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Kushagra Sharma
Department of Horticulture,
Jawaharlal Nehru Krishi Vishwa
Vidyalaya, Jabalpur, Madhya
Pradesh, India

Brijpal Bisen
Department of Horticulture,
Jawaharlal Nehru Krishi Vishwa
Vidyalaya, Jabalpur, Madhya
Pradesh, India

GS Tagore
Department of Soil Science and
Agricultural Chemistry,
Jawaharlal Nehru Krishi Vishwa
Vidyalaya, Jabalpur, Madhya
Pradesh, India

CS Pandey
Department of Horticulture,
Jawaharlal Nehru Krishi Vishwa
Vidyalaya, Jabalpur, Madhya
Pradesh, India

Umesh Singh
Department of Mathematics &
Statistics, Jawaharlal Nehru Krishi
Vishwa Vidyalaya, Jabalpur,
Madhya Pradesh, India

Swati Barche
Department of Horticulture,
Jawaharlal Nehru Krishi Vishwa
Vidyalaya, Jabalpur, Madhya
Pradesh, India

Corresponding Author:
Brijpal Bisen
Department of Horticulture,
Jawaharlal Nehru Krishi Vishwa
Vidyalaya, Jabalpur, Madhya
Pradesh, India

Economic feasibility of integrating botanical leaf extracts with recommended fertilization in strawberry production

Kushagra Sharma, Brijpal Bisen, GS Tagore, CS Pandey, Umesh Singh and Swati Barche

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Abstract

Strawberry (*Fragaria × ananassa* Duch.) is an economically important, high-value soft fruit whose intensive cultivation increasingly relies on costly fertilizers, underscoring the need for sustainable integrated nutrient management using botanical biostimulants. Comparative economic evaluation of tropical orchard leaf extracts remains limited, and no study has compared jamun, mango, guava and jackfruit leaf extracts at two concentrations under contrasting fertilizer levels for economic performance in strawberry. This study evaluated the economic feasibility of integrating four botanical leaf extracts, each at two concentrations, with the recommended dose of fertilizers (RDF) in strawberry through gross return, net return and benefit:cost (B:C) ratio. A two-year factorial randomized block field experiment evaluated eighteen treatment combinations on strawberry cv. Camarosa, with pooled data assessed for economic indicators. Foliar leaf extract application, alone or with RDF, generally raised all three economic parameters above the control, and RDF increased gross and net returns across all leaf extract treatments while generally, though not uniformly, improving B:C ratio. Jackfruit leaf extract 50% + RDF (T₁₇) recorded the highest pooled gross return (₹3,276,560.00 ha⁻¹), net return (₹2,297,418.33 ha⁻¹) and B:C ratio (3.35), with Jamun leaf extract 50% + RDF (T₅), Jackfruit leaf extract 100% + RDF (T₁₈) and Mango leaf extract 50% + RDF (T₉) also performing well, while the control without RDF (T₁) recorded the lowest values for all three indicators. Pooled B:C ratio across the eighteen treatment combinations ranged from 2.26 to 3.35, indicating that low-cost botanical leaf extracts, particularly jackfruit, hold potential as complementary inputs within RDF-based strawberry production, warranting further multi-location and multi-season validation.

Keywords: Benefit:cost ratio, Botanical biostimulants, Economic feasibility, Integrated nutrient management, Sustainable horticulture

1. Introduction

Strawberry (*Fragaria × ananassa* Duch.) has evolved from a temperate specialty crop into one of the most economically important soft fruits cultivated worldwide, with global production now exceeding nine million tonnes annually (FAOSTAT, 2024) [6]. Its short crop cycle, high market value and strong consumer demand have encouraged intensification of commercial cultivation, particularly across subtropical production belts where the crop has shifted from a novelty to a profitable smallholder and commercial venture (Chauhan *et al.*, 2024) [4]. As strawberry production systems intensify, growers increasingly depend on high levels of external inputs to sustain yield and fruit quality, raising cultivation costs and placing greater emphasis on the need to balance productivity gains with farm-level profitability. Economic sustainability, rather than yield alone, is therefore emerging as a decisive criterion in evaluating the long-term viability of intensive strawberry production systems. A major constraint on farm profitability in such systems is the rising cost of synthetic fertilizers, which continues to erode net returns even where fertilization improves yield. Reliance on synthetic nutrient sources alone has been associated with declining fertilizer-use efficiency, soil nutrient depletion and diminishing marginal economic benefit from additional input (Quddus *et al.*, 2025) [16], while fertigation studies in strawberry have shown that fertilizer expense efficiency itself declines as application levels rise (Jaswal and Sandal, 2019) [9]. These observations indicate that agronomic performance and economic

performance do not necessarily improve in parallel, and that nutrient management strategies must be evaluated on both fronts simultaneously (Rouphael and Colla, 2020) ^[20]. This recognition has driven growing interest in integrated nutrient management (INM), which combines mineral fertilization with low-cost biological inputs to sustain productivity while moderating dependence on costly synthetic sources, and underscores the necessity of assessing fertilizer strategies through explicit economic indicators rather than agronomic response alone.

Botanical leaf extracts have emerged as an accessible and low-cost component of integrated nutrient management. Foliar biostimulants derived from plant biomass are not nutrient sources in the conventional sense but function as physiological modulators, being rich in phenolics, flavonoids, amino acids, vitamins, minerals and hormone-like constituents capable of influencing plant metabolic and physiological processes (du Jardin, 2015; Yakhin *et al.*, 2017; Kisiriko *et al.*, 2021) ^[5, 26, 10]. Jackfruit leaf extracts have also been chemically characterized and reported to contain bioactive compounds with biological activity, highlighting their potential as plant-derived biostimulants (Vazquez-Gonzalez *et al.*, 2020) ^[22]. Applied as foliar sprays, such compounds bypass soil-binding constraints and act directly at the leaf surface to enhance stress tolerance, nutrient acquisition and physiological efficiency (Franzoni *et al.*, 2022) ^[7]. When combined with a recommended dose of fertilizers (RDF), this interaction may allow the crop to convert a given nutrient supply more completely into productive growth, positioning the leaf extract–RDF combination as a candidate strategy for improving resource-use efficiency and, by extension, farm-level economic outcomes. Economic evaluation of such integrated strategies has progressed considerably in recent horticultural literature. Studies combining organic amendments with recommended fertilization have reported measurable gains in benefit–cost (B:C) ratio over sole reliance on chemical fertilizers (Raj and Prasad, 2023) ^[18], while foliar biostimulant applications in strawberry have been shown to generate favourable gross and net returns alongside improved B:C ratios (Bagh and Mishra, 2024) ^[2]. At the same time, evidence from other horticultural systems indicates that the economic value of integration is not automatic: organic inputs with high procurement or bulk cost can depress rather than enhance the B:C ratio despite raising absolute returns (Quddus *et al.*, 2025) ^[16], whereas comparatively low-cost botanical foliar sprays have delivered favourable returns even where input costs were non-trivial (Vasuki *et al.*, 2025) ^[21]. Previous studies indicate that research on biostimulants has expanded from documenting biological responses to evaluating their economic value. This shift highlights the need to assess nutrient management strategies not only by crop performance but also by their contribution to farm profitability.

Despite this progress, important gaps remain in the economic evaluation of botanical biostimulant–RDF systems. Few studies have simultaneously quantified gross return, net return, and B:C ratio for multiple botanical leaf extracts within a single integrated framework, and comparative economic evaluations of jamun, mango, guava, and jackfruit leaf extracts applied at two concentrations in combination with the recommended dose of fertilizers (RDF) remain, to our knowledge, unavailable. Therefore, the present study was undertaken to evaluate the economic feasibility of integrating four botanical leaf extracts (jamun, mango, guava, and jackfruit), each applied at two concentrations, with the recommended dose of fertilizers in commercial strawberry cultivation. Gross return, net return, and B:C ratio were assessed across all leaf extract × RDF

combinations. The findings provide evidence that integrating botanical leaf extracts with recommended fertilization can improve the economic viability of strawberry production and support informed adoption of these biostimulants under commercial cultivation.

2. Materials and Methods

2.1 Experimental Site and Experimental Design

The experiment was conducted over two consecutive winter seasons (2024–25 and 2025–26) under open-field conditions at the New Nursery, Department of Horticulture, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Adhartal, Jabalpur, Madhya Pradesh, India (23°12'09" N, 79°57'29" E; 300 m amsl), a subtropical zone with cool winters favorable for strawberry cultivation. A factorial randomized block design (FRBD) with three replications was used to evaluate the effects of botanical leaf extracts and the recommended dose of fertilizers (RDF) on strawberry (*Fragaria × ananassa* Duch.) cv. Camarosa. Factor A comprised nine levels: a water-sprayed control and foliar sprays of jamun (*Syzygium cumini*), mango (*Mangifera indica*), guava (*Psidium guajava*), and jackfruit (*Artocarpus heterophyllus*) leaf extracts at 50% and 100% concentrations. Factor B comprised two fertilizer levels (with and without RDF), yielding 18 treatment combinations replicated thrice. Composite soil samples (0–30 cm) collected before transplanting were clay-textured (19.6% sand, 30.4% silt, 50.0% clay), slightly acidic to neutral (pH 6.8), with normal electrical conductivity (0.47 dS m⁻¹), medium organic carbon (0.48%), low available N (256 kg ha⁻¹), high available P (24.4 kg ha⁻¹), and medium available K (248 kg ha⁻¹), indicating moderate inherent fertility.

2.2 Plant Material and Crop Establishment

Disease-free, tissue-cultured Camarosa plants with well-developed root systems and 4–5 healthy leaves were procured from Jain Irrigation Systems Limited, Jalgaon, Maharashtra. Damaged roots and leaves were removed and plants were briefly field-acclimatized before transplanting on raised beds at 60 × 30 cm spacing (six plants per experimental unit) during the third week of October in both seasons. Beds were pre-laid with silver polyethylene mulch to conserve moisture, suppress weeds, and maintain fruit cleanliness. RDF (120:60:80 kg N:P₂O₅:K₂O ha⁻¹), supplied through urea, single super phosphate, and muriate of potash, was applied as a single basal dose before transplanting in RDF treatments. Irrigation, manual weeding, runner removal, and plant protection were applied uniformly across treatments. Vegetative growth, flowering, yield, and fruit quality traits were recorded from the six plants per unit and averaged for analysis.

2.3 Preparation and Application of Botanical Leaf Extracts

Fresh, fully expanded, disease- and insect-free leaves of jamun, mango, guava, and jackfruit were hand-picked from the mid-canopy of the current season's flush on campus trees, excluding young, senescent, or damaged foliage. Approximately 100 g of leaves per species were collected during early morning under dry conditions, washed under running tap water followed by distilled water, and shade-dried to remove surface moisture before extraction. Extracts were prepared by the aqueous decoction method, modified from Mukherjee (2019) ^[12], Nafiu *et al.* (2017) ^[13], and Persic *et al.* (2019) ^[15], leaves were chopped and boiled separately in 1 L distilled water for 15 min, allowing the volume to reduce to ~500 mL; the decoction was cooled for 5 min and filtered through muslin cloth and Whatman No. 1 paper. The filtrate constituted the 100% extract, while the 50% concentration

was prepared immediately before spraying by diluting the stock 1:1 (v/v) with distilled water; extracts were freshly prepared for each species and concentration before each application. Sprays were applied with a knapsack sprayer to runoff at 15-day intervals (30, 45, 60, and 75 DAT) during calm early-morning conditions; controls received distilled water on the same schedule.

2.4 Economic Analysis

Economic feasibility was assessed from prevailing local market prices and cultivation costs, comprising land preparation, planting material, fertilizers, extract preparation, plant protection, irrigation, and labour. Gross return (₹ ha⁻¹) was computed as yield × market price; net return (₹ ha⁻¹) as gross return minus total cultivation cost; and the B:C ratio as gross return divided by cultivation cost.

3. Results

3.1 Economics

Economic evaluation of strawberry cultivation showed variation in gross return, net return and B:C ratio among the leaf extract treatments, RDF levels and their combinations (Table 1). Foliar application of leaf extracts, either alone or in combination with RDF, generally raised all three economic parameters above the values recorded under the control, while RDF supplementation increased gross return and net return across all leaf extract treatments and generally increased B:C ratio. Jackfruit leaf extract 50% with RDF (T₁₇) recorded the maximum gross return, net

return and B:C ratio among all treatment combinations, while the control without RDF (T₁) recorded the minimum values for each of these parameters.

3.1.1 Gross Return (₹ ha⁻¹)

Pooled gross return varied among the eighteen treatment combinations (Table 1). Jackfruit leaf extract 50% with RDF (T₁₇) recorded the maximum pooled gross return (₹ 3,276,560.00 ha⁻¹), followed by Jamun leaf extract 50% with RDF (T₅, ₹ 3,157,025.00 ha⁻¹), Mango leaf extract 50% with RDF (T₉, ₹ 3,064,990.00 ha⁻¹) and Jackfruit leaf extract 100% with RDF (T₁₈, ₹ 3,062,812.50 ha⁻¹), while the control without RDF (T₁) recorded the minimum pooled gross return (₹ 2,146,432.50 ha⁻¹). RDF-supplemented treatments recorded higher gross return than their corresponding non-RDF treatments across all leaf extract levels.

3.1.2 Net Return (₹ ha⁻¹)

Pooled net return also varied among the treatment combinations (Table 1). Jackfruit leaf extract 50% with RDF (T₁₇) recorded the maximum pooled net return (₹ 2,297,418.33 ha⁻¹), followed by Jamun leaf extract 50% with RDF (T₅, ₹ 2,177,883.33 ha⁻¹), Mango leaf extract 50% with RDF (T₉, ₹ 2,085,848.33 ha⁻¹) and Jackfruit leaf extract 100% with RDF (T₁₈, ₹ 2,083,670.83 ha⁻¹), whereas the control without RDF (T₁) recorded the minimum pooled net return (₹ 1,195,922.50 ha⁻¹). RDF supplementation increased net return over the corresponding non-RDF treatment across all leaf extract levels.

Table 1: Effect of different leaf extract treatments and recommended dose of fertilizer (RDF) on gross return, net return and benefit:cost (B:C) ratio of strawberry cultivation during 2024–25, 2025–26 and pooled data.

Treatment	Yield (q ha ⁻¹)			Gross Return			Net Return			B:C Ratio		
	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled
T ₁ (Control + Without RDF)	235.02	229.23	232.13	2,115,180.00	2,177,685.00	2,146,432.50	1,191,980.00	1,199,865.00	1,195,922.50	2.29	2.23	2.26
T ₂ (Control + With RDF)	245.6	254.41	250.01	2,210,400.00	2,416,895.00	2,313,647.50	1,264,768.33	1,416,643.33	1,340,705.83	2.34	2.42	2.38
T ₃ (Jamun Leaf Extract 50% + Without RDF)	246.69	266.99	256.84	2,220,210.00	2,536,405.00	2,378,307.50	1,291,010.00	1,552,585.00	1,421,797.50	2.39	2.58	2.49
T ₄ (Jamun Leaf Extract 100% + Without RDF)	277.24	304.51	290.88	2,495,160.00	2,892,845.00	2,694,002.50	1,565,960.00	1,909,025.00	1,737,492.50	2.69	2.94	2.82
T ₅ (Jamun Leaf Extract 50% + With RDF)	343.39	339.32	341.36	3,090,510.00	3,223,540.00	3,157,025.00	2,138,678.33	2,217,088.33	2,177,883.33	3.25	3.2	3.23
T ₆ (Jamun Leaf Extract 100% + With RDF)	322.26	314.08	318.17	2,900,340.00	2,983,760.00	2,942,050.00	1,948,508.33	1,977,308.33	1,962,908.33	3.05	2.96	3.01
T ₇ (Mango Leaf Extract 50% + Without RDF)	251.16	248.57	249.87	2,260,440.00	2,361,415.00	2,310,927.50	1,331,240.00	1,377,595.00	1,354,417.50	2.43	2.4	2.42
T ₈ (Mango Leaf Extract 100% + Without RDF)	244.47	236.85	240.66	2,200,230.00	2,250,075.00	2,225,152.50	1,271,030.00	1,266,255.00	1,268,642.50	2.37	2.29	2.33
T ₉ (Mango Leaf Extract 50% + With RDF)	331.15	331.54	331.35	2,980,350.00	3,149,630.00	3,064,990.00	2,028,518.33	2,143,178.33	2,085,848.33	3.13	3.13	3.13
T ₁₀ (Mango Leaf Extract 100% + With RDF)	314.48	294.8	304.64	2,830,320.00	2,800,600.00	2,815,460.00	1,878,488.33	1,794,148.33	1,836,318.33	2.97	2.78	2.88
T ₁₁ (Guava Leaf Extract 50% + Without RDF)	236.13	238.13	237.13	2,125,170.00	2,262,235.00	2,193,702.50	1,195,970.00	1,278,415.00	1,237,192.50	2.29	2.3	2.30
T ₁₂ (Guava Leaf Extract 100% + Without RDF)	250.02	247.63	248.83	2,250,180.00	2,352,485.00	2,301,332.50	1,320,980.00	1,368,665.00	1,344,822.50	2.42	2.39	2.41
T ₁₃ (Guava Leaf Extract 50% + With RDF)	246.42	292.12	269.27	2,217,780.00	2,775,140.00	2,496,460.00	1,265,948.33	1,768,688.33	1,517,318.33	2.33	2.76	2.55
T ₁₄ (Guava Leaf Extract 100% + With RDF)	292.82	298.95	295.89	2,635,380.00	2,840,025.00	2,737,702.50	1,683,548.33	1,833,573.33	1,758,560.83	2.77	2.82	2.80
T ₁₅ (Jackfruit Leaf Extract 50% + Without RDF)	338.92	317.56	328.24	3,050,280.00	3,016,820.00	3,033,550.00	2,121,080.00	2,033,000.00	2,077,040.00	3.28	3.07	3.18
T ₁₆ (Jackfruit Leaf Extract 100% + Without RDF)	339.47	316.29	327.88	3,055,230.00	3,004,755.00	3,029,992.50	2,126,030.00	2,020,935.00	2,073,482.50	3.29	3.05	3.17
T ₁₇ (Jackfruit Leaf Extract 50% + With RDF)	361.15	347.66	354.41	3,250,350.00	3,302,770.00	3,276,560.00	2,298,518.33	2,296,318.33	2,297,418.33	3.41	3.28	3.35
T ₁₈ (Jackfruit Leaf Extract 100% + With RDF)	340.05	322.65	331.35	3,060,450.00	3,065,175.00	3,062,812.50	2,108,618.33	2,058,723.33	2,083,670.83	3.22	3.05	3.14

Note: The cost of cultivation was ₹9,23,200.00 ha⁻¹ for the control without RDF (T₁), ₹9,45,631.67 ha⁻¹ for the control with RDF (T₂), ₹9,29,200.00 ha⁻¹ for leaf extract treatments without RDF (B₁), and ₹9,51,831.67 ha⁻¹ for leaf extract treatments with RDF (B₂) during 2024–25. During 2025–26, the corresponding costs of cultivation were ₹9,77,820.00, ₹10,00,251.67, ₹9,83,820.00 and ₹10,06,451.67 ha⁻¹, respectively. The market price of strawberry was ₹90 kg⁻¹ during 2024–25 and ₹95 kg⁻¹ during 2025–26.

3.1.3 Benefit:Cost Ratio

Pooled B:C ratio ranged from 2.26 to 3.35 across the treatment combinations (Table 1). Jackfruit leaf extract 50% with RDF (T₁₇) recorded the maximum pooled B:C ratio (3.35), followed by Jamun leaf extract 50% with RDF (T₅, 3.23), Jackfruit leaf extract 50% without RDF (T₁₅, 3.18) and Jackfruit leaf extract 100% without RDF (T₁₆, 3.17), while the control without RDF (T₁) recorded the minimum pooled B:C ratio (2.26). RDF supplementation generally increased the B:C ratio over the corresponding non-RDF treatment, although this was not observed under Jackfruit leaf extract 100%, where the non-RDF treatment (T₁₆, 3.17) recorded a higher pooled B:C ratio than the RDF treatment (T₁₈, 3.14).

4. Discussion

4.1 Economic Response of Strawberry to Botanical Leaf Extracts and RDF

The economic performance of strawberry, assessed in terms of gross return, net return and B:C ratio, varied among botanical leaf extract treatments, RDF levels and their combinations. Foliar application of leaf extracts, either alone or in combination with RDF, generally improved economic returns relative to the control, suggesting that the extracts contributed to enhanced crop productivity and profitability. This response is consistent with the reported biostimulant effects of botanical leaf extracts, whose phytoconstituents may promote plant growth and productivity, thereby increasing yield and economic returns (du Jardin, 2015) [5].

Among the eighteen treatment combinations, jackfruit leaf extract 50% with RDF (T₁₇) recorded the highest pooled gross return, net return and B:C ratio, whereas the control without RDF (T₁) recorded the lowest values for all three parameters. The superior economic performance of T₁₇ may be attributed to the complementary effects of botanical extract application and adequate nutrient supply on crop growth and yield. Jackfruit leaf extract contains phytochemicals that may support photosynthetic activity and assimilate partitioning (Ranasinghe *et al.*, 2019) [19], while RDF provides balanced N-P-K nutrition essential for vegetative growth, flowering and fruit development. Their combined application therefore appeared to provide a favourable production environment, resulting in greater economic advantage. However, this interpretation represents an agronomic association rather than a statistically tested interaction between the two inputs.

RDF supplementation increased pooled gross and net returns relative to the corresponding non-RDF treatments across all leaf extract levels, indicating that adequate fertilization consistently enhanced productivity and profitability irrespective of the botanical extract applied. This response may be explained by improved nutrient availability for vegetative development, fruit growth and yield formation in strawberry (Lata *et al.*, 2016) [11]. However, the response of B:C ratio was not completely consistent across treatments. Although RDF generally increased the B:C ratio, the non-RDF treatment with jackfruit leaf extract 100% (T₁₆; B:C = 3.17) marginally exceeded its RDF counterpart (T₁₈; B:C = 3.14). This indicates that, at the higher jackfruit extract concentration, the additional cost of RDF was not accompanied by a proportional increase in economic return. Thus, while RDF supplementation generally improved profitability, its economic efficiency may depend on the type and concentration of botanical leaf extract used.

4.2 Economic Indicators: Gross Return, Net Return and Benefit:Cost Ratio

Gross return, determined by yield and prevailing market price,

broadly reflected the effects of botanical leaf extracts and RDF on crop productivity. T₁₇ recorded the highest pooled gross return (₹3,276,560.00 ha⁻¹), followed by T₅ (₹3,157,025.00 ha⁻¹), T₉ (₹3,064,990.00 ha⁻¹) and T₁₈ (₹3,062,812.50 ha⁻¹), whereas T₁ recorded the lowest (₹2,146,432.50 ha⁻¹). The similar gross returns under T₉ and T₁₈ indicate comparable numerical economic performance of the corresponding leaf extract treatments when combined with RDF; however, their close values should not be interpreted as statistically equivalent in the absence of a specific statistical comparison.

Net return showed a pattern largely consistent with gross return, with T₁₇ recording the highest pooled value (₹2,297,418.33 ha⁻¹), followed by T₅ (₹2,177,883.33 ha⁻¹), T₉ (₹2,085,848.33 ha⁻¹) and T₁₈ (₹2,083,670.83 ha⁻¹). The lowest net return was recorded under T₁ (₹1,195,922.50 ha⁻¹). The higher net returns under RDF-supplemented treatments indicate that the additional fertilizer cost was generally offset by the associated increase in productivity and gross revenue. This finding agrees with the principle that balanced fertilization can enhance the profitability of high-value horticultural crops when the additional yield and revenue exceed the associated input costs (Verma *et al.*, 2017) [23].

The B:C ratio, in contrast, reflects the efficiency of investment rather than the absolute magnitude of returns and therefore provides a complementary measure of economic performance. T₁₇ recorded the highest pooled B:C ratio (3.35), followed by T₅ (3.23), T₁₅ (3.18) and T₁₆ (3.17), whereas T₁ recorded the lowest (2.26). The occurrence of T₁₅ and T₁₆ among the higher-ranking treatments indicates that high economic efficiency was not confined to RDF-supplemented combinations. In particular, T₁₆ (jackfruit leaf extract 100% without RDF) recorded a slightly higher B:C ratio than T₁₈ (the corresponding RDF treatment), with values of 3.17 and 3.14, respectively. This marginal difference suggests that the additional cost of RDF at the higher jackfruit extract concentration did not generate a proportionate increase in returns per unit of investment. Thus, gross and net returns favoured treatments generating greater absolute revenue, whereas the B:C ratio highlighted differences in the efficiency with which production costs were converted into economic returns.

4.3 Physiological Basis of the Economic Advantage of Jackfruit Leaf Extract

The superior economic performance of jackfruit leaf extract may be partly related to the physiological effects associated with its phytochemical constituents. Phenolics, flavonoids and related metabolites present in plant-derived extracts can function as biostimulatory compounds and may enhance tolerance to oxidative stress during vegetative growth, flowering and fruit development (Bagh and Mishra, 2024; Alayafi *et al.*, 2025) [2, 1]. Their antioxidant activity may help limit reactive oxygen species accumulation and protect cellular membranes and photosynthetic machinery, thereby contributing to the maintenance of chlorophyll and photosynthetic activity under conditions of high metabolic demand. Such responses are broadly consistent with the metabolic effects reported for bioactive compounds such as mangiferin in mango leaf extracts (Bulgari *et al.*, 2015; Kisiriko *et al.*, 2021) [3, 10].

Maintaining photosynthetic activity during fruit development is important for sustaining assimilate supply and, consequently, fruit growth and yield in strawberry (Hidaka *et al.*, 2019) [8]. The higher gross return, net return and B:C ratio observed under jackfruit leaf extract with RDF (T₁₇) may therefore be consistent with improved physiological performance and assimilate availability. A favourable source–sink relationship could further support the allocation of assimilates to developing fruits and

contribute to fruit growth and yield.

4.4 Nutritional Role of RDF in Enhancing Profitability

The potential benefits of botanical biostimulation are likely to depend on adequate mineral nutrition, as physiological efficiency must be supported by sufficient nutrient availability for sustained growth and yield formation. RDF provides balanced nitrogen, phosphorus and potassium, with nitrogen supporting protein synthesis and canopy development, phosphorus contributing to energy metabolism and reproductive development, and potassium regulating stomatal activity and assimilate transport (Oosterhuis *et al.*, 2013; Wu *et al.*, 2024) [14, 25]. The generally higher pooled gross and net returns under RDF-supplemented treatments across leaf-extract levels are consistent with the importance of balanced mineral nutrition in supporting crop productivity (Quddus *et al.*, 2025) [16].

The higher net returns obtained with RDF further indicate that, in most treatment combinations, the additional revenue generated was sufficient to offset the cost of fertilizer application. This is consistent with the broader principle that balanced fertilization can improve economic returns when the value of the additional production exceeds the associated input cost (Jaswal and Sandal, 2019) [9]. Nevertheless, the economic response was not uniform for B:C ratio. Although RDF generally increased the ratio relative to the corresponding non-RDF treatment, the reverse occurred with jackfruit leaf extract 100%, where T₁₆ without RDF recorded a B:C ratio of 3.17 compared with 3.14 under T₁₈ with RDF. This marginal difference indicates that the additional fertilizer expenditure at this extract concentration did not produce a proportionate increase in economic efficiency.

4.5 Integrated Application of Botanical Leaf Extract and RDF

The combined application of RDF and botanical leaf extract appeared to provide complementary benefits, with jackfruit leaf extract 50% + RDF (T₁₇) showing the most favourable numerical economic performance. RDF supplies essential mineral nutrients, whereas botanical extracts may complement this nutrition through potential biostimulatory and antioxidant effects (Section 4.3). Thus, botanical extracts may serve as supplementary inputs rather than substitutes for recommended fertilization.

T₁₇ recorded the highest pooled gross return (₹3,276,560.00 ha⁻¹), net return (₹2,297,418.33 ha⁻¹) and B:C ratio (3.35), compared with the lowest values under T₁ (₹2,146,432.50 ha⁻¹, ₹1,195,922.50 ha⁻¹ and 2.26, respectively). This favourable performance suggests that combining botanical and mineral inputs can improve economic outcomes; however, formal interaction analysis was not conducted, so synergistic effects cannot be conclusively established. The relatively low cost of botanical leaf extracts may have contributed to the high B:C ratio, particularly when modest input costs are accompanied by increased productivity (Wei *et al.*, 2018) [24]. This interpretation is broadly consistent with reports that integrated foliar and mineral nutrient management can improve economic performance in strawberry and other crops (Bagh and Mishra, 2024; Raj and Prasad, 2023) [2, 18]. The response to RDF was not uniform across extract concentrations. T₁₆ without RDF recorded a slightly higher B:C ratio (3.17) than T₁₈ with RDF (3.14), indicating that additional fertilizer expenditure did not always produce a proportional improvement in return efficiency. Such responses may occur when fertilizer costs exceed the economic benefit of the associated yield increase (Quddus *et al.*, 2025; Vasuki *et al.*, 2025) [16, 21]. The results support botanical leaf extracts as complementary inputs within balanced nutrient management, although their economic advantage depends on

extract concentration and production response.

4.6 Commercial and Sustainability Implications

The feasibility of incorporating botanical leaf extracts into existing strawberry production systems supports their potential commercial relevance. Jackfruit leaf extract can be applied through conventional foliar practices with limited additional infrastructure, while locally available plant material may reduce dependence on costly external inputs (Rouphael and Colla, 2020) [20]. This may benefit smallholders seeking low-cost supplementary inputs, while compatibility with RDF-based management could facilitate adoption at larger scales without major changes to established practices. The economic results indicate potential value in combining botanical extracts with balanced fertilization. T₁₇ produced the highest pooled gross return, net return and B:C ratio, indicating the most favourable economic outcome among the treatments. However, the inconsistent B:C response across extract concentrations shows that RDF integration does not necessarily improve economic efficiency in every combination. Botanical extracts should therefore be considered complementary inputs rather than replacements for balanced mineral fertilization. From a sustainability perspective, locally available botanical materials may help diversify crop inputs and potentially reduce reliance on externally sourced products. However, nutrient-use efficiency, nutrient losses, resource consumption and environmental impacts were not directly measured. Sustainability benefits therefore remain prospective rather than demonstrated. Future research should evaluate these parameters alongside long-term soil and crop responses to determine whether the observed economic advantages are accompanied by measurable improvements in resource-use efficiency and environmental performance.

5. Conclusion

Economic performance varied among the eighteen treatment combinations evaluated. Jackfruit leaf extract 50% + RDF (T₁₇) recorded the highest pooled gross return (₹3,276,560.00 ha⁻¹), net return (₹2,297,418.33 ha⁻¹) and B:C ratio (3.35), while the control without RDF (T₁) recorded the lowest values for all three indicators. Jamun leaf extract 50% + RDF (T₅) and Jackfruit leaf extract 100% + RDF (T₁₈) also showed relatively high economic performance. RDF supplementation increased gross and net returns across the corresponding treatment pairs, and generally improved B:C ratio, although this response was not uniform, with T₁₆ exceeding T₁₈ for pooled B:C ratio. These findings indicate that botanical leaf extracts, particularly jackfruit leaf extract, hold potential as complementary inputs within RDF-based strawberry production. Multi-location, multi-season validation is recommended before generalizing these findings.

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Declarations

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Conflict of Interest

The authors declare that they have no conflict of interest.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Clinical trial number

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Consent to Publish declaration

not applicable.

Consent to Participate declaration

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Ethics declaration

not applicable.

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