation performed two to three times at 10 to 15 days interval depending up on the weed pressure and field condition. However, the inter-cultivation operation followed by hand weeding was found to be effective in controlling the weeds (Gowda and Dhananjaya 2000). Gowda and Dhananjaya (2000) conducted a comparison study between the improved tools with traditional hoe for weeding in finger millet. Improved blade hoe and improved bent type sweep hoe performed better, controlled the weeds effectively conserved the soil moisture at flowering and grain filling stages; yielded highest grain yield compared to traditional hoe. A blade type engine operated mechanical weeder was developed to perform weeding in finger millet; it could cover 2-4 rows at a time and had very good weeding efficiency. The weeding efficiency varied from 85 to 88%, plant damage varied from 2.5 to 3.6%, field capacity varied from 0.11 to 0.14 ha/h and weeding cost in developed weeder varied from Rs. 447.42 to 572 per hectare (Shrinivasa *et al.* 2017). The combination of wooden ploughing followed by power tiller rotovating or cultivating, with later inter-row cultivation by the improved bent tyne sweep hoe, gave higher yields of dryland finger millet than conventional methods of seedbed preparation by bullock ploughing followed by inter-row cultivation with the local hoe called 'chipkunte' (Gowda *et al.* 1999). Tillage has its influence on weed seed distribution in soil. More weed seeds were distributed in upper 10 cm soil depth in minimum tillage where as in conventional tillage weed seed distribution was more or less uniform in the soil profile (Hatti *et al.* 2018). Exhausting weed seedbank with

stale seedbed technique (Patil *et al.* 2014; Patil and Reddy 2014), under minimum tillage, may be explored as a means of weed management in finger millet. Bello *et al* (2022) concluded that Broadcasting method produced the highest grain yield. Adeyeye *et al.* (2014) also resulted that the use of broadcasting method of sowing was found to be superior to other methods used for sowing of finger millet. The lowest weed density and weed biomass was recorded from twice hand weeding at 20 and 40 days after emergence resulted in the highest yield as compared to other control practices in finger millet (Fufa and Etagegnehu ,2016).

(C) Cultural methods:

Sound knowledge about identification of weeds, its growth habit and life cycle, so that best control method may be adopted. The entire field should be examined and visited to identify the kind of weed and take a visual idea about population especially during the critical period of weed-crop competition. Cultural methods of weed control are the environment-friendly methods that are adopted during crop husbandry in a standing crop through different cultural management such as plant population management through seed rate, crop spacing management, intercropping, crop rotation, mulching, management of time, and method irrigation and nutrient application. Growing intercrops such as green gram, cowpea, soybean, and ground nut could suppress the weed population by their high growth rate during the early period of crop growth, which eventually smothers the weeds so that the weed plants do not get adequate sunlight. Among the establishment methods, higher seed rate of barnyard millet 15 kg/ha compared recommended seed rate of 10 kg/ha recorded significantly lower density and biomass of weeds. It might be due to higher population of crop plant which provides competition to the weed flora (Kumar *et al*, 2019. Samina *et al.* (2019) reported that in barnyard millet, 25 cm × 10 cm spacing recorded higher seed yield with higher weed control efficiency than 30 cm × 10 cm and 40 cm × 10 cm spacing. Weed competition was reported to be reduced by narrow row spacing (<30 cm) which increased the yield of foxtail and proso millets Nelson(1977 and Agdag (1995). Different conservation practices such as the opening of conservation furrow and intercropping of red gram with finger millet increased the yield of finger millet reducing the weed population and dry weight (Sidar and Thakur, 2017). Stale seedbed technique followed by two intercultivation at 20 and 35 days after planting showed higher crop growth parameters such as dry matter accumulation, leaf area index, plant height, crop growth rate, and lower weed density and dry weight which consequently resulted in higher grain yield(5365 kg/ ha) in finger millet (Patil and Reddy,2014). Fufa and Etagegnehu (2016) reported that the narrower inter row spacing (40cm) also resulted in reduced weed density, weed biomass and highest yield as compared to wider inter row spacing in finger millet . From weed control efficiency point of view, kharif finger millet should be grown by recommended transplanting at 20 x 15 cm techniques of crop establishment (Chavan *et al* ,2017). along with 60 kg N/ha by splitting it into four equal splits (at transplanting, 20, 40 and 60 DAT).

An essential agronomic practice for managing weeds is changing the sowing window. Crops sown at optimum time has the advantage of being exposed to congenial climate at all growth stages and this inturns improves the productivity of crop (Dhaka *et al* (2023), Kiranmai *et al* (2014)). Initial flush of weeds can be avoided through **manipulation of time of sowing** of a crop, a little earlier or later than its normal time of sowing. Hand weeding

twice with narrow spacing was the best weed management practice for WCE, higher productivity and profitability in line sown rainfed barnyard millet (Shamina *et al.*, 2019). Crops sown on late June and early July recorded significantly higher grain yield, while those sown on late July recorded the lowest (Bello *et al.* 2022). Revathi *et al.* (2017) and Pandiselvi *et al.* (2010) indicated that finger millet sown early produced better yield attributes and grain yield than the other times of sowing. Srikanya *et al.* (2020) concluded that sowing of foxtail millet variety SiA 3085 up to last fort night of August was profitable to the farmers in sandy loam soils of Northern Agro-climatic zone of Telangana compared to sowing in September. Dimple *et al.* (2022) concluded that second fortnight of June sown crop resulted in the higher yield attributes, grain and straw yield over first fortnight of August sown crop. Kiranmai (2021) concluded that maximum grain yield of foxtail millet (3530 kg/ha) and prosomillet (1876 kg/ha) were recorded when sown during second fortnight of July. But for little millet the highest grain yield (2024 kg/ha) was observed when sown at July first fortnight. Delayed sowing results in adverse situation of all these parameters by late sown crops and resulted in decreased values of these yield contributing characters. In Odisha, the crop is sown during middle of June and in Tamil Nadu in June, however, in Madhya Pradesh and Karnataka the crop sown from end June to first week of July resulted in better yield. Cultivation of little millet is also observed during rabi season in Tamil Nadu and sowing time starts from September to October (Maitra and Shankar (2019).

Selection of competitive and allelopathic cultivars, affected the weed seedling emergence by decreasing the light interception and releasing numerous allelochemicals (Peerzada *et al.*, 2017). Crop variety play an important role in crop weed competition because of variations in morphological features, canopy structure and relative growth rate which leads to weed suppression. Variety with quick initial growth and more leaf area must be preferred in order to reduce crop weed competitions. Crop vigour and competitiveness against weeds can differ among varieties. So, cultivar selection is a major part of integrated weed management. An ideal cultivar should have rapid seedling emergence and high seedling growth rate, rapid leaf area expansions, dense canopy maintained over time, rapid canopy closure, efficient in nutrient use with tall height and indeterminate growth habit (Davis *et al.*, 2005). Fast canopy forming and tall cultivars generally suffer less from the weed competition than the slow growing and short stature ones (Naylor, 2002 and Buhler, 2002).

Growing of intercrops in widely spaced row not only reduces intensity of weeds but also gives additional yield. Intercropping increases the use of natural resources, compared to sole crops. Finger millet intercropped with small onion drastically reduced the weed biomass and recorded higher weed control efficiency and yield (Vishalini *et al.*, 2020). 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. (Ponnuswami *et al.* 2003). Inter-cropping, finger millet with legumes such as urd bean, peanuts, cowpeas and pigeon pea is common among farmers as complementarity between crops in resource use is important in low input subsistence farming systems (Chandra *et al.* 2013). Inter-cropping results in highest grain yield/ha in finger millet (Sidar and Thakur 2017) and less weeds, insects and diseases infestation in the crop (Meena *et al.* 2017). The improved cropping systems including finger millet + pigeon pea in 8-10: 2 or finger millet + field bean in 8: 1 for Karnataka and Tamil Nadu and finger millet + field bean in 6 : 2 row proportion for Bihar;

finger millet + soybean (9:1 crop mixtures) for Garhwal region of Uttarakhand; finger millet + mothbean / blackgram (4:1) for Kolhapur (DMD 2014). In finger millet / blackgram (Chandra *et al.* 2013) and blackgram + finger millet (1:1 or 2:1) (Bhushan and Singh 2013) inter-crops, weed biomass was lower than sole crops. Hand weeding and inter-cultivation were found to be effective in managing weeds in inter-cropping systems. Intercropping of green gram or black gram with foxtail millet at 3:3 ratios is beneficial (AICRPSM, 2017). In Andhra Pradesh, intercropping system with foxtail millet + ground nut (2:1) and foxtail millet + cotton (5:1) are very common, whereas at Rayalseema region of Andhra Pradesh, intercropping of foxtail millet and pigeon pea (5:1) is preferred. Foxtail millet + pigeonpea (5:1) with sowing during first fortnight of August resulted is most successful (Himasree *et al.* (2017). Manjunath and Salakinkop (2017) showed that intercropping of soybean + foxtail millet at row proportion of 2:1 and 4:2 recorded maximum returns. Manjunath et al. (2018) reported superiority of intercropping pigeonpea + foxtail millet (1:2) in obtaining higher net returns over sole cropping. Groundnut + foxtail millet (6:1) was found more successful over their sole planting (Shwethanjali *et al.* 2018). In alfisols of Karnataka, little millet + pigeonpea intercropping (4:2) expressed highest little millet equivalent yield (LMEY). Relay intercropping of little millet + horsegram recorded more LMEY than pure stand of little millet alone. The intercropping combination of soybean + little millet (4:2) registered higher economics (Manjunath and Salakinkop (2017). Sharmili and Parasuraman (2018) reported that little millet + pigeonpea with 6:1 row ratio recorded greater LMEY in Tiruvannamalai district of Tamil Nadu during kharif season. Intercropping combination of groundnut and little millet (6:1) assured better resource use efficiency as LER and more B:C ratio (Shwethanjali *et al.* 2018). In Odisha intercropping of little millet + black gram (2:1) and in Madhya Pradesh little millet + sesame / soybean / pigeon pea (2:1) are considered beneficial. Shalini *et al.* (2019) opined that intercropping little millet and pigeon pea at either 6:1 or 6:2 is beneficial. The intercropping of finger millet with small onion intercrop had effective control over the weeds in finger millet over other intercroppings (Vishalini *et al.*, 2020). Intercropping of Finger millet + Pigeon pea in 8-10:2, Finger millet + Field bean in 8:1 Finger millet + Soybean in 4:1 in Karnataka, Tamilnadu and Andhara pradesh, while intercropping of Finger millet + Pigeon pea in 6:2 in Bihar and Finger millet + black gram / moong bean in 6-8:1 (Sub mountain regions) in Maharashtra (Kolhapur) are very successful (Chapke *et al.*, 2020). Intercropping of Foxtail millet + groundnut (2:1), foxtail millet + cotton (5:1) and foxtail millet + pigeon pea (5:1) and Little millet + black gram in 2:1; Little millet + Sesamum /soybean/pigeon pea in 2:1, Little millet + pigeon pea in 2:1 are popular in Bihar and Madhya Pradesh (Chapke *et al.*, 2020).

Crop rotation is the repetitive cultivation of an ordered succession of crops and crop and fallow on a given piece of land. Different crops obviously brought about different cultural practices and disrupted the growth cycle of weeds and prevented the selection of flora towards increased abundance of problem species (Barberi and Lo Cascio, 2001). Inclusion of leguminous crops in finger millet rotation, trigger the germination of striga but prevent its continued growth. Most of the annual weeds get strangled, if sweet potato or cowpea were grown after finger millet. 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). Growing of foxtail millet-mustard, foxtail millet-green gram, foxtail millet-pigeon pea and foxtail millet - sunflower are profitable than mono-cropping of foxtail millet. Relay cropping can also be practiced. In Andhra Pradesh, if monsoon sets early, foxtail millet is sown with a row spacing of 45 cm and rabi sorghum is introduced as relay crop when foxtail millet is close to maturity stage (Chapke *et al.* 2018). Maitra and Shankar (2019) resulted that safflower or cowpea can be grown as sequence crop after little millet (AICRPSM, 2017). Moreover, sequential cropping of little millet and niger or lentil or gaur can also be taken into consideration. In south Bihar conditions, little millet is followed by niger (Chapke *et al.* 2018).

Soil solarization is a simple and effective technique of controlling soil-borne pests, including weeds. It involves covering the moist soil surface with 25 to 50 mm polyethene sheet (LDPE film) to trap solar radiation during the summer months. This would raise the soil temperature by 8 to 10 C° as compared to non-solarized soils and would kill soil born pests as well as weeds. As heavy soil retains more water and produces sufficient steam everyday, this technique works well on heavy soil compared to light soil. Soil solarization of 4-6 weeks is needed for sufficient control of weeds. The other advantages include, improving the soil structure, increasing the availability of nutrients especially N and controlling soil-borne fungi. Soil solarization was found to be the best non chemical and agronomical weed management practice to reduce weed seed bank, since it reduced the density of grasses, sedges and broad-leaved weeds to a great extent (Arora and Tomar, 2012). Worldwide, solarization has managed to control annual weeds such as annual bluegrass, *Ageratum* spp., *Amaranthus* spp., barnyard grass, cogongrass, common purslane, *Digitaria* spp., *Portulaca* spp., redroot pigweed, *Setaria* spp. and many others (Daelemans, 1989; Benlloglu *et al.*, 2005).

Mulching is covering the soil with a thick layer of mulch, deprive weed seeds from sunlight necessary for germination, photosynthesis and growth. Weed suppression due to mulching was directly related to the amount of mulch applied, which influences the light extinction through the mulch and consequently reduced the weed seed germination (Teasdale and Mohler, 2000). Kaur and Singh (2006) reported that application of organic mulches @ 4 t ha⁻¹ decreased the weed density significantly as compared to no mulch. Small-seeded weed species appear to be more sensitive than large-seeded species due to physical effects of mulch. Mulching is effective against most of annual weeds and some perennial weeds like *Cynadon dactylon*, *Sorghum halepense*. Vishalini *et al.* (2020) reported that mulching with rice straw or shredded coconut waste significantly reduced the weed density and weed dry weight in finger millet. In addition to the favourable influence of mulching in weed suppression, mulching also reduces evaporation from the soil surface, improves the soil tilth and reduces the erosion. Mulching of crop residue @ 5t/ha proved to be useful in conserving of soil moisture and increasing productivity of finger millet (Bhumika *et al* (2022). The combination of rice straw mulch with small onion intercrop had effective control over the weeds in finger millet. Apart from small onion, rice straw mulch with palak and rice straw mulch with black gram were found to record reduced weed densities with their broad leaved canopy structure in finger millet (Vishalini *et al*, 2020)

Stale seedbed technique is a cultural-cum-preventive measure. Stale seedbed (SSB) is based on the principle that weed seeds are flushed out before the crop is planted, so that the

weed seed bank in the top layer of the soil is depleted and the occurrence of weeds are reduced (Johnson and Mullinix, 2000). It involves, creating a seedbed one or two weeks before the seed is sown in order to stimulate the emergence of weeds prior to seeding. Emerged weeds are then destroyed by cultivation or application of a non-selective herbicide. Weed species that need light to germinate, have low initial dormancy and are present on the top layer (3-5 cm) of the soil are more vulnerable to seedbed technique (Chauhan and Mahajan, 2012). *Cyperus iria*, *Echinochloa colonum*, *Eleusine indica* are sensitive to stale seedbed technique. Patil *et al.* (2013) reported that stale seedbed technique followed by inter cultivation twice at 20 and 35 DAP significantly reduced the weed density and weed dry weight in finger millet.

The fertility of the soil affects both the vigour of crop plants and weeds. Weeds can utilize fertilizers as well as or better than crop plants. Placement of the fertilizers in the crop rows has an advantage over broadcast fertilization because most of the fertilizer is directly available to the crop. Due to early availability of band placed fertilizers to crop plants and that too in higher amounts, the crop will make early good growth and will take lead in competition. Proper amount of nitrogen and phosphorus and their banding in or near crop seed row will make them more available to the crop during the seedling stage than to weeds. Crop competition against weeds is increased when nitrogen is banded instead of broad cast. Banding places the fertilizer where the crop has greater access to it over surface germinating weeds. Scientific manipulation of the crop weed environment in favour of crop plants by the application of fertilizers will lead to selective stimulation of crop growth, which itself may serve as a weed smothering measure. Chavan *et al.* (2017) reported that total dry weight of weeds at harvest was significantly higher due to application of 100 kg N ha⁻¹ followed by 80 kg N ha⁻¹ and 60 kg N ha⁻¹ and lowest level of nitrogen recorded higher weed control efficiency. It was also observed that application of N in four splits significantly lowered the density and dry weight of weeds. Tadesse *et al.* (2018) reported that application of N up to 46 kg ha⁻¹ significantly reduced the density of striga, 49.8 per cent over control. Chavan *et al.* (2017) observed that four splits of nitrogen application i.e. at transplanting, 20, 40 and 60 days after transplanting recorded significantly the lowest number and dry weight of grass as well as broadleaf weeds in finger millet and thus four splits of nitrogen application recorded the highest control efficiency followed by three and two splits of nitrogen application. Similar results were reported by Sharma (2006).

(D) Chemical methods :

Weed management in millets is not accomplished by using agronomical and cultural practices exclusively. Herbicides continue to be the most powerful, economically effective and reliable way to control weeds in most crop production situations. The very first step in the direction of chemical use for weed control is the determination of weed species and their densities present at the particular field. After the identification of weed species, their densities and consideration of their economic threshold levels, the next step is to choose the application scenario for an herbicide *i.e.* optimum dose of herbicide should be chosen by keeping in mind the competitiveness of crop stand, environmental conditions, application technology and the stage of growth of weeds.

In minor millets the herbicide recommendations have been limited. Sneha and Sheeja (2022) concluded that Saflufenacil (Kixor) @ 0.05 kg/ha as Pre emergence and 2,4-D

(Weedar) @ 0.50-0.75 kg/ha as Post emergence in proso millet, Oxadiazon (Ronstar) @ 0.75-1.0 and Butachlor (Mechete) @ 0.75 kg/ha as Pre emergence in finger millet, Isoproturon (Arelon) @ 0.50-0.75 kg/ha as Pre emergence in Finger mille and kodo millet, Propazine (Propinex)@ 0.28-0.56 kg/ha as Pre emergence in Proso millet are recommended herbicides in minor millets . Atrazine was the most commonly used pre-emergence herbicide for weed control in millets. Vinothini and Arthanari (2017) reported that preemergence application of isoproturon 750 g ha⁻¹ followed by hand weeding at 40 DAS significantly reduced the density of weed species in irrigated kodo millet. Lower weed dry weight and higher WCE in finger millet were recorded in pre emergence application of bensulfuron methyl 0.6 G at 60 g ha⁻¹+ pretilachlor 6 G at 600 g ha⁻¹ fb early post emergence application of bispyribac sodium 10 SC at 25 g ha⁻¹ (Shanmugapriya *et al.* 2019). Chapke *et al* (2020) and Mishra *et al* (2018) recommended that for pre-emergence spray with Isoproturon @ 0.5 kg a.i./ha. (rainfed areas) and Oxyflurofen @ 0.1 lit a.i./ha (irrigated areas), while for post-emergence spray 2, 4-D sodium salt (80%) @ 0.75 -1.0 kg a.i./ha around 20-25 days after sowing is recommended for weed control finger millet and Kodo millet . To control weeds in Foxtail millet, Barnyard millet and little millet post-emergence application of 2, 4-D sodium salt (80%) @ 1.0 kg a.i./ha at 20-25 DAS and Isoproturon @ 1.0 kg a.i./ha as pre-emergence spray is effective. Ravali *et al* (2021) and Sameer (2018) concluded that interculture at 15 DAS fb ethoxysulfuron @ 18.75 g a.i ha⁻¹ as post emergence at 30 DAS recorded the highest grain yield and weed control in foxtail millet. Maitra *et al* (2020) recommended that Post-emergence application of 2, 4-D sodium salt (80%) @ 1.0 kg a.i. ha⁻¹ at 20-25 days after sowing (DAS) is effective for controlling broadleaved weeds. AICRPSM (2017) stated that pre-emergence application of Oxadiargyl @ 70 gm/ha or Pretilachlor @0.75 kg/ha was effective in weed management of foxtail millet. In finger millet, isoproturon at 0.5 kg/ha (preemergence) fb 2,4-D (Na salt) at 0.5 kg/ha (post-emergence) Kujur (2016) and oxadiargyl at 0.08 kg/ha (Pre-emergence) at 3 DAS fb ethoxysulfuron at 0.012 kg/ha (post-emergence) at 30 DAS (Shubhashree and Sowmyalatha (2019) were reported to have broad-spectrum weed control. To obtain effective broad spectrum weed control in Finger millet, Oxadiargyl @ 0.08 kg/ha at 3 DAS fb Ethoxysulfuron @ 0.012 kg/ha at 30 DAS, Butachlor @ 0.75 kg/ha as Pre-emergence , Isoproturon as Pre-emergence fb 2,4-D Na salt as Post-emergence each @ 0.5 kg/ha, Bensulfuronmethyl + pretilachlor @ 0.06 + 0.60 kg/ha as Pre-emergence (2 DAT) are recommended (Shubhashree and Sowmyalatha (2019), Kujur(2016), Dhanapal(2015) and Banu *et al* (2016)). For weed control in Kodomillet, Bensulfuronmethyl + pretilachlor @ 0.33 kg/ha as Pre-emergence/early post-emergence against wide range of weedsand Bispyribacsodium @ 0.02 kg/ha as Post-emergence (20 DAT) against grassy weeds are recommended (Lekhana *et al* (2021), Jawahar *et al* (2020) and Chanu *et al* (2018)). For Prosomillet, Atrazine or Propazine @ 0.28–0.56 kg/ha as Pre-emergence for broad spectrum weed control, 2,4-D @ 0.56 kg/ha as Post-emergence (4–6 leaf stage) against broad leaf weeds, Carfentrazone +2, 4-D amine + dicamba @ 0.009+ 0.280 + 0.140 kg/ha as Post-emergence (2–5 leaf stage) are effective wide range of weeds (Anderson and Greb (1987), Grabouski (1971) and Lyon *et al* (2007)). To control weeds in Foxtail millet, Carfentrazone + 2,4-D amine + dicamba @ 0.009 + 0.280 + 0.140 kg/ha as Post-emergence (2–5 leaf stage) against wide range of weeds ,Carfentrazone @ 0.018 kg/ha as Post-emergence against sedges and broad leaf weeds, Tribenuron-Methyl @ 22.5 kg/ha as Post-

emergence against broad leaf weeds are recommended (Lyon *et al* (2007 and Ning *et al* (2015)). Dubey and Mishra (2023) concluded that Butachlor @ 0.75 kg/ha at 3 DAP was relatively better in controlling grasses and gave a yield higher than the plot treated with 2,4-D sodium salt 0.75 kg/ha (15 DAP) and was similar to hand weeding. Although 2,4 -D sodium salt was effective against broad leaf weeds and sedges, grasses emerged in large density and suppressed the growth of finger millet crop. At 20 DAS, Atrazine @ 500g/ha as Pre emergence fb metsulfuron methyl + chlorimuron ethyl @ 4 g/ha as Post emergence recorded the highest WCE of 78.34 while at later stages two HW at 20 and 40 DAS (53.13%) and Atrazine @ 500g/ha as Pre emergence fb 2,4-D sodium salt @ 800 g/ha as Post emergence (47.43%) recorded the highest WCE compared to other treatments in finger millet . In Odisha application of the ready mix herbicide Bensulfuron methyl + pretilachlor (RM) @ 0.660 kg/ha at 2 days after transplanting followed by 2, 4 D ethyl ester @ 0.50 kg/ha at 30 DAT was found to be the best combination of herbicides in controlling the mixed weed populations in the transplanted finger millet with a weed control efficiency of (86%). Pre-emergence application of bensulfuron methyl 0.6 G + pretilachlor 6.0 G @ 165 / 330g/ha and pendimethalin 38.7 CS @ 680/1000 g/ha can be recommended for controlling weeds effectively in Kodo millet in Karnataka. In Madhya Pradesh, higher weed control efficiency in Kodo millet was obtained with application of oxyfluorfen @ 100 g/ha fb one hand weeding at 40 DAP (91.2%). In Karnataka, application of post-emergence herbicides-metsulfuron methyl + chlorimuron ethyl WP-20 WP (2+2) @ 4 g/ha and 2, 4 D sodium salt 80 WP @ 1000 g/ha were found to be a promising herbicide in controlling complex weed flora in Foxtail millet . 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 millet. 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). At present atrazine is the only herbicide most commonly used as pre-emergence for weed control in millets at various doses. One supplementary weeding at 30 days after sowing following pre-emergence herbicides is required for broad-spectrum weed control and higher yields (Mishra, 2015). Use of Isoproturon @ 0.50-0.75 and Butachlor @ 0.75 as Preemergence herbicide is effective in weed control for finger millet (Ashok *et al.* (2003) and Prasad *et al.* (2010)). In kodo millet, isoproturon @ 500 g/ha as Preemergence fb hand weeding at 40 DAS found to be effective in reducing the density of weed species in irrigated kodo millet (Vinothini and Arthanari 2017). Lekhana *et al.* (2021) reported that bensulfuron-methyl @ 0.06 + pretilachlor @ 0.330 kg/ha at 3 days after sowing recorded lower total weed density and weed dry biomass with weed control efficiency (59.21%) without any phytotoxic effect on kodo millet. In barnyard millet, bensulfuron-methyl @ 60 + pretilachlor @ 495 g/ha (RM) as Preemergence at 3 days after sowing was found effective (Thambi *et al.* 2021). Sukanya *et al* (2021) revealed that pre-emergent application of Butachlor 50 EC 750 g a.i./ha within three days after sowing has recorded significantly higher weed control efficiency in Kodo millet. Application of Butachlor @ 0.5-0.75 kg/ha as pre emergence at 7 to 12 days after planting, Butachlor to - 0.75 kg/ha DAP (Kumara *et al.* 2007, Naik *et al.* 2000, Naik *et al.* 2005, Kumara *et al.* 2014, Prasad *et al.* 2010), Chlorimuron ethyl @ 5 and 10 g/ha as early Post emergence at 10 days after planting(Guruprasanna *et al.* 2004), Fluchloralin @ 0.9 kg/ha as Preemergence, Nitrofen @ 0.5 kg/ha as Pre emergence or 2,4-D @ 1.5 kg/ha as Post emergence (Sankaran

et al. 1974), Nitrofen @ 0.5 kg/ha at five days after planting fb propanil @ 2.0 kg/ha at 20 days after planting (TN Boopathi *et al.* 1985), Oxyfluorfen@ 0.1 kg/ha as Preemergence at three days after planting (Bhargavi *et al.* 2016 and Prakash et al. 2006), Propanil @ 2.24 kg/ha as Post emergence (Patro and Tosh 1982), Pyrazosulfuron-ethyl @ 15 g/ha as Preemergence at 2 days after planting (Rama Devi *et al.* 2021) and Penoxsulam @ 20 g/ha as Post emergence at 20 days after planting (Rama Devi *et al.* 2021) are effective to control broad range weeds in finger millet in India.

So, to avoid the development of resistance in weeds, to reduce weed seed bank, to improve the economic return, instead of any single method of weed control, all the feasible methods are to be integrated for the effective and sustainable management of weeds in minor millets. For integrated weed management in minor millets, 2-3 times inter-cultivation and 1-2 time hand weeding during initial 25 days after sowing in addition to pre-emergence spray with Isoproturon @ 0.5 -1.0 kg a.i./ha and post emergence spray of 2, 4-D sodium salt @ 0.75-1.0 kg a.i./ha at 20-25 days after sowing should be done for effective weed control. Oxyfluorfen @ 0.1 lit a.i./ha as pre emergence spray is also recommended for finger millet in irrigated areas.

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