



Weed management in finger millet in India- an overview

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ABSTRACT

Eleusine coracana (L.) Gaertn (finger millet) is one of the most nutritious and major staple food in some states of India. Finger millet is cultivated by using broadcast seeding, row (drill) seeding, and transplanting. In this review, the weeds associated with finger millet in different parts of India are listed, information on reported weed management options in finger millet is synthesized and future weed management research needs are enumerated. Weeds smother the finger millet resulting in significant reduction in the yield by 5 to 70%. The critical period for weed competition in finger millet is the first 4-6 weeks from planting/seeding. Physical/mechanical methods such as hand weeding at 20 and 30 days after planting (DAP) or passing wheel hoe twice with one manual weeding were found to be equally effective. In majority of the studies, inter-cropping was found helpful in reducing weed population substantially. Pre-emergence application of bensulfuron-methyl + pretilachlor, butachlor, isoproturon and post-emergence application of 2,4-D, chlorimuron-ethyl either alone or in combination with other methods were found effective in managing weeds in finger millet. Future research needs are: continuous monitoring of weeds and their shifts, understanding weed ecology and biology, developing improved mechanical tools and weed competitive cultivars along with location specific cost-effective and eco-friendly weed management strategies.

Introduction

Eleusine coracana (L.) Gaertn (finger millet) is an under-exploited minor millet with several edible and industrial uses (Chandra *et al.* 2016). It has several vernacular names all over the world, but it is known as ragi in India. Finger millet accounts for 12% of the global millet area and is grown in more than 25 countries across eastern Africa and southern Africa, and Asia from the Near East to the Far East. The major producers are India, Nigeria, Niger, Mali, Burkina Faso, Chad and China (Chandra *et al.* 2016). India continued to be the major producer of finger millet with cultivated area of 0.97 million ha and average yields of 1.62 t/ha, during 2019-20 (Tonapi 2020) and is one of the major staple foods of farming communities in some of the Indian states. The major finger millet growing states of India are Karnataka, Uttarakhand, Maharashtra, Tamil Nadu, Odisha, Andhra Pradesh, Gujarat, Jharkhand, West Bengal, Bihar and Chhattisgarh (GOI 2018). Of the total finger millet area and production in India, 13.30% and

20.58% was under irrigation (Shukla *et al.* 2015) mainly in states like Tamil Nadu and Gujarat, respectively. It is commonly grown both as sole crop and as mixed crop or in rotation with pulses and oilseeds. In state like Karnataka, pigeon pea - finger millet cropping system is predominantly followed under rainfed conditions.

Finger millet is cultivated by broadcast seeding (Sarawale *et al.* 2017), row (drill) seeding (Naik *et al.* 2000a, 2001) and transplanting (Naik *et al.* 2000, 2005) methods of establishment. Transplanting finger millet is more suitable and profitable under much delayed sowing conditions (ICAR 2008). Finger millet is grown in different seasons in different parts of the country. As a rainfed crop, during kharif season, it is sown in June-July in all Indian states except in Uttaranchal and Himachal Pradesh at hills of higher altitudes where it is sown in April-May. It is also grown in the winter season (*Rabi*) by planting in September-October in Karnataka, Tamil Nadu and Andhra Pradesh and as a summer irrigated crop by

planting in January-February in Karnataka, Tamil Nadu, Andhra Pradesh and Bihar.

The area under finger millet production has become nearly half of what it was in 1955-1956 (DMD 2014) due to several factors including inadequate removal of unwanted weeds (FAO 1996, Sakamma *et al.* 2018). Finger millet has a high yield potential (>10 t/ha under optimum irrigated conditions) and the grain stores very well (<http://www.icrisat.org/crop-fingermillet.htm>). The current (2019-20) yield is 1.62 t/ha (Tonapi 2020). However, improved finger millet varieties with yield potential of more than 4 t/ha (*L-5* and *GPU-28*) and > 5 t/ha (*ML-365* and *MR-6*) have been developed (DMD 2014). Thus, there is a wide gap in productivity that can be and needs to be narrowed. To realize higher productivity of finger millet, the major constraints limiting finger millet productivity in farmers' fields need to be addressed. Weeds are a major constraint and limit productivity as initial slow growth of the finger millet favours growth of weeds competing for sunlight, nutrient and water in early stages of growth (Pradhan *et al.* 2010, Mishra *et al.* 2018). Weeds associated with finger millet have the ability to adjust to fluctuating edaphic and climatic situations. In order to enhance the productivity, reduce production cost and increase profitability of finger millet farming, complete understanding of associated weeds and adoption of appropriate weed management practices is important. However, an effort to synthesise the published information on weeds and weed management in finger millet is yet to be attempted. Hence, in this review, the weeds associated with finger millet in different parts of India are listed, information on reported weed management options in finger millet is synthesized and future weed management research needs are enumerated.

Finger millet yield loss due to weeds

In unweeded situations, weeds smother the finger millet resulting in significant reduction in the yield by 5 to 70% (Prasad *et al.* 1991, Kumara *et al.* 2007, Rao and Chauhan 2015, Mishra *et al.* 2016, Rama Devi *et al.* 2021) depending on the agro-climatic conditions, associated weed flora and cropping systems adopted. Grain yield of finger millet decreases linearly with increase in weed population (Nanjappa and Hosmani 1985a). Weeds cause an appreciable reduction in density, dry weight and nutrients uptake of finger millet (Naik *et al.* 2000). Weed population and weed biomass of 295/m² and 239 g/m², were reported to cause 47% reduction in yield in transplanted finger millet, respectively (Bhargavi *et al.* 2016). Hence, it is important to

manage weeds during the critical period of crop weed competition to reduce the crop yield losses caused by weeds and improve the conditions favourable to crop.

In addition to direct losses caused by competition, weeds also cause losses indirectly by acting as alternate hosts to diseases. A dense population of weeds creates a good micro-environment for development of blast due to increased humidity around the crop (Berkowitz 1988). The fungus causing blast of finger millet has a wide host range, but the most common alternate hosts are grass weeds such as *Eleusine indica* (L.) Gaertn. *Eleusine africana* (Benth.) Stapf, *Digitaria* spp. *Setaria* spp. and *Dactyloctenium* spp. These serve as primary sources of inoculum (Sreenivasaprasad *et al.* 2004).

Critical period of crop-weed competition

Identifying the critical period of crop weed competition (CPCWC) in crops is one of the first steps in designing a successful integrated weed management (Rao and Nagamani 2010, Mishra 2015, Rao *et al.* 2015). The CPCWC for the finger millet varied from 25-60 days after sowing (DAS) (Yatish *et al.* 2020). In respect of irrigated transplanted finger millet, critical period for weed competition has been identified to be first 4-6 weeks from planting (Nanjappa and Hosmani 1985, Mishra 2015). Under rainfed conditions, finger millet should be kept weed-free during the first 5 weeks to prevent losses in yield (Sundaresh *et al.* 1975, Hedge *et al.* 1983). Grasses were found to be more competitive than sedges or broad-leaved weeds and weeds removed 50% of fertilizer N when weeding was delayed until 65 DAS (Hedge *et al.* 1983). In finger millet/soybean inter-cropping system, 4-5 weeks after sowing was the most critical period of competition (Mohapatra and Haldar 1998).

Weed flora

Eighty-five weed species have been reported to occur in association with the finger millet crop across India. *Cyperus rotundus* L. *Cynodon dactylon* (L.) Pers. *Commelina benghalensis* L. *Ageratum conyzoides* L. *Dactyloctenium aegyptium* (L.) Willd. *Echinochloa colona* (L.) Link, *Digitaria marginata* Stapf, *E. indica*. *Acanthospermum hispidum* DC. *Spilanthes acmella* (L.) Murray, *Eragrostis pilosa* (L.) P. Beauv. *Parthenium hysterophorus* L. *Amaranthus viridis* L. *Alternanthera sessilis* (L.) R. Br. ex DC. *Celosia argentea* L. *Euphorbia hirta* L. *Leucas aspera* (Willd.) Link, *Ocimum canum* Sims *etc.* were the most commonly reported species in the order of decreasing importance (**Table 1**). In a survey

Table 1. Major weeds associated with finger millet in India

Weed species	Ranking	States in which it was reported as a major weed
<i>Cyperus rotundus</i>	1	Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Orissa, Karnataka, Tamil Nadu, West Bengal, Uttar Pradesh,
<i>Cynodon dactylon</i>	2	Bihar, Chhattisgarh, Gujarat, Karnataka, Orissa, Tamil Nadu, Uttar Pradesh
<i>Commelina benghalensis</i>	3	Bihar, Chhattisgarh, Karnataka, Orissa, Uttar Pradesh, West Bengal
<i>Ageratum conyzoides</i>	4	Bihar, Chhattisgarh, Orissa, Karnataka
<i>Echinochloa colona</i>	5	Bihar, Chhattisgarh, Karnataka, Orissa, Uttar Pradesh
<i>Dactyloctenium aegyptium</i>	6	Bihar, Karnataka
<i>Digitaria marginata</i>	7	Andhra Pradesh, Karnataka
<i>Eleusine indica</i>	8	Chhattisgarh, Orissa,
<i>Spilanthus acmella</i>	9	Karnataka
<i>Acanthospermum hispidum</i>	10	Orissa, Karnataka
<i>Eragrostis pilosa</i>	10	Karnataka
<i>Celosia argentea</i>	11	Chhattisgarh, Karnataka, West Bengal
<i>Parthenium hysterophorus</i>	12	Andhra Pradesh, Karnataka
<i>Amaranthus viridis</i>	13	Chhattisgarh, Karnataka
<i>Euphorbia hirta</i>	13	Andhra Pradesh, Chhattisgarh, Karnataka
<i>Ocimum canum</i>	13	Karnataka
<i>Alternanthera sessilis</i>	14	Karnataka
<i>Digitaria sanguinalis</i> (L.) Scop.	14	Chhattisgarh, Orissa, Karnataka
<i>Leucas aspera</i>	14	Karnataka
<i>Sida acuta</i> Burm. f.	15	Karnataka

Based on maximum number of times of its report (Weed species with equal number of times of reporting were given the same number)

on the weed flora of crop fields of North coastal Andhra Pradesh, a total of thirty-five weed species were exclusively recorded in the finger millet crop. Of these, ten species are common including *Sida cordata* (Burm. f.) Borss. Waalk. *Zaleya decandra* (L.) Burm. fil. *Euphorbia indica* Lam. and *Cyanotis cristata* (L.) D. Don. Twenty species were occasional including *Citrullus colocynthis* (L.) Schrader, *Mollugo disticha* Ser. *Heliotropium curassavicum* L. and *Cyperus pilosus* Vahl. (Gaddeyya and Ratna Kumar 2014). The complete covering of finger millet seedlings with dominant grasses like *D. marginata*, *Portulaca oleracea* L. and *Borreria articularis* (L.f.) F.N. Williams at 30 DAS was reported (UAS 2004). *C. dactylon* was reported to become a difficult to control major weed problem after the second year during a fixed three crop rotation of cotton-sorghum-ragi, raised under zero tillage conditions with chemical weed control (Palaniappan 1988). Thus, weed flora was observed to change in response to management practices.

Weed ecology

Finger millet adapts well in adverse environmental conditions (Gupta *et al.* 2017). Weeds associated with finger millet are also adapted to those unfavourable conditions to compete with finger millet for the limited resources. Hence, it is essential to understand the ecology of weeds associated with finger millet to manage them properly.

Weed dominance was reported to vary with soil fertility (Kandasamy *et al.* 2000, Kumar *et al.* 2000) and irrigation (Sankaran *et al.* 1974). Irrigation at 50% available soil moisture decreased weed populations, compared with irrigation at 60% and 70% (Sankaran *et al.* 1974). Weed density and weed biomass increased significantly up to 40 kg N/ha while relative weed control efficiency and weed index decreased with an increased rate of N (Kumar *et al.* 2000). *Trianthema portulacastrum* L. *Digera arvensis* Forsk. and *C. dactylon*, were the most dominant weed species in fertilized plots, while *Digera arvensis*, *C. dactylon* and *Flaveria australasica* Hook dominated unfertilized plots (Kandasamy *et al.* 2000). The weed ecology in finger millet is yet to be more thoroughly understood for an effective management.

Methods of weed control in finger millet

Non-chemical and chemical methods were found to be effective in managing weeds in finger millet (Tables 2, 3 and 4).

Non-chemical methods of weed control: Early weeding was found essential for finger millet and hence first hoeing and weeding within 2 to 3 weeks of sowing and the second a fortnight after was advocated (DAO 2008). Among the non-chemical methods of weed control, physical/mechanical methods such as hand weeding at 20 and 30 days after planting (DAP) or stale seedbed combined with

two inter-cultivation or passing wheel hoe twice with one manual weeding were suggested as they were found to be equally effective (Patil *et al.* 2014). Hand

weeding and inter-cultivation are the common methods used by the farmers. However, their adoption is normally delayed by farmers. Hence, it is

Table 2. The weed management methods reported effective in drill-seeded finger millet in India

Weed management method	Location, State	Reference
<i>Non chemical</i>		
The conventional tillage (ploughing twice + harrowing once + inter-cultivation twice at 25 and 50 days after sowing (DAS) in Alfisols when compared to minimum and zero tillage practices	Bangalore, Karnataka	Hatti <i>et al.</i> 2018
Hand weeding (HW) thrice 20, 40 and 60 DAS	Bangalore, Karnataka	Naik <i>et al.</i> 2001, 2001a, 2005
HW twice 15 and 30 DAS	Madurai, Tamil Nadu	Boopathi <i>et al.</i> 1985a
HW twice 20 and 40 DAS	Almora, Uttarakhand; Bangalore, Karnataka; Berhampur, Orissa; Raipur, Chhattisgarh; Ranchi	Jena and Tripathy 1997, Tuti <i>et al.</i> 2016, Pandey <i>et al.</i> 2018, IIMR 2021
Hoing once 15 DAS followed by (<i>fb</i>) HW thrice 25,40, 60 DAS	Bhuvaneswar, Orissa	Tosh and Nanda 1983
Hoing once (30 DAS) <i>fb</i> HW once 30 DAS	Bangalore, Karnataka	Reddy <i>et al.</i> 1990
Hoing twice (28 and 41 DAS) (with the improved bent type sweep hoe)	Bangalore, Karnataka	Gowda and Dhananjaya 2000
Hoing twice by wheel hoe between rows + intra-row manual weeding <i>fb</i> HW twice 20 and 40 DAS	Raipur, Chhattisgarh	Kujur <i>et al.</i> 2018
Inter-cultivation twice 20 and 40 DAS <i>fb</i> HW once 35 DAS	Coimbatore, Tamil Nadu; Tehri Garhwal, Uttar Pradesh	Singh and Arya 1999, Ramamoorthy <i>et al.</i> 2002
Inter-cultivation once <i>fb</i> HW twice 30 and 45 DAS	Coimbatore, Tamil Nadu	Ramamoorthy <i>et al.</i> 2010
<i>Deris indica</i> leaf mulch	Ranchi, Jharkhand	IIMR, 2021
<i>Chemical</i>		
2, 4-D sodium salt 0.75 kg/ha post-emergence application (PoE) 15–20 DAS	Bangalore, Karnataka; Berhampur, Orissa	Jena and Tripathy 1997, Ashok <i>et al.</i> 2003, DOA 2008, DMD, 2014
2,4-D 1.0 kg/ha PoE 3-4 weeks after sowing	Ranchi, Jharkhand	Pradhan 1988
2,4-D-sodium salt 1.5 kg/ha PoE	Pandicherry	Subbiah <i>et al.</i> 1974
Bensulfuron-methyl (0.6 % G) + pretilachlor (6.0 % G) 0.75 kg/ha (ready-mix) pre-emergence application (PE) (3 DAS)	Bangalore, Karnataka	Kumar 2015, Kumar <i>et al.</i> 2015, 2015a
Butachlor 0.75 kg/ha PE (within 3 DAS)	Karnataka (Southern Transition zone, Southern Dry zone, Eastern Dry zone and Central Dry zone.)	DWR 2000
Isoproturon 0.5 kg/ha PE	Jagdapur, Chhattisgarh; Tehri Garhwal, Uttar Pradesh; Bangalore, Karnataka; Coimbatore, Tamil Nadu	Singh and Arya 1999, Ramamoorthy <i>et al.</i> 2002, Ashok <i>et al.</i> 2003, ICAR 2008, DOA 2008, Pradhan <i>et al.</i> 2012, DMD 2014
Isoproturon 0.5 PE <i>fb</i> 2, 4-D Na salt 0.5 kg/ha PoE	Raipur, Chhattisgarh	Kujur <i>et al.</i> 2018
Neburon 1.0 kg/ha and 2,4-D sodium 1.5 kg/ha PE	Bangalore, Karnataka	Reddy <i>et al.</i> 1990
Nitrofen 0.5 kg/ha PE	Pondicherry, India	Subbiah <i>et al.</i> 1974
Nitrofen 0.5 kg/ha PE <i>fb</i> propanil 2.0 kg/ha PoE	Madurai, Tamil Nadu	Boopathi and Kolandaiswamy 1981, Boopathi <i>et al.</i> 1985a
<i>Integrated</i>		
2,4-D amine or sodium salt at 0.5 and 1.5 kg/ha PoE 10 DAS <i>fb</i> hoeing and/or HW once 30-35 DAS	Bangalore, Karnataka	Prasad <i>et al.</i> 1991
Butachlor 0.5 to 0.75 kg/ha 12 DAS <i>fb</i> hoeing once 35 DAS	Bangalore, Karnataka	Naik <i>et al.</i> 1999, 2001
Chloramben 1.01 kg/ha (1 DAS) <i>fb</i> HW once 25 DAS	Bhuvaneswar, Orissa	Tosh and Nanda 1983
Isoproturon 0.25 kg/ha + metoxuron 0.375 kg/ha PE 1 DAS <i>fb</i> HW once 30 DAS	Bangalore, Karnataka	Manjunath and Muniyappa 1992
Isoproturon 0.5 kg/ha PE <i>fb</i> 2,4-D Na salt 0.75 kg/ha PoE 15 DAS <i>fb</i> inter-cultivation once 30 DAS	Coimbatore, Tamil Nadu	Ramamoorthy <i>et al.</i> 2010
Isoproturon 0.5 Kg/ha PE <i>fb</i> HW twice 20 and 40 DAS	Jagdapur (Chhattisgarh)	Pradhan and Singh 2009
Isoproturon 0.50 kg/ha <i>fb</i> hoeing up to 35 DAS	Bangalore, Karnataka	Naik <i>et al.</i> 2001a
Metoxuron 0.50 kg/ha PE 1 DAS <i>fb</i> HW 30 DAS	Bangalore, Karnataka	Manjunath and Muniyappa 1992
Oxyfluorfen 0.25 to 0.5 kg/ha <i>fb</i> HW twice 20 and 45 DAS	Jagdapur, Chhattisgarh	Pradhan <i>et al.</i> 2010
Oxadiargyl at 150 to 200 g/ha (within 3 DAS) <i>fb</i> one inter-cultivation once at 25-30 DAS	Kolhapur, Nandyal, Ranchi and Ranichauri	IIMR 2021
Bispyribac sodium 15 g/ha (within 15-20 DAS) <i>fb</i> inter-cultivation once 35-40 DAS	Kolhapur, Nandyal, Ranchi and Ranichauri	IIMR 2021

Table 3. Weed management practices found effective in transplanted finger millet in India

Weed management method	Location	Reference
<i>Non chemical</i>		
Hand weeding (HW) once between 2 to 3 weeks after transplanting. A second weeding may be done 15 to 20 days after, if necessary.	Orissa	DOA 2008
HW twice 20 and 30 days after planting (DAP)	Bangalore, Karnataka	Patil <i>et al.</i> 2014, 2014a; Patil and Reddy 2014
HW twice 15 and 30 DAP	Coimbatore, TN	Ramamoorthy <i>et al.</i> 2010
HW twice 20 and 40 DAP	Bangalore, Karnataka	Guruprasanna <i>et al.</i> 2004, Kumara <i>et al.</i> 2007, Rama Devi <i>et al.</i> 2021
Hoeing twice 20 and 35 DAP followed by (<i>fb</i>) HW once 45 DAP	Tirupati, Andhra Pradesh	Patil <i>et al.</i> 2014
Hoeing (wheel) thrice 20, 30 and 40 DAP <i>fb</i> HW once 45 DAP	Bangalore	Patil and Reddy 2014
Inter-culture twice <i>fb</i> HW once or twice	India	DMD 2014
Stale seed bed technique <i>fb</i> inter-cultivation twice at 20 and 35 DAP and it was at par with hand weeding twice at 20 and 30 DAP; passing wheel hoe at 20, 30 and 40 DAP + one HW at 45 DAP	Bangalore	Patil <i>et al.</i> 2013
Stale seedbed technique in combination with inter-cultivation twice at 20 and 35 DAP or passing wheel hoe at 20, 30 and 40 DAP with one hand weeding for weed management	Bangalore	Patil <i>et al.</i> 2014a
Stale seedbed with inter-cultivation twice at 20 and 35 DAP	Bangalore	Patil <i>et al.</i> 2014, Patil and Reddy 2014
<i>Chemical</i>		
Bensulfuron-methyl 60 g + pretilachlor 600 g (6.6% G pre-mix formulation) 1.0 kg/ha pre-emergence application (PE) 2 DAP	Mandya, Karnataka	Banu <i>et al.</i> 2016
Butachlor 0.75 kg/ha PE 3DAP	Bangalore, Karnataka	Kumara <i>et al.</i> 2007
Butachlor 0.5 to - 0.75 kg/ha 7 to 12 DAP	Bangalore, Karnataka	Naik <i>et al.</i> 2000, Naik <i>et al.</i> 2000a, 2005, Kumara <i>et al.</i> 2014
Butachlor 0.75 kg/ha PE 3 DAP	Bangalore, Karnataka	Prasad <i>et al.</i> 2010, Kumara <i>et al.</i> 2014
Chlorimuron ethyl 5 and 10 g/ha Early PoE10 DAP	Bangalore, Karnataka	Guruprasanna <i>et al.</i> 2004
2, 4-D Na salt 0.75 kg/ha PoE 15 DAP	Bangalore, Karnataka	Kumara <i>et al.</i> 2007
Fluchloralin 0.9 kg/ha PE and 2,4-D sodium 0.8 kg/ha PoE	Bangalore, Karnataka	Dhanapal 1987
Nitrofen 0.5 kg/ha PE or 2,4-D 1.5 kg/ha PoE	Coimbatore, Tamil Nadu	Sankaran <i>et al.</i> 1974
Nitrofen 0.5 kg/ha 5 DAP <i>fb</i> propanil 2.0 kg/ha 20 DAP	Madurai, TN	Boopathi <i>et al.</i> 1985
Oxyfluorfen 0.1 kg/ha PE 3 DAP azimsulfuron 20 g/ha PoE 20 DAP	Tirupati, Andhra Pradesh	Bhargavi <i>et al.</i> 2016.
Oxyfluorfen 0.1 kg/ha PE <i>fb</i> HW once 20 DAP	Tirupati, Andhra Pradesh	Bhargavi <i>et al.</i> 2016.
Oxyfluorfen 0.1 kg/ha PE	India; Mandya, Karnataka	Prakash <i>et al.</i> 2006, ICAR 2008, DMD 2014
Propanil 2.24 kg/ha PoE	Orissa	Patro and Tosh 1982
Pyrazosulfuron-ethyl 15 g/ha PE 2 DAP	Tirupati, Andhra Pradesh	Rama Devi <i>et al.</i> 2021
Pretilachlor 500 g/ha PE 2 DAP	Tirupati, Andhra Pradesh	Rama Devi <i>et al.</i> 2021
Penoxsulam 20 g/ha PoE 20 DAP	Tirupati, Andhra Pradesh	Rama Devi <i>et al.</i> 2021
<i>Integrated</i>		
Butachlor 0.5 kg/ha 12 DAP <i>fb</i> earthing-up once 35 DAP	Bangalore, Karnataka	Naik <i>et al.</i> 2005
Butachlor 1.0 kg/ha PE <i>fb</i> HW once 30 DAP	Coimbatore, TN	Kandasamy <i>et al.</i> 2000
Isoproturon or 2,4-D sodium salt 0.75 or 0.5 kg/ha 7 DAP <i>fb</i> earthing up once 35 DAP	Ranchi, Bihar; Bangalore, Karnataka	Yadav <i>et al.</i> 2005, Naik <i>et al.</i> 2000a
Nitrofen 0.5 kg/ha PE 5 DAT <i>fb</i> HW once 30 DAS	Madurai, TN	Boopathi <i>et al.</i> 1985, Kolandaiswamy 1981, Boopathi <i>et al.</i> 1985a
Oxadiargyl 100 g/ha PE 3 DAP <i>fb</i> inter-cultivation once 20 DAP	Bapatla, Andhra Pradesh	Prithvi <i>et al.</i> 2015
Oxadiazon 0.4 kg/ha PE <i>fb</i> HW once 30 DAP	South Konkan.	DWR 2000
Oxadiazon 0.50 kg/ha <i>fb</i> HW (30 DAP) HW once 30 DAP	Coimbatore, TN	Ramamoorthy <i>et al.</i> 2010
Pendimethalin 0.75 kg/ha PRE <i>fb</i> HW once 30 DAP	Coimbatore, TN	Ramamoorthy <i>et al.</i> 2010
Pretilachlor 0.45 kg/ha <i>fb</i> HW once 30 DAP	Coimbatore, TN	Ramamoorthy <i>et al.</i> 2010

essential to create awareness among farmers on the importance of carrying out those operations during critical period of crop weed competition.

Hand weeding: In regions where animal or machine power is not available, the weeding and cultivation operations are usually carried out by hand, manually. This may be done on an individual family or community basis. Hand weeding once to thrice (Table 2 and 3) was found to be the best and an efficient method for the weed control giving highest

yield and weed control efficiency (Bhushan and Singh 2013, Patil *et al.* 2014a, Patil and Reddy 2014). However, implementation of MGNERGA (Mahatma Gandhi National Rural Employment Guarantee Act) works has led to labour scarcity to the tune of 53% and 30% for agriculture operations like weeding and sowing, respectively, resulting in a decline in area for labour intensive crops like ragi to the extent of 30%, in Chikmagalur districts in central dry zone of Karnataka (Harish *et al.* 2011). The labour non-

availability and increasing labour cost are becoming serious limitations for the farming community to adopt the manual method of weed control. Hence, hand weeding may be used for managing weeds when family labour is available on small holdings or as a component of integrated weed management.

Tillage: The role of tillage in conserving soil moisture and its subsequent beneficial effect on crop productivity has long been recognized. Conventional tillage was found superior for finger millet under semiarid Alfisols (Sankar *et al.* 2006). However, conventional tillage had resulted in higher weed density particularly grasses and additional cost than zero tillage (UAS 2004). 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). Under rainfed pigeon pea-finger millet system in Alfisols, the infestation of *Borreria articularis*, *Cynodon dactylon* and *C. rotundus* was reduced with conventional tillage (3 ploughings + 3 inter cultivations) when compared to other tillage practices {reduced tillage (2 ploughings + 2 inter cultivations) and minimum tillage (1 ploughing + 1 inter-cultivation)} (Vijaymahantesh *et al.* 2016). 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 (Vijaymahantesh *et al.* 2016, Hatti *et al.* 2018). Exhausting weed seedbank with stale seedbed technique (Patil *et al.* 2014a, Patil and Reddy 2014),

under minimum tillage, may be explored as a means of weed management in finger millet.

Inter-cultivation: Traditionally, direct row seeded stands of finger millet are often cultivated by farmers with tined implements drawn by draft animals. This is done twice or thrice at ten-day intervals beginning about three weeks or a month after seeding. Inter-cultivation once or twice followed by hand weeding was found to be effective in managing weeds in finger millet (Table 2 and 3). Energy analyses indicated that among different operations of cultivation of irrigated crop of finger millet, weeding and inter-row cultivation used for managing weeds were the most energy intensive operations (Gowda *et al.* 1999). Inter-cultivation results in removing weeds, thinning the stand, particularly in the case of the broadcast one, and mulching the soil. Later the crop is hand-weeded and hand hoed once or twice. The use of improved blade hoe and improved bent type sweep hoe proved superior in conserving soil moisture at flowering and grain filling stages, controlled weeds more effectively and resulted in the highest grain yield, compared to inter-row cultivation using the local hoe (Gowda and Dhananjaya 2000).

Inter-cropping: Inter-cropping, finger millet with legumes such as urd bean (*Vigna mungo* L. Hepper), peanuts (*Arachis hypogea* L.), cowpeas (*Vigna unguiculata* (L.) Walp.) and pigeon pea (*Cajanus cajan* (L.) Huth), 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 (Sidar and Thakur 2017) and less weeds, insects and diseases infestation in the crop (Meena *et al.* 2017). The improved cropping

Table 4. Weed management practices found effective in finger millet based inter-cropping systems

Inter-cropping system	Herbicide/weed management method	Location	Reference
Finger millet inter-cropped with soybeans or mixtures of field bean, niger [<i>Guizotia abyssinica</i> (L.f.) Cass.], fodder jowar [<i>Sorghum bicolor</i> (L.) Moench] and mustard [<i>Brassica juncea</i> (L.) Czern.]	Hand weeding (HW) thrice gave the highest grain/seed yields in all cropping systems Neburon 2. 1.0 kg/ha pre-emergence treatment (PE)	Bangalore, Karnataka	Nanjappa and Hosmani 1986
Finger millet + sorghum (drill-seeded)	2,4-D ethyl-ester 1.0 kg/ha PE Fluchloralin 0.55 kg/ha post-emergence treatment (PoE)	Bangalore, Karnataka	Mahabaleswara 1987
Finger millet + pigeon pea (drill-seeded)	2,4-D amine 0.3 kg/ha PoE as directed sprays Conventional tillage (three ploughings -15 to 20 cm deep) <i>fb</i> inter-cultivation thrice – first after 30 days after seeding (DAS) and remaining at 15-day intervals) + integrated supply of nitrogen (50% N through urea +25% through FYM+25%N through Glyricidia [<i>Gliricidia sepium</i> (Jacq.) Kunth ex Walp.]	Bangalore, Karnataka	Vijaymahantesh <i>et al.</i> 2016
Finger millet + horsegram (<i>Macrotyloma uniflorum</i> (Lam.) Verdc.) (drill-seeded)	Finger millet-horsegram (2:1 ratio) (inter-row space 30 cm) with HW twice 25 and 40 DAS	Jagdalpur, Chhattisgarh	Pradhan <i>et al.</i> 2018

systems include: finger millet + pigeon pea in 8-10: 2 or finger millet + field bean (*Phaseolus vulgaris* L.) in 8: 1 for Karnataka and Tamil Nadu and finger millet + field bean in 6 : 2 row proportion for Bihar; finger millet + soybean (*Glycine max* (L.) Merr.) (9:1 crop mixtures) for Garhwal region of Uttarakhand; finger millet + mothbean (*Vigna aconitifolia* L.) / blackgram [*Vigna mungo* (L.) Hepper] (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, certain herbicides and inter-cultivation were found to be effective in managing weeds in inter-cropping systems (**Table 4**). A few of the inter-crops do not show the advantage of reducing weed biomass. For example: weed biomass was not significantly affected by inter-crops of finger millet with horse gram [*Macrotyloma uniflorum* (Lam.) Verdc.] or soybeans (Patil *et al.* 1987, Pradhan *et al.* 2018).

Weed control with herbicides

The labour availability is decreasing and the labour wages are increasing making labour use uneconomical in India. Hence, efforts were made to identify appropriate and cost-effective herbicides to control weeds and improve finger millet productivity (Mgonja *et al.* 2013).

Effective herbicides for managing weeds in finger millet: Several herbicides were found effective in managing weeds in finger millet in India (**Table 2** and **3**). Herbicide (butachlor at 0.75 kg/ha) application in finger millet gave similar grain yield to hand weeding twice due to good weed management (Dhanapal *et al.* 2015) and saved weeding cost (Rs. 6810 to 6980/ha) (Prasad *et al.* 2010). Several researchers reported herbicide use to be the most effective and economical method for managing weeds in finger millet (Guruprasanna *et al.* 2004, Ramamoorthy *et al.* 2010, Pradhan *et al.* 2012, Bhargavi *et al.* 2016). Application of 2,4-D reduced the number of broad-leaved weeds, with the exception of *A. conyzoides*, but resulted in higher densities of grasses (*D. marginata*, *D. aegyptium*, *E. pilosa* and *E. colona*) at all stages (Prasad *et al.* 1991). Weed population shifts were also reported in a few instances. For example: continuous application of butachlor in finger millet resulted in considerably lowered grass (*D. marginata* and *E. colona*) density and increased sedge density (Prasad *et al.* 2010). Density of *C. benghalensis* was also found to increase with continuous application of butachlor. Greater efforts are needed to understand the weeds species response to the herbicides used

and identify suitable herbicides and combinations to manage weed flora associated with finger millet.

Effect of residual herbicides and persistence

Finger millet is normally raised as succeeding crop in the same field after the harvest of crops like groundnut treated with herbicides. Fluazifop-p-butyl (Kumbar *et al.* 2014) and pendimethalin (Gowda *et al.* 2002) applied to groundnut and fluometuron (Balasubramanian and Sankaran 1976), glyphosate (Jagannathan and Nadanam 1996, Nadanassababady *et al.* 2000) and glufosinate (Nadanassababady *et al.* 2000) applied on cotton did not cause phytotoxicity on succeeding finger millet grown. However, straw yield of finger millet was lower when grown in plots treated with 1.0 kg atrazine/ha in preceding sorghum crop (Jagannathan and Nadanam 1996).

In a long-term study, no residual toxicity was observed due to any of the herbicides applied to the respective crops grown in rotation for over nine years in finger millet (butachlor or 2,4-D)-groundnut (pendimethalin or alachlor) cropping system (Prasad *et al.* 2010). Butachlor persisted in soil up to 21- 30 days in finger millet and the half-life ranged from 11.3 to 15.5 days in red sandy loam soil (Gowda *et al.* 2008). Continuous application of herbicides butachlor (0.75 kg/ha), 2,4-D (0.40 kg/ha) to finger millet did not affect the pH, EC, bulk density organic carbon, phosphorous and potassium contents of soil. Continuous application of herbicides 2,4-D (0.4 to 0.8 kg/ha), butachlor (0.75 to 1.5 kg/ha) in transplanted finger millet did not show herbicide residues in soil, grain, straw and underground water (in case of butachlor only) at 100 to 120 days of herbicide application (Gowda *et al.* 2008).

Herbicide toxicity to finger millet

Phytotoxicity to finger millet was reported due to application of fluchloralin at 1.0 or 1.25 kg/ha PE (Mahabaleswara *et al.* 1987). Simazine or atrazine 0.5 kg/ha PE was slightly toxic to *E. coracana*, even though it was most effective against weeds (Sankaran *et al.* 1974). Butralin, thiobencarb, alachlor, monuron, fluchloralin reduced the finger millet stand substantially within 10 DAS (Tosh and Nanda 1983). It is essential to take necessary care to educate farmers in avoiding the usage of herbicides that cause toxicity to finger millet.

Effect of herbicides on microbial population

The application 2,4-D, neburon, propanil and nitrofen, had a depressive effect on the soil microbial population during first 30 days of herbicide

application. However at a later stage, there was built up of population of soil bacteria, fungal, actinomycetes and azotobacter to the original level in soils of finger millet crop (Nanjappa *et al.* 1986). The application of butachlor and 2,4-D Na salt (0.75 kg/ha) in finger millet and butachlor and pendimethalin (1.0 kg/ha) in the succeeding groundnut showed higher microbial biomass in the soil at harvest as compared to hand weeding or unweeded (Kumara *et al.* 2014). Continuous monitoring of the influence of microbial population associated with finger millet grown soil is essential for sustainable soil health management.

Integrated weed management

Integrated weed management (IWM) with combination of herbicides, mechanical and hand weeding methods proved to result in efficient weed control and higher finger millet yields (Table 2, 3 and 4). IWM effectively manages weeds, reduces the uptake of nutrients by weeds, thereby making nutrients available to finger millet and reduces the cost on excess nutrients application (Gowda *et al.* 2012). The integration of hand weeding with 2,4-D resulted in higher yields of finger millet (Prasad *et al.* 1991). The stale seedbed technique in combination with inter-cultivation twice at 20 and 35 DAP or passing wheel hoe at 20, 30 and 40 DAP with one hand weeding was found effective and was suggested as a viable alternative to manual weed control (at 20, 30 and 40 DAP) in organic finger millet production (Patil *et al.* 2014a, Patil and Reddy 2014). Considering the increased cost and non-availability of labour, the integrated use of herbicides and mechanical weeding for weed control at critical stages proved to be an appropriate strategy for finger millet (Naik *et al.* 2001a, Yadav *et al.* 2005, Gowda *et al.* 2012, Rao *et al.* 2015).

Economics of weed management

Farmers' decision on the method of weed control depends on the profitability of various options available. Economic evaluation of weed management methods tested in finger millet indicated that the lesser weed density and biomass; higher yields of finger millet and higher B:C ratio were obtained with hand weeding twice (Boopathi *et al.* 1985a), isoproturon 0.50 kg/ha PE (Pradhan *et al.* 2012), chlorimuron-ethyl 5 g/ha (Guruprasanna *et al.* 2004), 0.5 kg/ha nitrofen + 2.0 kg/ha propanil (Boopathi *et al.* 1985a), integration of hand weeding once with 2, 4-D (Prasad *et al.* 1991) or nitrofen (Boopathi *et al.* 1985a) or oxyfluorfen 0.25 kg/ha PE (Pradhan *et al.* 2010),

integration of hand weeding twice (20 and 45 DAS) with oxyfluorfen 0.15 to 0.25 kg/ha (Pradhan *et al.* 2010), isoproturon PE at 0.5 kg/ha *fb* 2,4-D Na salt at 0.75 kg/ha PoE 15 DAS and inter-cultivation once on 30 DAS (Ramamoorthy *et al.* 2010); butachlor (0.5 kg/ha) *fb* hoeing once at 35 DAS (Naik *et al.* 2001), oxyfluorfen 0.1 kg/ha PE (3 DAT) *fb* azimsulfuron 20 g/ha PoE applied at 20 DAT (Bhargavi *et al.* 2016). However, Tuti *et al.* (2016) recorded the highest B:C ratio (1.39) with manual weeding at 20 DAS alone in rainfed finger millet in Uttarakhand. Farmers in India normally follow hand weeding or inter-cultivation or integration of both as they are most economical to them in their small holdings and as they are not aware of the herbicides available for managing weeds in finger millet. There is an urgent need to create awareness among finger millet farmers in India on the usefulness and economical advantage of integrating herbicides with either hand weeding or inter-cultivation.

Future research

The finger millet is known to be the food of resources poor farming community in the ecologically and socially fragile ecosystems of semi-arid tropical region of India. However, during recent years the importance of finger millet is being realized keeping in view of its nutritional and other values. One of the ways to increase the income of the finger millet farmers is to evolve improved crop management practices including weed management that enables farmer to incur less cultivation expenses and get higher income. Hence, there is an urgent need to increase the research on finger millet to evolve the integrated crop and weed management technologies that are cost-effective, eco-friendly and which suit to the needs of the finger millet farming community in India.

A few of the future areas of research include: i. Farmers need based weed management research; ii. Basic understanding of the biology and ecology of weeds, and assessing effect of climate change on weeds and their management; iii. Improved mechanical tools (*eg.*: finger millet crop specific power weeder) development for mechanical management of weeds and integrating as a component of IWM; iv. Evolve improved weed competitive finger millet cultivars; v. Identifying biological control agents in order to integrate with other methods and vi. Developing and scaling up IWM practices for enhancing productivity of finger millet with enhanced resources use efficiency.

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