

Studies on Feasibility of Castor Based Relay Intercropping System in Rainfed Alfisols of Karnataka

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ABSTRACT

A field experiment was carried out at ZARS, University of Agricultural Sciences, GKVK Bengaluru during *khari* 2022 and 2023 to study the feasibility of castor based relay intercropping system in rainfed alfisols of Karnataka. The experiment was laid out in split plot design with four main plot treatments (crop geometry with finger millet intercropping), four subplot treatments (relay intercropping) and seven sole cropping treatments. The results showed that wider paired row planting of castor (60-240 cm x 45 cm) with finger millet intercropping system has recorded significantly higher pooled number of branches (7.15), number of spikes plant⁻¹ (6.32), length of spike (50.08 cm), number of capsules spike⁻¹ (47.47), seed yield (1442 kg ha⁻¹), stalk yield (4417 kg ha⁻¹), biological yield (4071 kg ha⁻¹), castor equivalent ratio (2868 kg ha⁻¹) and benefit cost ratio (3.08) compared to narrow paired row planting (45-240 cm x 30 cm) and skipped row planting of castor (120 cm x 60cm and 90 cm x 60cm). However, the castor pooled plant height (99.17 cm) at harvest was significantly higher under narrow paired row planting of castor (45-240 cm x 30cm) than compared to other cropping geometry systems. In relay intercropping system, paired row planting of castor (60-240 cm x 45cm) with finger millet intercropping followed by fieldbean relay intercropping system has recorded significantly higher pooled number of branches (6.75), number of spikes plant⁻¹ (5.92), length of spike (50.31 cm), number of capsules spike⁻¹ (47.71), seed yield (1446 kg ha⁻¹), stalk yield (2636 kg ha⁻¹), biological yield (4082 kg ha⁻¹), castor equivalent ratio (2881 kg ha⁻¹) and benefit cost ratio (3.17) compared to all other relay intercropping systems.

Keywords : Castor, B:C ratio, Equivalent yield, Finger millet, Relay intercropping, Yield

CLIMATE change presents significant challenges to Agriculture by impacting crop productivity, soil health and resource efficiency, particularly in rainfed systems (Kabato *et al.*, 2025). To adapt, cropping systems must become more resilient and intercropping offers a promising strategy. Intercropping is method of growing two or more crops together enhances spatial and temporal diversity, boosts resource use efficiency, supports agro-ecological balance and

improves food security and farm income under climate stress (Bedoussac *et al.*, 2015). It exploits different rooting depths and growth patterns, leading to better water and nutrient utilization than monocropping, while also enriching soil health, increasing pest resistance and reducing dependence on external inputs. Dryland farming, often constrained by water scarcity and low soil fertility, requires crop combinations that offer resource complementarity

(Kumar *et al.* 2024). A successful example is castor (*Ricinus communis* L.) intercropped with finger millet (*Eleusine coracana*).

Castor is a drought-tolerant, non-edible oilseed crop having high demand for its high-quality oil, with India leading global production in states like Gujarat and Andhra Pradesh. While, castor having deep root system extract water from lower soil layers, the finger millet uses upper-layer moisture, minimizing competition (Vinay *et al.*, 2021). Additionally, castor provides shade that reduces heat stress on finger millet, which suppresses weeds and contributes to better soil cover. This synergy improves organic matter content in soil, reduces erosion and diversifies income for dryland farmers. However, this system is having low adoption among smallholder farmers being limited in food and fodder value (Kumar & Yamanura, 2019).

In Karnataka rainfed alfisols is characterized by bimodal rainfall (Ravindrababu *et al.*, 2010), with potential for extended cropping seasons with both *kharif* and *rabi* crops. Yet, this potential remains underutilized due to limited technical knowledge. Relay cropping, wherein a second crop is sown before the first is harvested, can help optimize the use of extended rainfall (Araya *et al.*, 2010). Legumes are particularly suitable for relay systems due to their nitrogen-fixing ability, which enhances soil fertility, suppresses weeds and improves overall land use efficiency (Mavarkar *et al.*, 2007). Short-duration legumes incorporated during late *kharif* can boost system productivity and sustainability through grain and fodder yield, which is the most important for farmer for their livestock feed and food for family. Intercropping and relay systems together offer low-input, eco-friendly alternatives that build resilience. To evaluate these benefits, a study titled 'Studies on feasibility of castor-based relay intercropping system under rainfed alfisols' was conducted at ZARS, GKVK, Bengaluru during 2022-2024 under rainfed conditions.

MATERIAL AND METHODS

The field experiment was conducted at castor field unit (K7), ZARS, UASB, GKVK, Bengaluru. This

site is located in Agro Climatic Zone V (Eastern Dry Zone) of Karnataka at a latitude of 12° 58' North, longitude of 77° 35' East and an altitude of 930 m above mean sea level. The actual rainfall received throughout the cropping period at the experimental site 1013.6 and 557.8 mm during 2022-23 and 2023-24, respectively. The soil was red sandy loam in texture that comes under Alfisols soil order. Soil was acidic in reaction (pH 6.25), low in organic carbon content (0.33%) with an electrical conductivity of 0.33 dS m⁻¹. The initially soil fertility status was low in available nitrogen (256.72 kg ha⁻¹), medium in available phosphorous (42.69 kg ha⁻¹) and available potassium (284.53 kg ha⁻¹). The study was conducted to know the feasibility of castor based relay intercropping system in rainfed alfisols of Karnataka during *kharif* and *rabi* seasons of 2022-23 and 2023-24.

The experiment was laid out in split plot design consisting of four main plots (cropping geometry) *i.e.*, G₁: Paired row planting (60-240 cm x 45 cm) + finger millet intercropping, G₂: Paired row planting (45-240 cm x 30 cm) + finger millet intercropping, G₃: Skipped row planting (120 cm x 60 cm) + finger millet intercropping and G₄: Skipped row planting (90 cm x 60 cm) + finger millet intercropping and four subplots (relay intercropping) *i.e.*, I₁: Fieldbean, I₂: Horse gram, I₃: Cowpea and I₄: Sorghum, with 16 interaction treatments and also considered sole cropping of all crops *i.e.*, C₁: Sole castor (90 cm x 60 cm), C₂: Sole castor (120 cm x 60 cm), C₃: Sole finger millet, C₄: Sole fieldbean, C₅: Sole horse gram, C₆: Sole cowpea and C₇: Sole sorghum to workout intercropping system advantages. Although, G₄ treatment is the recommended package of practice for castor by UAS, Bangalore. The castor hybrid (ICH 66) was sown with above mentioned spacings of individual cropping geometry treatments with seed rate of (5 kg ha⁻¹) at depth of 4-5 cm and simultaneously finger millet variety (GPU-66) was sown in between the rows of castor as intercrop at spacing of 30 cm x 10 cm with seed rate of 5 kg ha⁻¹. after the harvest

of finger millet the four relay intercrops (Fieldbean: Hebbal avare-4; Horsegram: CRIDA-18R; Cowpea: C-152 and Sorghum: Nirmal NSRR-259) were sown with slight tillage operations as relay intercrops. Nutrients were applied as per the recommended dosages for each crop in the form of urea, single super phosphate and murate of potash to supply nitrogen, phosphorus and potassium, respectively based on the plant population of individual treatments. The 50 per cent of nitrogen and total amount of phosphorus and potassium were applied at sowing time and remaining 50 per cent of nitrogen was applied as top dressing at 30 and 60 DAS in two equal splits (RDF used for castor: 45:45:25, finger millet: 50:40:25, fieldbean: 25:50:25, horsegram: 25:50:25, cowpea: 25:50:25 and sorghum: 50:25:25 kg ha⁻¹ NPK). The intercultural operations like thinning, gap filling, weeding, pest and disease control were taken as and when required for crop management.

Biometric observations on growth and yield attributes were recorded from five plants of each net plot on randomly selected plants. Data related to yield was recorded at the time of harvest of the crop. The plant height was measured from base of plant to the primary spike initiation point and all primary, secondary and tertiary branches were counted as total number of branches per plant, whereas yield attributes were recorded from each individual plant like total number of spikes at each harvest, length of spike from base to tip and total number of capsules from each spike. The plants from the net plot were harvested and threshed separately and the grain and straw yield were recorded and expressed on hectare basis. The oil content in seeds was analyzed by using NMR (Nuclear Magnetic Resonance) spectrophotometer and oil content was expressed in per cent. For the assessment of castor equivalent yield (CEY), the yield of intercrop was converted into castor seed yield on the basis of prevailing market prices (Rs.ha⁻¹) with below formula.

$$\text{Castor equivalent yield} = \frac{Y_{ab} \times P_a}{P_a} + \frac{Y_{ba} \times P_b}{P_b}$$

Where, Y_{ab} and Y_{ba} = The yields of castor and intercrop, respectively in intercropping system

P_a and P_b = Market value of castor and intercrop yield, respectively

Benefit Cost ratio is the rate of return per rupee invested on each cropping system was worked out by using the formula.

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

The statistical analysis of the data generated for various parameters during the investigation was carried out following the procedure of split-plot design described by Panse and Sukhatme (1985). The variances of different sources of variation in ANOVA were tested by the 'F' test and compared with the value of table 'F' at a 5 per cent ($p = 0.05$) level of significance. The mean values of main plot, sub-plot and highest order interaction effects were separately subjected to Duncan's Multiple Range Test (DMRT) using the corresponding error mean sum of squares and degrees of freedom values under OPSTAT program.

RESULTS AND DISCUSSION

Plant Height of Castor

The plant height of castor (Table 1) was significantly influenced by different cropping geometries at later growth stages. At 30 days after sowing (DAS), there was no notable difference among geometries, with plant height ranging from 14.08 cm (G_1) to 14.72 cm (G_4). However, by 90 DAS, G_2 (68.92 cm) had the tallest plants, significantly higher than G_3 (63.57 cm) and G_4 (64.79 cm), while G_1 was comparable to G_2 . This trend continued at 150 DAS, where G_2 recorded the tallest plants (95.85 cm), followed by G_1 (94.04 cm), with G_3 and G_4 producing significantly shorter plants (90.28 cm and 91.19 cm, respectively). At harvest, G_2 again maintained superiority (99.17 cm), while G_1 followed closely (97.86 cm); G_3 and G_4 had significantly shorter plants (94.15 cm and 95.33 cm). These results

TABLE 1
Pooled plant height (cm) of castor under different cropping geometry and relay intercropping conditions

Treatments	30 DAS	90 DAS	150 DAS	At harvest
Main plot : Cropping geometry (G)				
G ₁	14.08 ^a	67.67 ^a	94.04 ^b	97.86 ^a
G ₂	14.26 ^a	68.92 ^a	95.85 ^a	99.17 ^a
G ₃	14.53 ^a	63.57 ^b	90.28 ^c	94.15 ^b
G ₄	14.72 ^a	64.79 ^b	91.19 ^c	95.33 ^b
S.Em±	0.32	0.73	0.72	1.1
Sub plot : Relay cropping (I)				
I ₁	14.78 ^a	66.71 ^a	92.69 ^a	96.84 ^a
I ₂	14.58 ^a	66.18 ^a	93.07 ^a	96.85 ^a
I ₃	14.01 ^a	65.88 ^a	93.01 ^a	96.95 ^a
I ₄	14.22 ^a	66.19 ^a	92.59 ^a	95.87 ^a
S.Em±	0.4	0.85	0.91	1.02
Interaction : (GxI)				
G ₁ fb I ₁	13.94 ^a	68.42 ^{a-c}	92.95 ^{b-d}	98.35 ^a
G ₁ fb I ₂	14.56 ^a	67.65 ^{a-d}	94.08 ^{ab}	98.72 ^a
G ₁ fb I ₃	14.11 ^a	67.14 ^{b-d}	95.29 ^{ab}	98.60 ^a
G ₁ fb I ₄	13.72 ^a	67.48 ^{a-d}	93.84 ^{a-c}	95.76 ^{bc}
G ₂ fb I ₁	14.28 ^a	69.06 ^{ab}	96.07 ^a	99.56 ^a
G ₂ fb I ₂	15.39 ^a	69.18 ^{ab}	96.20 ^a	98.82 ^a
G ₂ fb I ₃	12.83 ^a	67.90 ^{a-d}	95.81 ^a	99.36 ^a
G ₂ fb I ₄	14.56 ^a	69.56 ^a	95.31 ^{ab}	98.96 ^a
G ₃ fb I ₁	15.61 ^a	63.66 ^{fg}	90.06 ^e	93.94 ^c
G ₃ fb I ₂	13.22 ^a	63.51 ^{fg}	90.72 ^{de}	94.06 ^c
G ₃ fb I ₃	15.44 ^a	63.97 ^{fg}	90.35 ^e	94.25 ^c
G ₃ fb I ₄	13.83 ^a	63.13 ^g	90.00 ^e	94.35 ^{bc}
G ₄ fb I ₁	15.28 ^a	65.69 ^{d-f}	91.67 ^{c-e}	95.50 ^{bc}
G ₄ fb I ₂	15.17 ^a	64.38 ^{e-g}	91.30 ^{de}	95.81 ^{bc}
G ₄ fb I ₃	13.67 ^a	64.50 ^{e-g}	90.58 ^{de}	95.59 ^{bc}
G ₄ fb I ₄	14.78 ^a	64.61 ^{e-g}	91.20 ^{de}	94.41 ^{bc}
S.Em±	0.8	1.7	1.82	2.04
Control plots : (C)				
C ₁	15.49 ^a	67.58 ^{a-d}	94.94 ^{ab}	97.00 ^{ab}
C ₂	13.98 ^a	66.50 ^{c-e}	92.90 ^{b-d}	93.47 ^c
S.Em±	0.75	1.56	1.71	1.98

Note : Main plot : G₁ : Paired row planting (60-240 cm x 45 cm) + finger millet; G₂ : Paired row planting (45-240 cm x 30 cm) + finger millet; G₃ : Skipped row planting (120 cm x 60 cm) + finger millet; G₄ : Skipped row planting (90 cm x 60 cm) + finger millet

Sub plot : I₁ : Fieldbean, I₂ : Horsegram, I₃ : Cowpea and I₄ : Sorghum; Control plot : C₁ : Sole castor (90 cm x 60 cm) and C₂ : Sole castor (120 cm x 60 cm)

indicate that G_2 (closer spacing with higher population) was most conducive to increased plant height throughout castor plant development.

Relay cropping treatments did not affect significantly on castor plant height at any stage, though slight numerical differences were observed. At 30 DAS, all treatments ranged from 14.01 cm (I_3) to 14.78 cm (I_1). At 90 DAS and 150 DAS, heights remained relatively uniform across all relay cropping systems, fluctuating narrowly between 65.88-66.71 cm and 92.59-93.07 cm, respectively. At harvest, I_3 recorded the tallest plants (96.95 cm), closely followed by I_1 and I_2 (96.84 and 96.85 cm, respectively), whereas I_4 had slightly shorter plants (95.87 cm). Overall, the plant height response to relay cropping was statistically non-significant, suggesting all relay crops had a comparable effect on castor growth.

The interaction between cropping geometry and relay cropping systems had significant effect at later stages crop, particularly on plant height at 90 DAS, 150 DAS and harvest. At 90 DAS, G_2 in combination with any intercropping system (especially G_2 fb I_4 at 69.56 cm and G_2 fb I_2 at 69.18 cm) showed superior height. At 150 DAS, G_2 fb I_2 (96.20 cm) and G_2 fb I_1 (96.07 cm) produced the tallest plants. G_3 based combinations consistently yielded shorter plants across stages, notably G_3 fb I_4 with 90.00 cm at 150 DAS and 94.35 cm at harvest. The tallest plant heights at harvest were observed in G_2 fb I_1 (99.56 cm) and G_2 fb I_3 (99.36 cm). These results reinforce that both geometry and intercropping systems jointly influence plant growth, with G_2 combinations being the most favorable.

Sole cropping treatments (C_1 and C_2) showed moderate plant heights compared to intercropping treatments. At 30 DAS, C_1 (15.49 cm) was slightly taller than C_2 (13.98 cm). At 90 DAS and 150 DAS, C_1 maintained its edge with heights of 67.58 cm and 94.94 cm, respectively, as compared to C_2 (66.50 cm and 92.90 cm). At harvest, C_1 also recorded taller plants (97.00 cm) than C_2 (93.47 cm). Though both control treatments performed well, C_1 consistently supported slightly greater plant height throughout

the growth stages. This suggests that sole cropping under C_1 was more favorable than C_2 , though still comparable to certain intercropping systems.

This higher plant height at paired row planting and lower plant height at skipped row planting was recorded due to the fact that closely spaced row has competition for sunlight and vice versa. Height increase was mainly due to increased inter nodal length, overcrowding of the plant population. It is common in the field trials of arable crops that taller plants would usually be associated with narrow spacing in both inter and intra rows. Increased plant height under narrow inter and intra row spacings might be due to higher competition for space and light with rapid meristematic activity and increase in size of cell which ultimately increases the plant height. Earlier findings of Aruna and Sagar (2016), Dodiya *et al.* (2016), Parmar *et al.* (2018) and Gangadhar *et al.* (2022) are in conformity with the results of the current investigation. Plant height was increased in intercropping system compared to sole planting of castor. Competition usually occurs when two crop plants compete for light, water and nutrient from the same limited pool or supply of these requirement to at least one of the plants is reduced by the presence of other, hence have a negative interaction between different population. These results are in close agreement with the results obtained by Vaghasia *et al.* (2016), Naik *et al.* (2020) and Veeramani *et al.*, (2024).

Number of Branches Per Plant of Castor

The number of branches per plant of castor (Table 2) varied significantly among different cropping geometries at all growth stages. At 90 days after sowing (DAS), G_1 recorded the highest number of branches (3.09), followed closely by G_4 (2.72), while G_3 had the lowest (1.48). This trend continued at 150 DAS, where G_1 again led (5.81), significantly higher than G_3 (3.52), with G_2 and G_4 showing intermediate values. At harvest, G_1 maintained the highest number of branches (7.15), followed by G_4 (6.15), while G_3 remained the lowest (5.05). The data suggest that G_1 consistently supports better vegetative growth in terms of branching, likely due to more favorable plant spacing and orientation.

TABLE 2
Effect on pooled number of branches of castor under different cropping geometry and relay intercropping system

Treatments	90 DAS	150 DAS	At harvest
Main plot: Cropping geometry (G)			
G ₁	3.09 ^a	5.81 ^a	7.15 ^a
G ₂	2.50 ^a	4.38 ^{bc}	5.83 ^b
G ₃	1.48 ^b	3.52 ^c	5.05 ^b
G ₄	2.72 ^a	4.71 ^b	6.15 ^{ab}
S.Em±	0.19	0.29	0.38
Sub plot: Relay cropping (I)			
I ₁	2.48 ^a	4.65 ^a	6.18 ^a
I ₂	2.49 ^a	4.47 ^a	6.09 ^a
I ₃	2.43 ^a	4.57 ^a	6.02 ^a
I ₄	2.39 ^a	4.73 ^a	5.90 ^a
S.Em±	0.17	0.48	0.33
Interaction: (GxI)			
G ₁ fb I ₁	3.09 ^{bc}	5.57 ^{cd}	6.75 ^{b-d}
G ₁ fb I ₂	3.25 ^{bc}	5.29 ^{c-e}	7.47 ^b
G ₁ fb I ₃	2.92 ^{bc}	6.24 ^{bc}	7.20 ^{bc}
G ₁ fb I ₄	3.09 ^{bc}	6.13 ^{bc}	7.17 ^{bc}
G ₂ fb I ₁	2.48 ^{c-f}	4.63 ^{c-f}	6.40 ^{b-e}
G ₂ fb I ₂	2.57 ^{c-e}	4.26 ^{d-f}	5.75 ^{c-e}
G ₂ fb I ₃	2.51 ^{c-f}	4.27 ^{d-f}	5.36 ^{de}
G ₂ fb I ₄	2.46 ^{c-g}	4.35 ^{d-f}	5.81 ^{c-e}
G ₃ fb I ₁	1.55 ^{e-g}	3.35 ^f	5.20 ^{de}
G ₃ fb I ₂	1.46 ^{fg}	3.84 ^{d-f}	4.95 ^e
G ₃ fb I ₃	1.59 ^{d-g}	3.41 ^f	5.00 ^e
G ₃ fb I ₄	1.30 ^g	3.50 ^{ef}	5.08 ^e
G ₄ fb I ₁	2.78 ^{bc}	5.03 ^{c-f}	6.35 ^{b-e}
G ₄ fb I ₂	2.68 ^{b-d}	4.50 ^{c-f}	6.17 ^{b-e}
G ₄ fb I ₃	2.71 ^{bc}	4.35 ^{d-f}	6.51 ^{b-e}
G ₄ fb I ₄	2.71 ^{bc}	4.96 ^{c-f}	5.55 ^{de}
S.Em±	0.35	0.97	0.66
Control plots: (C)			
C ₁	3.75 ^{ab}	7.29 ^{ab}	8.91 ^a
C ₂	4.59 ^a	8.63 ^a	9.60 ^a
S.Em±	0.34	0.85	0.64

Note : Main plot: G₁: Paired row planting (60-240 cm x 45 cm) + finger millet; G₂: Paired row planting (45-240 cm x 30 cm) + finger millet; G₃: Skipped row planting (120 cm x 60 cm) + finger millet; G₄: Skipped row planting (90 cm x 60 cm) + finger millet; Sub plot: I₁: Fieldbean, I₂: Horsegram, I₃: Cowpea and I₄: Sorghum; Control plot: C₁: Sole castor (90 cm x 60 cm) and C₂: Sole castor (120 cm x 60 cm)

The number of branches was not significantly influenced by the type of relay crop intercropped with castor. All intercropping systems (I₁ to I₄) showed statistically similar number of branches at all stages of growth. At 90 DAS, branch numbers ranged from 2.39 to 2.49, at 150 DAS from 4.47 to 4.73, and at harvest from 5.90 to 6.18. Although I₁ showed a marginally higher branch number at harvest, the differences were not significant. These results suggest that the choice of relay crop had a minimal impact on the branching pattern of castor.

The interaction between cropping geometry and relay cropping had a noticeable influence on branch development. At 90 DAS, combinations like G₁ fb I₂ (3.25) and G₁ fb I₁ (3.09) showed higher branch numbers, while G₃ fb I₄ (1.30) and G₃ fb I₂ (1.46) showed the lowest. At 150 DAS, G₁ fb I₃ (6.24) and G₁ fb I₄ (6.13) performed better compared to other treatments, while combinations involving G₃ generally lagged behind. At harvest, G₁ fb I₂ (7.47) recorded the highest number of branches among intercropped treatments, followed by G₁ fb I₃ (7.20) and G₁ fb I₄ (7.17). Conversely, G₃-based combinations consistently had lower values, confirming the limiting effect of that geometry regardless of intercropping type. This indicates that favorable geometries like G₁ can partially offset the competitive effects of intercropping on castor's vegetative growth.

Sole cropping treatments (C₁ and C₂) showed a distinct advantage over intercropped treatments in terms of the number of branches. At all three stages (90 DAS, 150 DAS and harvest) C₂ consistently recorded the highest number of branches (4.59, 8.63 and 9.60, respectively), followed by C₁ (3.75, 7.29 and 8.91, respectively). These results clearly demonstrate that the absence of competition from intercrops in sole cropping systems allows castor plants to produce more branches, reflecting better vegetative vigor and potentially higher yield potential.

Wider planting geometry (Paired row planting: 60-240 cm x 45 cm) provided more space around each plant resulting in more metabolic activities

through better utilization of light, space, water and nutrients which might have resulted in better vegetative growth. Optimum plant population along with paired row planting increases the number of branches per plant due to more availability of space for each plant with less competition among the plants for resources. Similar pattern of positive growth response to wider spacing was also observed by Thanki *et al.* (2020), Aruna & Chandrika *et al.* (2023) and Porwal *et al.* (2006). Castor intercropping treatments recorded remarkably lower number of branches per plant as compared to respective sole castor treatments. This might be due to competition among plants for resources *viz.*, light, space, water and nutrients, hence the number of branches per plant were decreased in intercropping system. This suggests the compatibility of growing castor crop with particular intercropping system playing crucial role in production of branches per plant. The present findings are in conformity with the results of Bhadu *et al.* (2020) and Ikeh *et al.* (2024).

Yield Attributes of Castor

The results indicate that cropping geometry significantly influenced the yield attributes of castor (Table 3). Among the different geometries, G₁ recorded superior performance (6.32 spikes plant⁻¹, 50.08 cm spike length and 47.47 capsules spike⁻¹) and followed by G₄ (5.89 spikes plant⁻¹, 48.68 cm spike length and 46.23 capsules spike⁻¹) compared to G₂ and G₃. G₂ showed moderate values, while G₃ recorded the lowest across all attributes, with only 4.53 spikes plant⁻¹, 44.28 cm spike length and 41.89 capsules spike⁻¹. These results suggest that G₁ and G₄ geometries are more favorable for enhancing castor yield attributes, likely due to better plant spacing and resource utilization.

The influence of different relay cropping systems (I₁ to I₄) on castor yield attributes was minimal, with no significant differences among treatments. The number of spikes per plant ranged narrowly between 5.37 (I₄) to 5.57 (I₂), while spike length varied slightly between 47.27 cm (I₃) to 47.46 cm (I₄). The number of capsules per spike also remained close, ranging

TABLE 3
Effect of different cropping geometry and relay intercropping systems on castor pooled yield attributes

Treatments	No. of spikes plant ⁻¹	Length of spike (cm)	No. of capsules spike ⁻¹
Main plot: Cropping geometry (G)			
G ₁	6.32 ^a	50.08 ^a	47.47 ^a
G ₂	5.20 ^{ab}	46.38 ^b	45.30 ^a
G ₃	4.53 ^b	44.28 ^b	41.89 ^b
G ₄	5.89 ^a	48.68 ^a	46.23 ^a
S.Em±	0.41	1.24	1.23
Sub plot: Relay cropping (I)			
I ₁	5.44 ^a	47.32 ^a	45.23 ^a
I ₂	5.57 ^a	47.37 ^a	44.89 ^a
I ₃	5.55 ^a	47.27 ^a	45.34 ^a
I ₄	5.37 ^a	47.46 ^a	45.42 ^a
S.Em±	0.37	1.12	1.35
Interaction: (GxI)			
G ₁ fb I ₁	5.92 ^{bc}	50.31 ^{bc}	47.71 ^b
G ₁ fb I ₂	6.14 ^{bc}	49.98 ^{bc}	47.50 ^b
G ₁ fb I ₃	6.42 ^b	49.43 ^c	46.57 ^{bc}
G ₁ fb I ₄	6.40 ^b	50.22 ^{bc}	47.84 ^b
G ₂ fb I ₁	5.26 ^{b-e}	45.63 ^{ef}	45.01 ^c
G ₂ fb I ₂	5.11 ^{b-e}	45.70 ^{ef}	45.09 ^c
G ₂ fb I ₃	5.28 ^{b-e}	46.96 ^{de}	45.77 ^{bc}
G ₂ fb I ₄	4.95 ^{c-e}	46.99 ^{de}	44.86 ^c
G ₃ fb I ₁	4.46 ^{de}	44.08 ^f	40.60 ^d
G ₃ fb I ₂	4.46 ^{de}	44.26 ^f	41.82 ^d
G ₃ fb I ₃	4.51 ^{de}	44.01 ^f	41.99 ^d
G ₃ fb I ₄	4.40 ^e	44.10 ^f	41.83 ^d
G ₄ fb I ₁	5.79 ^{b-e}	48.89 ^{cd}	46.17 ^{bc}
G ₄ fb I ₂	6.13 ^{bc}	48.72 ^{cd}	44.79 ^c
G ₄ fb I ₃	5.80 ^{b-d}	48.43 ^{cd}	46.88 ^{bc}
G ₄ fb I ₄	5.32 ^{b-e}	48.43 ^{cd}	46.90 ^{bc}
S.Em±	0.75	2.25	2.7
Control plots: (C)			
C ₁	8.71 ^a	51.66 ^b	50.48 ^a
C ₂	9.54 ^a	54.95 ^a	52.07 ^a
S.Em±	0.74	2.17	2.53

Note : Main plot: G₁: Paired row planting (60-240 cm x 45 cm) + fingermillet; G₂: Paired row planting (45-240 cm x 30 cm) + fingermillet; G₃: Skipped row planting (120 cm x 60 cm) + fingermillet; G₄: Skipped row planting (90 cm x 60 cm) + fingermillet; Sub plot: I₁: Fieldbean, I₂: Horsegram, I₃: Cowpea and I₄: Sorghum; Control plot: C₁: Sole castor (90 cm x 60 cm) and C₂: Sole castor (120 cm x 60 cm)

from 44.89 (I_2) to 45.42 (I_4). These findings indicate that the choice of relay crop had limited effect on the yield attributes of castor, maintaining consistency across all intercropping systems.

The interaction between cropping geometry and relay cropping showed varying effects on castor yield attributes. The G_1 combinations generally performed better across all parameters, particularly G_1 fb I_4 (6.40 spikes plant⁻¹, 50.22 cm spike length and 47.84 capsules spike⁻¹) and G_1 fb I_1 (5.92 spikes plant⁻¹, 50.31 cm and 47.71 capsules). Conversely, the G_3 interactions recorded the lowest values, especially G_3 fb I_4 with only 4.40 spikes plant⁻¹, 44.10 cm spike length and 41.83 capsules spike⁻¹. These interaction results suggest that the positive effects of favorable crop geometry like G_1 or G_4 can be partially retained under intercropping, whereas less optimal geometries (like G_3) suppress yield traits irrespective of the intercropping system.

Sole cropping treatments (C_1 and C_2) outperformed all intercropping combinations in terms of yield attributes. C_2 recorded the highest values with 9.54 spikes plant⁻¹, 54.95 cm spike length and 52.07 capsules spike⁻¹, followed closely by C_1 (8.71 spikes plant⁻¹, 51.66 cm and 50.48 capsules). This highlights that while intercropping and crop geometry modifications can sustain good yield attributes, sole cropping under optimal conditions remains the most effective approach for maximizing castor yield traits.

Castor sown in paired row planting (60-240 cm x 45 cm) produced significantly higher number of spikes per plant, main spike length, number of capsules per plant and seed yield per plant as compared to other planting geometry system (Table 3). The increase in yield attributes might be due to wider spacing at paired row planting facilitating better space, moisture, light and nutrition to individual plant which enhanced crop growth and development with more food storage which increased translocation of stored food for sink development. Similar results were also reported by Srilatha *et al.* (2002) and Gangadhar *et al.* (2023). More number of spikes per plant, main spike length, number of capsules per plant and seed

yield per plant obtained in sole castor than intercropping system might be due to more dry matter accumulation, maximum leaf area and more chlorophyll content which might have produced more photosynthates to the sink (spike). The increase in dry matter accumulation, better source-sink relationship might have contributed to more number of capsules per spike. More availability of resources and poor competition might have also increased the spike number, spike length and seed yield per plant. While in intercropping treatments due to competition on castor plants, the yield attributes were significantly reduced. These results are in close agreement with Mudalagiriappa *et al.* (2011), Sangeetha *et al.*, (2023) and Kumar *et al.* (2024).

Yield of Castor

The different crop geometries (G_1 to G_4) had a significant influence on seed yield, stalk yield and biological yield of castor (Table 4). The highest seed yield (1442 kg ha⁻¹), stalk yield (2628 kg ha⁻¹) and biological yield (4071 kg ha⁻¹) were recorded under the G_1 geometry, followed closely by G_2 (1381, 2517 and 3899 kg ha⁻¹, respectively). The lowest values were observed in G_3 , with seed yield of 1241 kg ha⁻¹, stalk yield of 2204 kg ha⁻¹ and biological yield of 3445 kg ha⁻¹. G_4 showed intermediate results. Despite significant differences in yield components, the harvest index remained statistically similar across geometries, ranging from 0.35 to 0.36, indicating that biomass partitioning towards seed production was stable irrespective of planting pattern.

The effect of different relay intercropping systems (I_1 to I_4) on castor yield parameters and harvest index was not statistically significant. Seed yield across intercropping treatments varied slightly from 1331 to 1341 kg ha⁻¹, with corresponding stalk yields from 2405 to 2432 kg ha⁻¹ and biological yields ranging from 3736 to 3768 kg ha⁻¹. Harvest index remained uniform at 0.36 across all intercropping systems. These findings suggest that the choice of relay crop had negligible impact on the productivity and partitioning of castor biomass.

The interaction between crop geometry and relay intercropping systems showed significant variation in

TABLE 4
Influence of different cropping geometry and relay intercropping systems on pooled seed yield, stalk yield, biological yield (kg ha⁻¹) and harvest index of castor

Treatments	30 DAS	90 DAS	150 DAS	At harvest
Main plot: Cropping geometry (G)				
G ₁	1442 ^a	2628 ^a	4071 ^a	0.35 ^a
G ₂	1381 ^b	2517 ^b	3899 ^b	0.36 ^a
G ₃	1241 ^d	2204 ^d	3445 ^d	0.36 ^a
G ₄	1276 ^c	2307 ^c	3583 ^c	0.36 ^a
S.Em±	10	24	31	0.01
Sub plot: Relay cropping (I)				
I ₁	1333 ^a	2408 ^a	3742 ^a	0.36 ^a
I ₂	1337 ^a	2432 ^a	3768 ^a	0.36 ^a
I ₃	1331 ^a	2405 ^a	3736 ^a	0.36 ^a
I ₄	1341 ^a	2411 ^a	3752 ^a	0.36 ^a
S.Em±	25	76	100	0.01
Interaction: (GxI)				
G ₁ fb I ₁	1446 ^b	2636 ^c	4082 ^c	0.36 ^a
G ₁ fb I ₂	1445 ^b	2663 ^b	4109 ^b	0.35 ^a
G ₁ fb I ₃	1435 ^b	2615 ^{de}	4049 ^d	0.35 ^a
G ₁ fb I ₄	1443 ^b	2599 ^e	4043 ^d	0.36 ^a
G ₂ fb I ₁	1372 ^e	2484 ^h	3856 ^g	0.36 ^a
G ₂ fb I ₂	1391 ^d	2536 ^g	3927 ^f	0.36 ^a
G ₂ fb I ₃	1375 ^e	2485 ^h	3860 ^g	0.36 ^a
G ₂ fb I ₄	1388 ^d	2564 ^f	3952 ^e	0.35 ^a
G ₃ fb I ₁	1248 ^h	2248 ^l	3496 ^k	0.36 ^a
G ₃ fb I ₂	1237 ^h	2210 ^m	3447 ^l	0.36 ^a
G ₃ fb I ₃	1241 ^h	2163 ⁿ	3403 ^m	0.36 ^a
G ₃ fb I ₄	1240 ^h	2194 ^m	3433 ^l	0.36 ^a
G ₄ fb I ₁	1267 ^g	2265 ^l	3532 ^j	0.36 ^a
G ₄ fb I ₂	1273 ^g	2318 ^j	3591 ⁱ	0.36 ^a
G ₄ fb I ₃	1273 ^g	2357 ⁱ	3630 ^h	0.35 ^a
G ₄ fb I ₄	1292 ^f	2287 ^k	3579 ⁱ	0.36 ^a
S.Em±	51	152	201	0.006
Control plots: (C)				
C ₁	1477 ^a	2777 ^a	4254 ^a	0.35 ^a
C ₂	1404 ^c	2632 ^{cd}	4035 ^d	0.35 ^a
S.Em±	43	130	171	0.006

Note : Main plot: G₁: Paired row planting (60-240 cm x 45 cm) + finger millet; G₂: Paired row planting (45-240 cm x 30 cm) + finger millet; G₃: Skipped row planting (120 cm x 60 cm) + finger millet; G₄: Skipped row planting (90 cm x 60 cm) + finger millet

Sub plot : I₁: Fieldbean, I₂: Horsegram, I₃: Cowpea and I₄: Sorghum; Control plot : C₁: Sole castor (90 cm x 60 cm) and C₂: Sole castor (120 cm x 60 cm)

yield attributes. The combination G_1 fb I_1 produced the highest seed yield (1446 kg ha^{-1}), while G_1 fb I_2 resulted in the highest biological yield (4109 kg ha^{-1}). In contrast, the G_3 fb I_3 interaction recorded the lowest seed yield (1241 kg ha^{-1}), stalk yield (2163 kg ha^{-1}) and biological yield (3403 kg ha^{-1}). Though the yield components were significantly affected by interactions, the harvest index remained statistically at par (0.35 to 0.36) across all combinations. This indicates that while castor yield is varied by treatments, the efficiency of converting biomass into economic yield was largely unaffected.

Sole cropping (C_1 and C_2) resulted in the highest productivity compared to relay intercropping system. C_1 recorded the maximum seed yield (1477 kg ha^{-1}), stalk yield (2777 kg ha^{-1}) and biological yield (4254 kg ha^{-1}), followed by C_2 (1404 , 2632 and 4035 kg ha^{-1} , respectively). Despite the significant differences in yield, the harvest index remained identical at 0.35 for both control treatments. These results indicate that sole cropping of castor leads to higher overall productivity compared to intercropping systems, although biomass allocation to seed production remains constant.

Castor grown under paired row planting (60-240 cm x 45 cm) has recorded significantly higher seed, stalk and biological yield (Table 4) compared to other planting geometries. This might be due to reflection of high yield attributing characters usually achieved well under optimum availability of space, light, nutrients and moisture, where competition within the crop plants was minimum. Closer plant geometry might have increased competition within the crop plant which resulted in poor growth *i.e.* dry matter accumulation per plant that decreased the seed, stalk and biological yield. Current results are strongly supported by the earlier findings of the scientists Gangadhar *et al.* (2022) and Aruna and Chandrika *et al.* (2023). Maximum seed, stalk and biological yield was observed with sole castor compared to castor based intercropping system, may be due to production of more dry matter, length of spike, number of capsules spike⁻¹, weight of spike and effective translocation of photosynthates from

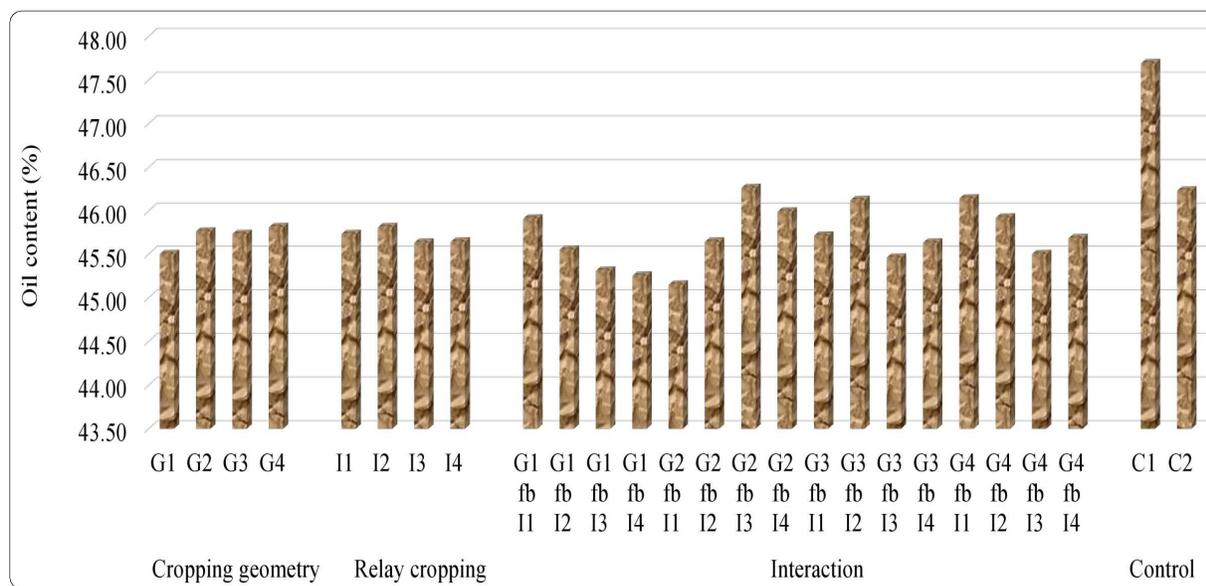
source to sink resulting in maximum yield. Additionally, it may also be due to less competition for various nutrients and moisture in sole cropping than intercropping. In intercropping, paired row planting of castor with legume crops has recorded maximum castor seed, stalk and biological yield which might be due to high nitrogen fixing capacity, heavy leaf fall which increased nutrient availability, maximum ground coverage with leaves which reduced evaporation losses and which might have increased more moisture availability, all these factors might have contributed to maximum growth of castor which in turn resulted in increased yield. These results corroborate with the findings of Vaghasia *et al.* (2016) and Veeramani *et al.* (2024).

Oil Content of Castor

The oil content of castor (Fig. 1) was not significantly influenced by the different cropping geometries. Among the four geometrical configurations, the oil content ranged narrowly from 45.50 to 45.81 per cent. G_1 recorded the lowest oil content (45.50%), while G_4 showed the highest (45.81%). However, the differences among the treatments were statistically non-significant, hence these findings suggest that modifying plant geometry alone has a minimal effect on oil accumulation in castor seeds.

The various relay intercropping systems also had a negligible impact on castor oil content. The oil content values were consistent across all intercropping treatments, with I_2 having the highest oil content (45.81%) and I_3 the lowest (45.63%). All treatments oil content has a narrow band (45.63 to 45.81%) and suggested no statistically significant difference. This indicates that the choice of relay crop does not substantially affect the oil synthesis capacity of castor.

Interactions between cropping geometry and relay cropping systems showed more variation, but no significant effects were observed. Oil content ranged from 45.15 per cent (G_2 fb I_1) to 46.26 per cent (G_2 fb I_3). While certain combinations like G_2 fb I_3 and G_4 fb I_1 showed relatively higher oil content (above 46.00%), others like G_1 fb I_4 and G_1 fb I_3 recorded lower values (below 45.50%). Despite



Note : G₁: Paired row planting (60-240 cm x 45 cm) + finger millet, G₂: Paired row planting (45-240 cm x 30 cm) + finger millet, G₃: Skipped row planting (120 cm x 60 cm) + finger millet, G₄: Skipped row planting (90 cm x 60 cm) + finger millet, I₁: Fieldbean, I₂: Horsegram, I₃: Cowpea and I₄: Sorghum C₁: Sole castor (90 cm x 60 cm) and C₂: Sole castor (120 cm x 60 cm)

Fig. 1 : Effect of cropping geometry and relay intercropping on pooled oil content of castor

these fluctuations, the high standard error (S.Em \pm 1.56) implies that these differences were statistically non-significant. Thus, interaction effects between geometry and intercropping were not decisive in influencing oil content in castor.

Sole cropping exhibited the highest oil content among all treatments. Control plots C₁ and C₂ recorded 47.69 and 46.23 per cent oil content, respectively, outperforming all intercropped and geometry treatments. This suggests that sole cropping allows castor to express its full oil yielding potential, likely due to the absence of interspecies competition. Though the variation within the controls was slightly higher (S.Em \pm 1.65), the marked increase in oil content compared to intercropped treatments was statistically non-significant.

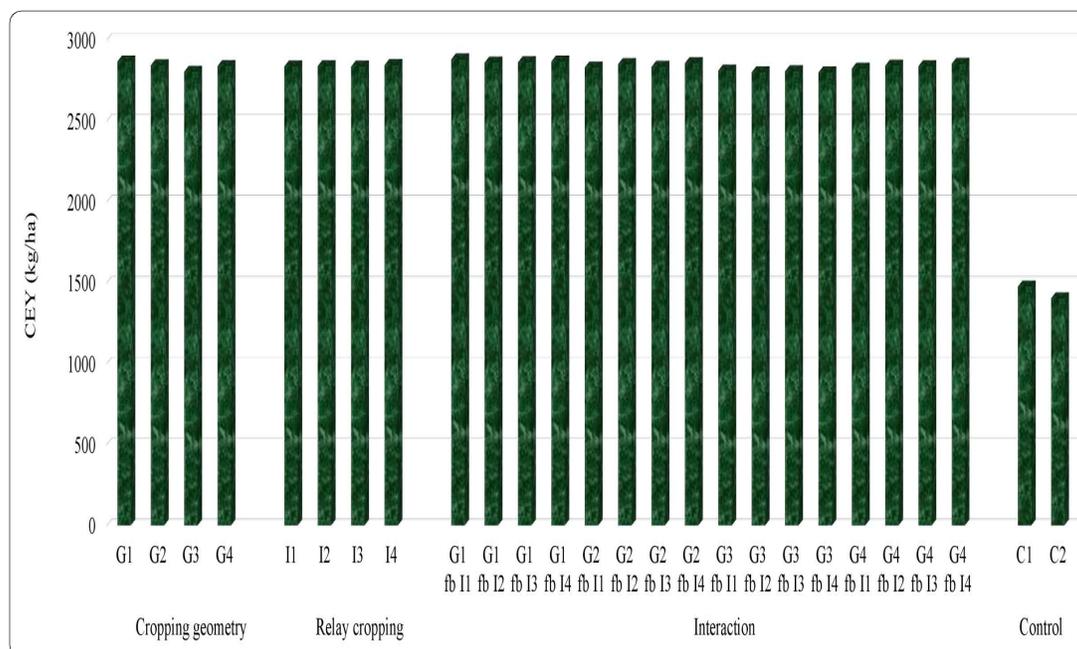
The data revealed that different intercropping systems and row spacing of castor have no significant influence on oil content of castor. Oil content of castor is a genetic factor, which might not have influence by production practices of the crops. These findings are in accordance with the findings of

Yadav *et al.* (2018). Similar result was also observed by Kumavat *et al.* (2016). Gangadhar *et al.* (2023) reported that among different intercropping systems and row spacing of castor have no significant influence on oil content of castor.

Castor Equivalent Yield

The effect of different cropping geometries on castor equivalent yield (Fig. 2) revealed statistically significant differences among the treatments. The highest equivalent yield was recorded under G₁ (2868 kg ha⁻¹), followed by G₂ (2844 kg ha⁻¹) and G₄ (2840 kg ha⁻¹), while G₃ produced the lowest yield (2805 kg ha⁻¹). The differences were statistically significant, as indicated by the distinct letter groupings. This suggests that the crop geometry under G₁ was more favorable for maximizing castor equivalent yield compared to the other crop geometries, with G₃ being the least productive.

The castor equivalent yield under different relay cropping systems (I₁, I₂, I₃ and I₄) showed no significant differences among treatments. Yields



Note : G₁: Paired row planting (60-240 cm x 45 cm) + finger millet, G₂: Paired row planting (45-240 cm x 30 cm) + finger millet, G₃: Skipped row planting (120 cm x 60 cm) + finger millet, G₄: Skipped row planting (90 cm x 60 cm) + finger millet, I₁: Fieldbean, I₂: Horsegram, I₃: Cowpea and I₄: Sorghum, C₁: Sole castor (90 cm x 60 cm) and C₂: Sole castor (120 cm x 60 cm)

Fig. 2 : Effect of crop geometry and relay intercropping on pooled castor equivalent yield of a system

ranged narrowly from 2836 to 2845 kg ha⁻¹, with I₄ recording the highest yield (2845 kg ha⁻¹) and I₃ the lowest (2836 kg ha⁻¹). The statistical grouping showed all relay crop treatments as similar, suggesting that the choice of relay crop had a negligible effect on castor equivalent yield when averaged across geometries.

The interaction between crop geometry and relay intercropping showed notable variability in castor equivalent yield. The highest yield (2881 kg ha⁻¹) was observed in the G₁ fb I₁ combination, followed closely by G₁ fb I₄ (2868 kg ha⁻¹) and G₁ fb I₃ (2863 kg ha⁻¹). In contrast, the lowest yields were observed under G₃ fb I₂ (2801 kg ha⁻¹), G₃ fb I₄ (2800 kg ha⁻¹) and G₃ fb I₁ (2812 kg ha⁻¹), indicating that the geometry G₃ consistently underperformed across relay crop combinations. This interaction indicates that optimal combinations of geometry and relay cropping (particularly G₁ with I₁ or I₄) can enhance productivity, while suboptimal combinations (e.g., G₃ with any relay crop) can significantly limit yield.

Sole cropping treatments (C₁ and C₂) yielded significantly lower castor equivalent yields compared to all intercropped treatments. C₁ recorded 1477 kg ha⁻¹ and C₂ only 1404 kg ha⁻¹, which were markedly lower than the yields observed under any intercropping geometry or relay cropping combination. The significant differences highlight the benefit of intercropping systems over sole cropping in terms of castor equivalent yield, underscoring the agronomic and economic advantage of adopting intercropping strategies.

The castor equivalent yield is a quantitative measure for evaluating the economic performance of intercropping systems. It is especially useful when the primary focus is on mixed or intercropping system and the aim is to quantify the combined output of both crops in terms of castor yield equivalents. Castor equivalent yield was significantly higher in paired row planting (60-240 cm x 45 cm) with finger millet intercropping followed by fieldbean relay intercropping system over sole castor and other intercropping systems which was due to higher

biomass production and efficient use of available resources under paired row planting system and also high price along with higher yield of intercrops as well as less reduction of castor seed yield in this intercropping system. Similar, results of higher CEY were also reported in castor intercropping systems under rainfed condition (Ramachandrappa *et al.*, 2016, Thanunathan *et al.*, 2008 and Mavarkar *et al.*, 2007). Vaghela *et al.* (2019) reported similar results that castor intercropped with mungbean recorded higher castor equivalent yield. Veeramani *et al.* (2024) revealed that castor equivalent yield was significantly greater in castor + groundnut (1:3) than in sole castor system.

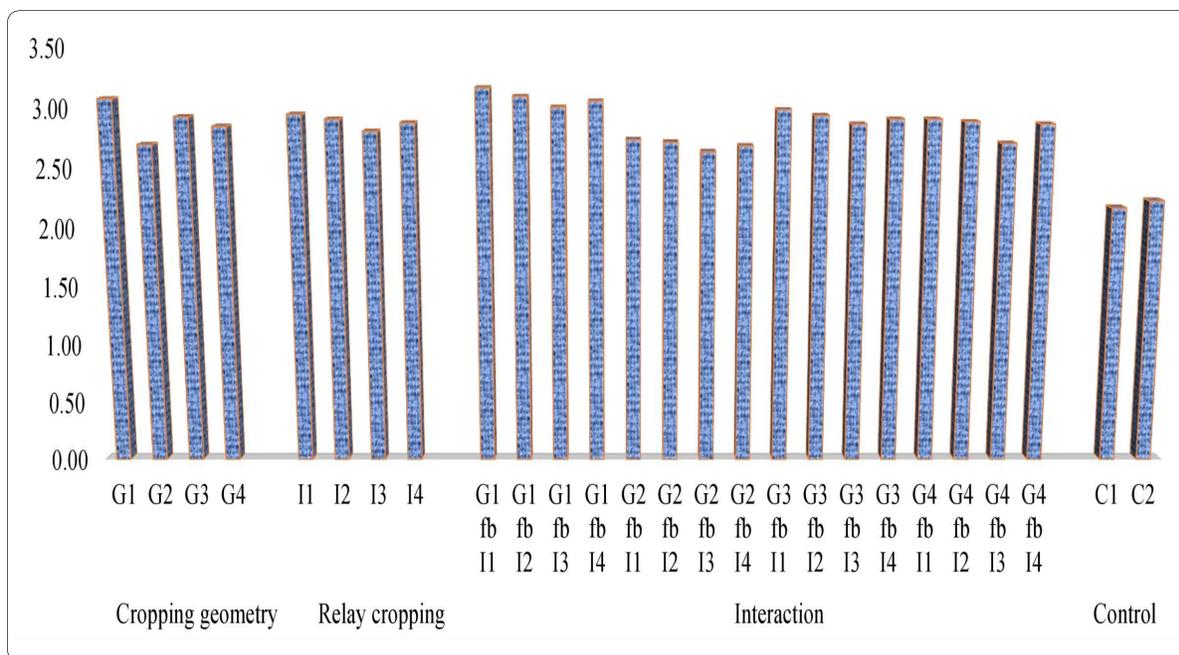
Benefit Cost Ratio of System

The benefit-cost (B:C) ratio of the cropping system was marginally influenced by different crop geometries represented in Fig. 3. Among the treatments, G₁ recorded the highest B:C ratio of 3.08, followed by G₃ (2.93), G₄ (2.85) and G₂ (2.70). Although these values suggest a slight advantage

for G₁ in terms of economic return, the statistical analysis indicates that the differences among geometries were not statistically significant. Therefore, all crop geometry treatments performed comparably in terms of profitability.

Relay cropping systems also showed minimal variation in their effect on the B:C ratio. The highest B:C ratio was observed in I₁ (2.95), followed closely by I₂ (2.91), I₄ (2.88) and I₃ (2.81). The small numerical differences among treatments and a standard error of 0.05 suggest that none of the intercropping systems significantly outperformed the others in economic terms, although I₁ showed a slight numerical edge.

The interaction between crop geometry and relay intercropping showed more visible differences. The highest B:C ratio was achieved in the G₁ fb I₁ combination (3.17), followed by G₁ fb I₂ (3.10) and G₁ fb I₄ (3.06), indicating that G₁ performed better with all intercropping systems. In contrast, combinations involving G₂ consistently recorded



Note : G₁: Paired row planting (60-240 cm x 45 cm) + finger millet, G₂: Paired row planting (45-240 cm x 30 cm) + finger millet, G₃: Skipped row planting (120 cm x 60 cm) + finger millet, G₄: Skipped row planting (90 cm x 60 cm) + finger millet, I₁: Fieldbean, I₂: Horsegram, I₃: Cowpea and I₄: Sorghum, C₁: Sole castor (90 cm x 60 cm) and C₂: Sole castor (120 cm x 60 cm)

Fig. 3 : Effect of different cropping geometry and relay intercropping systems on pooled benefit cost ratio of system

lower B:C ratios, ranging from 2.64 to 2.74. Although some of the lower values (particularly with G₂ and G₄) approached significance, the overall interaction effects remained statistically nonsignificant, highlighting that G₁ generally performed better across all intercropping types but not to a statistically significant level.

The control plots (sole cropping) showed significantly lower B:C ratios compared to intercropped treatments. C₁ and C₂ recorded values of 2.17 and 2.23, respectively, both significantly inferior to all other interaction treatments. These results indicate that relay intercropping systems under any geometry were more economically beneficial than sole cropping, confirming the advantage of intercropping in improving profitability in castor-based cropping systems.

The benefit cost ratio is a financial metric used to evaluate the feasibility and profitability of agricultural crop production. The BCR compares the benefits (gross returns) generated by a crop production to its costs, helping farmers, investors and policymakers make informed decisions. Sole cropping produced significantly lower B:C ratio compared to castor relay intercropping system. Among different intercropping system, paired row planting (60-240 cm x 45 cm) of castor with finger millet intercropping followed by field bean relay intercropping system (3.17) found significantly higher B:C ratio over sole and other intercropping systems. This was found more efficient in terms of gross and net returns, which also incurred lower cost of cultivation as compared to other intercropping and sole cropping system resulting in higher benefit cost ratio. Similar results were also reported by Vaghela *et al.* (2019) that castor with summer mungbean intercropping system realized higher B:C ratio as compared to sole castor. Gangadhar *et al.* (2024) concluded that the castor (200 cm) with green gram (4 rows) intercropping system yielded the higher net profit and with benefit-cost ratio. Similar results of higher B:C was reported in castor with cluster bean intercropping system by Mudalagiriyappa *et al.*, (2011).

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