



Growth Performance and Seed Yield of Fennel (*Foeniculum vulgare* Mill.) Varieties under Shisham (*Dalbergia sissoo* Roxb.) Based Agroforestry System in South-Eastern Rajasthan, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/ijecc/2024/v14i84378>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/120439>

Original Research Article

Received: 02/06/2024
Accepted: 06/08/2024
Published: 20/08/2024

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Cite as: Kumari, Nikita, S.B.S Pandey, Kanica Upadhyay, Prerak Bhatnagar, Prahlad V.C, and Ajit Tippannavar. 2024. "Growth Performance and Seed Yield of Fennel (*Foeniculum Vulgare* Mill.) Varieties under Shisham (*Dalbergia Sissoo* Roxb.) Based Agroforestry System in South-Eastern Rajasthan, India". *International Journal of Environment and Climate Change* 14 (8):582-90. <https://doi.org/10.9734/ijecc/2024/v14i84378>.

ABSTRACT

Agroforestry is defined as the direct mixing of trees and crops on the same piece of land in a spatial and temporal sequence. This investigation was carried out in a completely randomized block design (CRBD) with three replications during the September, 2022 to April, 2023. It was conducted at Herbal Garden of the Department of Silviculture and Agroforestry, College of Horticulture and Forestry, Jhalawar (Agriculture University, Kota). Four years old Plantations of Shisham (*Dalbergia sissoo* Roxb.) at 5 m × 5 m spacing were used for intercropping of selected five varieties of Fennel (*Foeniculum vulgare* Mill.) viz. 'AF-1, AF-2, RF-125, RF-205 and RF-290' and also these varieties were grown separately as pure crop. These were planted at 50 cm × 20 cm spacing. The gross plot area and net plot area of fennel was 5 m × 5 m and 4 m × 3 m respectively. The analysis of variance showed significant differences between intercropping fennel under Shisham based Agroforestry system and pure cropping system. The analysis of variance showed non-significant differences in plant height (m), number of primary branches, collar diameter (cm), crown spread East-West (m) and crown spread North-South (m) among varieties mixed with trees. Maximum plant height for Fennel at 30 DAS (16.15), 60 DAS (106.42), 90 DAS (157.50) and at harvest (182.14 cm), number of branches per plant (8.12), number of umbels per plant (20.30), number of seeds per umbel (683.40), diameter of umbel (115.93 mm), seed yield per plant (25.64 g), seed yield per plot (3.08 kg) and minimum days taken to 50% flowering (86.78) was recorded in the T₁ (Shisham+ *Foeniculum vulgare* Mill. var. AF-1). However, maximum economical yield (25.64 quintals/ha) and biological yield (68.92 quintals/ha) was found in T₆ (*Foeniculum vulgare* Mill. var. AF-1 sole).

Keywords: Agroforestry; fennel; intercropping; seed yield; shisham.

1. INTRODUCTION

Agroforestry is defined as the direct mixing of trees and crops on the same piece of land in a spatial and temporal sequence. It involves the deliberate growing of trees and shrubs with crops and/or animals in interacting combinations for a variety of objectives. Such farming practices have been used throughout the world for a long time; but scientific attention was focused on them and thus they attained prominence as a land-use practice, only since the late 1970s.

Fennel (*Foeniculum vulgare* Mill.) is a perennial herb. The fruit is a dry schizocarp from 4-10 millimeters ($\frac{3}{16}$ - $\frac{3}{8}$ inch) long, half as wide or less and grooved. Since the seed in the fruit is attached to the pericarp, the whole fruit is often mistakenly called "seed". The variety and quantity of vitamins contained is variable: folates, 270 mg/ kg; vitamin B3, 6.4 mg/kg; vitamin C, 8.7–340 mg/kg. Fennel contains potassium (4.24–5.85 g/kg), phosphorus (500 mg/kg), calcium (5.6–363 mg/kg), magnesium (8.2–389 mg/k) and sodium (7.7–512 mg/kg) [1]. As per ministry of agriculture and farmers welfare (2021-22) 3rd advance estimate, the total area in India under Fennel cultivation is 0.79 lakh hectares and production is

1.28 lakh metric tonnes [2]. The major Fennel growing states are Gujarat, Rajasthan, Madhya Pradesh, West Bengal, Uttar Pradesh, Punjab and Bihar.

Shisham (*Dalbergia sissoo* Roxb.) is an important tree species belonging to the family Fabaceae. It is a medium to large tree of about 25 meters high with grey-yellow trunk, longitudinal crack, and downcast twig. Leaves are leathery, pinnately compound, with about five alternate leaflets. Leaf stalk (petiole) measures about 15 cm long, each leaflet widest at the base, to 6 cm long with a fine pointed tip [3]. The Shisham tree is a characteristic species of Khair–Sissoo (*Acacia catechu*–*Dalbergia sissoo* Roxb.) primary seral type forest.

Intercropping fennel (*Foeniculum vulgare* Mill.) under Shisham (*Dalbergia sissoo* Roxb.) based agroforestry system could be an interesting research topic with potential benefits for both agricultural productivity and sustainable land use. Many potential aspects such as agroforestry system design, crop performance and interaction, soil health and nutrient cycling, microclimate modifications, economic viability and sustainability and environmental impact (climate change) could be considered for exploring the research.

2. MATERIALS AND METHODS

2.1 Research Area

The present investigation was conducted at the Herbal Garden, College of Horticulture and Forestry, Jhalawar. Geographically, District Jhalawar falls in Zone-V i.e., Humid south eastern plains, which extends over 6.32 lakh hectare land area between among 23°4' to 24°52' N (latitude) and 75°29' to 76°56' E (longitude). The average rainfall in the region is 954.7 mm and the district receives maximum rainfall with heavy rainstorms in the months of July-August upto the first week of September. Maximum temperature range in the summer is 43 - 48°C and minimum 1.0 - 2.6°C during winter.

2.2 Methods

The experiment was laid out in CRBD with three replications and 11 treatments during summer season (September, 2022 to April, 2023). Four years old plantations of Shisham (*Dalbergia sissoo* Roxb.) grown at 5 m x 5 m spacing was used for intercropping study. Five varieties of fennel (*Foeniculum vulgare* Mill.) crop viz. AF-1, AF-2, RF-125, RF-205 and RF-290 were selected for the present study. These fennel varieties were also grown separately as pure crop. The Shisham plants of uniform size and growth were selected at Herbal Garden for experimentation. The gross plot area and net plot area of fennel was 5 m x 5 m and 4 m x 3 m respectively. In order to assess the physico-

chemical properties of the soil at the experimental site, the soil samples were drawn randomly from different spots in the experimental site at a depth of 0-30 cm before the commencement of the experiment. The soil of the experimental site was clayey with a pH of 7.95 [4], having 0.45 Organic Carbon [5] and 289.50, 38.14 and 256.3 kg per ha available N [6], P₂O₅ [7] and K₂O [8] respectively.

2.3 Statistical Analysis

The data obtained from were subjected to statistical analysis of variance (ANOVA) in MS Excel programme on computer system through the procedure of randomized block design (RBD) for various characters studied. The treatment differences were tested by "F" test for significance based on null hypothesis. The appropriate standard error (S.Em.±) was calculated in each case and critical difference (CD) at 5 per cent level of probability was worked out to compare the treatment means, where the treatment effects were significant [9].

3. RESULTS AND DISCUSSION

3.1 Growth Parameters of Shisham in Agroforestry System

The analysis of variance showed non-significant differences in plant height (m), number of primary branches, collar diameter (cm), crown spread East-West (m) and crown spread North-South (m) among varieties mixed with trees (Shisham).

List 1. The experiment was conducted in winter season, 2022-23 with following details

A) Treatment details	
T ₀	Shisham (<i>Dalbergia sissoo</i> Roxb.) alone
T ₁	Shisham (<i>Dalbergia sissoo</i> Roxb.) + <i>Foeniculum vulgare</i> Mill. var. Ajmer fennel-1 (AF-1)
T ₂	Shisham (<i>Dalbergia sissoo</i> Roxb.) + <i>Foeniculum vulgare</i> Mill. var. Ajmer fennel- 2 (AF-2)
T ₃	Shisham (<i>Dalbergia sissoo</i> Roxb.) + <i>Foeniculum vulgare</i> Mill. var. Rajasthan fennel-125 (RF-125)
T ₄	Shisham (<i>Dalbergia sissoo</i> Roxb.) + <i>Foeniculum vulgare</i> Mill. var. Rajasthan fennel- 205 (RF-205)
T ₅	Shisham (<i>Dalbergia sissoo</i> Roxb.) + <i>Foeniculum vulgare</i> Mill. var. Rajasthan fennel- 290 (RF-290)
T ₆	<i>Foeniculum vulgare</i> Mill. var. Ajmer fennel-1 (AF-1)
T ₇	<i>Foeniculum vulgare</i> Mill. var. Ajmer fennel- 2 (AF-2)
T ₈	<i>Foeniculum vulgare</i> Mill. var. Rajasthan fennel- 125 (RF-125)
T ₉	<i>Foeniculum vulgare</i> Mill. var. Rajasthan fennel-205 (RF-205)
T ₁₀	<i>Foeniculum vulgare</i> Mill. var. Rajasthan fennel- 290 (RF-290)

3.2 Plant Height and Days to 50% Flowering

Both agroforestry systems and pure cropping influenced the plant height significantly at all the growth stages. After 30 DAS, 60 DAS, 90 DAS and at harvest of intercrop, plant height was found to be highest in T₁ (Shisham + *Foeniculum vulgare* Mill. var. AF-1) under Shisham based agroforestry system viz. (16.15 cm, 106.42 cm, 157.50 cm and 182.14 cm respectively). However, minimum plant height was recorded in T₈ (Shisham+ *Foeniculum vulgare* Mill. var. RF-125) (11.50 cm, 75.13 cm, 114.94 cm and 132.21 cm respectively) at different interval as 30 DAS, 60 DAS, 90 DAS and at harvest respectively. The reason behind the maximum plant height of Fennel under Shisham based agroforestry might be due to the importance of nitrogen for the proper growth of the plant because N is necessary for most of the physiological growth processes and its absence or deficiency causes stunted growth also sowing in September affect the plant height. Somehow the canopy shading which is considered as the major factor responsible for the general trend of increased plant height also high moisture content in soil affect the height [10, 11].

Minimum days to 50% flowering was found in the treatment T₁ (Shisham + *Foeniculum vulgare* Mill. var. AF-1) (86.78) whereas maximum days to the flowering was found in T₈ (*Foeniculum vulgare* Mill. var. RF -125 sole) (95.67). Among the climatic factors, temperature plays a prominent role in determining the duration of various phenophases. This might be due to its genetics potential of performing better within short duration under adequate supply of nutrients and moisture [12].

3.3 Number of Branches per Plant, Umbels per Plant, Seeds per Umbel and Diameter of Umbel

The maximum total number of branches per plant (8.12), number of umbels per plant (20.30), number of seeds per umbel (683.40) and diameter of umbel (115.93 mm) was recorded in treatment T₁ (Shisham + *Foeniculum vulgare* Mill. var. AF-1) and minimum total number of branches per plant (5.45), number of umbels per plant (17.70), number of seeds per umbel (560.11) and diameter of umbel (94.09 mm) was

recorded in T₈ (*Foeniculum vulgare* Mill var. RF-125) (5.45). The greater number of umbels per plant, seeds per umbel, diameter of umbel and primary branches were attributed to favourable microclimatic conditions including higher moisture availability throughout trail period under tree as compared outside tree canopy and also Shisham is a nitrogen fixing tree which provide proper amount of nitrogen over RDF which helps to improve all these characteristics in the treatments. The number of umbels per plant, seeds per umbel, diameter of umbel and primary branches in five varieties under study showed significant difference [13,14].

3.4 Seed yield per Plant, Seed Yield per Plot

The maximum seed yield per plant (25.64 g) and seed yield per plot (3.08 kg) was found in T₁ (Shisham + *Foeniculum vulgare* Mill. var. AF-1) and the minimum seed yield per plant (17.53 g) and seed yield per plot (1.05 kg) was found in T₈ (*Foeniculum vulgare* Mill. var. RF-125 sole). This results obtained so might be also due to as crop distance from tree increased, yield also increased. Somehow, tree interaction causes improvement in soil physical condition in agroforestry system as compared to sole cropping system, which is responsible for better metabolic activity and seed formation [15].

3.5 Biological Yield of Fennel

Biological yield is the total dry matter produced per plant or per unit area. It includes all of the leaf, stem, umbel and root dry matter produced by the plant. Highest total biological yield (68.92 quintals/ha) was found in the treatment T₆ (*Foeniculum vulgare* Mill. var. Ajmer Fennel- 1 sole). However, lowest total biomass (36.32 quintals/ha) was recorded in the treatment T₃ (Shisham + *Foeniculum vulgare* Mill. var. RF -125). This might due to higher seed yield and straw yield which is directly correlated with sowing time, more availability of nitrogen over RDF, better microclimate, reduction in EC, pH and adding more organic carbon and moisture content during the experimental period under Shisham tree as compare to sole. These results are in confirmation with the findings of [16] in Fennel and [17] in Wheat and Cowpea under Shisham.

Table 1. Growth parameters of Shisham plants

S. No.	Treatments	Plant height Initial (m)	Plant height after (m)	percent increase	Collar diameter per plant (cm) initial	Collar diameter per plant (cm) after	percent increase	Number of primary branches initial and after	Crown spread (m) (E-W) initial	Crown spread (m) (E-W) after	Percent increase	Crown spread (m) (N-S) initial	Crown spread (m) (N-S) after	percent increase
1.	T ₀ Shisham Sole	4.86	5.68	16.87	98.47	100.50	2.06	2.83	2.71	3.17	16.97	2.67	3.19	19.48
2.	T ₁ Shisham + Fennel var. AF – 1	4.38	5.66	29.22	93.62	95.56	2.07	3.67	2.80	3.15	12.50	2.76	3.24	17.39
3.	T ₂ Shisham + Fennel var. AF – 2	4.51	5.66	25.5	95.43	97.60	2.27	3.58	2.68	3.05	13.81	2.57	3.00	16.73
4.	T ₃ Shisham + Fennel. var. RF -125	4.88	5.61	14.96	98.95	100.64	1.71	3.33	2.66	3.14	18.05	2.88	3.33	15.63
5.	T ₄ Shisham + Fennel. var. RF – 205	4.64	5.60	20.69	96.44	98.61	2.25	3.50	2.63	3.23	22.81	2.98	3.43	15.10
6.	T ₅ Shisham + Fennel var. RF- 290	4.78	5.53	15.69	97.20	99.29	2.15	3.25	2.77	3.26	17.69	2.81	3.29	17.08
	SEm (±)	0.26	0.21		2.28	3.77		0.17	0.13	0.11		0.15	0.14	
	C.D. (5%)	NS	NS		NS	NS		NS	NS	NS		NS	NS	

Table 2. Mean performance of plant height (cm) of Fennel sole and under Shisham based intercropping

S. No.	Treatments	Plant height (cm)				Days taken to 50% flowering
		30 DAS	60 DAS	90 DAS	at harvest	
1.	T ₁ Shisham + Fennel var. AF – 1	16.15	106.42	157.50	182.14	86.78
2.	T ₂ Shisham + Fennel var. AF – 2	15.47	98.20	155.29	176.81	87.8
3.	T ₃ Shisham + Fennel. var. RF125	11.80	75.53	115.44	141.62	94.61
4.	T ₄ Shisham + Fennel. var. RF – 205	14.60	95.38	148.52	169.79	88.92
5.	T ₅ Shisham + Fennel var. RF- 290	13.88	83.80	121.49	153.37	94.29
6.	T ₆ Fennel var. AF – 1 Sole	15.98	106.02	156.99	179.81	88.29
7.	T ₇ Fennel var. AF – 2 Sole	15.20	97.85	154.70	170.26	89.01
8.	T ₈ Fennel. var. RF -125 Sole	11.50	75.13	114.94	132.21	95.67
9.	T ₉ Fennel. var. RF - 205 Sole	14.39	94.98	148.01	163.23	90.83
10.	T ₁₀ Fennel var. RF- 290 Sole	13.50	83.29	120.99	149.91	95.33
	SEm (±)	0.34	1.20	1.75	2.81	1.34
	C.D. (5%)	1.03	3.57	5.20	8.35	3.98

Table 3. Mean performance of Number of branch per plant, Number of umbels per plant, Number of seed per umbel and Diameter of umbel (mm) of Fennel sole and under Shisham based intercropping

S. No.	Treatments	Number of branch per plant	Number of umbels per plant	Number of seed per umbel	Diameter of umbel (mm)
1.	T ₁ Shisham + Fennel var. AF – 1	8.12	20.30	683.40	115.93
2.	T ₂ Shisham + Fennel var. AF – 2	7.43	19.26	671.15	111.58
3.	T ₃ Shisham + Fennel. var. RF125	6.15	18.25	561.11	94.82
4.	T ₄ Shisham + Fennel. var. RF – 205	7.22	18.60	621.36	113.92
5.	T ₅ Shisham + Fennel var. RF- 290	6.42	18.30	581.74	110.15
6.	T ₆ Fennel var. AF – 1 Sole	6.41	19.70	682.40	115.71
7.	T ₇ Fennel var. AF – 2 Sole	6.15	18.45	670.15	111.94
8.	T ₈ Fennel. var. RF -125 Sole	5.45	17.70	560.11	94.09
9.	T ₉ Fennel. var. RF - 205 Sole	6.09	18.25	620.36	113.7
10.	T ₁₀ Fennel var. RF- 290 Sole	5.98	17.90	580.74	109.87
	SEm (±)	0.10	0.23	11.07	1.30
	C.D. (5%)	0.29	0.68	32.89	3.86

Table 4. Mean performance of Seed yield (g) per plant, Seed yield (kg) per plot, Biological yield (q/ha) and Economic yield (q/ha) of Fennel sole and under Shisham based intercropping

S. No.	Treatments	Seed yield (g) per plant	Seed yield (kg) per plot	Biological yield (q/ha)	Economic yield (q/ha)
1.	T ₁ Shisham + Fennel var. AF – 1	25.64	3.08	43.47	18.65
2.	T ₂ Shisham + Fennel var. AF – 2	25.42	3.05	40.49	18.52
3.	T ₃ Shisham + Fennel. var. RF125	23.87	2.86	36.32	17.53
4.	T ₄ Shisham + Fennel. var. RF – 205	24.46	2.94	39.99	17.90
5.	T ₅ Shisham + Fennel var. RF- 290	24.14	2.90	38.85	17.71
6.	T ₆ Fennel var. AF – 1 Sole	18.65	1.12	68.92	25.64
7.	T ₇ Fennel var. AF – 2 Sole	18.52	1.11	65.86	25.42
8.	T ₈ Fennel. var. RF -125 Sole	17.53	1.05	60.78	23.87
9.	T ₉ Fennel. var. RF - 205 Sole	17.90	1.07	64.85	24.46
10.	T ₁₀ Fennel var. RF- 290 Sole	17.71	1.06	62.32	24.14
	SEm (±)	0.28	0.03	0.79	0.37
	C.D. (5%)	0.86	0.09	2.36	1.10

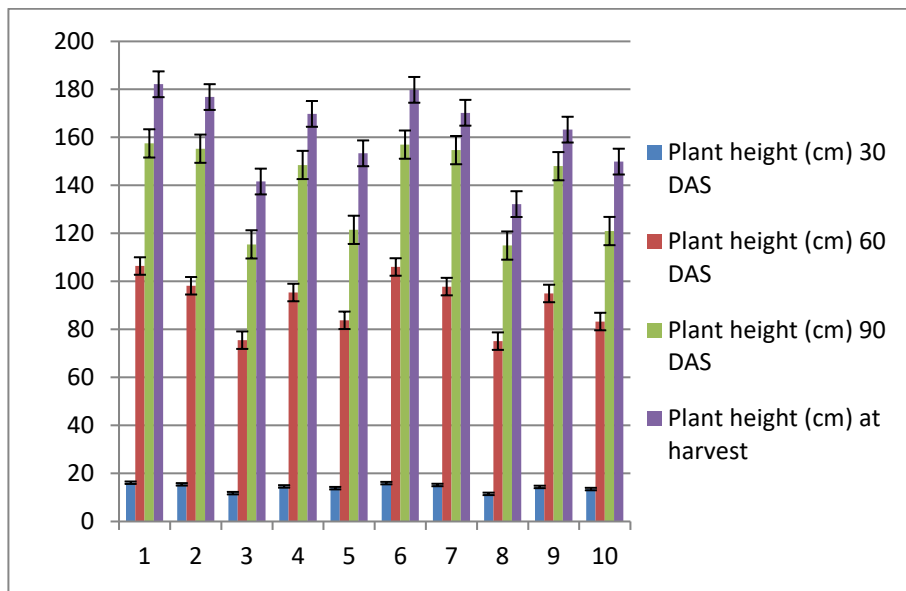


Fig. 1. Mean performance of plant height (cm) of Fennel sole and under Shisham based intercropping

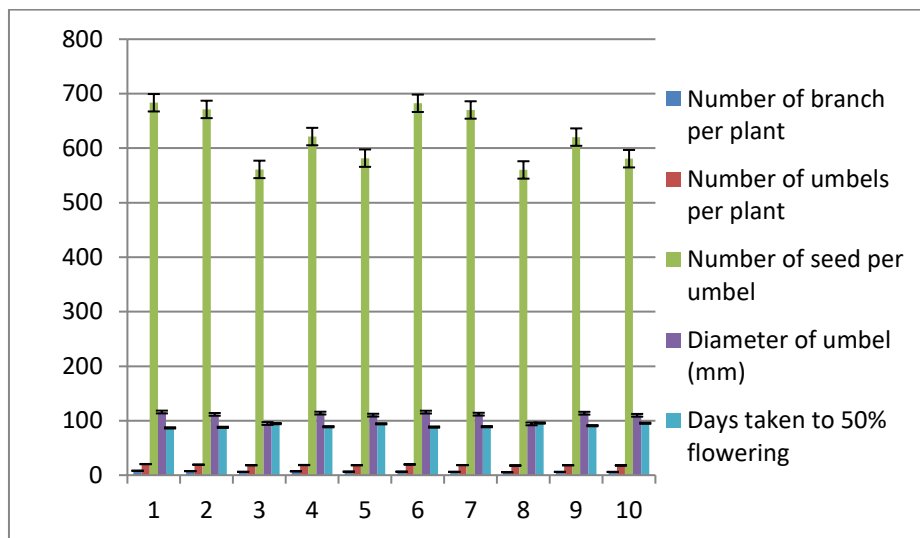


Fig. 2. Mean performance of Number of branch per plant, Number of umbels per plant, Number of seed per umbel and Diameter of umbel (mm) of Fennel sole and under Shisham based intercropping

3.6 Seed Yield of Fennel

Seed Yield (economic yield) is the volume or weight per unit area of only those plant parts (seeds) that have marketable value. Highest total seed yield (25.64 quintals/ha) was found in the treatment T₆ (*Foeniculum vulgare* Mill. var. Ajmer Fennel- 1 sole) whereas lowest total seed yield (17.53 quintals/ha) was recorded in the treatment

T₃ (Shisham + *Foeniculum vulgare* Mill. var. RF - 125). The economical yield (quintals/ha) showed minimum yield in intercropping and maximum in sole cropping system which is only because the per ha. yield is calculated as per the gross plot area size and not as per the net plot area size. Further, overall if the yield is calculated as per the net plot area size, then the intercropping yield will be superior in both the system [10].

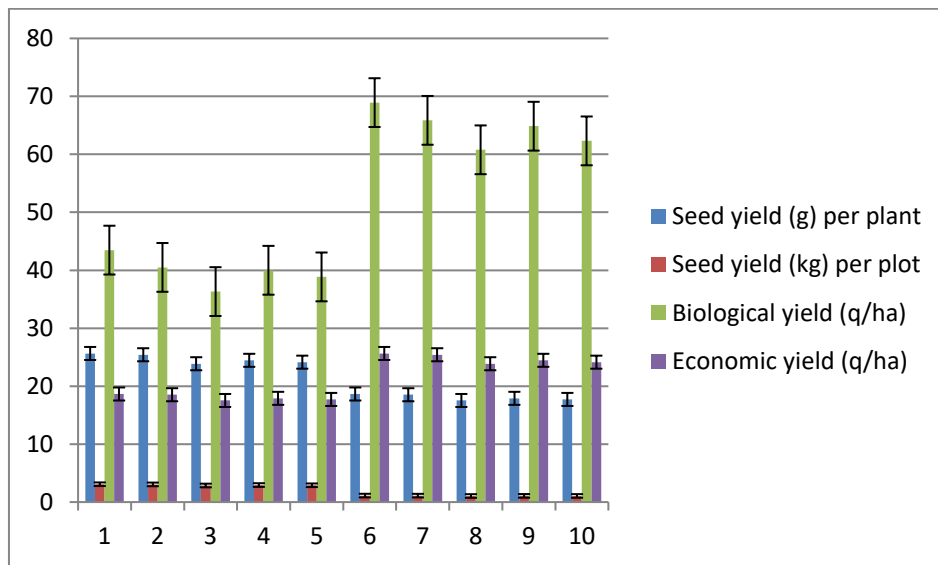


Fig. 3. Mean performance of Seed yield (g) per plant, Seed yield (kg) per plot, Biological yield (q/ha) and Economic yield (q/ha) of Fennel sole and under Shisham based intercropping

4. CONCLUSION

From the present investigation, it can be concluded that the growth and yield of Fennel under Shisham based Agroforestry system is higher as compared to pure cropping, with respect to all the varieties except for the biological yield and economic yield as net area was considered for its calculation. Under Shisham the performance was higher than pure cropping system because Shisham provide some extra N to the plants which helps to its metabolic activities. AF-1 variety of Fennel performed better among all the Five varieties of the Fennel intercropped under Shisham based Agroforestry system (as per net plot size area) as well as sole cropping.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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