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, following the green revolution, the primary emphasis shifted towards the production of major cereals, specifically rice and wheat, causing millets to be relegated to the status of neglected grains. Moreover, urbanization, rising income levels, and shifts in dietary preferences labelled millets as a food choice associated with lower economic status. However, in recent times, there has been a resurgence in the recognition of millets, driven by a re-evaluation of their nutritional attributes, leading to a restoration of their esteemed status. (Maitra, 2020). The adverse effects of climate change, including reduced yields, heightened food insecurity, increased susceptibility to pest and disease attacks, soil degradation, altered crop schedules, and the onset of desertification, underscore the imperative of considering millets as a superior alternative crop. It can be asserted that millets represent a forward-looking and sustainable choice for the future of agriculture. There is an urgent requirement to advocate for the widespread cultivation of millets to guarantee national food and nutritional security. At present, the agricultural sector is confronted with formidable challenges arising from climate change and global warming. The primary consequences of climate change encompass rising temperatures, irregularities in rainfall patterns, and the escalation of greenhouse gas emissions, predominantly carbon dioxide. As C_4 plants, millets can use enhanced atmospheric CO_2 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 hactares) and production (76000 tonnes) of minor millets was reported from Madhaya 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 60 per 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), Shubhashree and Sowmyalatha (2019), Asargew and Shibabawu (2014), Dubey and Mishra (2023), Ramadevi *et al.* 2021)), 55-67.3 percent reduction in Kodo millet (Lekhana *et al* (2021), Prajapathi *et al* (2007), Jawahar *et al* (2019), Vinothini and Arthanari (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 Raj, 2022). To effectively address this challenge, it is imperative to diminish reliance on singular or limited weed control methods. The optimal solution lies in the integration of various preventive, physical, mechanical, agronomic, cultural, biological, and chemical weed management practices into a cohesive system that is environmentally sustainable. This integrated approach aims to maintain weed densities below economically detrimental thresholds while concurrently maximizing millet yield and profitability. Consequently, the design and implementation of integrated weed management practices should be tailored to specific sites and times, orchestrating a long-term strategy that considers weeds within a broader ecological and management framework. Through this integrated approach, the amalgamation of the finest options and tools creates a cropping system that is inherently unfavorable for weed proliferation (Singh *et al*, 2013).

Critical period of crop weed competition: Every crop has it's 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 post emergence stages is essential. Weed control no longer affects the yields after attainment of approximately 0.5 m height in millets. Consequently, the timing of weed removal is of equal significance as the act of removal itself to minimize crop-weed competition to the utmost extent. 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 *et al* (2020)
Barnyard millet	25-30	TNAU (2021)
	20-25	Chapke *et al* (2020)
Foxtail millet	20-35	TNAU (2016)
	20-25	Chapke *et al* (2020)
Proso millet	Up to 35	TNAU (2021)
Little millet	20-25	Chapke *et al* (2020)
Kodo millet	20-25	Chapke *et al* (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), 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 ramose* (Brown top millet), *Echinochloa colona* (Jungli rice), *Enchinochloa 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 halepanse* (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 argentia* (chilimil/ White cock's comb), *Boerhaavia diffusa* (Hog weed) *Commelina benghalensis* (kankoua/ Tropical spider wort), *Phylanthus 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), *Tridex procumbeans* (Coat buttons), *Amaranthus viridis* (chaulai/Pig weed), *Amaranthus retroflexus* (Redroot pigweed), *Portulaca olerecea* (Common purslane), *Eclipta alba* (False daisy), *Ipomoea haderacea* (Morning glory), *Trianthema portulacastrum* (Horse puslane), *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 Glorry), *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 diphylla* (Forked fimbry/Eight day grass), *Cyperus esculentus* (Yellow nut sedge) and *Cyperus defformis* (Small flower 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 fundamental tactics within an integrated weed management framework encompass preventive, agronomic, cultural, and chemical strategies. In essence, integrated weed management constitutes a methodical approach to weed control that integrates monitoring, prevention, and control measures. This approach does not center around the complete eradication of weeds; instead, it focuses on controlling weed populations below thresholds that are deemed agronomically, environmentally, and economically acceptable.

(A) <u>Preventive methods</u>:

As we know that "Prevention is better than cure," so it is better to prevent the weed species to spread in the crop lands and infest the crop. Prevention stands out as the most cost-effective strategy, yet it is frequently the least employed method of control. Preventive approaches, commonly termed cultural methods, encompass strategic agronomic choices designed to inhibit weed germination, emergence, growth, spread, and dispersion (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). Employ farm equipment and machinery that are thoroughly cleaned to prevent the introduction of weeds. Implement the practice of manually removing weeds before they reach the seed-setting stage. Exercise control over weeds in areas associated with animal feed, fodder, and bedding grounds, as certain weed seeds retain viability and activity even after passing through the digestive tracts of animals. Utilize exclusively well-rotted manure, ensuring a minimum aging period of 4-5 months, as unrotted or partially decomposed manures may introduce viable weed seeds to fields and contribute to their spread. While organic manures like FYM and vermi-compost are valuable sources of crop nutrition, it's crucial to acknowledge their drawback of potentially carrying weed seeds, thereby escalating weed infestation and introducing new weed species to cultivated fields. Maintenance of farm hygiene is must that prevents every year production of seeds, tubers, and rhizomes of already present weed species on the farm. (Mahapatra *et al* ,2023; Singh and Singh, 2005).

(B) <u>Mechanical methods:</u>

The elimination of weeds through diverse tools, implements, and manual interventions such as hand weeding and pulling falls within the purview of mechanical and physical practices in weed control, respectively. The mechanical approach to weed control serves the dual purpose of burying weed seeds and extracting both weed plants and vegetative propagules from the cultivated field soil. This process diminishes weed pressure in the field, ultimately mitigating crop-weed competition and augmenting 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. In the spectrum of weed management practices, the implementation of twice-weekly hoeing with a wheel hoe between the rows in finger millet resulted in notably reduced weed density and dry matter, coupled with heightened weed control efficiency and a diminished weed index (Kujur *et al.,* 2018). For all millets except Brown top 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 Brown top 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*, 2019). 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 weedings at 20, 40 and 60 DAS were recommended by Naik *et al.* 2001. Inter-cultivation twice at 20 and 40 DAS fb hand weeding once at 35 DAS resulted significantly higher yield of finger millet (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 weedings at 20 and 40 DAS plot was observed by Thambi *et al,* 2021. Within the array of weed management treatments, the application of one inter-culture at 20 days after sowing (DAS) and one hand weeding at 40 DAS demonstrated markedly diminished weed population and dry biomass in comparison to alternative treatments for barnyard millet (Kumar *et al.* 2019). 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). Gowda and Dhananjaya, 2000 conducted a comparison study between the improved tools with traditional hoe for weeding in finger millet. The enhanced efficacy of weed control and efficient conservation of soil moisture during the flowering and grain-filling stages were observed with the superior performance of the improved blade hoe and improved bent-type sweep hoe; 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 impact of tillage on the distribution of weed seeds in the soil is evident. In minimum tillage, a higher concentration of weed seeds was observed in the upper 10 cm of soil, whereas in conventional tillage, the distribution of weed seeds was relatively uniform throughout the soil profile (Hatti *et al.* 2018). Exploring the use of the stale seedbed technique under minimum tillage as a method to deplete the weed seedbank could be considered for weed management in finger millet (Patil *et al.* 2014; Patil and Reddy 2014).

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 Mariam, 2016).

(C) <u>Cultural methods</u>:

A robust understanding of weed identification, encompassing knowledge about growth habits and life cycles, is imperative for selecting optimal control methods. A comprehensive field examination and visitation are necessary to identify weed species and gain visual insights into their population dynamics, particularly during the critical stages of weed-crop competition. Environmentally friendly cultural methods of weed control are implemented during crop husbandry within a standing crop, employing various cultural management techniques such as regulating plant population through seed rate, managing crop spacing, adopting intercropping strategies, incorporating crop rotation practices, utilizing mulching techniques, and optimizing the timing and method of irrigation and nutrient application. Introducing intercrops like green gram, cowpea, soybean, and groundnut has the potential to suppress weed populations due to their rapid growth in the early stages of crop development, effectively overshadowing weeds and restricting their access to adequate sunlight. Within the spectrum of establishment methods, the utilization of a higher seed rate for barnyard millet at 15 kg/ha, as opposed to the recommended rate of 10 kg/ha, demonstrated a notable reduction in both weed density and biomass. This outcome can be attributed to the increased population of crop plants, fostering heightened competition against the weed flora (Kumar *et al*, 2019). 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 inter cultivation 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 Mariam (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 in turns improves the productivity of crop (Dhaka *et al*, (2023), Kiranmai *et al*, (2021)). 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). 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. Kiranmai *et al*, (2021) concluded that maximum grain yield of foxtail millet (3530 kg/ha) and proso millet (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). The selection of crop varieties significantly influences the dynamics of crop-weed competition, driven by variations in morphological characteristics, canopy structure, and relative growth rates that contribute to weed suppression. Optimal choices include varieties with swift initial growth and expansive leaf area, facilitating the reduction of crop-weed competition. Variances in crop vigor and competitiveness against weeds are inherent among different varieties, making cultivar selection a pivotal aspect of integrated weed management. An ideal cultivar should exhibit rapid seedling emergence, a high rate of seedling growth, swift leaf area expansion, the maintenance of a dense canopy over time, rapid canopy closure, efficient nutrient utilization, tall stature, and an indeterminate growth habit (Davies *et al*, 2005). Cultivars characterized by rapid canopy formation and tall stature typically experience lower susceptibility to weed competition compared to their slower-growing and shorter counterparts (Buhler *et al*, 2000).

Growing of intercrops in widely spaced row not only reduces intensity of weeds but also gives additional yield. Intercropping amplifies the utilization of natural resources in contrast to sole crops. The intercropping of finger millet with small onions resulted in a significant reduction in weed biomass, accompanied by elevated weed control efficiency and increased crop 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. 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). Hand weeding and inter-cultivation were found to be effective in managing weeds in intercropping 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 successfull (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 + pigeon pea intercropping (4:2) expressed highest little millet equivalent yield (LMEY). Relay intercropping of little millet + horse gram 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). 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 + Filed bean in 8:1 Finger millet + Soybean in 4:1 in Karnataka, Tamil Nadu 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. The cultivation of diverse crops naturally introduces varied cultural practices, disrupting the growth cycle of weeds and averting the tendency for the selection of flora favoring an increased abundance of problematic 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. The cultivation of foxtail millet in combination with mustard, green gram, pigeon pea, and sunflower has proven to be more economically advantageous than the sole cultivation of foxtail millet. Additionally, adopting relay cropping practices has demonstrated profitability. In Andhra Pradesh, a relay cropping strategy is employed, wherein, if the monsoon onset is early, foxtail millet is initially sown with a row spacing of 45 cm. Subsequently, rabi sorghum is introduced as a relay crop when the foxtail millet reaches the advanced stages of maturity (Chapke *et al*. 2020). 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.* 2020).

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 every day, 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).

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 favorable 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^{-1} proved to be useful in conserving of soil moisture and increasing productivity of finger millet (Painkra *et al*, 2022). The utilization of rice straw mulch in conjunction with a small onion intercrop demonstrated efficient weed control in finger millet. Beyond small onions, the incorporation of rice straw mulch alongside palak and rice straw mulch coupled with black gram exhibited notable reductions in weed densities, attributed to their expansive broad-leaved canopy structures within the finger millet crop (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. Weeds that have surfaced are subsequently eliminated through either cultivation or the application of a non-selective herbicide. Weed varieties requiring light for germination, exhibiting low initial dormancy, and residing within the uppermost layer (3-5 cm) of the soil are particularly susceptible to the seedbed technique (Chauhan and Mahajan, 2012). 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. 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 weed control efficiency followed by three and two splits of nitrogen application.

(D) Chemical methods :

The effective management of weeds in millets extends beyond agronomic and cultural practices alone. Herbicides persist as the most potent, economically efficient, and dependable method for weed control across diverse crop production scenarios. The initial stride towards incorporating chemical interventions for weed control involves the thorough identification of weed species and their respective densities in the specific field. Subsequent to the identification process, taking into account the densities and economic threshold levels of the identified weed species, the subsequent stage involves selecting the ideal herbicide application scenario. This entails choosing the optimal herbicide dosage, considering factors such as the competitiveness of the crop stand, prevailing environmental conditions, application technology, and the growth stage of the weeds.

In minor millets the herbicide recommendations have been limited. Sneha and Raj (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, Oxadiazone (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 preemergence 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) 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. 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), Dhanapal *et al* (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 weeds and Bispyribacsodium @ 0.02 kg/ha as post-emergence (20 DAT) against grassy weeds are recommended (Lekhana *et al* (2021), Jawahar *et al* (2019) 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) 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). 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 Odissa 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 Pre emergence 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 Oxyfluorfen@ 0.1 kg/ha as Pre emergence at three days after planting Propanil @ 2.24 kg/ha as Post emergence, Pyrazosulfuron-ethyl @ 15 g/ha as Pre emergence at 2 days after planting and Penoxsulam @ 20 g/ha as Post emergence at 20 days after planting are effective to control broad range weeds in finger millet in India (Bhargavi *et al.* 2016; Ramadevi *et al.* 2021).

Conclusion: 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. Oxyflurofen @ 0.1 lit a.i./ha as pre-emergence spray is also recommended for finger millet in irrigated areas.

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