Sustainable Processes Connect
ISSN: 3079-1421
2025, Article ID. 2025.0019, Cite as: https://doi.org/10.69709/SusProc.2025.101023

SCIFINITI PUBLISHING

Research Article

OPEN ACCESS

Enhancing Fiber Yield and Environmental Sustainability Through Integrated Fertilization Strategies and Waste Valorization of Ramie (*Boehmeria nivea* L.)

Espita Palwan Abinash Debbarma Sampili Debbarma Shaon Ray Chaudhuri*

Microbial Technology Laboratory, Department of Microbiology, Tripura University, Suryamaninagar, Tripura West, Tripura 799022, India

Article History

Received: June 20, 2025 Accepted: December 18, 2025 Published: December 30, 2025

Abstract

Ramie (*Boehmeria nivea*) is one of the oldest natural fiber plants, producing fibers with high strength and luster. Ramie has the potential to be an essential component of the natural fiber-based textile market owing to its excellent properties. Synthetic fibers are non-biodegradable finite resources, and hence, there is a need to replace synthetic fibers with natural fibers. The processing of Ramie fiber for fine yarn production continues to improve. However, the challenge is to ensure a consistent supply of raw Ramie fiber for commercial purposes while minimizing environmental impact. The climate of the northeastern states of India is favorable for Ramie cultivation. However, limited community awareness and the lack of scientific cultivation manuals are major constraints to commercial-scale Ramie cultivation. Ramie is a rapidly growing plant that requires adequate fertilizer application from the second year onward through the sixteenth year after planting. The leaching of inorganic fertilizer (IF) used in Ramie cultivation has adverse environmental impacts. In this study, Ramie cultivation using a 1:1 combination of IF and bacterial biofertilizer (BF) increased biomass and fiber yield compared with IF or BF alone, supporting practical adoption. The mode of action is to ensure the availability of nitrogen (N), phosphorus (P), and potassium (K) through the application of IF while preventing their leaching into the environment by restricting them within the plant root zone, thereby indirectly facilitating their uptake. Briquettes made from decortication waste (generated at 3.92 kg waste per kg fresh decorticated fiber) provided sustained combustion and, when used as fuel for lemongrass leaf distillation, yielded more essential oil than firewood or 100% bamboo briquettes. Thus, this paper highlights environmental protection achieved through process optimization, from cultivation to end-product valorization via eco-friendly product development.

Keywords:

bacterial biofertilizer; inorganic fertilizer; ramie fiber; sustainable cultivation; waste valorization

1. Introduction

The textile industry in India is rapidly growing, accounting for 14% of total industrial manufacturing [1,2]. The primary raw materials used in the textile industry include synthetic fibers, natural fibers, synthetic dyes, chemicals, and water [1]. Cultivation of natural fiber crops can increase competition with food production because agricultural land is limited [3]. On the other hand, synthetic fibers dominate the manufacturing industries. However, synthetic fibers are non-biodegradable and not eco-friendly [4]. Natural fiber-based textiles, including hemp, silk, jute, cotton, and Ramie, can serve as alternatives to synthetic fibers [5]. Ramie (*Boehmeria nivea*), also known as Chinese silk or China grass, is one of the strongest, longest, and oldest natural bast fiber plants [6–8]. Ramie

* **Corresponding Author:**
Shaon Ray Chaudhuri, Microbial Technology Laboratory, Department of Microbiology, Tripura University, Suryamaninagar, Tripura West, Tripura 799022, India, shaonraychaudhuri@tripurauniv.ac.in

fibers show high tenacity and tensile strength (greater than cotton and silk), luster, thermostability (>200 °C), and moisture absorption, producing high-quality fabric after degumming [6,9–11]. Ramie exhibits a high length-to-breadth ratio of 3500, making it well-suited for the production of fine yarn. There are around 100 Boehmeria species, with 19 reported in India [6,7]. The two most common Ramie species are white Ramie and green Ramie. Native to southwestern China, Ramie has been used for clothmaking and mummification since ancient times. Originating in the mountain valleys of southwest China, it was a major fiber used before cotton arrived around AD 1300. This plant grows in tropical, subtropical, and temperate regions globally [6,7]. China, Indonesia, the Philippines, Korea, Vietnam, and Japan are the primary global raw material suppliers, with China accounting for more than 95% of world production [8,10]. Around 72,934 hectares (ha) of area is under Ramie cultivation in China [8]. The literature indicates that about 320 ha is cultivated with Ramie across India. In India, Ramie is grown in Assam, Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Mizoram, and the northern part of West Bengal [7]. However, Ramie is also grown in Kharagpur, Tripura, and Bhubaneswar for research purposes [12]. In India, Ramie is known as Rhea, Popah, KhunKoora, Kurkunda, etc. [13]. Despite the massive demand for Ramie fiber, production is very low [14]. India has suitable climatic conditions for Ramie cultivation, but raw Ramie fibers are imported from other producing countries [8]. Ramie is a versatile fiber used across various industries, including traditional Korean custom hanbok and Japanese kimono materials. Ramie fibers can be blended with other fibers to create high-quality dress materials, tablecloths, towels, napkins, and canvas [6,11,15]. Ramie can also be used for bioethanol production, as medicines, as animal feed, and as mulch [16]. Its protein-rich leaves can be used as animal feed [17].

Ramie can be grown in various climatic conditions and soil types, with better growth and fiber yields occurring in areas with favorable climatic conditions and soil types [18]. Deep, fertile sandy-loamy soils are preferred to retain moisture. Such organic-matter-rich soil with a pH of 6–7 is preferred for Ramie cultivation [7,18]. In sandy soil, both water and fertilizer leach out, and in clay soil, root system development is obstructed by compaction on drying. An average of 1500–2500 mm of rainfall is suitable for Ramie cultivation, with temperatures between 25 °C and 31 °C [7,18]. Ramie stems begin to turn brown, necessitating harvesting before reaching maximum height when rainfall is below 1000 mm [18]. Ramie cultivation requires adequate moisture, but waterlogging should be avoided [8,18]. Vegetative propagation of Ramie can be done through rhizome cuttings, plantlets, stem cuttings, and seeds [7,18]. Ramie can be grown throughout the year under irrigated conditions using flat or ridge-and-furrow planting methods [7,18]. The ideal distance between rows is 60 centimeters (cm), and between plants is 30 cm [7,19].

According to Oshiumi (1951), Ramie is planted in late March to early April in warmer areas and late April in cooler areas [18]. Ramie can be harvested up to six times a year under ideal conditions [6]. Farmers can start harvesting from the second year every 45 days for up to 16 years [11]. Harvesting can be done by cutting the stem a few cm above the root [6]. Ramie fibers are extracted by decortication, which removes the outer bark, cortex, and pectin, followed by washing and drying [6]. Decorticated waste generated during fiber production can be used as mulch, reducing waste and making the process more profitable and environmentally friendly [8]. The yield of Ramie fiber ranges from 1600 to 2200 kg ha^{-1} [7]. The fiber recovered represents only 4–5% of the total plant biomass [6]. The cost of raw Ramie fiber is reported as ~INR 115 kg^{-1} [8] and may vary from INR 90 and INR 200 kg^{-1}. Fertilizers, primarily N, P, and K, are important for plant growth [20]. Routine fertilization is needed to maintain soil health and to enhance fiber yield [7,8,18]. It was reported that nitrogen (N) and phosphorus (P) increased Ramie fiber yield, whereas potassium (K) improved fiber quality [21]. However, chemical fertilizers can have adverse environmental impacts due to leaching, and their excessive use may deplete essential soil micronutrients [22]. Organically rich soil and proper fertilization positively impact fiber yield [23]. Ray Chaudhuri et al. (2021) reported that biofertilizer-based cultivation improves fiber yield while maintaining soil nutrient levels [8]. Gogoi et al. (2021) reported that ammonia-rich liquid biofertilizer enhanced Ramie fiber yield [24]. Integrated Nutrient Management (INM), which combines organic, inorganic, and microbial inoculants to enhance crop yield, is crucial for the efficient and sustainable use of resources [25]. A patented [26] BF with indole acetic acid (auxin) secretion reportedly retains nitrate and phosphate within the root zone up to 11 cm and thereby prevents leaching of unutilized fertilizer, which furthermore helps in plant growth [27]. This BF (a 1:1 combination of aerobic and anaerobic consortium) has been reported to promote the growth of mung bean, lemongrass, and cassava [27,28].

The BF is made up of two bacterial consortiums namely NB1 which is an anaerobic consortium (*Pseudomonas* sp, *E. coli*, and uncultured bacterium in a ratio of 44:37:19) and an aerobic BN7 (*Pseudomonas* sp., *Bacillus* sp., *Azoarcus* sp., and uncultured bacterium in a ratio of 20:3:31:46). While NB1 was isolated from the soil of

East Kolkata Wetlands, BN7 was obtained from the immobilized biomass of a nitrate-reducing bioreactor at the Waste Management Department of Bhabha Atomic Research Center, Mumbai, India, using nitrate broth [27,29]. The consortia were selectively enriched in nitrate broth from the environmental samples. After multiple rounds of cultivation and characterization, the consortia, when mixed in a 1:1 proportion [26], could prevent leaching of nitrate from the soil up to 11 cm depth [27]. Pot trial experiments confirmed enhanced yield with higher chlorophyll content of the leaves, hence leading to the development of this biofertilizer formulation [26,30]. To use a BF at a commercial scale, it is essential to test its performance across a variety of crops before recommending it for large-scale application. Hence, in this current study, the authors hypothesize that a combination of BF and IF at lower than recommended doses can enhance plant growth and fiber yield through sustained supply of plant growth nutrients throughout the growth period, preventing nutrient leaching and so retaining soil fertility. Ramie cultivation was conducted under four treatments: a control (no fertilizer), inorganic fertilizer (IF), biofertilizer (BF), and a combination of IF and BF applied at half the recommended dose.

2. Materials and Methods

2.1. Agronomy

2.1.1. Location of the Experiment

The experiment was conducted at Tripura University premises (23.9408° latitude and 91.9882° longitude), Tripura, India. The cultivation duration was from April 2023 to February 2024. The average temperature of the area varied from 18 °C to 28 °C.

2.1.2. Cultivation of Ramie

To assess the impact of different fertilizers on agronomic parameters and yield of Ramie, a standard variety (var. R1411) was cultivated. Ramie cultivation was carried out from April 2023 to February 2024 with four different treatments:

T0 = Control (no fertilizer),
T1 = 100% IF,
T2 = 100% BF,
T3 = Combination of 50% IF and 50% BF.

Ramie was planted using ridge and furrow methods to prevent waterlogging during the rainy season. The distance between two rows was 60 cm, and between two consecutive plants in a row was 30 cm. The furrows were oriented north–south to ensure adequate sunlight. The area of each field was 13.86 m^2. Rhizomes measuring about 12–15 cm were taken from 3- to 4-year-old plantations and planted within 72 h of collection to retain viability. Rhizomes were placed horizontally into the soil about 5 cm deep and covered with soil. Applications of IF (with irrigation), BF, and a combination of IF and BF were done in their respective fields immediately after the plantation of the rhizome. No fertilizer was applied in the control field. Fertilization was performed only once, at the time of rhizome planting. As per Gogoi (2022), the recommended dose of 100% IF used in this study includes N, P, and K in a ratio of 20:15:15 kg/ha (60.15 g of urea, 129.93 g of single superphosphate, and 33.264 g of muriate of potash were applied) [19], and the 100% dose of BF was 1.33 L/m^2 with 3.68×10^9 cells/m^2 [29]. The combination (IF + BF) was made up of 50% IF (N:P:K 10:7.5:7.5 kg.ha) and 50% BF (0.665 L/m^2 with 1.84×10^9 cells/m^2). Nitrate broth was prepared and autoclaved at 121 °C for 15 min (15 psi) to prepare BF. Following an overnight contamination check at 37 °C, 1% anaerobic consortium was inoculated into degassed (purged with CO_2 and N_2) vials, and 1% aerobic consortium was inoculated into conical flasks containing sterile nitrate broth, respectively. After 24 hours of confluent growth, the two bacterial consortia were mixed in a 1:1 ratio and applied to the field.

2.1.3. Data Collection

Mature stems were harvested by cutting them just above ground level. The first harvest took 106 days for the stem to mature. The second harvest was conducted 50 days after the first, and the third harvest was carried out 30 days after the second. Harvesting was performed when the stem began to show a color change (brown) above ground level. Harvesting was done using a sickle. The height of the stem was measured using a measuring tape, the diameter of the stems was measured using a vernier caliper, the number of stems per plant was counted, and stem weight per rhizome (leaf weight plus strip weight), strip weight (stem without leaves) per rhizome, and fiber weight per rhizome were measured using a weighing balance (SF-400) and documented after every harvest. The stems were decorticated by using a decorticator machine (Akriti, India). After decortication, Ramie fibers were immersed in water at a 1:8 fiber-to-liquid ratio. After 6 h of dipping, the Ramie fibers were washed with tap water and dried in the sun [11].

2.1.4. Soil Analysis

The soil was collected pre-cultivation and post-cultivation for T3 treatment after third round of harvesting (186 days)

The chemical parameters were analyzed in terms of concentration of N [31] (IS 14684-1999), P [32] (IS 6361:1971), K [33] (IS 9497:1980), sodium [33] (IS 9497:1980), magnesium [34] (IS 5949:1990 RA 2003), and organic matter [35] [IS 2720 (Part XXII): 1972] through an outsourcing facility (Precision Laboratory, Kolkata, India).

2.1.5. Data Analysis

The recorded data for each harvest were analyzed using an F-test followed by a T-test to determine whether the treatments differed significantly at the 95% confidence level. The treatments compared were T0 vs. T3, T1 vs. T3, and T2 vs. T3. The graphical representation was generated using GraphPad Prism 8.0.1.

2.2. Ramie Briquette as a Fuel Source

Ramie decorticated waste collected after fiber extraction through decortication was oven-dried. A portion of the waste was ground using a mixer grinder. The particle size of the ground waste used for forming the pellet was measured. Thirty particles were measured, and the results were expressed as the mean ± standard error. The ground waste was used for pellet formation without additives in a pelletizer (KBr Press) at UGC DAE Centre, Kolkata (India), using 100 kg cm^{-2} pressure for 30 s. This was done to test the material's self-adhering properties. The particle and the pellet formed were visualized under a Field Emission Scanning Electron Microscope (SUPRA 55 VP-4132, Carl Zeiss) with platinum coating, as per standard protocol [28], to examine the surface structure and understand the reason for the self-adhering property. Oven-dried Ramie decorticated waste was converted into briquettes at G-Cube Sticks Pvt. Ltd., using 80% Ramie waste and 20% bamboo waste (dust generated during stick production). The mixture was maintained at a moisture content of 7–10% and compressed under a pressure of 2 tons per square centimeter. The formed briquettes were used as an alternative fuel, replacing firewood during lemongrass oil extraction with an indigenous steam distillation system.

3. Results

3.1. Average Number of Stems

The average number of stems per rhizome was found to be 16.50 ± 5.47, 26.65 ± 8.65, and 29.23 ± 9.66 during the 1st, 2nd, and 3rd rounds of harvesting with T3 treatment, which was significantly higher as compared to T0, T1, and T2 during the 1st harvest (6.74 ± 3.30, 9.13 ± 4.41, and 7.52 ± 4.24 with p-values of 4.54×10^{-5} , 3.14×10^{-5}, and 8.93×10^{-7}, respectively), 2nd harvest (12.23 ± 5.51, 13.35 ± 5.43, and 13.55 ± 6.53 with p-values of 8.97×10^{-5}, 1×10^{-4}, and 2.70×10^{-6}, respectively), and 3rd harvest (13.19 ± 5.50, 15.52 ± 5.33, and 14.26 ± 5.71 with p-values of 1×10^{-4}, 3.8×10^{-4}, and 1.5×10^{-4}, respectively). Plants treated with T0 produced the fewest stems. In contrast, those receiving T3 had the highest number of stems across all harvests, as shown in Figure 1.

3.2. Average Height of Stem

Figure 2 shows that the average height of stems was highest with T3 treatment, and the height of stems was 91.24 ± 21.51 cm, 93.10 ± 21.64 cm, and 95.79 ± 12.41 cm during the 1st, 2nd, and 3rd harvests, respectively. The average height of T3-treated plants was found to be significantly superior to that of T0, T1, and T2 during the 1st harvest (52.74 ± 15.81 cm, 51.06 ± 17.72 cm, and 46.38 ± 12.18 cm with p-values of 8.9×10^{-8}, 1.7×10^{-7}, and 1.4×10^{-5} , respectively), 2nd harvest (61.40 ± 16.63 cm, 58.55 ± 14.03 cm, and 62.96 ± 15.65 cm with p-values of 5.63×10^{-6}, 1.3×10^{-4}, and 6.85×10^{-6}, respectively), and 3rd harvest (63.48 ± 12.91 cm, 67.56 ± 19.13 cm, and 67.86 ± 11.17 cm with p-values of 4.96×10^{-9}, 2.47×10^{-5} , and 1.18×10^{-8}, respectively).

3.3. Average Diameter of Stem

The average diameter of the stem shown in Figure 3 was significantly improved using T3 treatment (12.09 ± 3.04 mm) as compared to T0 (4.45 ± 1.36 mm), T1 (6.45 ± 1.52 mm), and T2 (4.71 ± 1.64 mm) during the 1st round of harvesting, with p-values of 3.1×10^{-6}, 3.7×10^{-5}, and 2.9×10^{-6}, respectively. During the 2nd round of harvesting, the diameter of the stem was significantly higher with T3 treatment (13.30 ± 4.54 mm) as compared to T0 (7.13 ± 1.48 mm), T1 (8.06 ± 1.84 mm), and T2 (6.61 ± 1.89 mm) with p-values of 5.1×10^{-4}, 1.6×10^{-3}, and 3×10^{-4}, respectively. Similarly, the average diameter of stems was significantly higher with T3 treatment (14.81 ± 3.35 mm) during the 3rd round of harvesting as compared to T0 (7.26 ± 1.32 mm), T1 (9.13 ± 2.23 mm), and T2 (7.61 ± 1.26 mm) with p-values of 8.01×10^{-6}, 8.25×10^{-5}, and 1.22×10^{-5}, respectively.

3.4. Average Weight of Stem

The average weight of stem per rhizome (Figure 4) with T3 treatment was found to be 574.05 ± 250.73 g, 1216.44 ± 693.94 g, and 1320.53 ± 584.34 g during the 1st, 2nd, and 3rd rounds of harvesting, respectively, which was significantly enhanced as compared to T0, T1, and T2 during the 1st harvest (244.55 ± 118.97 g, 234.35 ± 103.47

2025, Vol. 1, Article ID. 2025.0019
https://doi.org/10.69709/SusProc.2025.101023

g, and 188.39 ± 103.30 g with p-values of 6.2×10^{-4}, 5.6×10^{-4}, and 2.2×10^{-4}, respectively), the 2nd harvest (364.61 ± 155.35 g, 539.61 ± 414.40 g, and 368.87 ± 235.91 g with p-values of 1.1×10^{-3}, 4.6×10^{-3}, and 1×10^{-3}, respectively), and the 3rd harvest (443.77 ± 260.21 g, 689.94 ± 330.24 g, and 424.45 ± 218.25 g with p-value of 2.7×10^{-4}, 2.6×10^{-3}, and 2.1×10^{-4}, respectively).

3.5. Average Strip Weight

The average strip weight (Figure 5) was 280.88 ± 123.87 g with T3 treatment, which was found to be significantly increased as compared to T0 (107.77 ± 58.01 g), T1 (123.35 ± 67.89 g), and T2 (101.84 ± 57.21 g) during the 1st harvesting with p-values of 3.9×10^{-4}, 8.6×10^{-4}, and 2.9×10^{-4}, respectively. Similarly, during the 2nd round of harvesting, the strip weight was significantly higher with T3 treatment (555.34 ± 309.94 g) than T0 (189.61 ± 83.73 g), T1 (223.32 ± 169.39 g), and T2 (197.71 ± 126.24 g) with p-values of 1.3×10^{-3}, 2.7×10^{-3}, and 1.7×10^{-3}, respectively. Average strip weight was significantly higher with T3 treatment (774.25 ± 337.91 g) during the 3rd harvesting as compared to T0 (239.87 ± 144.19 g), T1 (344.10 ± 193.62 g), and T2 (235.48 ± 120.82 g) with p-values of 1.76×10^{-4}, 8.87×10^{-4}, and 1.53×10^{-4}, respectively.

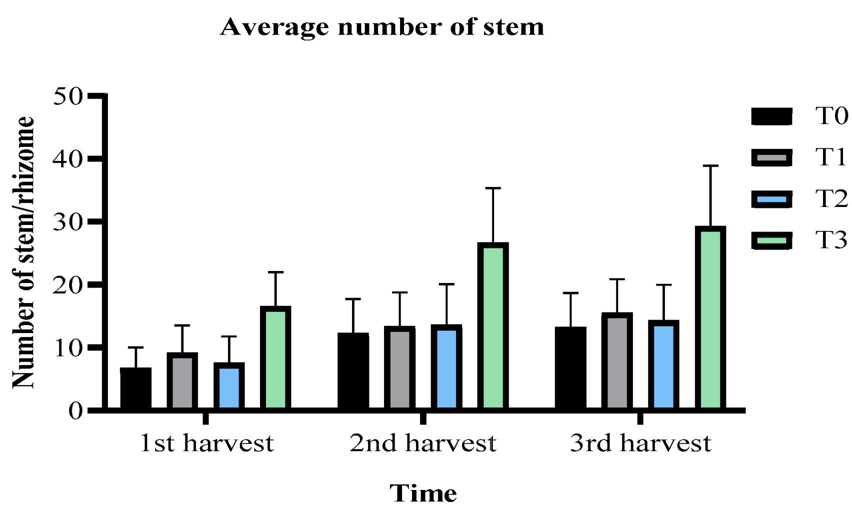

Figure 1: Average number of stems per rhizome using different fertilization regimes.

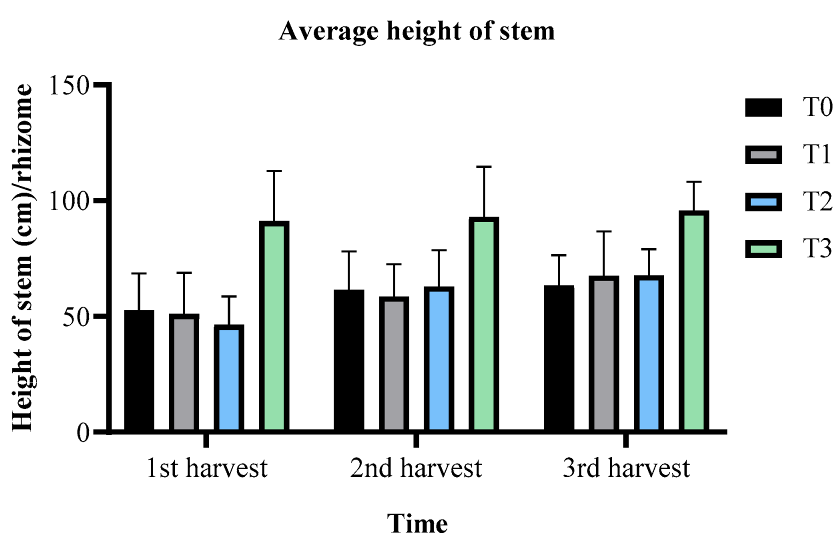

Figure 2: Average height of stems (cm) per rhizome using different fertilization regimes.

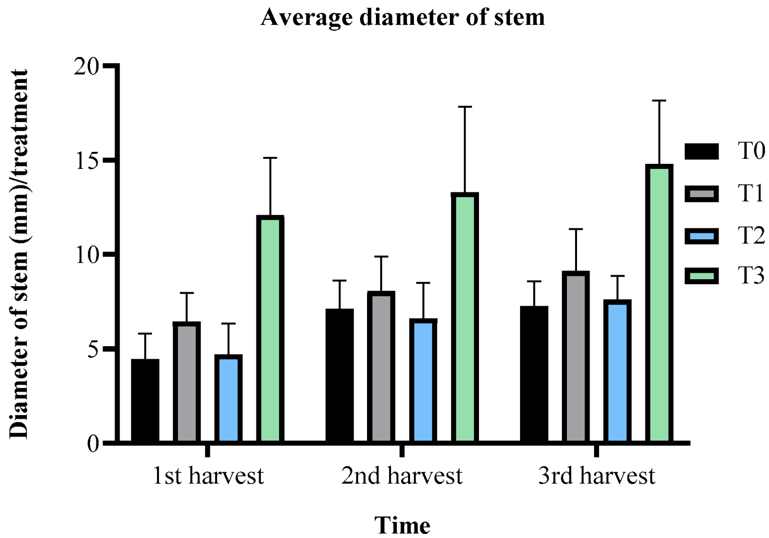

Figure 3: Average diameter of stem (mm) using different fertilization regimes.

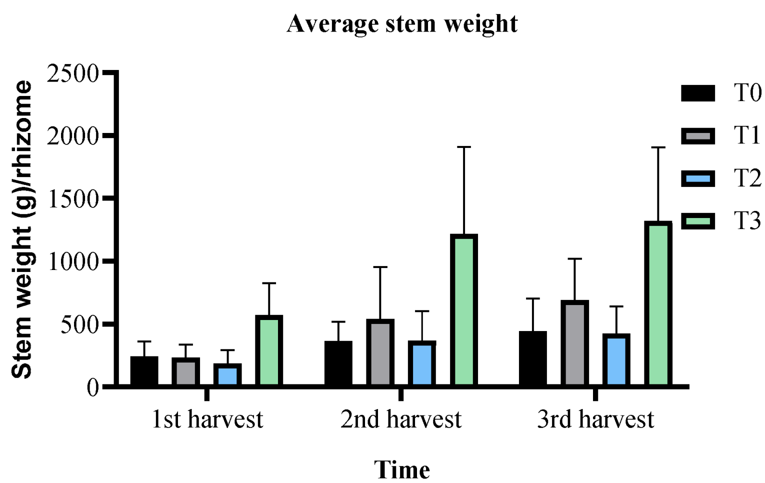

Figure 4: Average stem weight (g) per rhizome using different fertilization regimes.

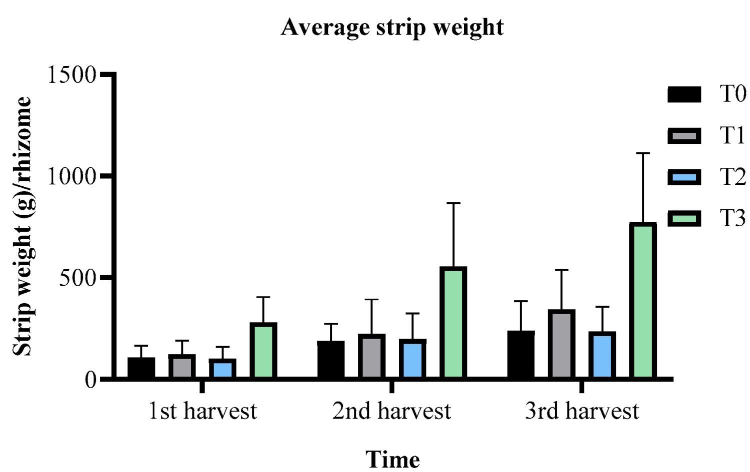

Figure 5: Average strip weight (g) per rhizome using different fertilization regimes.

2025, Vol. 1, Article ID. 2025.0019
https://doi.org/10.69709/SusProc.2025.101023

3.6. Fiber Yield

Like other agronomic parameters, the average fiber weight (Figure 6) was also significantly enhanced using T3 treatment (4.58 ± 1.92 g) as compared to T0 (1.29 ± 0.70 g), T1 (2.34 ± 1.29 g), and T2 (1.73 ± 0.97 g) during the 1st round of harvesting, with p-values of 1.3×10^{-4}, 2.2×10^{-3}, and 3.7×10^{-4}, respectively. The T3 treatment (25.97 ± 14.50 g) also showed significantly higher fiber weight during the 2nd round of harvesting as compared to the T0 (8.34 ± 3.68 g), T1 (8.93 ± 6.78 g), and T2 (7.12 ± 4.54 g) with p-values of 1.3×10^{-3}, 1.4×10^{-3}, and 6.9×10^{-4}, respectively. Similarly, the average fiber weight was significantly higher with T3 treatment (22.81 ± 9.95 g) during the 3rd harvest as compared to T0 (9.35 ± 5.62 g), T1 (10.32 ± 5.81 g), and T2 (9.89 ± 5.07 g) with a p-value of 5.65×10^{-4}, 8.64×10^{-4}, and 7.12×10^{-4}, respectively.

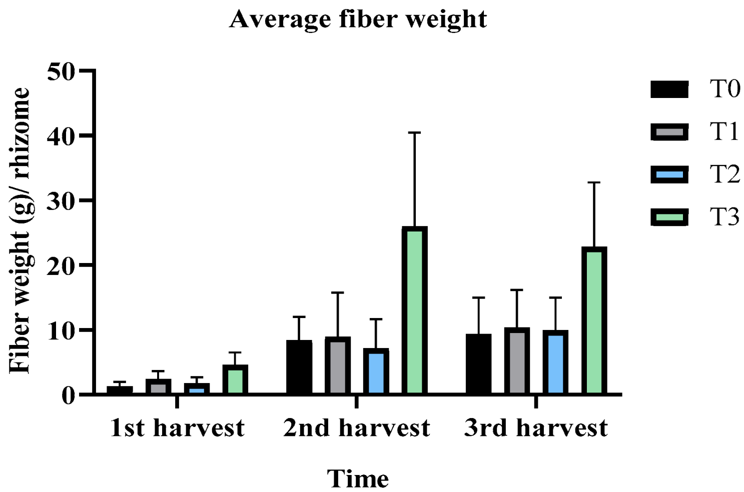

Figure 6: Average fiber weight (g) per rhizome using different fertilization regimes.

All the above parameters were assessed after the 3rd harvest (4th harvest after 45 days of 3rd harvest, 5th harvest after 45 days of 4th harvest, and 6th harvest after 45 days of 5th harvest), as shown in Table 1. Regarding fiber weight, an increase was observed in treatments T0, T1, and T2, whereas T3 showed a decrease, leading to an overall non-significant difference among treatments from the fourth harvest onward. Hence, fertilizer reapplication will be recommended after the 3rd harvest for maintaining fiber yield. For stem weight, there was no significant difference between T3 and T1 during the fourth harvest, indicating that IF application resulted in a gradual increase in yield. For stem height, treatment T3 showed a significant increase compared to T1, even after the fourth and sixth harvests. For the number of stems and stem diameter, there was a substantial increase in treatment T3 at the 4th, 5th, and 6th harvests. For strip weight, the 4th and 5th harvests showed insignificant differences between T3 and T1 (with T3 higher). In contrast, the 6th harvest shows significant differences between the same combinations. (Table 1). The statistical data are shown in Supplementary Table S1.

Table 1: Tabulation of the agronomic parameters of Ramie cultivation with four treatments (T0, T1, T2, T3) over 6 harvests.

Agronomic Parameters	Time	T0	T1	T2	T3
Number of stems	1st harvest	6.74 ± 3.30	9.13 ± 4.41	7.52 ± 4.24	16.50 ± 5.47
	2nd harvest	12.23 ± 5.51	13.35 ± 5.43	13.55 ± 6.53	26.65 ± 8.65
	3rd harvest	13.19 ± 5.50	15.52 ± 5.33	14.26 ± 5.71	29.23 ± 9.66
	4th harvest	12.87 ± 5.87	14.71 ± 4.89	13.87 ± 5.48	23.43 ± 5.70
	5th harvest	13.61 ± 5.49	15.29 ± 5.43	12.06 ± 5.10	21.64 ± 6.09
	6th harvest	14.38 ± 6.87	15.80 ± 5.69	13.74 ± 5.86	23.04 ± 7.12

Table 1: *Cont.*

Agronomic Parameters	Time	T0	T1	T2	T3
Height of stem (cm)	1st harvest	52.74 ± 15.81	51.06 ± 17.72	46.38 ± 12.18	91.24 ± 21.51
	2nd harvest	61.40 ± 16.63	58.55 ± 14.03	62.96 ± 15.65	93.10 ± 21.64
	3rd harvest	63.48 ± 12.91	67.56 ± 19.13	67.86 ± 11.17	95.79 ± 12.41
	4th harvest	83.83 ± 20.41	94.57 ± 17.93	79.49 ± 18.47	128.28 ± 49.77
	5th harvest	65.44 ± 24.17	79.33 ± 25.06	55.55 ± 13.60	101.61 ± 61.24
	6th harvest	69.65 ± 18.54	78.93 ± 26.73	58.60 ± 18.64	110.50 ± 19.56
Diameter of stem (mm)	1st harvest	4.45 ± 1.36	6.45 ± 1.52	4.71 ± 1.64	12.09 ± 3.04
	2nd harvest	7.13 ± 1.48	8.06 ± 1.84	6.61 ± 1.89	13.30 ± 4.54
	3rd harvest	7.26 ± 1.32	9.13 ± 2.23	7.61 ± 1.26	14.81 ± 3.35
	4th harvest	8.65 ± 1.11	8.23 ± 0.88	8.16 ± 1.59	10.49 ± 2.88
	5th harvest	8.94 ± 2.46	9.58 ± 1.93	8.55 ± 1.85	11.70 ± 3.27
	6th harvest	9.06 ± 2.28	9.16 ± 2.37	8.93 ± 1.89	15.17 ± 2.84
Stem weight (g)	1st harvest	244.55 ± 118.97	234.35 ± 103.47	188.39 ± 103.30	574.05 ± 250.73
	2nd harvest	364.61 ± 155.35	539.61 ± 414.40	368.87 ± 235.91	1216.44 ± 693.94
	3rd harvest	443.77 ± 260.21	689.94 ± 330.24	424.45 ± 218.25	1320.53 ± 584.34
	4th harvest	671.52 ± 466.62	851.42 ± 552	507.10 ± 295.91	960.50 ± 255.82
	5th harvest	576.32 ± 464.36	838.32 ± 667.64	370.48 ± 303.12	1218.83 ± 1073.55
	6th harvest	537.12 ± 435.58	883.83 ± 756.58	329.64 ± 206.34	1739.67 ± 909.13
Strip weight (g)	1st harvest	107.77 ± 58.01	123.35 ± 67.89	101.84 ± 57.21	280.88 ± 123.87
	2nd harvest	189.61 ± 83.73	223.32 ± 169.39	197.71 ± 126.24	555.34 ± 309.94
	3rd harvest	239.87 ± 144.19	344.10 ± 193.62	235.48 ± 120.82	774.25 ± 337.91
	4th harvest	382.42 ± 275.59	468.39 ± 322.43	287.58 ± 167.34	522.06 ± 176.91
	5th harvest	315.87 ± 269.48	508.23 ± 409.56	189.45 ± 161.32	954.15 ± 943.59
	6th harvest	336.74 ± 293.97	543.09 ± 454.82	191.16 ± 116.97	1113.93 ± 753.80
Fiber weight (g)	1st harvest	1.29 ± 0.70	2.34 ± 1.29	1.73 ± 0.97	4.58 ± 1.92
	2nd harvest	8.34 ± 3.68	8.93 ± 6.78	7.12 ± 4.54	25.97 ± 14.50
	3rd harvest	9.35 ± 5.62	10.32 ± 5.81	9.89 ± 5.07	22.81 ± 9.95
	4th harvest	17.10 ± 12.32	17.35 ± 11.95	15.77 ± 9.18	20.35 ± 9.37
	5th harvest	16.55 ± 14.12	17.26 ± 13.91	16.73 ± 14.24	27.55 ± 29.46
	6th harvest	16.63 ± 14.52	18.89 ± 15.82	16.47 ± 10.08	25.70 ± 17.39

The data indicate that Ramie cultivation with T3 can reduce IF use by 50% without compromising productivity. Moreover, 1.80-fold, 1.99-fold, and 1.88-fold higher number of stems were obtained by T3 treatment than by T1 treatment alone during the first, second, and third rounds of harvesting, respectively. The height of stems was 1.78-fold, 1.59-fold, and 1.41-fold higher with T3 treatment than with T1 treatment alone during the first, second, and third rounds of harvesting, respectively. The diameter of stems was 1.87-fold, 1.65-fold, and 1.62-fold higher with T3 treatment than with T1 treatment alone during the first, second, and third rounds of harvesting, respectively. For stem weight, T3 treatment resulted in 2.44-, 2.25-, and 1.91-fold increases compared to T1 during the first, second, and third harvests, respectively. The strip weight was 2.27-fold, 2.48-fold, and 2.25-fold higher with T3 treatment than with T1 treatment alone during the first, second, and third rounds of harvesting, respectively. It was found

2025, Vol. 1, Article ID. 2025.0019
https://doi.org/10.69709/SusProc.2025.101023

that fiber yields were 1.95-, 2.9-, and 2.20-fold higher with T3 treatment than with T1 treatment alone during the first, second, and third rounds of harvesting, respectively. According to Ray Chaudhuri et al. (2017), the BF works by restricting nutrient availability in the root zone to a depth of up to 11 cm. Hence, 50% BF used in the T3 treatment may restrict the 50% IF (N, P, K) in the root zone, ensuring steady nutrient availability throughout the growth season and enhancing plant growth [27,28]. It was observed that BF alone cannot meet the nutritional requirements of Ramie. Hence, when combined with IF, it can ensure a continuous supply of nutrients to the plant root zone and its uptake by the plants. This, in turn, can deplete soil nutrients, necessitating their replenishment after a certain period to maintain sustained production.

3.7. Soil Analysis

Ramie is a rapidly growing plant that requires adequate fertilization. Nutrient composition of the soil before and after Ramie cultivation with combination treatment revealed that 50% microbial inoculation facilitates the uptake of nutrients such as N, P, K, sodium, magnesium, and organic matter by the plant (Table 2). This, in turn, ensured significantly higher plant growth and fiber yield with T3 treatment. To maintain soil fertility, it is necessary to replenish plant nutrients in the soil after a few (3rd) rounds of harvesting.

3.8. Briquettes of Ramie Decorticated Waste

The ground oven-dried Ramie decorticated waste particles were 1.45 ± 0.69 mm in length. Under the scanning electron microscope, an uneven surface with gum-like material was observed (Figure 7a). Upon pelletization without a binder, strong and stable pellets of varying thicknesses were formed (Figure 7b), which exhibited a rough, gummy surface under FESEM (Figure 7c). The presence of gum in the waste might be responsible for its self-adhering property. Ramie briquettes, composed of 80% Ramie decorticated waste and 20% bamboo waste (Figure 7d), produced more lemongrass essential oil within one hour of hydro-distillation compared to firewood and 100% bamboo briquettes. The total weight of the fuel used was also less in the case of Ramie: Bamboo briquettes than Bamboo briquettes or firewood (Table 3). To sustain combustion for one hour, only 48.03% of the weight of Ramie briquettes (compared to firewood) was required. The oil extraction was highest with the Ramie: Bamboo briquette, followed by the bamboo briquette and then firewood, indicating a sustained heat release over the entire period, resulting in higher oil production. Thus, blending dried, decorticated Ramie waste with bamboo can enhance its calorific value, promoting the valorization of the waste into an eco-friendly and cost-effective by-product.

Table 2: Nutrient composition of the soil before and after Ramie cultivation with a combination treatment.

Treatments	Available Nitrogen as N (mg/100 g)	Available Phosphorus as P (mg/100 g)	Available Potassium as K (mg/kg)	Sodium as Na (mg/kg)	Magnesium as MgO (mg/100 g)	Organic Matter (% w/w)
Pre-cultivation	8.4	2101.6	81.53	9.94	4009.9	0.671
Post cultivation	8.0	80	23.77	4.38	98.61	0.655

Table 3: Weight of briquette and firewood used in one hour, and the amount of oil extracted per kilogram of leaves during one hour of indigenous steam distillation.

Briquette Types	Briquettes Used per Hour (kg)	Oil Extracted Within One Hour (g) per kg of Leaves
Firewood (100%)	4.309	1.784
Bamboo (100%)	2.252	1.851
80% Ramie decorticated waste + 20% Bamboo waste	2.070	2.647

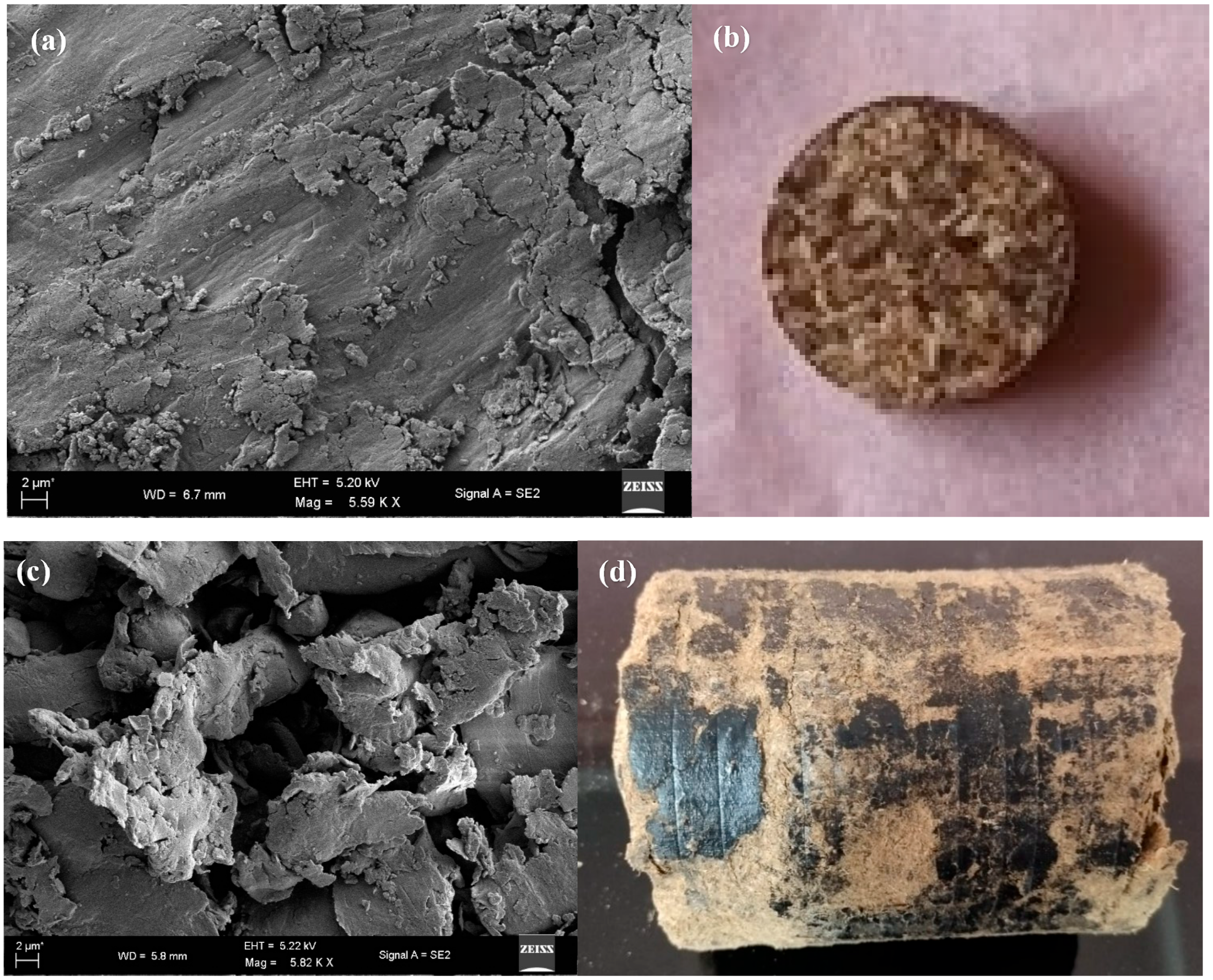

Figure 7: (**a**) FESEM image of grounded Ramie biomass particle (5.59KX magnification), (**b**) Ramie pellet made using pelletizer without any binder, (**c**) FESEM of the Ramie pellet at 5.82KX magnification, (**d**) Ramie briquette (80% Ramie decorticated waste and 20% bamboo waste).

4. Discussion

Literature shows that nitrogen fertilizer application enhances plant growth and Ramie fiber yield [21]. Wang et al. (2024) conducted a pot trial using four Bacillus *velezensis* strains, which promoted plant growth [36]. Crop yield may decrease when the amount of chemical fertilizer is reduced [37]. However, studies have reported maintained yield when chemical fertilizers are combined with biofertilizers at 1:1 to 1:2 ratios, with a 50% reduction in chemical fertilizer application [38,39]. This would ensure better nutrient uptake by preventing leaching, as seen in the current study. Biofertilizer often results in higher yield (as in the case of coffee) due to prevention of root damage by nematode infestation [40].

According to Ray Chaudhuri et al. (2021), Ramie cultivation with vermicompost significantly increased stem height, basal diameter, and fiber yield compared with chemical fertilizer [8]. In the present study, T3 significantly increased agronomic parameters, including the number of stems, stem diameter, stem height, stem weight, strip weight, and fiber weight, compared with T0, T1, and T2. The BF used in this study restricts nutrients to the root zone and ensures they remain available to the plant, thereby preventing nutrient leaching. This BF also works efficiently on mung beans and okra [30] and on lemongrass and cassava [28], as reported earlier. In these cases, 100% BF significantly increased the yield and quality of the organic produce, completely replacing the use of IF without compromising the productivity. However, unlike the other tested crops mentioned above, cultivation of Ramie with this BF alone compromised yield. It required a combination of 50% of the recommended IF dose and 50% of the recommended BF dose to enhance productivity. This might be due to the higher fertilization requirements to support Ramie's exuberant growth. This combination prevented the NPK reserve provided by IF from leaching from the root zone due to BF washing, ensuring its constant uptake by the plant. However, as shown in Table 1 and the supplementary data, fertilizer needs to be reapplied, preferably after the 3rd harvest, to ensure sustained production. This study showed that BF performance varies from crop to crop. Therefore, testing the BF across different crop varieties is necessary before moving to commercial-scale production. This study also finds that Ramie decorticated waste, which is often dumped into landfills, can serve as an alternative fuel source with high combustion efficiency and could consequently reduce greenhouse gas emissions.

5. Conclusions

Ramie can be a major fiber crop in the natural textile market. The climate of Tripura and other northeastern states of India is suitable for Ramie cultivation. Proper nutrient management, supported by scientific intervention, can improve productivity per unit of land area, thereby reducing dependence on synthetic fibers. A combination of IF and BF minimizes the use of IF to 50% of the recommended dose with enhanced productivity, with minimized plant growth nutrient leaching, which furthermore reduces the environmental damage. Hence, these findings suggest that integrated nutrient management is beneficial for the sustainable cultivation of Ramie with the use of healthy rhizomes from 3 to 4-year-old plantations, within 72 h of uprooting, with sufficient humidity during cultivation, but avoiding waterlogging. Furthermore, the developed formulation needs to be tested for process scalability, and the impact of soil type and climate on Ramie growth. This shall be followed by a life cycle analysis to understand the environmental impact of the developed scheme of cultivation on the valorization of the waste.

List of Abbreviations

AD	Anno Domini
BF	Biofertilizer
cm	Centimeter
g	Grams
h	Hour
ha	Hectares
IAA	Indole acetic acid
IF	Inorganic fertilizer
INM	Integrated Nutrient Management
INR	Indian Rupee
IS	Indian standard
kg	Kilogram
K	Potassium
L	Liter
m^2	Meter Square
mm	Millimeter
N	Nitrogen
P	Phosphorus
T0	Control (no fertilizer)
T1	100% Inorganic fertilizer
T2	100% Bacterial biofertilizer
T3	Combination of 50% inorganic fertilizer and 50% bacterial biofertilizer

Author Contributions

Conceptualization, validation, funding acquisition, writing—review and editing, resources, supervision, project administration: S.R.C.; Writing—original draft preparation, investigation, data curation, methodology, formal analysis, software, visualization: E.P.; Investigation, data curation, methodology, formal analysis: A.D.; Data curation: S.D. All authors have read and agreed to the published version of the manuscript.

Availability of Data and Materials

The data supporting the findings of this study are included within the manuscript.

Ethical Committee Approval

This study does not require separate ethical approval or institutional permission at the scale at which it was conducted. There are no specific institutional or national guidelines applicable to this type of work involving bacterial biofertilizers at the stated scale. However, all standard scientific and biosafety protocols for handling and disposal of microbial cultures were strictly followed, as required in research laboratory practices.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Funding

The authors acknowledge the Department of Science & Technology, SEED Scheme (SEED/WS/2023/1033), Government of India, for the fellowship (funding) of EP and Micro, Small, and Medium Enterprises (MSME), Government of India (G-23011/1/2021-22) under the Idea Challenge Scheme 2020.

Acknowledgments

The authors thank Tripura University for the computational facility, laboratory, and the experimental field for conducting the trial, and Prof Punyasloke Bhadury from the Indian Institute of Science Education and Research, Kolkata, India, for the FESEM analysis, while Dr Goutam

Pramanik of UGC DAE Kolkata Centre, India, for the pellet forming facility.

AI Declaration

Figures 1–6 were generated by using GraphPad Prism 8.0.1. The authors confirm that no AI tools were used to generate any content of this manuscript.

Supplementary Materials

Supplementary material associated with this article has been published online and is available at: https://doi.org/10.69709/SusProc.2025.101023.

References

[1] Adane, T.; Adugna, A.T.; Alemayehu, E. Textile Industry Effluent Treatment Techniques. *J. Chem.* **2021**, *2021*, 5314404. [CrossRef]

[2] Madhav, S.; Ahamad, A.; Singh, P.; Mishra, P.K. A Review of Textile Industry: Wet Processing, Environmental Impacts, and Effluent Treatment Methods. *Environ. Qual. Manag.* **2018**, *27*, 31–41. [CrossRef]

[3] Fernando, A.L.; Duarte, M.P.; Vatsanidou, A.; Alexopoulou, E. Environmental Aspects of Fiber Crops Cultivation and Use. *Ind. Crops Prod.* **2015**, *68*, 105–115. [CrossRef]

[4] Karthik, T.; Rathinamoorthy, R. Sustainable Synthetic Fibre Production. In *Sustainable Fibres and Textiles*; Woodhead Publishing: Sawston, UK, 2017; pp. 191–240. [CrossRef]

[5] Islam, T.; Hossain, M.M.; Covington, S.M. Natural Fibers Towards Fashion Sustainability: A Review of Raw Materials, Production, Application, and Perspective. *J. Nat. Fibers* **2025**, *22*, 2462218. [CrossRef]

[6] Roy, S.; Lutfar, L.B. Bast Fibres: Ramie. In *Handbook of Natural Fibres*; Woodhead Publishing: Sawston, UK, 2012; Volume 1, pp. 61–69. [CrossRef]

[7] Mitra, S.; Saha, S.; Guha, B.; Chakrabarti, K.; Satya, P.; Sharma, A.K.; Gawande, S.P.; Kumar, M.; Saha, M. Ramie: The Strongest Bast Fibre of Nature. *Tech. Bull.* **2013**, *8*, 1–38. [CrossRef]

[8] Ray Chaudhuri, S.; Agarwala, B.K.; Setti, S.K.; Chaudhuri, P.; Paul, P.; Bhattacharjee, G.; Deb, S.; Chowdhury, S.; Devi, P.; Barman, S.; et al. Self-Sustained Ramie Cultivation in Tripura: A Source of Multiple Commercial Uses for Adoption as an Alternative Livelihood. In *Bioresource Utilization in Therapeutics, Biofuel, Agriculture and Environment Protection*; Das, T., Mahapatra, S., Eds.; Apple Academic Press (APP), Inc.: Palm Bay, FL, USA, 2021; pp. 365–382. [CrossRef]

[9] Nam, S.; Netravali, A.N. Green Composites. I. Physical Properties of Ramie Fibers for Environment-Friendly Green Composites. *Fibers Polym.* **2006**, *7*, 372–379. [CrossRef]

[10] Cheng, L.; Duan, S.; Feng, X.; Zheng, K.; Yang, Q.; Xu, H.; Luo, W.; Peng, Y. Ramie-Degumming Methodologies: A Short Review. *J. Eng. Fibers Fabr.* **2020**, *15*, 1558925020940105. [CrossRef]

[11] Ray Chaudhuri, S.; Gogoi, M.; Biswas, T.; Chatterjee, S.; Chanda, C.; Jamatia, R.; Modak, A.; Sett, S.K.; Mukherjee, I. Optimization of Bio-Chemical Degumming of Ramie Fiber for Improved Strength & Luster. *Biotechnol. Rep.* **2020**, *28*, e00532. [CrossRef]

[12] Modak, A.; Gogoi, A.; Singha, P.; Majumder, P.; Sengupta, S.; Ray Chaudhuri, S. An Attempt to Make Ramie Degumming Effective, Ecofriendly and Economical. In Proceedings of the Thirty-Fifth National Convention of Textile Engineers and National Seminar, Kolkata, India, 11–12 March 2023; pp. 155–168. Available online: https://www.researchgate.net/publication/404762026_AN_ATTEMPT_TO_MAKE_RAMIE_DEGUMMING_EFFECTIVE_ECOFRIENDLY_AND_ECONOMICAL.

[13] Jose, S.; Rajna, S.; Ghosh, P. Ramie Fibre Processing and Value Addition. *Asian J. Text.* **2017**, *7*, 1–9. [CrossRef]

[14] Ray, D.P.; Banerjee, P.; Satya, P.; Ghosh, R.K.; Biswas, P.K. Exploration of Profitability in the Cultivation of Ramie (*Boehmeria nivea* L. Gaudich.) Fibre for Sustaining Rural Livelihood. *Int. J. Agric. Environ. Biotechnol.* **2017**, *10*, 277–281. [CrossRef]

[15] Pandey, S.N. Ramie Fibre: Part II. Physical Fibre Properties. A Critical Appreciation of Recent Developments. *Text. Prog.* **2007**, *39*, 189–268. [CrossRef]

[16] Ullah, S.; Liu, L.; Anwar, S.; Tuo, X.; Khan, S.; Wang, B.; Peng, D. Effects of Fertilization on Ramie (*Boehmeria nivea* L.) Growth, Yield and Fiber Quality. *Sustainability* **2016**, *8*, 887. [CrossRef]

[17] Zhang, B.; Liu, H.; Huang, J.; Tian, K.; Shen, C.; Li, X.; Wang, X. Ramie Field Distribution Model and Miss Cutting Rate Prediction Based on the Statistical Analysis. *Agriculture* **2022**, *12*, 651. [CrossRef]

[18] Oshiumi, F. *Ramie Cultivation*; International Cooperation Administration: Washington, DC, USA, 1951. Available online: https://www.scribd.com/document/819115227/Ramie-cultivation.

[19] Gogoi, M. Development of Microbial Prototype for Effluent Treatment and Reuse in Dairy and Aquaculture Industry. Ph.D. Dissertation, Tripura University, Agartala, India, 2022. Available online: http://hdl.handle.net/10603/377535.

[20] Jiaying, M.; Tingting, C.; Jie, L.; Weimeng, F.; Baohua, F.; Guangyan, L.; Guanfu, F. Functions of Nitrogen, Phosphorus and Potassium in Energy Status and Their Influences on Rice Growth and Development. *Rice Sci.* **2022**, *29*, 166–178. [CrossRef]

[21] Liu, L.J.; Chen, H.Q.; Dai, X.B.; Wang, H.; Peng, D.X. Effect of Planting Density and Fertilizer Application on Fiber Yield of Ramie (*Boehmeria nivea*). *J. Integr. Agric.* **2012**, *11*, 1199–1206. [CrossRef]

[22] Mehata, D.K.; Kattel, I.; Sapkota, P.; Ghimire, N.P.; Mehta, R.K. Biofertilizers: A Sustainable Strategy for Organic Farming That Would Increase Crop Pro-

duction and Soil Health. *Plant Physiol. Soil Chem.* **2023**, *3*, 35–39. [CrossRef]

[23] Banerjee, P.; Ray, D.P.; Satya, P.; Debnath, S.; Mondal, D.; Saha, S.C.; Biswas, P.K. Evaluation of Ramie Fibre Quality: A Review. *Int. J. Bioresour. Sci.* **2015**, *2*(1), 65–69. [View Online]

[24] Gogoi, M.; Biswas, T.; Biswal, P.; Saha, T.; Modak, A.; Gantayet, L.M.; Nath, R.; Mukherjee, I.; Thakur, A.R.; Sudarshan, M.; et al. A Novel Strategy for Microbial Conversion of Dairy Wastewater into Biofertilizer. *J. Clean. Prod.* **2021**, *293*, 126051. [CrossRef]

[25] Hazarika, T.K.; Bhattacharyya, R.K.; Nautiyal, B.P. Growth Parameters, Leaf Characteristics and Nutrient Status of Banana as Influenced by Organics, Biofertilizers and Bioagents. *J. Plant Nutr.* **2015**, *38*, 1275–1288. [CrossRef]

[26] Ray Chaudhuri, S. Microbial Combination for Environmental Protection and Agricultural Sustenance. Indian Patent 347939, 28 September 2020. Available online: https://iprsearch.ipindia.gov.in/DynamicUtility/EregisterReport/SearchByPatentNo.

[27] Ray Chaudhuri, S.; Mishra, M.; De, S.; Samal, B.; Saha, A.; Banerjee, S.; Chakraborty, A.; Chakraborty, A.; Pardhiya, S.; Gola, D.; et al. Microbe-Based Strategy for Plant Nutrient Management. In *Waste Water Treatment and Resource Recovery*; Farooq, R., Ahmed, Z., Eds.; IntechOpen: London, UK, 2017; Chapter 3; pp. 38–52. [CrossRef]

[28] Ray Chaudhuri, S.; Palwan, E.; Das, N.; Das, A.; Biswas, P.R.; Dutta, A.K.; Bhadury, P. Bacterial Biofertilizer Based Sustainable Farming: A Step Toward Green, Low Carbon Economy. *J. Plant Nutr.* **2025**, *48*, 3350–3365. [CrossRef]

[29] Mishra, M.; Jain, S.; Thakur, A.R.; Ray Chaudhuri, S. Microbial Community in Packed Bed Bioreactor Involved in Nitrate Remediation from Low Level Radioactive Waste. *J. Basic Microbiol.* **2014**, *54*, 198–203. [CrossRef] [PubMed]

[30] Banerjee, S. Understanding the Effect of Plant Growth Promoting Bacteria (PGPB) Formulation on Nutritional Quality of Mung Bean Seeds. Ph.D. Dissertation, Maulana Abul Kalam Azad University of Technology, Kolkata, India, 2018.

[31] *IS 14684*; Determination of Nitrogen and Nitrogenous Compounds in Soils. Bureau of Indian Standards: New Delhi, India, 1999. Available online: https://archive.org/details/gov.in.is.14684.1999.

[32] *IS 6361*; Methods of Colorimetric Determination of Phosphorous. Bureau of Indian Standards: New Delhi, India, 1971. Available online: https://archive.org/details/gov.in.is.6361.1971.

[33] *IS 9497*; Method for Determination of Sodium, Potassium and Calcium (Flame Photometric). Bureau of Indian Standards: New Delhi, India, 1980. Available online: https://archive.org/details/gov.in.is.9497.1980.

[34] *IS 5949:1990 RA*; Methods for Volumetric Determination of Calcium and Magnesium Using EDTA. Bureau of Indian Standards: New Delhi, India, 2003. Available online: https://archive.org/details/gov.in.is.5949.1990.

[35] *IS 2720 (Part XXII)*; Methods of Test for Soils Part 22 Determination of Organic Matter. Bureau of Indian Standards: New Delhi, India, 1972. Available online: https://archive.org/details/gov.in.is.2720.22.1972.

[36] Wang, X.; Wang, Y.; Fu, Y.; Zhai, Y.; Bai, X.; Liu, T.; Li, G.; Zeng, L.; Zhu, S. Multiple Omics Revealed the Growth-Promoting Mechanism of *Bacillus velezensis* Strains on Ramie. *Front. Plant Sci.* **2024**, *15*, 1367862. [CrossRef]

[37] Hu, M.; Xue, H.; Wade, A.J.; Gao, N.; Qiu, Z.; Long, Y.; Shen, W. Biofertilizer Supplements Allow Nitrogen Fertilizer Reduction, Maintain Yields, and Reduce Nitrogen Losses to Air and Water in China Paddy Fields. *Agric. Ecosyst. Environ.* **2024**, *362*, 108838. [CrossRef]

[38] Demir, H.; Sönmez, İ.; Uçan, U.; Akgün, İ.H. Biofertilizers Improve the Plant Growth, Yield, and Mineral Concentration of Lettuce and Broccoli. *Agronomy* **2023**, *13*, 2031. [CrossRef]

[39] Setiawati, M.R.; Afrilandha, N.; Hindersah, R.; Suryatmana, P.; Fitriatin, B.N.; Kamaluddin, N.N. The Effect of Beneficial Microorganism as Biofertilizer Application in Hydroponic-Grown Tomato. *SAINS TANAH-J. Soil Sci. Agroclimatol.* **2023**, *20*, 66–77. [CrossRef]

[40] Harni, R.; Sasmita, K.D.; Amaria, W. Efficacy of Organic Fertilizer, Biofertilizer and Endophytic Bacteria to Control Nematodes in Robusta Coffee. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Bandung, Indonesia, 14–15 August 2023; Volume 1208, p. 012017. [CrossRef]