ACCEPTED ARTICLE

Castor (*Ricinus communis* L.) and Cucurbits relay intercropping system for enhancing resource conservation and productivity

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ABSTRACT

Sustainable improvements in agricultural production and productivity necessitate efficient resource utilization; relay intercropping can improve crop yield and land productivity while using fewer inputs. Thus, in a three year field trial, different cucurbit vegetable crops were tested to see if they were suitable for relay intercropping with castor (*Ricinus communis* L.). These treatments encompassed various intercropping strategies involving castor, each paired with a different cucurbits **such as** bitter gourd (*Momordica charantia*), ridge gourd (*Luffa acutangula*), snake gourd (*Trichsanthus cucumerina*), bottle gourd (*Legenaria siceraria*), coccinia (*Trichsanthus dioica*), and cucumber (*Cucumis sativus*). **The results showed that the castor** and cucumber relay intercropping systems produced the highest castor equivalent yield (1701 kg ha^{-1}), followed by castor and ridge gourd (1596 kg ha^{-1}). Among all the cucurbit intercropping systems, the castor + cucumber relay system had the highest productivity (4.66 kg/ha/day), profitability (4.07 $/ha/day), and relative economic efficiency (198.5%). The best moisture-use efficiency was achieved by castor and bitter gourd relay intercropping (6.58 kg/ha/mm), followed by castor and bottle gourd relay intercropping (6.35 kg/ha/mm). There was a higher net return for relay intercropping of castor and cucumber ($ 1483.9 ha^{-1}), followed by castor and ridge gourd ($ 1446.2 ha^{-1}). Sole castor produced 1312 kg ha^{-1}, despite its low monetary returns of $ 501.6 ha^{-1}. It has been found that relay intercropping between castor and ridge gourd (3.29), followed by castor and bitter gourd (3.29), produces the highest benefit-cost ratio. As a result, the relay intercropping system, which determines the competitive interaction and productivity of castor and cucurbits, can provide the greatest benefits.

Keywords: Oilseeds, Vegetables, Intercropping, Moisture.

INTRODUCTION

Mixed cropping, unlike monoculture, fosters biodiversity, soil health, and resilience to pests and climate change. It enhances ecological balance, reduces chemical inputs, and promotes sustainable agriculture. Through diverse crop combinations, it sustains

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ecosystems, supports farmers' livelihoods, and ensures food security in the face of environmental challenges. Castor (*Ricinus communis* L.), a significant oilseed crop renowned for its industrial applications worldwide, faces challenges such as poor soil fertility and unpredictable, erratic rainfall patterns, which elevate the risk of crop failure in traditional solitary farming approaches. To mitigate these risks, intercropping, defined as the simultaneous or sequential cultivation of multiple crop species on the same land area, emerges as a promising strategy to enhance resilience and reduce the vulnerability of crops. Intercropping uses multiple crops sown and harvested at the same time, while relay intercropping uses intercrops with different growth stages Raza *et al.,* 2019. Notably, relay intercropping, identified as a form of biological insurance against climatic uncertainties in regions with unusual weather conditions by Koli *et al.* (2004), presents an intriguing avenue for safeguarding crop yields. **Castor, adaptable as both a mixed or intercrop and a standalone crop, exhibits characteristics conducive to intercropping systems owing to its generous inter and intra row spacing (Vaghela et al, 2019). In rainfed and irrigated settings, castor finds application as a border crop or live fencing, enriching its versatility. However, the realm of cucurbit intercropping within the castor ecosystem remains relatively unexplored, with limited investigations in India comparing castor intercropping with cucurbit vegetable crops. Intercropping, while offering advantages, also introduces the challenge of resource competition among plants (Mohsin *et al,* 2018).** Raza *et al*., 2022 described that intercropping system can save 20-50 % of water and land, especially under the present scenario of limited resources and climate change. This higher and stable yield, particularly with reduced inputs, are mainly ascribed to resources complementarity (Raza *et al*., 2019), in which intercrop species utilize available resources more adequately due to different spatial (Raza *et al.*, 2021), temporal and phonological characteristic (Li *et al*., 2013).

Distinguishing itself from conventional intercropping methods, relay cropping systems entail the cultivation of two or more crops on the same bed at distinct time intervals, ensuring the second crop is sown after the first has matured. This approach potentially mitigates rivalry, especially concerning the main crop, in contrast to other intercropping techniques like mixed intercropping strips **(Keshavamurthy and Yadav, 1997).** Within the context of castor farming areas, leguminous intercrops such as black gram, green gram, and groundnut hold pivotal roles in enhancing food security, revenue generation, and environmental preservation. While cucurbit relay intercropping hasn't been extensively integrated with castor, a comprehensive scientific exploration of productivity and potential economic gains within each relay intercropping system is notably absent. It becomes imperative to identify dependable relay intercropping systems to ensure the sustainable utilization of natural resources while upholding and optimizing productivity. In light of these considerations, the present study embarks on an exploration to evaluate various cucurbit species as potential relay intercrops within widely spaced castor rows, forming the foundation of a resilient and resource-efficient castor-based relay intercropping system. **The objectives of this study were to investigate the effect of castor-cucurbits relay cropping on the growth, yield attributing characters and yield of cucurbits for higher resource use efficiency, system productivity and monitory returns.**

MATERIALS AND METHODS

Site Description and Experimental Design

The Tapioca and Castor Research Station in Yethapur, Tamil Nadu, India situated at coordinates 11.6627° N, 78.4751° E, and an altitude of 200 meters **above mean sea level,** served as the backdrop for a comprehensive three-year field experiment spanning the *Kharif* seasons of **2020-2021, 2021-2022 and 2022-2023**. **Sowing of castor was on August 23rd in 2020 (1st year), August 28th in 2021 (2nd year), September 4th in 2022 (3rd year), Castor was harvested on January 25th in 2021(1st year), January 22nd in 2022 (2nd year), January 28th in 2023 (3rd year). Following the castor harvest, the castor plants were pruned (removing the terminal shoots and foliage) and cucurbits were sown in between the castor plants on the following dates. Sowing dates for cucurbits were February 10th, 2021 (1st year), February 12th, 2022 (2nd year) and February 16th, 2023 (3rd year). Cucurbits crops were harvested on July 3rd in 2021(1st year), July 10th in 2022 (2nd year), July 12th in 2023 (3rd year).** Nestled within a tropical landscape, this region is characterized by its distinct wet and dry seasons, with bimodal rainfall exceeding 980 mm. Against this backdrop, an elaborate agricultural study was meticulously carried out. The foundation of this research was rooted in a randomized block design, incorporating seven distinct treatments replicated three times. These treatments encompassed various intercropping strategies involving castor, each paired with a different cucurbits: **T_1-Castor sole (YTP-1), T_2-Castor-Bitter gourd (*Momordica charantia*), T_3-Castor-Ridge gourd (*Luffa acutangula*), T_4-Castor-Snake gourd (*Trichsanthus cucumerina*), T_5-Castor-Bottle gourd (*Legenaria siceraria*), T_6-Castor-Coccinia (*Trichsanthus dioica*), T_7-Castor-Cucumber (*Cucumis sativus*).** The key variety of castor utilized was the cultivar YTP 1, and optimal spacing recommendations of 3 × 3 meters for castor and 2.5 × 2.5 meters for cucurbits were diligently adhered to. The experiment was inaugurated during the *Kharif* growing season.

Average seasonal (June–January) rainfall during the experimental period was 968 mm. **Table 1 shows the monthly climatic conditions at the experimental site for the growing season.** Average annual maximum and minimum temperatures during the experimental period were 35°C and 21°C, respectively. Before the field experimentation, the soil samples were collected to depths of 0–15 cm from each corresponding experimental unit and accurately analyzed to determine the different physicochemical properties of the soil profile. The soil composition at this experimental site exhibited characteristics of a clay loamy texture, with a pH value of 7.3. Organic carbon content was found to be relatively low, measuring at 0.29%. The soil of the experimental field was non-calcareous red soil, and with the **three**-year average available nutrient status of the experimental site, it was low in available N (216 kg ha^{-1}) and high in **available** P and **available** K (26.0 kg ha^{-1} and 364 kg ha^{-1}). Armed with this understanding, the research team implemented an array of innovative agronomic techniques to optimize crop performance. Notably, a unique approach was adopted in the form of "nipping" at the 10th node, carried out around 42 days after sowing (DAS), which effectively promoted branching and subsequent productivity. This was complemented by a meticulous pruning regimen, wherein each primary and secondary branch retained seven nodes. This pruning practice was applied immediately after harvesting spikes of secondary, third, and fourth orders, leading to enhanced branching dynamics per plant and an overall uptick in productivity. Intriguingly, the arrangement of cucurbit seeds was orchestrated along the bunds, placed at a distance of 0.5 meters from the main castor trunk (YTP 1). This ingenious setup facilitated the cultivation of cucurbits at a spacing of 2.5 × 2.5 meters, thereby streamlining intercultural operations for both castor and cucurbits. Moreover, irrigation channels, each spanning a width of 50 **cm**, were thoughtfully established between adjacent rows of castor (3m × 3m), ensuring optimal water management. Throughout the course of this extensive experiment, all procedures and methodologies were meticulously executed in accordance with established cultural norms and agricultural practices.

Table 1. A synopsis of weather conditions in 2020-2023 growing seasons.

	Precipitation (mm)		
Month	2020-21	2021-22	2022-23
January	0	7.8	2.6
February	0	13.8	0
March	0	99.8	9.8
April	56.2	46.4	6.4
May	41	61.4	65
June	50.2	36	19.8
July	83.8	131.6	30
August	212.2	245	60.2
September	54	60.6	36.8
October	218.8	170	10.8
November	56	334.7	185.6
December	151	33.9	77.2
Total	923.2	1241	504.2

Measurements and analytical procedures

Based on current market pricing ($\$ \text{ kg}^{-1}$), **Castor Equivalent Yield** (CEY) was determined as the castor yield of all intercropping regimens. The formula suggested by Lal and Ray (1976) was used to calculate it.

$$\text{Castor equivalent yield (CEY)} = \frac{\text{Yield of intercrop} \times \text{Price of intercrop (\$)}}{\text{Price of castor (\$)}} \times 100$$

The determination of the Land Equivalent Ratio (LER) was a crucial facet of the study, involving the utilization of the following mathematical expression:

LER = (AI/AS) + (BI/BS)

In this equation, LA and LB symbolize the respective LERs attributed to two distinct crops, denoted as A and B. The computation of LA is accomplished by dividing the yield of crop A in an intercropping arrangement (AI) by the yield of the same crop A when grown individually (AS). This identical formula is equally applied to derive the LER for LB, following the methodology established by Vandermeer (1989).

Moisture Use Efficiency is an operationalized concept for resource use efficiency and is a common metric used to assess ratio of plant production to water consumed. The evaluation of Moisture Usage Efficiency (MUE) constituted an additional significant parameter, ascertained by dividing the cumulative water consumption (measured **as mm**) spanning the period from planting to harvest by the achieved **seed yield** (expressed in kilograms per hectare). This pivotal metric was computed in line with the framework outlined by Sharma and colleagues, 2013. Furthermore, a comparative assessment of economic enhancements vis-à-vis the prevailing agricultural system was determined through the lens of Relative Economic Efficiency (REE). This assessment sheds light on the economic viability and gains brought about by the proposed interventions, providing insights into the economic effectiveness of the different cropping strategies under scrutiny.

$$\text{REE (\%)} = \frac{\text{Net income from improved system - Net income in existing system}}{\text{Net income in existing system}} \times 100$$

As elucidated by Tomar and Tiwari (1990), the concept of system profitability pertains to the monetary gain engendered by the cultivated crops. Net returns, quantified on a per-hectare basis, find expression in rupees per hectare per day ($/ha/day). System productivity, on the other hand, involves the conversion of diverse crop yields into a unified equivalent yield for a single crop, denominated in **kg** per **ha** per day. **For the calculation of net revenue per hectare, the gross return per hectare was meticulously offset by the total cost of cultivation. In tandem, the assessment of benefit-cost ratio was executed by dividing the gross returns by the corresponding cost of cultivation. These financial metrics collectively offer insights into the economic viability and profitability of the agricultural system under consideration.**

Statistical analysis

To assess the significance of treatment effects on the diverse parameters under scrutiny, Analysis of Variance (ANOVA) was methodically conducted. In cases where the treatment means displayed notable disparities, the Least Significant Difference (LSD) method was aptly employed to discern the nuanced differences among the means. The analytical approach outlined by Gomez and Gomez (1984) was skilfully applied to facilitate this statistical analysis.

RESULTS AND DISCUSSION

Growth and yield parameters of castor

The findings of the study unveiled that the utilization of diverse relay intercropping systems had minimal discernible impact on the growth and yield attributes of castor, as outlined in Table 2. Among the observed parameters, the towering stature of castor plants was most pronounced in the context of sole cultivation, reaching an impressive height of 152.3 **cm**. Following closely behind, the castor-snake gourd relay intercropping system exhibited a commendable plant height of 148.5 **cm**. In terms of branch development, it was intriguing to note that the castor-snake gourd relay intercropping and standalone castor systems demonstrated the highest branch proliferation rates, boasting 14.2 and 14.9 branches per plant, respectively. Remarkably, the productivity of castor itself appeared relatively unscathed by the incorporation of cucurbits in relay intercropping configurations, as indicated in Table 2. A detailed analysis (Figure 1) showcased that the various relay intercropping setups did not exert significant influence on the castor yield. In fact, the solo castor cultivation exhibited the most impressive seed output, culminating in a remarkable 1,312 kg ha^{-1}.

It is worth noting that the lack of substantial divergence in the yield of castor across the diverse intercropping strategies might stem from several underlying factors. One potential explanation could be the equitable distribution and utilization of available resources among the crops, leading to a balanced competition for essential elements like nutrients, water, and sunlight. Alternatively, this outcome could be attributed to a strategic farming approach where cucurbits are selectively cultivated, thereby avoiding potential resource conflicts with the castor. These findings find resonance with previous research conducted by Srilatha and colleagues (2002) who investigated castor intercropped with leguminous systems and arrived at analogous conclusions. The apparent similarity in outcomes across different studies underscores the consistency of these observations and provides valuable insights into the intricacies of intercropping dynamics within the realm of agricultural practices.

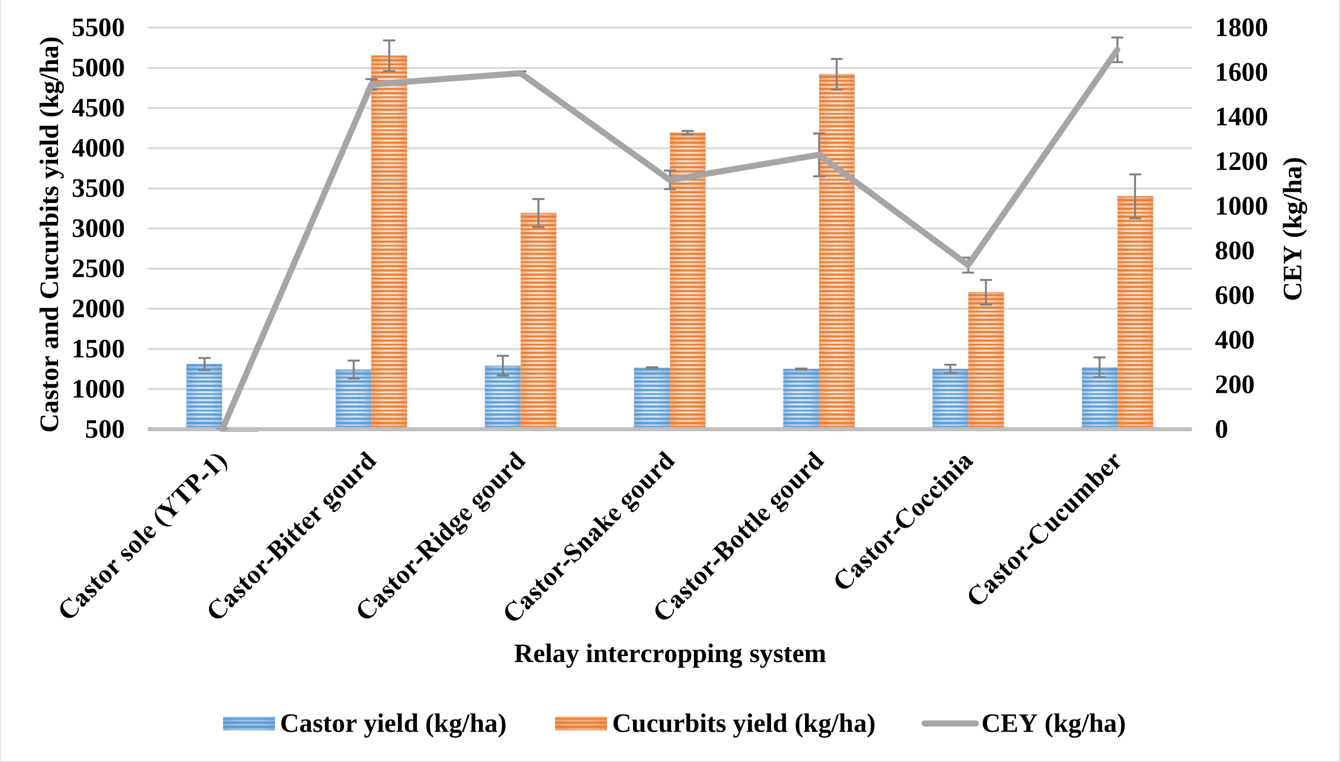

Figure 1. Mean comparisons for castor – cucurbits yield affected as relay intercropping.

Cucurbits yield and system productivity

Upon conducting a comprehensive pooled analysis, intriguing insights emerged regarding the interplay between castor and various studied cucurbits. Among the assortment of cucurbits scrutinized, the castor + bitter gourd relay intercropping arrangement stood out as a notable performer, yielding an impressive 5,151 kg ha^{-1}. This heightened yield of bitter gourd can be predominantly attributed to its intrinsic capacity for prolific production, surpassing its cucurbit counterparts (Figure 1). An intriguing aspect contributing to this success is the trailing nature of the bitter gourd climber, which adroitly navigates and weaves through the branches of the castor plant. This growth pattern not only enhances resistance to pests and diseases but also circumvents ground-level contact, mitigating soil-related vulnerabilities. A similar observation was documented by Schultz *et al.,* 1982, wherein intercropping cucumber and tomato was shown to be beneficial compared to monoculture, aligning with the principle that associating crops can often harness resources more efficiently, ultimately translating into higher yields.

Further probing the realm of system productivity, two distinct intercropping systems demonstrated exceptional performance. The castor-cucumber relay intercropping system, recording a system productivity of 4.66 kg/ha/day, and the castor-ridge gourd system, boasting a commendable 4.37 kg/ha/day, emerged as frontrunners in this domain. Contrastingly, the castor-snake gourd system (Table 2) lagged behind, yielding a comparatively lower system productivity of 3.06 kg/ha/day. This divergence can be attributed to the relatively lower fruit yields observed in the case of snake gourd, despite its favorable market prices in cucumber. The findings echoed the research of Koli *et al,* 2004, underscoring the correlation between better net returns and enhanced system productivity within castor-based intercropping systems. Collectively, these observations underscore the potential inherent in the relay intercropping approach, particularly in the context of castor and cucumber. This positive outcome implies a judicious utilization of resources, leading to heightened efficiency, and notably, a reduction in competition among castor plants.

Castor Equivalent Yield (CEY) and Land Equivalent Ratio (LER)

A crucial aspect of the study was the conversion of the yield obtained from each individual crop into Castor Equivalent Yield (CEY), a parameter that was calculated based on prevailing market prices. This conversion allowed for a comprehensive evaluation of the relative efficiency of various treatment combinations. Notably, the castor-ridge gourd relay intercropping system emerged as a standout performer in terms of CEY, registering a significantly higher output of 1596 kg ha^{-1} compared to the sole cultivation of castor (Figure

1). This result underscored the potential profitability and productivity of relay intercropping, particularly evident in the castor and ridge gourd pairing.

This conclusion found resonance with earlier research conducted by Padmavathi and Raghavaiah (2004), who similarly observed advantageous outcomes in castor combined with cluster bean intercropping systems. The marked increase in castor equivalent yield was primarily attributed to the complementary nature of the intercrop, which contributed an additional yield without causing substantial reduction in the primary crop's output. These findings harmonized with the research conducted by Tanunathan *et al*., 2006. Among the diverse relay intercropping systems assessed, the castor-bitter gourd combination stood out, boasting a notably higher Land Equivalent Ratio (LER) of 1.81 when compared to other intercropping systems. This metric indicated that a relay intercropping setup demanded 81% less land than a pure cropping system to achieve an equivalent yield. Conversely, the castor-coccinia relay intercropping system exhibited the lowest LER, implying that its intercropping advantage was relatively diminished. When assessed with the land equivalent ratio (LER), the productivity benefits of relay intercropping systems are often higher than those of intercrops, because under intercropping systems, both intercrops have the same growth stages and the competition to use land, light, water, and nutrients is high. In contrast, in relay intercropping systems, both intercrops have different growth stages, and the competition for available resources is less (Raza *et al.,* 2019).

The observation of an LER value exceeding 1.00 indicated the advantage of intercropping over sole stands in terms of optimized utilization of environmental resources for plant growth, aligning with the principles established by Mead and Willey, 1980. This elevated LER value elucidated the prevalence of interspecific interaction and complementarity, wherein the benefits derived from cooperative growth exceeded the competitive pressures. This finding aligned with the perspectives put forth by Mohammadi Nassab *et al*., 2011 and Zhang *et al.,* 2011, highlighting the inherent land-use efficiency and productivity advantages associated with well-structured intercropping systems.

Moisture Use Efficiency (MUE)

The metric used to evaluate the performance of these intercropping systems is "moisture use efficiency," which refers to the amount of biomass produced per unit of water used (kg/ha/mm). The intercropping system that combined castor with bitter gourd recorded the highest moisture use efficiency, with 6.58 kg/ha/mm. The second most efficient intercropping system was the combination of castor and bottle gourd, with 6.35 kg/ha/mm. On the other hand, the lowest moisture use efficiency of 1.27 kg/ha/mm was observed in the sole planting of castor without any intercropping (Table 3).

The higher moisture use efficiency observed in the intercropping systems, especially with bitter gourd, suggests that the combination of castor and bitter gourd is more effective in utilizing available moisture from the soil compared to other intercropping combinations and the sole castor crop. This might be attributed to the ability of bitter gourd to extract and utilize water more efficiently from the soil, resulting in increased biomass production for both crops. It's worth noting that similar findings were reported in a study conducted by Rao *et al.* 2010, further supporting the idea that bitter gourd has a positive impact on moisture use efficiency when intercropped with castor.

Economics, Relative Economic Efficiency (REE) and System Profitability (SP)

When examining the array of cucurbit-based relay intercropping systems, a distinct pattern of economic returns emerged, shedding light on the financial advantages of certain combinations. Notably, the relay intercropping arrangement involving castor and cucumber emerged as a frontrunner, yielding significantly higher net returns amounting to \$ 1483.9 ha^{-1}. This was closely followed by the castor and ridge gourd system, which yielded impressive net returns of \$ 1446.2 ha^{-1} (Table 3). These findings aligned harmoniously with the research conducted by (Varghese, 2000) underscoring the positive impact of intercropping on vegetable productivity per unit area and overall gross returns.

Delving into the economic efficiency metrics, it became apparent that certain relay intercropping systems exhibited notably advantageous ratios. The castor + ridge gourd and castor + bitter gourd systems achieved the highest benefit-cost ratios of 3.29, followed closely by the castor + cucumber system with a ratio of 3.27. This phenomenon was in line with the conclusions drawn by Sanwal *et al.*, 2006, who highlighted the heightened productivity and growth benefits associated with intercropping, especially when coupled with vegetable crops.

In terms of Relative Economic Efficiency (REE), all the relay intercropping systems surpassed the economic gain of sole castor cultivation. Among the relay intercropping systems, the castor + cucumber arrangement stood out, recording the highest economic gain at an impressive 196%. This was closely trailed by the castor-ridge gourd system, boasting an REE of 188% (Table 3). This observation further resonated with the principle that diversifying the crop composition within an existing system can amplify productivity, generate employment opportunities, and consequently lead to heightened economic output, as articulated by Mukherjee, 2010.

Furthermore, the aspect of system profitability came to the fore, with the castor-cucumber relay intercropping system attaining the maximum profitability at 4.07 $/ha/day, closely followed by the castor-ridge gourd system at 3.96 $/ha/day. This variance in profitability can be attributed to nuanced differences in factors such as yield, cultivation costs, and market prices of the harvested produce within these relay intercropping sequences. These results were in alignment with the conclusions drawn by Prasad, 2013, reinforcing the recurring theme of enhanced economic viability and profitability in intercropping scenarios.

Table 2. Growth characters of different castor - cucurbits based relay intercropping system (Pooled mean of three years).

Relay intercropping system	Plant height (cm)	No. productive branches/plant	Spike length (cm)	No. of capsules/Spike	Shelling %	100 seed weight (g)	Oil content (%)	Land Equivalent Ratio (LER)
Castor sole (YTP-1)	152.3 ^{a}	14.9 ^{a}	71.6 ^{a}	111.1 ^{a}	66.1 ^{a}	43.3 ^{a}	45.2 ^{a}	1.00 ^{c}
Castor-Bitter gourd	142.6 ^{a}	12.5 ^{a}	76.9 ^{a}	113.6 ^{a}	66.3 ^{a}	43.2 ^{a}	45.0 ^{a}	1.81 ^{a}
Castor-Ridge gourd	143.2 ^{a}	12.8 ^{a}	79.0 ^{a}	111.8 ^{a}	65.4 ^{a}	43.2 ^{a}	46.6 ^{a}	1.78 ^{a}
Castor-Snake gourd	148.5 ^{a}	14.2 ^{a}	73.2 ^{a}	113.5 ^{a}	65.8 ^{a}	43.4 ^{a}	46.1 ^{a}	1.75 ^{ab}
Castor-Bottle gourd	145.8 ^{a}	13.6 ^{a}	69.2 ^{a}	117.2 ^{a}	64.2 ^{a}	43.2 ^{a}	45.9 ^{a}	1.76 ^{ab}
Castor-Coccinia	139.3 ^{a}	12.4 ^{a}	70.9 ^{a}	114.1 ^{a}	66.5 ^{a}	43.1 ^{a}	45.6 ^{a}	1.69 ^{ab}
Castor-Cucumber	139.8 ^{a}	13.2 ^{a}	72.7 ^{a}	112.5 ^{a}	66.6 ^{a}	43.0 ^{a}	45.9 ^{a}	1.70 ^{ab}

[a] Mean±standard error for each trait; different letters indicate significant differences (LSD test, P< 0.05).

Table 3. Economics, system productivity, profitability relative economic efficiency and moisture use efficiency of castor - cucurbits based relay intercropping system (Pooled mean of three years).

Relay intercropping system	Cost of cultivation ($/ha)	Gross returns ($s/ha)	Net returns ($/ha)	Benefit Cost Ratio	System productivity (kg/ha/day)	System profitability ($/ha/day)	Relative Economic Efficiency (%)	Moisture Use Efficiency (kg/ha/mm)
Castor sole (YTP-1)	383.6	885.2	501.6	2.32	-	1.37 ^{d}	-	1.27 ^{d}
Castor-Bitter gourd	613.1	2007.6	1394.4	3.29	4.23 ^{ab}	3.82 ^{ab}	178 ^{ab}	6.58 ^{ab}
Castor-Ridge gourd	633.6	2079.7	1446.2	3.29	4.37 ^{a}	3.96 ^{a}	188 ^{a}	4.62 ^{a}
Castor-Snake gourd	596.9	1718.1	1121.2	2.88	3.06 ^{b}	3.07 ^{b}	124 ^{b}	5.62 ^{b}
Castor-Bottle gourd	641.0	1786.0	1145.0	2.79	3.37 ^{b}	3.14 ^{b}	128 ^{b}	6.35 ^{b}
Castor-Coccinia	595.7	1430.8	835.1	2.41	2.02 ^{c}	2.29 ^{c}	66 ^{c}	3.56 ^{c}
Castor-Cucumber	656.1	2140.0	1483.9	3.27	4.66 ^{a}	4.07 ^{a}	196 ^{a}	4.81 ^{a}

[a] Mean±standard error for each trait; different letters indicate significant differences (LSD test, P< 0.05).

CONCLUSIONS

After an exhaustive three-year field investigation, the study firmly validates a notable phenomenon: the resilience of castor in relay intercropping systems with various cucurbit vegetable crops. This adaptability underscores castor's ability to coexist without yielding to competition. The relay intercropping of cucurbits positively impacts agricultural productivity and economic viability, evident in the remarkable increase in Castor Equivalent Yield (CEY) and enhanced system productivity, economic efficiency, and profitability. Particularly pronounced with cucumber, bitter gourd, or ridge gourd, relay intercropping demonstrates substantial yield advantages over sole castor cultivation. These findings highlight relay intercropping's potential to augment production, increase income, create employment opportunities, and enhance resilience against climatic uncertainties. As a multi-dimensional catalyst, relay intercropping not only benefits individual plots but also entire farming communities, driving positive changes towards a more secure and prosperous agricultural future.

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