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Synergistic Effect of Finger Millet–legume Intercropping Systems on Growth Dynamics and Sustainable Crop Productivity in Semi-arid Tropics

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Authors' contributions

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

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Abstract

Semi-arid crop production is frequently constrained by erratic rainfall, declining soil fertility, and inefficient use of available resources, necessitating resilient and sustainable cropping systems. This study aimed to evaluate the effects of finger millet–legume intercropping combinations and row ratios on the growth, yield attributes, and productivity of finger millet under semi-arid conditions. A field experiment was conducted

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during the kharif seasons of 2023–24 and 2024–25 at the Agricultural Research Station, Karimnagar, Telangana, India. The experiment was laid out in a randomised block design with three replications. The finger millet component comprised intercropping with greengram and blackgram at 4:2 and 6:2 row ratios, pigeonpea at 4:1 and 5:1 row ratios, and sole finger millet. Among the intercropping treatments, finger millet + pigeonpea at 4:1 and 5:1 produced greater plant height, tiller density, dry matter accumulation, number of ear heads, ear length, and ear-head weight than the greengram- and blackgram-based systems. Finger millet + pigeonpea at 5:1 recorded the highest grain yield among the intercropping treatments, with 3,739 and 3,749 kg ha^{-1} during 2023–24 and 2024–25, respectively. Sole finger millet recorded the highest overall grain yield of 3,927 and 3,848 kg ha^{-1} in the respective seasons. Grain weight per ear head and 1,000-grain weight were not significantly influenced by the intercropping treatments. The findings indicate that finger millet + pigeonpea at a 5:1 row ratio was the most productive intercropping option evaluated under the study conditions.

Keywords: Finger millet; pigeonpea; greengram; blackgram; Cereal–legume intercropping; yield attributes; semi-arid tropics; sustainable productivity.

1. Introduction

Semi-arid regions are characterised by uneven rainfall distribution, prolonged dry spells, high evapotranspiration losses, and degraded soils with reduced organic matter, resulting in low agricultural productivity. Rising temperatures and the increasing frequency of droughts and floods associated with climate change further intensify moisture stress and production risks. Repeated cultivation of the same crop depletes nutrients, reduces soil microbial activity, and lowers resource-use efficiency. Under these conditions, resilient cropping systems are urgently needed. Careful selection of crops with contrasting growth patterns may increase system productivity while conserving natural resources.

Intercropping involves growing two or more crops simultaneously on the same piece of land in a defined spatial arrangement. Because plant growth and yield depend on the efficient utilisation of resources, integrating compatible crops can improve the use of water, nutrients, light, and space. Finger millet has tall, erect leaves, whereas legumes develop a spreading canopy. This vertical stratification promotes a more even distribution of light within the crop stand and may enhance the photosynthetic activity of both component crops. Differences in rooting pattern, nutrient acquisition, canopy architecture, and crop duration in millet–legume systems may reduce interspecific competition while strengthening complementary interactions. In semi-arid regions, where crop production is frequently constrained by unpredictable weather, intercropping millets with legumes such as greengram, blackgram, and pigeonpea has emerged as a potentially effective and sustainable production system. Recent field evidence indicates that the performance of millet–legume intercropping depends on crop combination, row arrangement, moisture availability, and nutrient management, with appropriately configured systems improving productivity and resource-use efficiency under semi-arid conditions (Adam et al., 2025; Senghor et al., 2023; Sukanya et al., 2024). In finger millet–pulse associations, the component pulse and row ratio also influence crop growth and yield responses (Peter et al., 2024). Millet adaptation to abiotic stress is further associated with below-ground processes affecting nutrient acquisition and rhizosphere interactions (Ruhi & Upadhyay, 2025). Recent finger millet-based evidence further indicates that legume choice and crop management can influence the productivity of millet–legume associations, reinforcing the need to evaluate locally appropriate combinations (Panotra et al., 2025; Shilpa et al., 2025). Evidence from a cereal–legume system evaluated under drought conditions likewise indicates that the legume component can influence crop response, supporting careful selection of companion species in water-limited production environments (Iza & Pascual, 2025). At a broader scale, recent syntheses describe intercropping performance as context dependent and sensitive to species traits, planting configuration, and management, while also identifying variation in temporal yield stability among cereal–legume systems (Ruillé et al., 2026; Song et al., 2026). Despite this growing evidence, direct two-season comparisons of greengram, blackgram, and pigeonpea in finger millet at contrasting row ratios under the same semi-arid environment remain limited. This evidence gap restricts locally specific recommendations on legume choice and spatial arrangement for maintaining finger millet productivity under weather-limited conditions. Therefore, the present study evaluated promising finger millet–legume intercropping systems at different row ratios to determine their effects on growth dynamics and yield potential.

2. Material and Methods

A field experiment was conducted during the *kharif* seasons of 2023–24 and 2024–25 at the Agricultural Research Station, Karimnagar, Telangana, India. The experimental soil was red sandy loam with a neutral pH (6.6), low electrical conductivity (0.2), medium organic carbon (0.6%), low available nitrogen (207 kg ha^{-1}), and high available phosphorus (28.8 kg ha^{-1}) and potassium (303.3 kg ha^{-1}). The experiment was laid out in a randomised block design with 14 treatments and three replications. The treatments were T1: finger millet + greengram (4:2), T2: finger millet + greengram (6:2), T3: finger millet + blackgram (4:2), T4: finger millet + blackgram (6:2), T5: finger millet + pigeonpea (4:1), T6: finger millet + pigeonpea (5:1), T7: foxtail millet + greengram (4:2), T8: foxtail millet + greengram (6:2), T9: foxtail millet + blackgram (4:2), T10: foxtail millet + blackgram (6:2), T11: foxtail millet + pigeonpea (4:1), T12: foxtail millet + pigeonpea (5:1), T13: sole finger millet, and T14: sole foxtail millet. The main crops and short-duration component crops were sown by dibbling at 30 × 10 cm, while pigeonpea was sown at 60 × 20 cm, following the standard package of practices. Although the experiment included two millets, their distinct phenological and morphological characteristics required separate analyses. Accordingly, only the finger millet–legume treatments and the sole finger millet treatment are presented in this article.

2.1 Statistical Analysis

Data on growth, yield attributes, and yield were subjected to analysis of variance for a randomised block design, following Gomez and Gomez (1984). Statistical significance was assessed using the F-test at $p = 0.05$, and the critical difference was calculated for significant treatment effects. Non-significant treatment differences were denoted as NS.

3. Results and Discussion

3.1 Plant Height (cm)

Plant height at 30, 60, and 90 DAS and at harvest, as influenced by finger millet + legume intercropping during the *kharif* seasons of 2023–24 and 2024–25, is presented in Table 1.

Table 1. Plant height (cm) of finger millet as influenced by finger millet–legume intercropping during kharif 2023–24 and 2024–25

Plant height (cm) of finger millet						
Treatments	**At 30 DAS**			**At 60 DAS**		
	2023–24	**2024–25**	**Mean**	**2023–24**	**2024–25**	**Mean**
T1: Finger millet + greengram (4:2)	18.0	17.3	17.7	60.9	59.5	60.2
T2: Finger millet + greengram (6:2)	14.8	15.5	15.2	58.7	57.4	58.1
T3: Finger millet + blackgram (4:2)	18.0	17.6	17.8	61.7	61.0	61.4
T4: Finger millet + blackgram (6:2)	16.2	16.5	16.3	60.6	59.2	59.9
T5: Finger millet + pigeonpea (4:1)	18.5	18.8	18.6	67.6	68.6	68.1
T6: Finger millet + pigeonpea (5:1)	18.5	18.5	18.5	65.5	67.4	66.4
T13: Sole finger millet	20.1	19.9	20.0	68.3	70.4	69.4
SEm±	**0.68**	**0.58**		**2.08**	**2.74**	
CD (p = 0.05)	**2.02**	**1.75**		**6.22**	**8.21**	
Treatments	**At 90 DAS**			**At harvest**		
	2023–24	**2024–25**	**Mean**	**2023–24**	**2024–25**	**Mean**
T1: Finger millet + greengram (4:2)	95.1	92.3	93.7	102.9	100.3	101.6
T2: Finger millet + greengram (6:2)	92.8	89.2	91.0	101.5	97.2	99.3
T3: Finger millet + blackgram (4:2)	96.3	92.5	94.4	103.7	100.5	102.1
T4: Finger millet + blackgram (6:2)	93.0	92.0	92.5	102.1	100.0	101.1
T5: Finger millet + pigeonpea (4:1)	102.6	100.1	101.4	114.2	108.1	111.1
T6: Finger millet + pigeonpea (5:1)	100.6	98.9	99.8	107.0	106.9	106.9
T13: Sole finger millet	106.7	101.9	104.3	115.3	114.6	115.0
SEm±	**2.97**	**2.81**		**3.05**	**2.99**	
CD (p = 0.05)	**8.91**	**8.43**		**9.15**	**8.95**	

Among the finger millet-based intercropping systems, finger millet + pigeonpea at 4:1 (T5) recorded the greatest plant height at 30, 60, and 90 DAS and at harvest, with values of 18.5 and 18.8 cm, 67.6 and 68.6 cm, 102.6 and 100.1 cm, and 114.2 and 108.1 cm during 2023–24 and 2024–25, respectively. At 30 DAS, T5 was statistically on par with T6, T3, and T1 in both years. At 60 and 90 DAS, it was on par with T6 and T3 in both years and with T1 at 90 DAS. At harvest, T5 was on par with T6 in both years and with T3 and T1 during 2024–25. Sole finger millet (T13) recorded the greatest plant height at all growth stages and was statistically on par with T5 and T6 in both years. Finger millet + greengram at 6:2 (T2) recorded the lowest plant height at 30, 60, and 90 DAS and at harvest, with values of 14.8 and 15.5 cm, 58.7 and 57.4 cm, 92.8 and 89.2 cm, and 101.5 and 97.2 cm during 2023–24 and 2024–25, respectively.

Among the intercropping treatments, T5 recorded the greatest plant height at all growth stages and remained statistically on par with T6 and sole finger millet (T13) from 60 DAS onwards. The greater plant height may be attributed to the complementary growth pattern of pigeonpea, its wider row spacing, and its deep root system, which may have reduced direct competition for soil water and nutrients, together with its capacity for biological nitrogen fixation.

Reddy and Gowda (2020) and Meena *et al.* (2017) reported improved growth responses in finger millet under favourable resource conditions and millet-based cropping systems. Bedoussac *et al.* (2015) concluded that appropriately designed cereal–legume intercropping systems can increase crop growth by enhancing resource-use efficiency and reducing competition between component crops. Similarly, Lithourgidis *et al.* (2011) reported that compatible spatial arrangements in cereal–legume intercropping improve resource utilisation while minimising interspecific competition. The greater plant height of sole finger millet may be attributed to the absence of interspecific competition for essential growth resources. In contrast, greengram- and blackgram-based intercropping systems recorded relatively lower plant height, possibly because of greater competition for resources in the upper soil layers during the early growth stages.

3.2 Tiller Density (m^{-2})

Tiller density (m^{-2}) at 60 and 90 DAS and at harvest, as influenced by finger millet + legume intercropping during the kharif seasons of 2023–24 and 2024–25, is presented in Table 2.

Among the finger millet–legume intercropping systems, T5 recorded the greatest number of tillers, with 111.2 and 115.0 m^{-2} at 60 DAS, 140.4 and 145.8 m^{-2} at 90 DAS, and 141.9 and 147.0 m^{-2} at harvest during 2023–24 and 2024–25, respectively. At 60 DAS, T5 was statistically on par with T6 in both years and with T3 during 2024–25. Sole finger millet (T13) recorded the greatest tiller density, with 113.7 and 117.6 m^{-2} at 60 DAS, 152.1 and 151.8 m^{-2} at 90 DAS, and 153.6 and 154.3 m^{-2} at harvest during 2023–24 and 2024–25, respectively. In contrast, T2 recorded the lowest tiller density at 60 and 90 DAS and at harvest, with values of 90.0 and 93.4 m^{-2}, 129.3 and 129.3 m^{-2}, and 130.8 and 130.5 m^{-2}, respectively.

The greater tiller density under sole finger millet, which was comparable with T5 and T6 at some stages, may be associated with reduced competition for available resources in the sole crop and the complementary growth habit of pigeonpea in the intercropping treatments. In addition, peak pigeonpea nodulation at 60–80 DAS coincided with the flowering stage of finger millet, which may have supported tiller production and survival in T5 and T6. Manjunath and Salakinkop (2017) reported that sole finger millet produced a greater number of tillers m^{-2} because of the efficient utilisation of space, nutrients, and light compared with intercropping systems. Similar findings were reported by Pradhan *et al.* (2014) and Maitra *et al.* (2001).

3.3 Dry Matter Production (kg ha^{-1})

Dry matter production at 30, 60, and 90 DAS and at harvest, as influenced by finger millet + legume intercropping during the *kharif* seasons of 2023–24 and 2024–25, is presented in Table 3.

Among the finger millet-based intercropping systems, T6 recorded the greatest dry matter production at 30, 60, and 90 DAS and at harvest, with values of 1048 and 1055 kg ha^{-1}, 4563 and 4306 kg ha^{-1}, 6156 and 6101 kg ha^{-1}, and 7956 and 7799 kg ha^{-1} during 2023–24 and 2024–25, respectively. The lowest dry matter production at these stages was recorded under T1, with values of 798, 2822, 4425, and 6225 kg ha^{-1} during 2023–24 and 825, 3012, 4812, and 6662 kg ha^{-1} during 2024–25. Sole finger millet (T13) recorded the greatest dry matter production at all stages, with values of 1699, 4756, 6306, and 8106 kg ha^{-1} during 2023–24 and 1791, 4611, 6318, and 8168 kg ha^{-1} during 2024–25. It was statistically on par with T6 at 60 and 90 DAS and at harvest during 2023–24 and at 90 DAS during 2024–25.

Table 2. Tiller density (m⁻²) of finger millet as influenced by finger millet–legume intercropping during kharif 2023–24 and 2024–25

	Tiller density (m^{-2}) of finger millet								
Treatments	**At 60 DAS**			**At 90 DAS**			**At harvest**		
	2023–24	**2024–25**	**Mean**	**2023–24**	**2024–25**	**Mean**	**2023–24**	**2024–25**	**Mean**
T1: FM + GG (4:2)	94.8	100.5	97.7	136.6	134.7	135.6	138.1	135.9	137.0
T2: FM + GG (6:2)	90.0	93.4	91.7	129.3	129.3	129.3	130.8	130.5	130.7
T3: FM + BG (4:2)	97.7	107.0	102.4	137.3	135.6	136.5	138.8	136.8	137.8
T4: FM + BG (6:2)	92.5	96.3	94.4	133.6	130.7	132.1	135.1	131.9	133.5
T5: FM + PP (4:1)	111.2	115.0	113.1	140.4	145.8	143.1	141.9	147.0	144.5
T6: FM + PP (5:1)	105.1	110.7	107.9	139.9	145.8	142.9	141.4	147.0	144.2
T13: Sole FM	113.7	117.6	115.6	152.1	151.8	152.0	153.6	154.3	154.0
SEm±	**2.96**	**3.45**		**4.18**	**4.25**		**4.18**	**4.56**	
CD (p = 0.05)	**8.88**	**10.35**		**12.53**	**12.73**		**12.53**	**13.68**	

Note: FM = finger millet; GG = greengram; BG = blackgram; PP = pigeonpea

Table 3. Dry matter production (kg ha⁻¹) of finger millet as influenced by finger millet–legume intercropping during kharif 2023–24 and 2024–25

Dry matter production (kg ha^{-1}) of finger millet						
Treatments	**At 30 DAS**			**At 60 DAS**		
	2023–24	**2024–25**	**Mean**	**2023–24**	**2024–25**	**Mean**
T1: Finger millet + greengram (4:2)	798	825	811	2822	3012	2917
T2: Finger millet + greengram (6:2)	884	906	895	3415	3636	3525
T3: Finger millet + blackgram (4:2)	834	841	837	3013	3289	3151
T4: Finger millet + blackgram (6:2)	896	938	917	3512	3859	3685
T_5: Finger millet + pigeonpea (4:1)	998	1003	1001	4206	4218	4212
T_6: Finger millet + pigeonpea (5:1)	1048	1055	1051	4563	4306	4435
T_{13}: Sole finger millet	1699	1791	1745	4756	4611	4683
SEm±	**9**	**15**		**121**	**78**	
CD (p = 0.05)	**27**	**45**		**361**	**233**	
Treatments	**At 90 DAS**			**At harvest**		
	2023–24	**2024–25**	**Mean**	**2023–24**	**2024–25**	**Mean**
T1: Finger millet + greengram (4:2)	4425	4812	4619	6225	6662	6444
T2: Finger millet + greengram (6:2)	5010	5411	5210	6760	7236	6998
T3: Finger millet + blackgram (4:2)	4599	5079	4839	6377	6918	6648

Dry matter production (kg ha⁻¹) of finger millet						
Treatments	**At 30 DAS**			**At 60 DAS**		
	2023–24	**2024–25**	**Mean**	**2023–24**	**2024–25**	**Mean**
T4: Finger millet + blackgram (6:2)	5088	5459	5273	6888	7284	7086
T5: Finger millet + pigeonpea (4:1)	6123	5799	5961	7623	7529	7576
T6: Finger millet + pigeonpea (5:1)	6156	6101	6128	7956	7799	7877
T13: Sole finger millet	6306	6318	6312	8106	8168	8137
SEm±	**133**	**77**		**133**	**77**	
CD (p = 0.05)	**397**	**232**		**397**	**232**	

The greater dry matter production in the finger millet + pigeonpea systems at 5:1 and 4:1 may be attributed to reduced competition, improved nitrogen availability through biological nitrogen fixation, greater tillering, enhanced leaf-area development, and increased biomass accumulation. Kalal and Virdia (2023) reported that, in addition to symbiotic nitrogen fixation, legumes can recycle nutrients from deeper soil layers. Similar findings were reported by Reddy *et al.* (2023) and Amanullah *et al.* (2021). The greater dry matter production under sole finger millet may have resulted from unrestricted root development, efficient nutrient uptake, and a larger photosynthetic area.

3.4 Yield Attributes and Yield of Finger Millet

3.4.1 Number of Ear Heads (m^{-2}) in Finger Millet

The number of ear heads m^{-2} in finger millet, as influenced by millet–legume intercropping during the *kharif* seasons of 2023–24 and 2024–25, is presented in Table 4.

Among the finger millet-based intercropping systems, T5 recorded the greatest number of ear heads, with 144.6 and 144.5 m^{-2} during 2023–24 and 2024–25, respectively. It was statistically on par with T6 and T3 in both years and with T1 during 2024–25. T2 recorded the lowest number of ear heads, with 122.9 and 128.0 m^{-2} during 2023–24 and 2024–25, respectively. Sole finger millet (T13) recorded the greatest number of ear heads, with 150.3 and 151.8 m^{-2}, and was statistically on par with T5 and T6. The favourable performance of T5 and T6 may be associated with the ability of pigeonpea to fix atmospheric nitrogen through *Rhizobium* symbiosis, which may have improved nitrogen availability and supported ear-head initiation and development. The lower number of ear heads under T2 may have resulted from early competition with greengram for nutrients and moisture, reducing the conversion of tillers into productive ear heads. Sharmili and Manoharan (2018) reported that the number of panicles per tiller and 1,000-grain weight of little millet increased when intercropped with pulses. Similar findings were reported by Aravind *et al.* (2023).

3.4.2 Ear-Head Length and Weight, Grain Weight per Ear Head, and 1,000-Grain Weight of Finger Millet

Ear length, ear-head weight, grain weight per ear head, and 1,000-grain weight of finger millet, as influenced by the millet–legume intercropping systems during the kharif seasons of 2023–24 and 2024–25, are presented in Table 5.

Table 4. Number of ear heads (m^{-2}) of finger millet as influenced by finger millet–legume intercropping during kharif 2023–24 and 2024–25

Treatments	Number of ear heads (m^{-2})		
	2023–24	**2024–25**	**Mean**
T1: Finger millet + greengram (4:2)	126.9	133.4	130.1
T2: Finger millet + greengram (6:2)	122.9	128.0	125.4
T3: Finger millet + blackgram (4:2)	132.9	134.3	133.6
T4: Finger millet + blackgram (6:2)	123.2	129.4	126.3
T5: Finger millet + pigeonpea (4:1)	144.6	144.5	144.6
T6: Finger millet + pigeonpea (5:1)	142.7	144.5	143.6
T_{13}: Sole finger millet	150.3	151.8	151.1
SEm±	4.20	4.56	
CD (p = 0.05)	12.60	13.68	

Among the finger millet–legume treatments, T5 recorded the greatest ear length and ear-head weight, with values of 13.3 and 13.1 cm and 12.3 and 11.5 g during 2023–24 and 2024–25, respectively. These values were statistically on par with T6 in both years and with T3 and T1 during 2023–24. T2 recorded the lowest ear length and ear-head weight, with values of 11.4 and 10.3 cm and 10.4 and 10.1 g during 2023–24 and 2024–25, respectively. Sole finger millet (T13) recorded the greatest ear length and ear-head weight, with values of 13.4 and 13.5 cm and 13.0 and 12.3 g, respectively, and was statistically on par with T5 and T6. The favourable performance of the pigeonpea intercropping systems may have resulted from lower competition, enabling finger millet to use resources more efficiently for vegetative growth, dry matter accumulation, and the translocation of photosynthates from source to sink during the reproductive stage. These findings are consistent with Maitra *et al.* (2001) and Lithourgidis *et al.* (2011), who reported that cereal–legume intercropping can improve resource use without substantially affecting individual grain weight, which is predominantly controlled by genotype.

Grain weight per ear head and 1,000-grain weight were not significantly influenced by the millet–legume intercropping systems during 2023–24 or 2024–25. These traits may therefore be governed primarily by the genetic characteristics of the variety and may be less responsive to the intercropping arrangements evaluated. Although intercropping affected vegetative growth and several yield attributes, it had little effect on individual grain size and weight, suggesting that source–sink relations during grain filling were comparatively stable across treatments.

3.4.3 Grain, Stalk, and Biological Yield (kg ha^{-1}) and Harvest Index of Finger Millet

The grain, stalk, and biological yields and harvest index of finger millet, as influenced by millet–legume intercropping during the *kharif* seasons of 2023–24 and 2024–25, are presented in Table 6.

Among the finger millet–legume intercropping systems, T6 recorded the greatest grain yield, with 3739 and 3749 kg ha^{-1} during 2023–24 and 2024–25, respectively, and was statistically on par with T5. T1 recorded the lowest grain yield, with 3080 and 3203 kg ha^{-1} during 2023–24 and 2024–25, respectively. Sole finger millet (T13) recorded the greatest grain yield among all treatments, with 3927 and 3848 kg ha^{-1} during 2023–24 and 2024–25, respectively. T6 was statistically on par with T13 during 2024–25.

The greater grain, stalk, and biological yields under T5 and T6 than under the other intercropping systems may be attributed to the wider row spacing of pigeonpea, which facilitated light transmission and aeration within the crop canopy and may have improved photosynthetic efficiency and biomass production. Sole finger millet maintained a greater number of tillers, leaf area, and dry matter accumulation, resulting in greater grain and stalk yields. Shiyal *et al.* (2024) reported that the greater yield of sole pearl millet than of intercropped pearl millet may result from the absence of interspecific competition. The higher grain yield of finger millet in the pigeonpea treatments may also be associated with improved nitrogen availability through biological nitrogen fixation, which supported growth and yield attributes. Das *et al.* (2018) reported that finger millet–pulse intercropping systems can improve the use of nutrients, moisture, light, and space. Similar findings were reported by Abinaya *et al.* (2020), Kumar *et al.* (2020), and Shashidhara *et al.* (2000). The lower yield under the greengram treatments may have resulted from competition for growth resources when the peak flowering period of the short-duration greengram coincided with the vegetative growth of finger millet.

Among the finger millet intercropping systems, T6 recorded the greatest stalk yield, with 4179 and 4049 kg ha^{-1}, and biological yield, with 7918 and 7799 kg ha^{-1}, during 2023–24 and 2024–25, respectively. Sole finger millet (T13) recorded the greatest stalk yield, with 4217 and 4320 kg ha^{-1}, and biological yield, with 8144 and 8168 kg ha^{-1}, among all treatments. During 2023–24, T13 was statistically on par with T6 for both stalk and biological yield. T1 recorded the lowest stalk yield, with 3144 and 3459 kg ha^{-1}, and biological yield, with 6225 and 6662 kg ha^{-1}, during 2023–24 and 2024–25, respectively.

The greater yields under the finger millet–pigeonpea intercropping systems may be associated with biological nitrogen fixation by pigeonpea. Although substantial quantities of fixed nitrogen may not be transferred directly to finger millet during the growing period, improved rhizosphere conditions and microbial activity may increase nutrient availability. Vinay *et al.* (2021) reported that reductions in grain and stalk yields under intercropping may result from increased competition for nutrients, water, space, and light compared with sole cropping. Similar reductions in grain yield under intercropping were reported by Tiwari *et al.* (2011). Ramamoorthy *et al.* (2004) observed that finger millet intercropped with pigeonpea produced better growth and grain yield than other intercropping combinations because of efficient resource utilisation and complementarity between the component crops. Basavarajappa and Basavaraj (2003) also reported improved millet productivity under favourable resource availability. The greater biological yield under sole finger millet may be attributed to uninterrupted access to resources, a larger leaf-area index, and consequently greater photosynthetic efficiency and biomass accumulation.

Table 5. Yield attributes of finger millet as influenced by finger millet–legume intercropping during kharif 2023–24 and 2024–25

Treatments	Yield attributes of finger millet											
	Length of ear (cm)			Ear head weight (g)			Grain weight per ear head (g)			1,000-grain weight (g)		
	2023–24	2024–25	Mean	2023–24	2024–25	Mean	2023–24	2024–25	Mean	2023–24	2024–25	Mean
T1: Finger millet + greengram (4:2)	12.1	11.2	11.7	11.0	10.4	10.7	4.6	4.5	4.5	2.9	2.5	2.7
T2: Finger millet + greengram (6:2)	11.4	10.3	10.9	10.4	10.1	10.3	4.5	4.4	4.5	2.7	2.4	2.6
T3: Finger millet + blackgram (4:2)	12.1	11.6	11.8	11.4	10.8	11.1	4.8	4.5	4.7	2.9	2.6	2.8
T4: Finger millet + blackgram (6:2)	11.7	10.8	11.2	10.7	10.2	10.5	4.6	4.4	4.5	2.9	2.4	2.7
T5: Finger millet + pigeonpea (4:1)	13.3	13.1	13.2	12.3	11.5	11.9	4.9	4.6	4.8	3.0	2.8	2.9
T6: Finger millet + pigeonpea (5:1)	13.0	12.7	12.9	11.8	11.3	11.6	4.9	4.6	4.7	2.9	2.8	2.8
T_{13}: Sole finger millet	13.4	13.5	13.4	13.0	12.3	12.6	4.9	4.7	4.8	3.0	2.8	2.9
SEm±	**0.40**	**0.27**		**0.44**	**0.34**		**0.10**	**0.08**		**0.11**	**0.11**	
CD (p = 0.05)	**1.20**	**0.81**		**1.32**	**1.02**		**NS**	**NS**		**NS**	**NS**	

Table 6. Grain, stalk, and biological yield (kg ha^{-1}) and harvest index of finger millet as influenced by finger millet–legume intercropping during kharif 2023–24 and 2024–25

Treatments	Grain yield (kg ha^{-1})			Stalk yield (kg ha^{-1})			Biological yield (kg ha^{-1})			Harvest index		
	2023–24	2024–25	Mean	2023–24	2024–25	Mean	2023–24	2024–25	Mean	2023–24	2024–25	Mean
T1: Finger millet + greengram (4:2)	3080	3203	3142	3144	3459	3302	6225	6662	6444	49.48	48.08	48.78
T2: Finger millet + greengram (6:2)	3258	3479	3369	3501	3757	3629	6760	7236	6998	48.20	48.08	48.14
T3: Finger millet + blackgram (4:2)	3159	3326	3243	3218	3592	3405	6377	6918	6648	49.54	48.08	48.81
T4: Finger millet + blackgram (6:2)	3337	3502	3420	3550	3782	3666	6888	7284	7086	48.45	48.08	48.26
T5: Finger millet + pigeonpea (4:1)	3706	3663	3684	3918	3866	3892	7623	7529	7576	48.59	48.64	48.62
T6: Finger millet + pigeonpea (5:1)	3739	3749	3744	4179	4049	4114	7918	7799	7858	47.20	48.08	47.64
T13: Sole finger millet	3927	3848	3888	4217	4320	4269	8144	8168	8156	48.31	47.12	47.71
SEm±	**58**	**42**		**83**	**43**		**72**	**77**		**0.79**	**0.22**	
CD (p = 0.05)	**173**	**125**		**249**	**130**		**215**	**232**		**NS**	**0.65**	

The harvest index was not significantly influenced by the intercropping systems during 2023–24, whereas significant differences were observed during 2024–25. During 2023–24, the numerically highest harvest index was recorded under T3 (49.54), although the treatment effect was non-significant. During 2024–25, T5 recorded the highest harvest index (48.64), while T13 recorded the lowest value (47.12).

4. Conclusion

The two-year study showed that the choice of legume and row ratio strongly influenced the growth and yield performance of finger millet under semi-arid conditions. Among the intercropping treatments, finger millet + pigeonpea at 5:1 produced the greatest grain yield in both seasons, while the 4:1 pigeonpea arrangement also performed better than the greengram- and blackgram-based systems. These responses were associated with greater plant height, tiller density, dry matter accumulation, ear-head number, ear length, and ear-head weight. Sole finger millet retained the greatest overall yield, indicating that intercropping reduced the yield of the main crop to some extent. Nevertheless, the comparatively strong performance of the pigeonpea combinations suggests that their contrasting canopy and rooting characteristics reduced competition relative to the other legume combinations. Under the conditions of this experiment, finger millet–pigeonpea intercropping at a 5:1 row ratio appears to be the most suitable of the evaluated intercropping options for sustaining finger millet productivity while including a legume component.

5. Limitation

This study was conducted at a single research station over two kharif seasons; therefore, the findings are specific to the prevailing soil and climatic conditions of the experimental site. The assessment was limited to the growth and yield performance of finger millet under selected legume combinations and row ratios. Long-term effects on soil properties, system productivity, and economic returns were not evaluated.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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