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ECONOMIC PERFORMANCE OF MUSTARD (*BRASSICA JUNCEA* L.) VARIETIES UNDER *TERMINALIA ARJUNA* BASED AGRISILVICULTURE IN SEMI-ARID REGION OF BUNDELKHAND, INDIA

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ABSTRACT

Agroforestry has emerged as a promising land-use strategy for semi-arid India because it can diversify farm output, stabilize income, improve soil functioning, and reduce the risk associated with rainfall variability and crop failure. The present study evaluated the economic performance of six Indian mustard varieties under an Arjun (*Terminalia arjuna*) -based agrisilviculture system in Bundelkhand, a region characterized by erratic rainfall, high evaporative demand, recurrent moisture stress, and widespread resource degradation. The field experiment was conducted during the rabi season of 2022-23 at the Forestry Farm of Banda University of Agriculture and Technology, Banda, Uttar Pradesh, under a 4.5-year-old Arjun plantation spaced at 5 m x 5 m. Six mustard varieties, namely RH-725, RH-406, RH-749, Radhika, RGN-73, and Giriraj, were assessed in a randomized block design with six replications and compared with their corresponding sole-crop situations. Economic indicators included cost of cultivation, gross return, net return, and benefit-cost ratio. The treatment-wise data showed that Giriraj under Arjun generated the highest gross return (Rs. 184,584 ha^{-1}), net return (Rs. 134,602 ha^{-1}), and benefit-cost ratio (2.69), whereas Radhika recorded the lowest economic performance among the agroforestry treatments. Although the agrisilviculture options involved higher cultivation costs than sole cropping, they produced substantially larger gross and net returns. Across varieties, the integrated system increased average gross return by about 102%, net return by about 144%, and benefit-cost ratio by about 73% over sole cropping. The findings indicate that varietal choice is critical for improving the profitability of tree-crop systems and that Giriraj is the most economically suitable mustard variety for Arjun-based agrisilviculture under Bundelkhand conditions.
Keywords **:** Agroforestry, agrisilviculture, Arjun, Bundelkhand, Brassica juncea, economic analysis, benefit-cost ratio, semi-arid agriculture.

Introduction

Agroforestry is increasingly recognized as one of the most practical pathways for improving the ecological and economic resilience of smallholder agriculture in fragile environments. Classic agroforestry scholarship has long emphasized that combining trees with crops can increase overall land-use efficiency, diversify outputs, and generate both private and public benefits when system design is ecologically sound (Garrity, 2004; Mbow *et al.*, 2013; Nair, 1993; Nair *et al.*, 2010). By integrating woody perennials with annual crops and, in some cases, livestock, agroforestry can improve resource capture, moderate microclimate, diversify production, strengthen soil processes, and spread risk across different farm outputs (Fahad *et al.*, 2022; Jose, 2009;

Mukhlis *et al.*, 2022). In both tropical and semi-arid regions, tree-based systems are valued not only for their role in supporting household livelihoods but also for their contributions to soil organic matter, nutrient cycling, biodiversity, and climate adaptation (Datta *et al.*, 2023; Gonçalves *et al.*, 2021). For regions where monocropping is increasingly exposed to rainfall uncertainty, high temperatures, soil degradation, and volatile markets, well-designed agroforestry systems can function as a more resilient land-use option than conventional field cropping alone.

India has a long history of tree-crop integration, yet the strategic importance of agroforestry has become especially visible in the context of climate vulnerability, land degradation, and livelihood stress. The National Agroforestry Policy marked important institutional recognition of tree-based farming as a means to enhance farm income, improve ecosystem services, and support raw material supply for industry while reducing pressure on natural forests (Chavan *et al.*, 2015). More recently, policy analyses have shown that agroforestry is increasingly embedded in state-level climate adaptation thinking, although implementation remains uneven and often constrained by institutional, financial, and market barriers (Datta *et al.*, 2024). This broad policy interest is particularly relevant for dryland regions such as Bundelkhand, where recurring drought, degraded soils, and unstable farm returns make diversification a necessity rather than a luxury.

The Bundelkhand region of central India is widely known for its harsh agro-ecological conditions. The region experiences recurrent moisture stress, substantial rainfall variability, prolonged dry spells, poor groundwater access, and degraded agricultural landscapes, all of which undermine crop productivity and farm income (Garg *et al.*, 2020; Pandey *et al.*, 2021). Studies from Bundelkhand further show that farm productivity and household earnings are strongly shaped by access to water, soil and water conservation measures, and the capacity of the production system to absorb climatic shocks (Choudhary *et al.*, 2022; Singh *et al.*, 2021). Under such circumstances, any land-use model that can simultaneously improve profitability and reduce production risk deserves careful evaluation. Agroforestry has been repeatedly identified as a suitable strategy for Bundelkhand because it offers a combination of productive, restorative, and protective functions, especially when tree species and intercrops are chosen to match local climate and farmer priorities (Ramanan *et al.*, 2024).

Among the annual crops grown in Rabi Season, Indian mustard (*Brassica juncea* L.) is one of the most economically important oilseed crops in north and central India. It contributes to edible oil supply, fits well into dryland and limited-irrigation systems, and responds strongly to management factors such as sowing time, row spacing, establishment practice, and varietal selection (Kumari *et al.*, 2012; Sharma & Kumar, 2022; Shekhawat *et al.*, 2016). Recent assessments of mustard production in India also emphasize the continued need to close yield gaps and improve the economic efficiency of cultivation, especially in resource-constrained regions (Kumbhare *et al.*, 2025). In rainfed and semi-arid ecologies, varietal performance is not merely a question of yield potential. It is also a question of how effectively a genotype converts limited resources into economic return under real field conditions.

The tree component selected in this study was Arjun (*Terminalia arjuna*), a multipurpose species of ecological, medicinal, and agroforestry importance. Although the present paper does not evaluate tree growth traits directly, prior studies on lesser-used agroforestry tree species and tree-associated soil effects in India reinforce the need for species-specific economic evaluation rather than generic recommendation (Dhaka & Prajapati, 2022; Gupta & Sharma, 2009). Although *Terminalia arjuna* is widely recognized for its adaptability and utility in rehabilitative and production landscapes, its integration with high-value annual crops requires location-specific economic assessment. Tree-crop interactions are rarely uniform across sites or varieties. The competitive and facilitative effects of trees on understory crops depend on spacing, canopy architecture, age of plantation, moisture regime, root overlap, light availability, and the biological characteristics of the crop itself. Consequently, farmers require evidence not only on whether an agroforestry system works, but also on which crop variety works best within that system.

This point is especially important because economic superiority in agroforestry cannot be assumed from sole-crop performance. A variety that performs acceptably under open conditions may not be the most profitable under tree influence, where altered light, soil moisture dynamics, and nutrient competition can modify plant growth and final economic returns. Earlier agroforestry studies with different tree-crop combinations have shown that economic outcomes vary substantially depending on crop species, spacing, and management. Better net returns under tree-based systems have been reported in several contexts, including fruit- and timber-based intercrops, vegetable-based systems, and medicinal or short-duration crop combinations (Dash *et al.*, 2024; Nayak *et al.*, 2014;

Panwar & Wani, 2014). However, evidence remains limited for economics of mustard varieties under an Arjun-based agrisilviculture system under Bundelkhand conditions.

In the broader Bundelkhand context, related work on mung bean under Melia dubia-based agroforestry has shown that planting geometry and tree-crop arrangement can materially affect crop performance and subsequent system economics (Parasriya *et al*., 2022; Patel & Gangwar, 2023). Legume-based intercrops in semi-arid systems are often discussed for their adaptability, short duration, and contribution to farm diversification, although their economic role remains highly context dependent (Muchomba *et al*., 2023). The manuscript compares six mustard varieties under Arjun with their corresponding sole-crop counterparts and reports cost of cultivation, gross income, net income, and benefit-cost ratio for each treatment. These data offer a useful foundation but in their original form, the manuscript remains too brief and structurally underdeveloped for submission to a strong journal. The introduction is short, the literature framing is limited, the methodological description needs clarification, and the discussion does not sufficiently connect the results to the broader agroforestry, dryland, and oilseed literature. In addition, the economic interpretation needs to be presented with greater analytical depth and care regarding what the treatment-wise values imply for variety selection, farm profitability, and system suitability in semi-arid landscapes.

Against this background, the objectives of the study were: (i) to evaluate the comparative economics of six mustard varieties under Arjun-based agrisilviculture and sole cropping; (ii) to identify the most profitable varietal option for Bundelkhand conditions; and (iii) to discuss the practical implications of the results for dryland agroforestry promotion, varietal choice, and farm-level income enhancement in semi-arid India.

Materials and Methods

Study site

The field experiment was conducted during the rabi season of 2022-23 at the Forestry Farm of Banda University of Agriculture and Technology, Banda, Uttar Pradesh, India. The experimental site is located at 25.52° N latitude and 80.34° E longitude, with an elevation of 143 m above mean sea level. The region falls within the Central Plateau and Hills agro-climatic zone and is representative of the semi-arid conditions of Bundelkhand. The climate is characterized by hot summers, cool winters, erratic rainfall, and pronounced intra-seasonal variability. Summer temperature may rise to nearly 49°C, winter temperature may decline to around 10°C, and around 90% of annual rainfall is concentrated between June and September, a monsoonal concentration pattern also highlighted in related dryland work from the region (Tewari *et al*., 2016).

Soil characteristics

Before sowing, the soil was analyzed and described as silt loam in texture, comprising 18% sand, 54% silt, and 28% clay. Soil reaction was slightly alkaline (pH 7.89), organic carbon status was low, nitrogen and potassium were in the medium range, available phosphorus was low, and electrical conductivity was within the normal range. These conditions are consistent with the kinds of fertility and moisture limitations commonly reported for semi-arid and degradation-prone agricultural lands. In such environments, tree-based systems may influence soil moisture retention, litter inputs, biological activity, and microclimate, thereby affecting crop economics over time (Jose, 2009; Fahad *et al*., 2022).

Experimental material and treatment structure

The tree component consisted of a 4.5-year-old plantation of Arjun (*Terminalia arjuna*) established at a spacing of 5 m x 5 m. Within this tree stand, six mustard varieties were evaluated as intercrops: RH-725, RH-406, RH-749, Radhika, RGN-73, and Giriraj. The crop was sown at a spacing of 45 cm x 10 cm. The experimental design reported in the uploaded manuscript was a Randomized Block Design with six replications, and each plot measured 4 m x 4 m. For economic comparison, each mustard variety was evaluated under two production situations: (i) under Arjun-based agrisilviculture, and (ii) as a corresponding sole crop. The uploaded treatment table therefore, permits direct pairwise comparison between agroforestry and sole-crop performance for each variety. In the present manuscript, these paired observations constitute the central economic dataset.

Economic indicators and analytical approach

The present study focuses on four core indicators of economic performance: cost of cultivation, gross return, net return, and benefit-cost ratio. Economic analysis was based on treatment-wise records of production cost and monetary return. Cost of cultivation was calculated using prevailing input prices and operational expenses. Gross return was estimated on a treatment basis using the prevailing minimum support price for mustard grain during marketing season 2022-23, and net return was derived by subtracting treatment-wise cost from gross return.

The following economic expressions were used:

Cost of cultivation (Rs. ha^{-1}) = total variable and operational cost incurred under the specific treatment.

Gross return (Rs. ha^{-1}) = total monetary value generated per treatment.

Net return (Rs. ha^{-1}) = gross return - cost of cultivation.

Benefit-cost ratio = net return / cost of cultivation.

Benefit–cost ratio (B:C) was calculated as net return divided by cost of cultivation to reflect actual profit per unit investment, which is commonly used in farm-level economic evaluation studies.

Percentage increase in gross return under agrisilviculture over sole cropping = [(Agroforestry gross return - Sole gross return) / Sole gross return] x 100.

Percentage increase in net return under agrisilviculture over sole cropping = [(Agroforestry net return - Sole net return) / Sole net return] x 100.

Percentage increase in benefit-cost ratio under agrisilviculture over sole cropping = [(Agroforestry B:C Ratio - Sole B:C ratio) / Sole B:C ratio] x 100.

Results and Discussion

The differences among treatments for all economic parameters were statistically significant at $p \leq 0.05$, indicating that varietal performance and production system had a significant influence on economic outcomes. The economic performance of mustard varieties under agrisilviculture and sole cropping systems is presented in Table 1.

Cost of cultivation

The economic dataset showed a clear separation between Arjun-based agrisilviculture and sole-crop mustard with respect to cost of cultivation. Across the six tested varieties, the mean cultivation cost under agrisilviculture was Rs 49,894.50 ha^{-1}, whereas the corresponding mean under sole cropping was Rs 35,294.50 ha^{-1}. Thus, integration with Arjun increased the average production cost by about 41.4%. Within the tree-based system, Giriraj + Arjun recorded the highest cost of cultivation (Rs 49,982.00 ha^{-1}), followed very closely by Radhika + Arjun (Rs 49,932.00 ha^{-1}), while RH-406 + Arjun recorded the lowest cultivation cost (Rs 49,807.00 ha^{-1}). In the sole-crop condition, RH-406 recorded the minimum cultivation cost (Rs 35,207.00 ha^{-1}) and Giriraj the maximum (Rs 35,382.00 ha^{-1}). The narrow spread between treatments in cost in both situations indicates that varietal differences in expenditure were minor and that the main economic contrast arose from the production environment rather than from sharply different input requirements among mustard genotypes. Similar increases in establishment or management cost have been documented in other agroforestry studies, where the integrated system initially appears more expensive but later compensates through stronger returns (Dash *et al.*, 2024; Nayak *et al.*, 2014).

Table 1 : Economic performance of mustard varieties under Arjun-based agrisilviculture and sole cropping

Variety	Arjun-based Agri silviculture				Sole crop			
	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B:C ratio	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B:C ratio
RH-725	49,907	177,753.33	127,846.33	2.56	35,307	91,560.00	56,253.00	1.59
RH-406	49,807	169,396.67	119,589.67	2.4	35,207	84,475.00	49,268.00	1.4
RH-749	49,857	174,301.67	124,444.67	2.5	35,257	82,204.17	46,947.17	1.33
Radhika	49,932	165,581.67	115,649.67	2.32	35,332	80,387.50	45,055.50	1.28
RGN-73	49,882	172,212.50	122,330.50	2.45	35,282	82,658.33	47,376.33	1.34
Giriraj	49,982	184,584.00	134,602.00	2.69	35,382	95,465.83	60,083.83	1.7

Gross return

Gross return varied markedly among varieties and between the two production situations. Under Arjun-based agrisilviculture, gross return ranged from Rs. 165,581.67 ha^{-1}in Radhika to Rs. 184,584.00 ha^{-1}in Giriraj. Under sole cropping, the corresponding values were much lower, ranging from Rs. 80,387.50 ha^{-1}in Radhika to Rs. 95,465.83 ha^{-1} in Giriraj. The mean gross return across all six varieties was Rs. 173,971.64 ha^{-1}under agrisilviculture compared with Rs. 86,125.14 ha^{-1} under sole cropping, indicating an average increase of about 102.0% in favor of the integrated system. Every variety showed a gross-return advantage under Arjun. The percentage increase over sole cropping was 94.1% for RH-725, 100.5% for RH-406, 112.0% for RH-749, 106.0% for Radhika, 108.3% for RGN-73, and 93.4% for Giriraj.

In absolute terms, Giriraj was the best-performing variety in both production environments, but its superiority became especially important under agrisilviculture because it produced the highest monetary return from the integrated land-use unit. RH-725 and RH-749 also performed strongly, both exceeding Rs. 174,000 ha^{-1} under Arjun, whereas Radhika consistently remained the lowest-returning variety. These results suggest that the Arjun-mustard system created a larger economic envelope than sole mustard cultivation. Agroforestry outcomes are governed by the balance between competition and complementarity; appropriately matched crop-tree combinations can improve resource-use efficiency, moderate the field microclimate, and diversify value generation at the system level (Fahad *et al.*, 2022; Jose, 2009; Rathore *et al.*, 2022). Similar economic superiority of integrated systems over monocropping has been reported in other agroforestry studies in India and elsewhere (Gonçalves *et al.*, 2021; Mukhlis *et al.*, 2022; Nayak *et al.*, 2014; Yadav *et al.*, 2014). Although yield data are not presented separately, the economic differences observed among treatments reflect the combined effect of crop productivity and system-level interactions under agrisilviculture conditions. The comparative performance of varieties under both systems is illustrated in Figure 1.

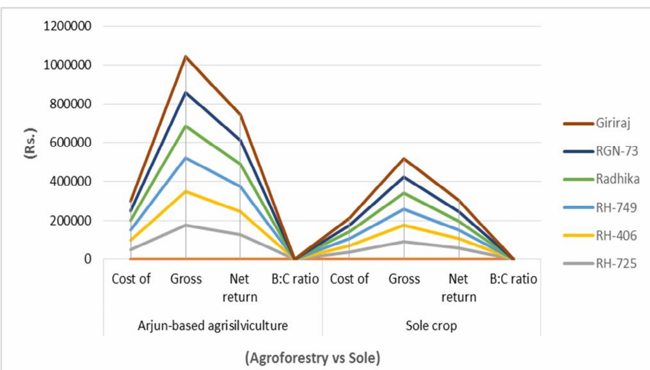

Fig. 1 : Comparative economic performance of mustard varieties under agrisilviculture and sole cropping systems.

Net return

Net return provides the clearest measure of whether the additional cost of agrisilviculture is economically justified. In the present study, all six integrated treatments produced substantially larger net returns than their sole-crop counterparts. The mean net return under Arjun-based agrisilviculture was Rs. 124,077.14 ha^{-1} compared with Rs. 50,830.64 ha^{-1} under sole cropping, representing an increase of about 144.1%. Among the integrated treatments, Giriraj + Arjun recorded the highest net return (Rs. 134,602.00 ha^{-1}), followed by RH-725 + Arjun (Rs. 127,846.33 ha^{-1}), RH-749 + Arjun (Rs. 124,444.67 ha^{-1}), RGN-73 + Arjun (Rs. 122,330.50 ha^{-1}), RH-406 + Arjun (Rs. 119,589.67 ha^{-1}), and Radhika + Arjun (Rs. 115,649.67 ha^{-1}). In the sole-crop situation, Giriraj again recorded the highest net return (Rs. 60,083.83 ha^{-1}), while Radhika remained the lowest (Rs. 45,055.50 ha^{-1}).

The varietal pattern becomes even more informative when relative gain over sole cropping is considered. RH-749 showed the largest proportional increase in net return (+165.1%), followed by RGN-73 (+158.2%), Radhika (+156.7%), RH-406 (+142.7%), RH-725 (+127.3%), and Giriraj (+124.0%). The relative economic advantage of agrisilviculture over sole cropping is summarized in Table 2. Thus, Giriraj was the strongest variety in absolute profit terms, whereas RH-749 appeared most responsive to the shift from sole crop to agrisilviculture. Diversified land-use systems are often preferred in such environments because they provide stronger income buffering than monoculture (Datta *et al.*, 2023; Garg *et al.*, 2020; Ramanan *et al.*, 2024; Singh *et al.*, 2021). The present findings, therefore, suggest that the additional investment under Arjun not merely recovered but also transformed into substantially higher profit. This conclusion is also consistent with earlier studies showing that the profitability of mustard depends strongly on the interaction between genotype and production environment (Das *et al.*, 2020; Kumari *et al.*, 2012; Sharma & Kumar, 2022; Shekhawat *et al.*, 2016).

Table 2 : Relative economic advantage of Agri silviculture over sole cropping

Variety	Increase in gross return (%)	Increase in net return (%)	Increase in B:C ratio (%)
RH-725	94.1	127.3	61
RH-406	100.5	142.7	71.4
RH-749	112	165.1	88
Radhika	106	156.7	81.2
RGN-73	108.3	158.2	82.8
Giriraj	93.4	124	58.2
Mean advantage	**102.4**	**145.7**	**73.8**

Benefit-cost ratio

The benefit-cost ratio further confirmed the economic superiority of Arjun-based agrisilviculture. In accordance with the convention followed in the uploaded dataset, the ratio represented net return divided by cost of cultivation. The average benefit-cost ratio across varieties was 2.49 under agrisilviculture compared with 1.44 under sole cropping, which represents an average relative gain of about 72.7%. Among the integrated treatments, Giriraj + Arjun recorded the maximum ratio (2.69), followed by RH-725 + Arjun (2.56), RH-749 + Arjun (2.50), RGN-73 + Arjun (2.45), RH-406 + Arjun (2.40), and Radhika +

Arjun (2.32). Under sole cropping, the values were much lower, ranging from 1.28 in Radhika to 1.70 in Giriraj. The proportional improvement in benefit-cost ratio under agrisilviculture over sole cropping was 61.0% for RH-725, 71.4% for RH-406, 88.0% for RH-749, 81.2% for Radhika, 82.8% for RGN-73, and 58.2% for Giriraj. The magnitude of percentage improvement across varieties is further visualized in Figure 2. Once again, RH-749 displayed the strongest relative economic response, whereas Giriraj maintained the highest absolute investment efficiency. Previous agroforestry studies have likewise shown that well-matched tree-crop combinations can improve benefit-cost relations by generating more value from each unit of expenditure (Dash *et al*., 2024).

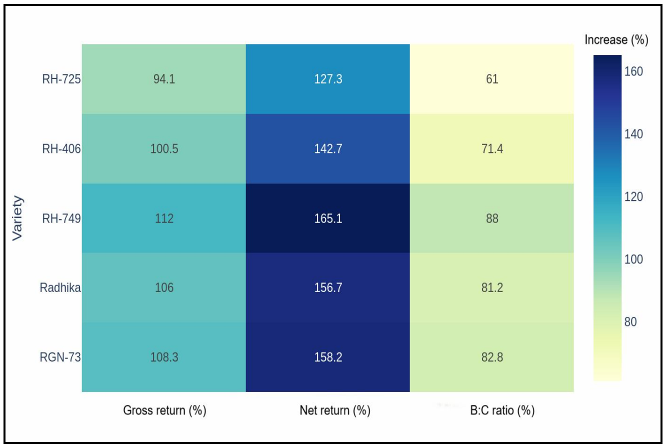

Fig. 2 : Heatmap showing the magnitude of percentage increase in gross return, net return, and B:C ratio across varieties.

Conclusion

The present study demonstrates that Arjun-based agrisilviculture significantly enhances the economic performance of mustard compared to sole cropping under semi-arid Bundelkhand conditions. Despite higher cultivation costs, the integrated system produced substantially higher gross returns, net returns, and benefit–cost ratios across all varieties. Among the evaluated varieties, Giriraj emerged as the most economically viable option, while RH-749 showed the highest responsiveness to system integration. These findings highlight that varietal selection is a critical determinant of profitability in agroforestry systems. The study supports the promotion of context-specific agroforestry models as a strategy for enhancing farm income, reducing risk, and improving sustainability in climate-vulnerable regions.

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