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Economic Feasibility and Yield of Fennel (*Foeniculum vulgare* Mill.) as Influenced by Weed Control Measures and Nutrient Management

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ABSTRACT: A field experiment was conducted at Instructional farm, College of Agriculture, SKRAU, Bikaner during the *rabi* season of 2021-22. There were 16 treatment combinations with four nutrient managements (control, 75% RDF, 100% RDF and 125% RDF) and four weed control measures (weed free, pendimethalin @ 0.75 kg ha^{-1} (PE), Oxyfluorfen at 50 g ha^{-1} (PoE AT 25 DAS) and weedy check) and were evaluated under factorial randomized design with three replications. The results revealed that among the weed control measures weed-free treatment obtained significantly higher seed yield (1313 kg ha^{-1}), straw yield (3282 kg ha^{-1}) and net return (₹76,783 ha^{-1}). However, pendimethalin @ 0.75 kg ha^{-1} (PE) achieved the highest B: C ratio (2.97) making it the most economical herbicidal option. Among nutrient management treatments 100% RDF recorded superior growth and yield attributes, seed yield (1131 kg ha^{-1}) and net return (₹68,712 ha^{-1}) with a B:C ratio of 2.78.

Keywords: Weed Management, Pendimethalin, Net returns, Yield, B: C ratio.

INTRODUCTION

India is referred as the "Land of Spices" and has held a prominent position in the global spice trade since ancient times. Seed spices as "high-value, low-volume crops" are highly remunerative and play a significant role in the economy of arid and semi-arid regions of the country. Seed spices possess a wide range of medicinal attributes, including carminative, appetizer, digestive, stimulant, tonic and antipyretic properties which greatly enhance their economic and health value. Their distinct aroma, flavor and taste make them indispensable in culinary and medicinal applications. India holds the premier position globally in the production of seed spices. It is the largest producer, consumer and exporter of spices in the world (Kaur *et al.*, 2022).

Fennel is one of the major seed spice crop cultivated across the world. Its seeds contain approximately 42.3% carbohydrates, 18.5% crude fibre, 13.4% minerals, 10% fat, and 9.5% protein. The seeds also contain 0.7% to 6.0% volatile oil, depending on the variety (Devi *et al.*, 2023). It is considered a good vermicide against hookworms and possesses insecticidal and fungicidal properties (Choudhary *et al.*, 2022).

In India, the major fennel-producing states are Gujarat, Rajasthan and Uttar Pradesh. Additionally, several other states cultivate fennel on a smaller scale, including Punjab, Tamil Nadu, Bihar, Karnataka, Maharashtra and Jammu and Kashmir. Rajasthan and Gujarat together contribute over 80% of the country's total production (Jankiram and Lal 2018). During 2022–23, Rajasthan ranked second in fennel seed production with production of 29308 tonnes grown over an area of 28103 hectares (Spices Board of India, GOI, 2024). Within Rajasthan, the primary fennel-growing districts include Nagaur, Sirohi, Jodhpur, Pali, Sawai Madhopur, Dausa, Jalore and Tonk. More than 60% area of Rajasthan falls within the arid zone characterized by light-textured soils with low fertility and poor water-holding capacity. In such conditions, reducing the cost of cultivation remains a major

challenge particularly in light of the ongoing increase in agricultural input prices (Choudhary and Kharwal 2023). Fennel typically requires a longer period for germination and exhibits slow initial growth often resulting in significant weed infestations. If these weeds are not managed promptly, they can negatively impact growth and lead to substantial yield losses. According to Mali and Suwalka (1987), yield losses can reach as high as 91.4%. Consequently, effective weed management is a critical factor in achieving optimal yields. Manual weeding is the prevalent method used in fennel cultivation to control weeds. However, the timely unavailability of labor and the associated high costs pose significant challenges to effective weed management in fennel. There is an urgent need for suitable alternatives, including the use of herbicides to ensure effective and efficient weed control in fennel. Research has indicated that the application of herbicides can effectively manage weeds and potentially increase fennel seed yields by 43.2% to 86.9% (Voevodin and Borisenko 1981). Therefore, employing herbicides either pre-emergence or post-emergence in conjunction with cultural practices for weed management has emerged as the best alternative to maintain fennel productivity while minimizing soil and air pollution (Patel *et al.,* 2017). Recognizing the importance of the crop, its average productivity is lower, thus the initiatives have been undertaken to improve the productivity of the fennel through the management of cultural practices and fertilizers. Macro nutrients such as N, Pand K are vital for all crops. Nitrogen is the element that most restricts crop yields. The majority of the N in plants exists in organic form: nucleic acids, certain vitamins, hormones, membrane components, coenzymes and pigments. P is a crucial component of the energy transfer compounds (ATP and other nucleoproteins), the genetic information system and cell membranes and K functions as an enzyme activator or cofactor for various enzymes. It also assists in maintaining osmotic potential and facilitating water uptake (Waskela *et al.,* 2017).

MATERIALS AND METHODS

The experiment was conducted at the Instructional farm, Swami Keshwanand Rajasthan Agricultural University (SKRAU), Bikaner. The site is located in the state of Rajasthan, approximately 9 km from Bikaner city on National Highway No. 15, which leads towards Sriganganagar. Geographically, it is positioned at 28°10′ N latitude, 73°22′ E longitude and an elevation of 234.70 meters above mean sea level. The study area receives an average annual rainfall ranging between 350–600 mm. According to agro-climatic classifications, Bikaner falls under Zone I-C (Hyper Arid Partially Irrigated Western Plain Zone) as per the National Agricultural Research Project (NARP) and Zone XIV (Western Dry Region) according to the Planning Commission of India. The soil at the experimental site was loamy sand in texture, with a pH of 8.5, organic carbon content of 0.18%, low available nitrogen (121.4 kg ha^{-1}), medium phosphorus (19.08 kg ha^{-1}) and low potassium (191.42 kg ha^{-1}).

Before sowing, fennel seeds were split into two halves and treated with Bavistin @ 2.0 g kg^{-1} seed to prevent seed-borne diseases. Sowing was carried out on 31 October 2021 using a *Deshi* plough at row spacing of 50 cm and a seed rate of 8 kg ha^{-1} with seeds placed at a depth of 2–3 cm. Fertilizers were applied as per treatment using **Urea** (N)**,** SSP (P) and MOP (K)**.** Nitrogen was applied in three equal splits: one-third as basal at sowing, one-third at 30 DAS and the remaining one-third at 60 DAS along with irrigation. full dose of phosphorus and potassium were drilled about 5-7 cm deep through hand plough as basal at sowing time. The crop was harvested manually on 01 April 2022 from the net plot area. To avoid border effects, two rows from each side of the plot and two plants from both the proximal and distal ends of each row were excluded from harvesting. After complete sun drying, the produce from each net plot was threshed, cleaned and weighed individually (kg plot^{-1}) and subsequently converted to kg ha^{-1} for determining the seed yield.

The economics of different treatments was evaluated in terms of net returns (₹ ha^{-1}) and benefit-cost ratio on the basis of prevailing market prices of inputs and outputs. Gross returns were calculated for each treatment and the cost of cultivation corresponding to each treatment was subtracted to determine the net returns**.**

Net Returns (₹ ha^{-1}) = Gross Returns (₹ ha^{-1}) – Total Cost of Cultivation (₹ ha^{-1})

Treatment wise benefit: cost ratio was calculated to ascertain economic viability of the treatment using the following formula:

$$\text{B : C ratio} = \frac{\text{Gross returns (Rs ha}^{-1})}{\text{Cost of cultivation (Rs ha}^{-1})}$$

The experimental data recorded for various parameters were subjected to statistical analysis using the ANOVA technique as suggested by Fisher (1950). The critical difference (CD) for the treatment comparisons were worked out wherever the variance ratio (F test) was found significant at 5 per cent level of probability The critical difference (CD) for the treatment comparisons were worked out wherever the variance ratio (F test) was found significant at 5 per cent level of probability ($P = 0.05$).

RESULT AND DISCUSSION

A. Effect of weed control measures

Maintaining a weed-free environment throughout the crop season resulted in the most favorable yield attributes and overall productivity. The weed-free treatment recorded the highest seed yield (1313 kg ha^{-1}) and straw yield (3782 kg ha^{-1})**.** The absence of weed competition throughout the growth period enabled the crop to make full use of available nutrients, moisture and sunlight, thereby enhancing vegetative growth and reproductive development. Among the chemical control measures, the pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} proved to be the most effective, followed closely by the post-emergence application of oxyfluorfen @ 50 g ha^{-1} at 25 DAS. The herbicidal action of pendimethalin is primarily attributed to the inhibition of microtubule formation in

the cells of susceptible monocot and dicot weeds. By disrupting microtubule assembly, it effectively halts mitosis, which in turn impedes protein and nucleic acid synthesis processes essential for cell division and growth (Devine *et al.*, 1993). These chemical treatments significantly improved yield components and overall productivity compared to the weedy check, which experienced continuous and intense weed competition throughout the season. The unchecked weed growth in the control plots led to excessive depletion of soil moisture and nutrients, ultimately suppressing crop development. The presence of a diverse and mixed weed population further intensified competition, as mixed infestations tend to be more competitive than single-species weed pressure. Overall, **season-**long weed control was found to be a critical factor in enhancing crop performance and maximizing yield. These findings are in close agreement with the earlier reports of Thakral *et al.* (2007); Gohil *et al.* (2015); Patel *et al.* (2016); Dhakad *et al.* (2017); Patil *et al.* (2020); Choudhary *et al.* (2021); Singh (2023); Abhishek *et al.* (2024) who also highlighted the importance of effective weed management in improving crop productivity.

All weed control measures recorded significantly higher net returns and B: C ratio compared to the weedy check, primarily due to increased seed yield under these treatments (Table 6). The weed-free resulted in the highest net returns of ₹76,783 ha^{-1} with a B: C ratio of 2.67**,** representing an increase of ₹44,546 ha^{-1} over the weedy check. Among the herbicides, pendimethalin @ 0.75 kg ha^{-1} (PE) emerged as the most profitable, yielding ₹70,335 ha^{-1} in net returns with the highest B: C ratio of 2.97 attributed to both enhanced yield and relatively lower treatment cost. In contrast, the weedy check due to unchecked weed growth and the lowest seed yield recorded the lowest net returns (₹32,237 ha^{-1}) and B: C ratio (1.98). The economic superiority of weed-free and pendimethalin @ 0.75 kg ha^{-1} (PE) clearly reflects effective weed suppression, improved yield and cost-efficiency. These findings align with the reports of Yadav *et al.* (2016); Patel *et al.* (2019); Choudhary *et al.* (2021); Kumar and Gupta (2021).

B. Effect of Nutrient management

All yield attributes were found significantly higher with application of 100 % RDF over control. These parameters were closed to 125 % RDF. The yield attributes and yield was found higher due to higher nutrient availability under the recommended dose of fertilizer. The longer period of reproductive phase due to higher nutrition (N P and K) resulted into higher seed yield per hectare. The significantly higher seed yield (1131 kg ha^{-1}) and straw yield (2823 kg ha^{-1}) recorded under treatment 100 % RDF and lowest under control. These results show the importance of balanced fertilization in enhancing crop productivity. These findings are in strong agreement with earlier studies conducted by Pariari *et al.* (2015); Kumawat *et al.* (2015); Kalasare *et al.* (2021); Kusuma *et al.* (2019); Kumar *et al.* (2021).

The application of 100% RDF recorded the highest net return (₹68,712 ha^{-1}) along with a benefit: cost ratio of 2.78 which is statistically economic superior among all treatments evaluated. This economic advantage can be attributed to the significantly higher seed and straw yields achieved under this treatment coupled with relatively lower input costs**.** The balanced nutrient supply under 100% RDF likely fulfilled the crop's nutritional requirements efficiently, thereby enhancing both yield and quality, which translated into greater market returns. Furthermore, this treatment offered a cost-effective approach, avoiding the unnecessary expenditure associated with excessive fertilization. These findings are confirmation with the reports of Tripathi *et al.* (2013); Dadiga *et al.* (2015); Kumar *et al.* (2022).

Table 1: The details of treatments with their symbols.

Sr. No.	Treatments	Symbols
	Nutrient Management	
1.	Control (no fertilizer applied)	N_0
2.	75 % recommended dose of fertilizer	N_1
3.	100 % RDF	N_2
4.	125 % RDF	N_3
	Weed Control Measures	
1.	Weed Free	W_0
2.	Pendimethalin 750g ha^{-1} PRE	W_1
3.	Oxyfluorfen 50g ha^{-1} POE at 25 DAS	W_2
4.	Weedy check	W_3

*Recommended dose of fertilizer (90 kg ha^{-1} N and 40 kg ha^{-1} P_2O_5**)**

Table 2: Details of the experiment.

Season	:	*Rabi*, 2021-22
Test crop	:	Fennel
Design	:	Factorial RBD
Total No. of plots	:	48
Total No. of treatments	:	16
No. of replication	:	03
Plot Size	:	3.0 m × 4.0 m
Crop geometry	:	50 cm × 20 cm (R × P)
RDF	:	90 kg ha^{-1} N and 40 kg ha^{-1} P_2O_5
Seed rate	:	8 kg ha^{-1}
Variety	:	*RF-143*

Table 3: Effect of weed control measures and nutrient management on yield of crop.

Treatment	Yield (kg ha^{-1})	
	Seed yield	Straw yield
Nutrient management		
Control	815	2040
75% RDF	1007	2541
100 % RDF	1131	2838
125 % RDF	1173	2934
SEm±	26	69
CD (p=0.05)	75	200
Weed control measures		
Weed free	1313	3282
Pendimethelin 750g ha^{-1} PE	1122	2773
Oxyfluorfan50g ha^{-1} PoE at 25 DAS	1004	2644
Weedy check	686	1654
SEm±	26	69
CD (p=0.05)	75	200

Table 4: Effect of weed control measures and nutrient management on economics of crop.

Treatment	Net returns (₹ ha^{-1})	Gross returns (₹ ha^{-1})	B: C ratio
Nutrient management			
Control	41946	76991	2.19
75% RDF	58003	95139	2.56
100 % RDF	68712	106711	2.78
125 % RDF	71665	110527	2.82
SEm±	2293	2293	0.06
CD (p=0.05)	6622	6622	0.16
Weed control measures			
Weed free	76783	123874	2.62
Pendimethelin 750g ha^{-1} PE	70335	105850	2.97
Oxyfluorfan50g ha^{-1}PoE at 25 DAS	60972	94817	2.79
Weedy check	32237	64827	1.98
SEm±	2293	2293	0.06
CD (p=0.05)	6622	6622	0.16

CONCLUSIONS

The study concluded that weed and nutrient management plays a crucial role in enhancing fennel productivity and profitability in arid regions. Season long weed-free conditions recorded the highest yield, while the pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} proved to be the most economical herbicidal treatment. Among nutrient levels, 100% RDF resulted in significantly higher yield and net return indicating its efficiency in meeting the crop's nutritional requirements. Therefore, combining 100% RDF with pendimethalin application can be recommended as a viable and cost-effective strategy to maximize yield and economic returns in fennel cultivation.

FUTURE SCOPE

- Long-term studies should be conducted to assess the residual effect of herbicides on soil health and succeeding crops.
- Precision nutrient management based on soil testing and crop requirements can further enhance input efficiency.
- Further research is needed to optimize nutrient doses under varying agro-climatic zones for higher input-use efficiency.
- Adoption of integrated weed and nutrient management should be promoted through farmer-participatory trials and demonstrations.

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Conflict of Interest. None.

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