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Studies on weed management practices in fennel (*Foeniculum vulgare* Mill.)

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Abstract
The present study was carried out during *Rabi*, 2019 to study the various weed management in fennel (*Foeniculum vulgare* Mill.) at Kittur Rani Channamma College of Horticulture, Arabhavi. Results revealed that, the highest plant height (172.20 cm), number of branches (23.56/plant), plant spread (63.36 cm), number of umbels (32.34/plant), number of umbellates (24.22/umbel), seed yield (2205.53 kg/ha), straw yield (6100.24 kg/ha) and harvest index (36.15%) of fennel were recorded with hand weeded plot which was *on par* effect with pre-emergent application of pendimethalin 30% EC + post-emergent application of quizalopfop-ethyl 5% EC. The lowest number of weeds and weed index at harvest (8.26/m^2 and 10.91%) recorded in pre-emergent application of pendimethalin 30% EC + post-emergent application of quizalopfop-ethyl 5% EC. Highest cost of cultivation (₹1,28,189.94 /ha) and gross returns (₹2,20,553 /ha) was obtained in hand weeding plot. B:C ratio of 1.74 was found in pre-emergent application of pendimethalin 30 EC + post-emergent application of quizalopfop-ethyl 5% EC. Hence, effective management of weeds along with better growth, yield attributes and profitable production in *rabi* fennel can be obtained by pre-emergent application of pendimethalin 30% EC + post-emergent application of quizalopfop-ethyl 5% EC.

Keywords: Fennel, pendimethalin, Oxyflurofen, quizalofop-ethyl, weeds

Introduction
India is indigenous to various spices and known as the "land of spices". At present, India is the largest producer, exporter and user of spices in the world. Among spices, the category seed spices denote all those annuals whose dried fruit or seeds are used. Seed spices originate in the tropical regions and are used primarily for seasoning or garnishing foods and beverages in pulverized form. In the preparation of various value added products seed spices are used as spice oils, spice powders and oleoresins

In 208-19, 25.49 lakh ha of area was occupied by seed spices producing 31.38 lakh tonnes (Anon., 2019) [1]. Among seed spices, fennel (*Foeniculum vulgare* Mill.) is one of the major seed spice belonging to the family Apiaceae. The generic name is derived from the Latin "*foenum"*, which means 'hay', referring to the foliar structure. It is rich in Vitamin A and contains a fair amount of calcium, phosphorous and potassium in which India is the leading producer of fennel seeds with an area of approximately 90000 ha with a productivity of 1.74 tonne per ha and an annual production of 1,57,000 MT (Anon., 2020) [2]. The production of fennel is concentrated mainly in Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Haryana, Uttar Pradesh and Punjab in India. Rajasthan and Gujarat contribute more than 80% of the country's total seed spice production. This belt can also be referred to as India's "seed spice bowl" (Janakiram and Lal, 2018) [9].

In spite of this, the fennel area is slowly picking up in Gadag and Bengaluru urban districts of Karnataka (Anon., 2020) [3].

In India, fennel seeds are used for mastication and chewing separate or with betel leaves. The principal constituent of the sweet fennel oil is *trans*-anethole (50-60%), fenchone (12-33%) and methyl chavicol (estragole 2-5%). Indian fennel seed oil comprises of 70% anethole and 6% fenchone. The higher amount of anethole (up to 90%) and absence of fenchone are important for its fine sweet odour and flavour. The other constituents are α-pinene, camphene, p-cymene, myrcene, limonene, α and β-phellandrene, γ-terpinene, terpineol andcis-ocimene γ-fenchone (Farooqi *et al.* 2005) [8].

A dearth of knowledge concerning the use and economic importance of fennel and lacking production technologies for *rabi* fennel are the major constraints among fennel growers in

India. Weeds interfere with the main crops to utilize space, nutrient and soil moisture which eventually withholds the plant growth reduces yield and quality of seed spices. Initial moderate growth of seed spices leads to a critical competition of crop and weed which in turn reduces growth and production up-to 91.40% (Mali and Suwalka, 1987) [11].

The weed control method combining chemical, cultural and manual methods are effective in management of weeds in fennel. This field experiment was conducted with an objective to find the suitable weed management method for higher growth, yield and quality of fennel and to work out the economics of fennel.

Material and Methods

The field experiment was conducted during *rabi* 2019 at the Kittur Rani Channamma College of Horticulture, Arabhavi, University of Horticultural Sciences, Bagalkot, Karnataka, India. Arabhavi is situated in Northern dry Zone of Karnataka (Zone-3, Region-2) at 16°14' N latitude and 74°45' E longitude, 612 m above mean sea level. The experimental sites receive, on an average about 362.9 mm during the experiment and irrigation was given in 5-7 days interval. The soil at the experimental site was sandy clay loam with basic pH during 2019.

The current experiment was conducted on fennel variety Ajmer Fennel-1 (AF-1), laid out in randomized block design with three replications. Fennel seeds were line sown (9 kg/ha) at a spacing of 45 cm in 2.7m × 2.7m plots which were later thinned to 30cm apart. All the recommended agronomical practices were followed to raise a good crop. Pre-emergent herbicides were applied immediately after sowing, while post-emergent herbicides were applied at 30 days after sowing as per the treatments.

Observations of growth parameters like plant height, plant spread, number of branches were recorded at 60, 90 DAS and at the time of harvest and weed in fennel from randomly selected plants in each plot. The yield attributes *viz*., number of umbels per plant, number of umbellate per umbel, seed yield per plant (g), straw yield (kg/ha) and harvest index (%) were recorded. Weed count (No./m^2) was recorded at 60, 90 DAS and at the time of harvest and weed index was calculated. Data on weed count was transformed using $\sqrt{(x+0.5)}$ before statistical analysis. Cost of cultivation and net returns were calculated to find out B:C ratio. The experimental data recorded for growth, yields were statistically analyzed (Chandel, 1984) [4].

Treatment details

T_1: Hand weeding at 30, 45 and 60 DAS
T_2: Sugarcane trash mulch (0.5 kg/m2) at 15 DAS
T_3: PE Pendimethalin 30% EC (1.0 kg/ha)
T_4: PE Oxyflurofen 23.5% EC (30 g/ha)
T_5: PE Pendimethalin 30% EC (1.0 kg/ha) + Intercultivation at 30 DAS
T_6: PE Pendimethalin 30% EC (1.0 kg/ha) + PoE Quizalopfop-Ethyl 5% EC (40 g/ha)
T_7: PE Oxyflurofen 23.5 EC (30 g/ha) + PoE Quizalofop-Ethyl 5% EC (40 g/ha)
T_8: Un-weeded (control)

Note: PE-Pre emergent application, PoE-Post emergent application

Result and Discussion

Data on growth characters of fennel as influenced by various weed managements (Table 1) showed that the higher plant height was recorded in hand weeded plot (38.37, 99.90 and 172.20 cm at 60 DAS, 90 DAS and at harvest, respectively). Pre-emergent application of pendimethalin 30% EC at 1.00 kg/ha + post-emergent application of quizalopfop-ethyl 5% EC at 40g/ha showed *on par* effect at all the stages (34.02, 94.61 and 162.07 cm, respectively). However, pre-emergent application of oxyflurofen 23.5% EC at 30g/ha + post-emergent application of quizalopfop-ethyl 5% EC at 40 g/ha had on par influence at 90 DAS and at harvest (93.20 and 158. 10 cm, respectively). Throughout the crop growth lower plant height was recorded in un-weeded plot (23.13 cm, 81.40 and 139.67 cm respectively).

Maximum number of branches was also recorded in hand weeded plot (14.67, 19.11 and 23.56/plant at 60 DAS, 90 DAS and at harvest, respectively). Pre-emergent application of pendimethalin 30% EC at 1.00kg/ha + post-emergent application of quizalopfop-ethyl 5% EC at 40g/ha showed *on par* effect at all the stages (13.33, 17.33 and 21.78/plant, respectively). However, the influence of pre-emergent application of oxyflurofen 23.5% EC at 30g/ha + post-emergent application of quizalopfop-ethyl 5% EC at 40g/ha was on par at 60 DAS (11.67/plant). Similar to plant height, number of branches was also lower in un-weeded check throughout the crop duration (7.11, 11.89 and 14.67/plant, respectively).

The plant spread was also maximum in hand weeded plot (35.32, 41.00 and 63.36 cm at 60, 90 DAS and at harvest, respectively). Pre-emergent application of pendimethalin 30 EC at 1.00 kg/ha+ post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha (35.00, 40.20 and 60.11 cm, respectively), and pre-emergent application of oxyflurofen 23.5 EC at 30 g/ha + post emergent application of quizalofop-ethyl 5 EC at 40 g/ha (33.77, 38.41 and 57.78 cm, respectively) had *on par* influence at 60, 90DAS and at harvest. Removal of weeds any time during the growth season is good enough for obtaining maximum benefits of weeding in terms of increased crop productivity. Among herbicidal treatment the maximum values of plant height, plant spread, number of branches/plant was observed under treatment T_6 (pre-emergent application of pendimethalin 30 EC at 1.00 kg/ha + post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha at 30 DAS) was ascribed to better initial control of weeds, rise in water and nutrient uptake, which might have increased photosynthetic rate, thereby addition supply of carbohydrates, which in addition increased cell division, elongation and multiplication leading to overall plant height. These findings are in agreement with those of Nagar *et al.* (2009a) [14].

Among the treatments, the maximum number of umbels per plant, umbellates per umbel, seed yield and straw yield (table 2) were observed in hand weeded plot (32.34, 24.22, 2205.53 kg/ha and 6100.24 kg/ha respectively). It was *on par* with pre-emergent application of pendimethalin 30 EC at 1.00 kg/ha + post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha (30.11, 22.44, 1964.95 kg/ha and 5948.39 kg/ha respectively). However on par values for straw yield was also observed in pre-emergent application of oxyflurofen 23.5 EC at 30g/ha + post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha treatment (5326.17 kg/ha). Harvest index was found maximum in hand weeded plot (36.15%). This might be due to the periodical exclusion of weeds by hand weeding as evidenced by less number of weeds and dry weight of weeds, which might have sustained higher soil fertility status

and moisture content. These findings are in conformity with those reported by Kothari *et al.* (1989) [10], Mehriya *et al.* (2007a) [13], Meena and Mehta *et al.* (2009) [12], Nagar *et al.* (2009a) [14], Yadav *et al.* (2013) [20] and Sagarka *et al.* (2005) [16]. The primary mode of action of pendimethalin is to inhibit microtubule formation in cells of susceptible monocots and dicot weeds. Pendimethalin has also a role to play in micro-tubal disruption and stop mitosis because it blocks synthesis of proteins, nucleic acids or any other requisites for mitosis (Devine *et al*., 1993) [7].

At all the stages of crop growth the number of weeds/m^2 differed significantly as presented table 3. Significantly minimum number of weeds were recorded in hand weeding (22.33, 39.33 and 48.67/m^2 at 60, 90 DAS and at harvest, reapectively), which was followed by pre-emergent application of pendimethalin 30 EC at 1.00 kg/ha + post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha (39.67, 55.33 and 67.67/m^2, respectively). Among the treatments lower weed index of 10.91% was recorded with pre-emergent application of pendimethalin 30 EC at 1.00 kg/ha + post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha, which was followed by pre-emergent application of oxyflurofen 23.5 EC at 30 g/ha + post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha (23.70%). While the higher weed index was recorded in un-weeded plot (56.40%) because of severe weed competition. The combined effect of seed yield and dry weight of weeds might have been responsible for increased weed indices. These findings are in close conformity with those reported by Chaudhary (1999) [5], Mehriya *et al.* (2007a) [13], Yadav *et al.* (2010) [19] and Thakral *et al.* (1995) [18].

The maximum cost of cultivation and gross returns (Table 4.) were recorded with hand weeding (₹1,28,189.94/ha and ₹ 2,20,553 /ha respectively), While the higher B:C ratio was registered under T_6 (pre-emergent application of pendimethalin 30 EC at 1.00 kg/ha + post-emergent application of quizalopfop-ethyl 5 EC at 40 g/ha) (1:1.74), followed by hand weeding (1:1.72). Minimum benefit: cost ratio was observed with un-weeded control. This might due to the effective and efficient control of weeds by application of pre and post-emergent herbicides with integration of hand weeding. The higher benefits obtained under these treatments were due to comparatively less cost of herbicides than the manual weeding. Similar findings have been reported by Chaudhary *et al.* (2014) [6], Senthivel (2001) [17], and Patel *et al.* (2004) [15].

Table 1: Growth of fennel as influenced by integrated weed management practices at different stages of crop growth

Treatments	Dosage (*a.i.*/ha)	Plant height (cm)			Number of branches			Plant spread (cm)		
		60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
T_1: Hand weeding	30, 45 and 60 DAS	38.37	99.90	172.20	14.67	19.11	23.56	35.52	41.00	63.36
T_2: Sugarcane trash mulch	0.50 kg/m^2 (15 DAS)	31.04	88.05	154.73	11.02	15.00	18.44	30.82	35.58	55.21
T_3: Pendimethalin 30 EC (pre)	1.00 kg	28.26	86.79	147.00	10.11	14.11	16.89	27.63	33.54	53.14
T_4: Oxyflurofen 23.5 EC (pre)	30 g/ha	25.82	86.53	144.60	8.56	13.00	15.22	24.83	35.52	51.48
T_5: Pendimethalin 30 EC (pre) + inter-cultivation	1.00 kg + (30 DAS)	30.25	81.88	150.33	10.67	14.89	18.11	29.21	34.85	54.28
T_6: Pendimethalin (pre) + Quizalopfop–Ethyl (post)	1.00 kg + 40 g/ha (30 DAS)	34.02	94.61	162.07	13.33	17.33	21.78	35.00	40.20	60.11
T_7: Oxyflurofen (pre) + Quizalofop-Ethyl (post)	30 g/ha + at 40 g/ha (30 DAS)	31.32	93.20	158.10	11.67	15.56	20.45	33.77	38.41	57.78
T_8: Un-weeded (control)	-	23.13	81.40	139.67	7.11	11.89	14.67	23.81	31.20	51.33
S.Em+		1.58	3.75	5.26	1.03	0.98	0.95	1.32	1.23	2.11
C.D. at 5%		4.80	11.38	15.97	3.12	2.98	2.89	4.02	3.73	6.39

Note: DAS- Days after Sowing

Table 2: Yield and yield attributes of fennel as influenced by integrated weed management practices

Treatments	Dosage (*a.i.*/ha)	Number of umbels/plant	Number of Umbellates/umbel	Seed yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
T_1: Hand weeding	30, 45 and 60 DAS	32.34	24.22	2205.53	6100.24	36.15
T_2: Sugarcane trash mulch	0.50 kg/m^2 (15 DAS)	27.11	19.56	1442.64	5177.03	27.87
T_3: Pendimethalin 30 EC (pre)	1.00 kg	22.89	14.89	1209.55	4719.25	25.63
T_4: Oxyflurofen 23.5 EC (pre)	30 g/ha	21.44	13.11	1114.89	4533.33	24.59
T_5: Pendimethalin 30 EC (pre) + inter-cultivation	1.00 kg + (30 DAS)	25.22	16.22	1295.05	4834.07	26.79
T_6: Pendimethalin (pre) + Quizalopfop–Ethyl (post)	1.00 kg + 40 g/ha (30 DAS)	30.11	22.44	1964.95	5948.39	33.03
T_7: Oxyflurofen (pre) + Quizalofop-Ethyl (post)	30 g/ha + at 40 g/ha (30 DAS)	28.11	20.33	1682.89	5326.17	31.60
T_8: Un-weeded (control)	-	19.56	13.00	961.57	4309.38	22.31
S.Em+		0.91	0.91	93.62	262.36	0.87
C.D. at 5%		2.77	2.75	283.99	795.86	2.64

Note: DAS- Days after Sowing

Table 3: Weed parameters of fennel as influenced by integrated weed management practices at different stages

Treatments	Dosage (*a.i.*/ha)	Number of weeds/ m^2			Weed index (%)
		60 DAS	90 DAS	At harvest	
T_1: Hand weeding	30, 45 and 60 DAS	22.33(4.78)	39.33(6.31)	48.67 (7.01)	0.00
T_2: Sugarcane trash mulch	0.50 kg/m^2 (15 DAS)	48.33(6.99)	63.00(7.97)	76.33 (8.77)	34.59

T_3: Pendimethalin 30 EC (pre)	1.00 kg	62.00 (7.91)	72.67(8.55)	84.33 (9.21)	45.16
T_4: Oxyflurofen 23.5 EC (pre)	30 g/ha	68.00 (8.28)	85.33(9.26)	94.33 (9.74)	49.45
T_5: Pendimethalin 30 EC (pre) + inter-cultivation	1.00 kg + (30 DAS)	52.67 (7.29)	67.67(8.26)	75.33 (8.71)	41.28
T_6: Pendimethalin (pre) + Quizalopfop-Ethyl (post)	1.00 kg + 40 g/ha (30 DAS)	39.67 (6.34)	55.33(7.47)	67.67 (8.26)	10.91
T_7: Oxyflurofen (pre) + Quizalofop-Ethyl (post)	30 g/ha + at 40 g/ha (30 DAS)	46.33 (6.84)	60.33(7.80)	76.33 (8.77)	23.70
T_8: Un-weeded (control)	-	95.00 (9.77)	101.67(10.11)	112.00(10.61)	56.40
S.Em+		2.98 (1.87)	3.25 (1.94)	4.35 (2.20)	
C.D. at 5%		9.05 (3.09)	9.86 (3.22)	13.19 (3.70)	

Note: Figures in parenthesis are indicating transformed values ($\sqrt{x}+0.5$).
DAS- Days after Sowing

Table 4: Influence of integrated weed management practices on economics of fennel

Treatments	Dosage (*a.i.*/ha)	Cost of cultivation (□/ha)	Gross returns (□/ha)	B:C Ratio
T_1: Hand weeding	30, 45 and 60 DAS	128189.94	220553.00	1.72
T_2: Sugarcane trash mulch	0.50 kg/m^2 (15 DAS)	117812.56	144264.33	1.22
T_3: Pendimethalin 30 EC (pre)	1.00 kg	111240.78	120954.67	1.09
T_4: Oxyflurofen 23.5 EC (pre)	30 g/ha	111178.99	111489.33	1.00
T_5: Pendimethalin 30 EC (pre) + inter-cultivation	1.00 kg + (30 DAS)	115654.53	129504.67	1.12
T_6: Pendimethalin (pre) + Quizalopfop-Ethyl (post)	1.00 kg + 40 g/ha (30 DAS)	112887.99	196495.33	1.74
T_7: Oxyflurofen (pre) + Quizalofop-Ethyl (post)	30 g/ha + at 40 g/ha (30 DAS)	112826.20	168289.00	1.49
T_8: Un-weeded (control)	-	110413.94	96156.67	0.87

Note: DAS- Days after Sowing; Fennel price – ₹100/kg

Conclusion

Pre-emergent application of pendimethalin 30EC at 1.00 kg/ha + post-emergent application of quizalofop-ethyl 5EC 40g/ha obtained better growth, yield and economics of fennel as influenced by various weed management practices.

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