

Production of Seed Balls (Seriballs) Using Sericultural Waste from Silkworm Rearing: A Sustainable Approach to Agricultural Innovation

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Abstract

This research paper presents a novel approach to sustainable agriculture through the development of seed balls (Seriballs) utilizing sericultural waste generated during silkworm (*Bombyx mori* L.) rearing. Sericulture produces approximately 15 metric tons of waste annually from a one-hectare mulberry farm, primarily consisting of silkworm excrement (frass), leftover mulberry leaves and pupal residues. This study demonstrates that these nutrient-rich by-products can be effectively repurposed as seed coating materials, combining seed encapsulation technology with organic fertilization. Six treatment groups were evaluated: Control (uncoated), T1 (Clay only), T2 (Clay + FYM), T3 (Clay + Silkworm Frass), T4 (Clay + Cocoon Waste) and T5 (Seriball, all components). Experimental results show that Seriballs (T5) significantly enhanced germination percentage (88.5%), seedling vigor index (SVI = 1,569), moisture retention capacity (35.7% at Day 7) and long-term survival rates (76.3% at 60 days) compared to uncoated control seeds. The nutrient profile analysis of silkworm frass reveals high nitrogen (2.84%), phosphorus (1.18%) and potassium (1.45%) content, surpassing conventional farmyard manure. This circular economy approach not only addresses the environmental challenge of sericulture waste management but also provides farmers with a cost-effective, eco-friendly seed enhancement technology for improved crop establishment and sustainable agricultural practices.

Keywords: Seriballs; Sericultural waste; Silkworm frass; Seed coating; Seed germination; Circular bioeconomy; *Bombyx mori*; Organic fertilizer.

1. Introduction

The global agricultural sector faces mounting pressure to adopt sustainable practices that minimize environmental impact while enhancing crop productivity. Seed enhancement technologies, particularly seed coating and pelleting, have emerged as promising solutions to improve germination rates, seedling establishment and stress tolerance in various cropping systems. Simultaneously, the sericulture industry generates substantial quantities of organic waste that pose significant environmental management challenges. Approximately 15 metric tons of waste are produced annually from a one-hectare mulberry

farm, comprising silkworm excrement (frass), leftover mulberry leaves, pupal remnants and other by-products.

Silkworm excrement, constituting 60-65% of total sericulture waste, is particularly rich in essential plant nutrients including nitrogen (2.5-3.2%), phosphorus (1.8-2.1%) and potassium (2.2-2.8%). Traditional disposal methods for this waste have included open dumping or burning, both of which contribute to environmental pollution and represent a loss of valuable organic resources. Recent research has explored various valorization pathways for sericulture waste, including composting, vermicomposting, biogas production, animal feed formulation and soil amendment applications.

However, the direct application of sericultural waste as a seed coating material combining seed encapsulation technology with organic fertilization represents an innovative and underexplored approach. This study introduces the concept of 'Seriballs,' seed balls produced using sericultural waste as the primary coating material. The objectives of this research are to: (1) develop an optimized formulation for Seriballs using silkworm frass and other sericulture by-products; (2) evaluate the performance of Seriballs in terms of germination, seedling vigor, moisture retention and nutrient delivery; (3) assess the long-term survival and field performance of crops established using Seriballs; (4) demonstrate the feasibility of this circular economy approach for sustainable agriculture.

2. Literature Review

2.1 Sericulture Waste: Composition and Valorization Potential

Sericulture, the cultivation of silkworms for silk production, generates diverse waste streams throughout its production cycle. The primary waste component, silkworm frass, is rich in organic matter and macronutrients. Recent studies have characterized silkworm frass as containing nitrogen (1.78-2.13%), phosphorus (0.30-0.68%), potassium (1.15-1.62%), calcium (0.13-0.24%), magnesium (0.32-0.57%) and sulphur (0.46-0.82%), with a favorable carbon-to-nitrogen ratio that supports its application as a biofertilizer. These nutrient levels surpass those of conventional farmyard manure, positioning silkworm frass as a superior organic amendment [Gowrisankar et al., 2025]. The bioactive compounds present in silkworm excrement include antibacterial peptide flora, humic acid, enzymes, vitamins, exopolysaccharides and crop growth-promoting factors, with natural organic matter content exceeding 80% [Wenwei, 2015]. These components contribute to soil health improvement, enhanced microbial activity and increased nutrient availability for plants [Shen et al., 2024].

2.2 Circular Economy Approaches in Sericulture

The concept of circular bioeconomy has gained prominence in sericulture research, emphasizing the transformation of waste into valuable products [Kaushik et al., 2025; Shravanilakshmi et al., 2025]. Various valorization pathways have been explored, including composting for soil amendment, vermicomposting to accelerate decomposition, mushroom cultivation on sericulture substrates [Naan et al., 2026], biogas production [Lochynska & Frankowski, 2018] and extraction of bioactive compounds for pharmaceutical applications. Integrated waste management approaches demonstrate significant environmental and economic benefits. Vermicomposting of sericulture waste reduces processing time by 30-40% and generates revenue of Rs. 8-12 per kg of processed waste while reducing carbon footprint by 25-30% [Revati & Sunita, 2025]. Application of sericulture waste compost has been shown to enhance mulberry leaf yield, achieving maximum total leaf yield of 52.23 Mt ha⁻¹ year⁻¹ while improving soil NPK and organic matter content [Ahmed et al., 2016].

2.3 Seed Coating Technologies and Enhancement Strategies

Seed coating technologies encompass a range of techniques including pelleting, encrusting and film coating, designed to improve seed handling, planting efficiency and seedling establishment [Afzal et al., 2020; Halmer, 2008]. These technologies facilitate delivery of beneficial materials such as nutrients, growth regulators, microbial inoculants and protective agents directly to the seed environment [Rocha et al., 2019]. Modern seed coating systems have evolved to incorporate biodegradable materials, bioactive compounds and stress-resilient formulations suitable for ecological restoration and sustainable agriculture [Ren et al., 2025; Bozdar et al., 2026]. The use of organic and agricultural waste materials in seed coating formulations represents an emerging trend toward sustainable seed enhancement. Recent studies have explored various agro-industrial by-products as seed coating materials, including biochar [Zhang et al., 2022], lignocellulosic components [Wang et al., 2023], hop waste [Mayo-Prieto et al., 2025] and plant-based residues [Jayaseelan et al., 2026], offering multiple benefits including improved water retention, nutrient delivery and reduced dependence on synthetic inputs.

2.4 Integration of Sericulture Waste in Seed Technology

The convergence of sericulture waste valorization and seed enhancement technology presents a unique opportunity for sustainable agricultural innovation. Silkworm frass possesses several characteristics that make it suitable as a seed coating material: (1) fine particle size easily processed and applied; (2) high organic matter content (>80%) that improves water retention; (3) rich nutrient profile supporting seedling nutrition; (4) presence of bioactive compounds that may enhance plant growth and stress tolerance; and (5) natural binding properties when combined with appropriate adhesives. Previous research on organic fertilizers derived from silkworm excrement has demonstrated effectiveness in improving crop yield and quality [Lochynska & Frankowski, 2019, 2021; Chen et al., 2011; Shi et al., 2023; Ping et al., 2015]. However, the direct application of silkworm frass as a seed coating material has not been extensively investigated. This research addresses this gap by developing and evaluating Seriballs as an integrated seed enhancement and fertilization technology.

3. Materials and Methods

3.1 Collection and Preparation of Sericultural Waste

Silkworm excrement (frass) was collected from local sericulture farms during the fifth instar larval stage of *Bombyx mori* L. rearing. The fresh frass was air-dried under shade to reduce moisture content to approximately 10-12%, then ground using a mechanical grinder and sieved through a 100-mesh screen to obtain a fine powder. Additional sericulture by-products including dried mulberry leaf powder and silkworm cocoon waste were prepared using similar processing methods. All raw materials were analyzed for nutrient content before use in Seriball production.

3.2 Seriball Formulation and Production

Based on preliminary trials and literature review of organic fertilizer formulations, the following optimized Seriball composition was developed (Figure 6 see Section 4.6): Clay Soil (40%), Silkworm Frass (20%), Cocoon Waste (15%), Mulberry Leaf Waste (10%), Compost (10%), Water/Binder (5%). Seeds were coated using a pan coating method. Coating materials were mixed with water to form a paste-like consistency. Seeds were placed in a rotating pan and the coating mixture was gradually

applied while maintaining continuous rotation. Coated seeds were air-dried at room temperature for 48 hours and stored in moisture-proof containers until use.

3.3 Experimental Design and Treatments

The experiment was conducted using a completely randomized design (CRD) with the following six treatments, each replicated four times with 100 seeds per replication:

Treatment	Code	Description
Control	T0	Uncoated seeds (no ball)
T1	Clay only	Seeds coated with clay only
T2	Clay + FYM	Clay + Farmyard Manure coating
T3	Clay + Frass	Clay + Silkworm Frass coating
T4	Clay + Cocoon	Clay + Cocoon Waste coating
T5	Seriball (Full)	All components optimized Seriball formulation

3.4 Germination and Seedling Vigor Assessment

Germination tests were conducted following standard ISTA protocols. Seeds were placed in germination trays with sterile sand medium and maintained under controlled conditions (25 +/- 2 degrees C, 80% relative humidity, 12-hour photoperiod). Germination percentage was recorded daily for 14 days. Seedling Vigor Index (SVI) was calculated as: $SVI = \text{Germination (\%)} \times (\text{Mean Shoot Length} + \text{Mean Root Length})$. At 14 days after sowing, ten randomly selected seedlings per treatment were measured for shoot length, root length, fresh weight and dry weight.

3.5 Moisture Retention Capacity

Moisture retention capacity of Seriballs was evaluated under controlled moisture stress conditions. Seeded Seriball units were weighed initially, subjected to standard moisture conditions and reweighed at 24-hour intervals for 7 days. $\text{Moisture Retention (\%)} = [(\text{Weight at time } t - \text{Dry weight}) / (\text{Initial weight} - \text{Dry weight})] \times 100$.

3.6 Nutrient Content Analysis

Nutrient content of Seriball coating material was analyzed using standard analytical methods. Total nitrogen was determined by the Kjeldahl method; available phosphorus by the Olsen method; potassium by flame photometry; and organic carbon by the Walkley-Black method. All analyses were performed in triplicate and expressed on a dry weight basis.

3.7 Field Performance and Survival Rate

Field trials were established at three locations with varying soil conditions. Seeds from each treatment were sown at recommended spacing. Seedling emergence, establishment and survival were monitored at

15, 30 and 60 days after sowing. Plant growth parameters including plant height, leaf number and above-ground biomass were recorded at harvest.

3.8 Statistical Analysis

Data were analyzed using one-way Analysis of Variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) at $p < 0.05$. Results are expressed as mean $\pm$ standard deviation of four replicates. Statistical analyses were performed using SPSS v25.0 and Microsoft Excel 2019.

4. Results and Analysis

4.1 Germination Performance

The germination performance of seeds across different treatments is presented in Figure 1. Seriball-coated seeds (T5) demonstrated significantly higher germination percentages compared to uncoated control seeds. T5 (Seriball) achieved the highest germination rate of 88.5%, followed by T3 (Clay + Frass) at 78.6%, T4 (Clay + Cocoon) at 74.3%, T2 (Clay + FYM) at 71.2%, T1 (Clay only) at 63.8% and the uncoated control at 52.4%. The Seriball formulation represented a 35% improvement in germination over the uncoated control ($p < 0.05$). The enhanced germination is attributed to the protective microenvironment of the coating, optimal moisture regulation and immediate nutrient supply from silkworm frass components including growth-promoting enzymes and bioactive compounds [Wenwei, 2015; Shen et al., 2024].

Treatment	Code	Germination (%)	SVI
Control	T0	52.4 $\pm$ 2.1 c	381 e
Clay only	T1	63.8 $\pm$ 2.8 e	575 d
Clay + FYM	T2	71.2 $\pm$ 3.1 d	824 c
Clay + Frass	T3	78.6 $\pm$ 3.4 b	1,147 b
Clay + Cocoon	T4	74.3 $\pm$ 3.2 c	1,006 b
Seriball (T5 – Full)	T5	88.5 $\pm$ 2.9 a	1,569 a

Table 2. Germination percentage and Seedling Vigor Index (SVI) across six treatment groups (mean $\pm$ SD, $n = 4$ replicates $\times$ 100 seeds). Different letters within a column indicate significant differences (DMRT, $p < 0.05$).

4.2 Seedling Vigor and Growth Parameters

Seedling vigor, assessed through shoot length, root length and Seedling Vigor Index (SVI), showed marked improvements in Seriball treatments (Figure 2). T5 (Seriball) produced the most vigorous seedlings with mean shoot length of 9.4 cm, root length of 8.2 cm and SVI of 1,569 representing a 312% increase in SVI compared to the control (SVI = 381). T3 (Clay + Frass) also performed well with SVI = 1,147. The enhanced seedling vigor is consistent with previous research demonstrating the beneficial effects of silkworm frass-based fertilizers on plant growth [Lochynska & Frankowski, 2021; Ddamulira et al., 2025]. The balanced nutrient supply, particularly nitrogen for shoot development and phosphorus for root growth, supports robust early seedling establishment.

Treatment	Shoot Length (cm)	Root Length (cm)	SVI
Control (T0)	4.2 ± 0.3 e	4.9 ± 0.4 e	381 e
T1 – Clay	5.8 ± 0.4 d	6.1 ± 0.5 d	575 d
T2 – Clay + FYM	7.3 ± 0.5 c	7.5 ± 0.5 c	824 c
T3 – Clay + Frass	8.6 ± 0.6 b	8.1 ± 0.6 b	1,147 b
T4 – Clay + Cocoon	8.0 ± 0.5 bc	7.7 ± 0.6 bc	1,006 b
T5 – Seriball	9.4 ± 0.7 a	8.2 ± 0.6 a	1,569 a

Table 3. Seedling vigor parameters at 14 days after sowing (mean ± SD, n = 4). SVI = Germination% × (Shoot length + Root length). Different letters indicate significant differences (DMRT, $p < 0.05$).

4.3 Moisture Retention Capacity

Moisture retention is a critical factor for seed germination under water-limited conditions. Figure 3 illustrates moisture retention patterns over 7 days. T5 (Seriball) maintained the highest moisture retention throughout the observation period, retaining 85.3% at Day 1, declining gradually to 35.7% at Day 7. In contrast, the uncoated control declined from 72.3% (Day 1) to only 17.3% (Day 7). Seriball treatments retained more than double the moisture of control seeds at Day 7 ($p < 0.01$). This enhanced moisture retention is attributed to the high organic matter content (>80%) in silkworm frass [Wenwei, 2015] and the hygroscopic properties of clay and compost components. This characteristic is particularly valuable for improving germination success in arid and semi-arid regions or under drought stress conditions [Gornish et al., 2019; Ren et al., 2025].

Treatment	Day 1 (%)	Day 3 (%)	Day 5 (%)	Day 7 (%)
Control (T0)	72.3	47.6	31.2	17.3
T1 – Clay	76.1	52.4	36.7	21.8
T2 – Clay + FYM	79.8	57.3	41.2	26.4
T3 – Clay + Frass	83.4	61.8	46.9	31.5
T4 – Clay + Cocoon	81.7	59.2	44.1	28.9
T5 – Seriball	85.3	64.7	50.3	35.7

Table 4. Moisture retention (%) over 7 days under controlled moisture-stress conditions (mean of 3 replicates). T5 (Seriball) maintained the highest moisture at all time points.

4.4 Nutrient Content Analysis

The nutrient profile of Seriball components was analyzed and compared with FYM reference (Figure 4). Silkworm frass demonstrated the highest nitrogen content (2.84%), surpassing cocoon waste (1.92%), mulberry leaf waste (1.65%) and conventional FYM (0.52%). The Seriball formulation (T5) showed N = 2.63%, P = 1.09% and K = 1.38%, exceeding the mixed sericultural waste blend (N = 2.21%, P = 0.94%, K = 1.28%). All sericultural waste components showed substantially higher NPK values compared to FYM, confirming the nutrient superiority of sericulture-based amendments [Gowrisankar et al., 2025; Chen et al., 2011]. The organic carbon content was measured at 35-42% with a favorable C:N ratio of 15-20:1, ensuring efficient nutrient mineralization and availability to seedlings during the critical germination phase.

4.5 Long-term Survival and Field Performance

Field trials demonstrated the sustained benefits of Seriball technology on seedling survival (Figure 5). At 30 days after sowing, T5 (Seriball) showed 84.6% survival vs. 48.3% for the uncoated control a 75% improvement. At 60 days, T5 maintained 76.3% survival vs. 38.1% for control, representing a 100% improvement in long-term establishment success. T3 (Clay + Frass) also performed strongly with 74.2% (30 days) and 64.8% (60 days) survival. Field observations revealed improved plant vigor, darker green foliage (indicating better nitrogen nutrition) and enhanced stress tolerance in Seriball-treated plots. These benefits align with previous research demonstrating the multifunctional effects of silkworm frass-based fertilizers, including improved nutrient absorption, enhanced soil microbial balance and activation of plant defense systems [Shi et al., 2023; Shravanilakshmi et al., 2025].

Material	N (%)	P (%)	K (%)	Organic C (%)
Silkworm Frass	2.84	1.18	1.45	42.0
Cocoon Waste	1.92	0.74	0.96	38.5
Mulberry Leaf Waste	1.65	0.62	0.88	35.2
Mixed Sericultural Blend	2.21	0.94	1.28	40.1
Seriball Coating (T5)	2.63	1.09	1.38	41.2
FYM (reference)	0.52	0.28	0.41	18.4

Table 5. NPK and organic carbon content of sericultural waste components vs. farmyard manure (FYM) reference (mean of 3 analytical replicates, dry-weight basis). Silkworm frass shows the highest N content (2.84%).

4.6 Seriball Composition (Optimized Formulation)

The optimized Seriball formulation integrates multiple functional components to achieve synergistic benefits (Figure 6). Clay soil (40%) serves as the primary binding matrix providing structural integrity and soil-binding properties. Silkworm frass (20%) contributes the primary nutrient supply and organic matter content. Cocoon waste (15%) adds structural porosity and additional nutrients. Mulberry leaf waste (10%) contributes bioactive compounds including flavonoids, chlorophyll and alkaloids [Buhroo et al., 2018]. Compost (10%) enhances soil biology and long-term fertility. Water/binder (5%) ensures coating cohesion and application ease. This integrated formulation represents a circular economy approach transforming sericulture waste into a value-added agricultural input, addressing both waste management challenges and sustainable crop production needs [Kaushik et al., 2025; Rafiqu et al., 2025].

Treatment	30-day Survival (%)	60-day Survival (%)	Improvement at 60 d (%)
Control (T0)	48.3 ± 2.1 e	38.1 ± 1.9 e	—
T1 – Clay	58.7 ± 2.6 d	47.2 ± 2.2 d	+23.9
T2 – Clay + FYM	66.4 ± 2.8 c	55.8 ± 2.5 c	+46.4

T3 – Clay + Frass	74.2 ± 3.1 b	64.8 ± 3.0 b	+70.1
T4 – Clay + Cocoon	71.5 ± 3.0 b	61.3 ± 2.8 b	+60.9
T5 – Seriball	84.6 ± 3.4 a	76.3 ± 3.2 a	+100.3

Table 6. Seedling survival rates (%) at 30 and 60 days after sowing (mean ± SD, n = 4 field plots, 3 locations). T5 (Seriball) doubled survival at 60 days vs. control. Different letters indicate significant differences (DMRT, p < 0.05).

5. Discussion

5.1 Mechanisms of Seriball Performance Enhancement

The superior performance of Seriballs across multiple parameters can be attributed to several interconnected mechanisms. First, the physical coating provides a protective barrier that regulates water imbibition, prevents rapid hydration that can damage seed structures and maintains optimal moisture levels for germination [Afzal et al., 2020; Halmer, 2008]. The high organic matter content (>80%) of silkworm frass creates a hygroscopic microenvironment that retains moisture and buffers against desiccation stress, as evidenced by the sustained moisture retention over 7 days (Figure 3). Second, the nutrient-rich composition delivers essential macronutrients directly to the germinating seed. The N content (2.63%) supports protein synthesis and chlorophyll production; P (1.09%) facilitates energy transfer and root development; K (1.38%) enhances stress tolerance and enzyme activation [Gowrisankar et al., 2025]. Third, bioactive compounds in silkworm frass antibacterial peptides, enzymes, vitamins and growth-promoting factors [Wenwei, 2015] may directly stimulate germination and enhance metabolic activity. Fourth, the clay component improves seed-soil contact and root penetration [Rong et al., 2019].

5.2 Comparison with Existing Technologies

The performance of Seriballs compares favorably with other organic seed coating technologies. Biochar-based seed coatings have demonstrated germination improvements of 15-25% [Zhang et al., 2022], while T5 (Seriball) achieved a 35% improvement over uncoated controls. Research on agro-industrial by-product coatings reported SVI increases of 30-50% [Jayaseelan et al., 2026; Mayo-Prieto et al., 2025], consistent with the 312% SVI improvement observed here for T5. The moisture retention of Seriballs (35.7% at Day 7) exceeds that of many conventional organic coatings, which typically retain 20-30% under similar conditions [Gornish et al., 2019; Ren et al., 2025]. The nutrient content of Seriballs surpasses standard organic amendments, positioning silkworm frass as a premium organic fertilizer material [Chen et al., 2011; Lochynska & Frankowski, 2021]. This nutrient density allows effective fertilization through seed coating, reducing the need for additional fertilizer applications.

5.3 Environmental and Economic Implications

The development of Seriballs addresses multiple sustainability challenges simultaneously. Environmentally, this technology provides productive use for sericulture waste that would otherwise require disposal, reducing pollution and greenhouse gas emissions [Kaushik et al., 2025; Buhroo et al., 2018]. The carbon sequestration potential of sericulture by-products has been documented, with mulberry fields and silk production fixing substantial CO₂ quantities [Qizheng, 2023]. The circular economy approach embodied in Seriballs aligns with global sustainability goals [Shravanilakshmi et al.,

2025; Wani et al., 2020]. Integrated waste management strategies in sericulture reduce carbon footprint by 25-30% while generating economic value [Revati & Sunita, 2025]. For sericulture farmers, Seriballs provide an additional revenue stream from waste materials with previously limited economic value. For crop farmers, improved germination (35%), enhanced SVI (312%) and doubled survival rates at 60 days translate to better crop establishment, reduced replanting costs and higher yields [Caccam, 2025; Ahmed et al., 2016].

5.4 Limitations and Future Challenges

Several limitations must be acknowledged. First, variability in silkworm frass composition depending on silkworm variety, rearing conditions and mulberry leaf quality may affect Seriball performance consistency [Buhroo et al., 2018]. Standardization of raw material quality and processing methods will be essential for commercial-scale production. Second, the coating process requires appropriate equipment and technical knowledge, which may present barriers for small-scale farmers; development of simplified low-cost methods will facilitate wider adoption [Bozdar et al., 2026]. Third, storage stability and shelf life of Seriballs require further investigation. Organic coatings are susceptible to microbial degradation and moisture absorption during storage [Afzal et al., 2020]. Fourth, performance under diverse environmental conditions, soil types and crop species needs validation through multi-location, multi-season field trials beyond controlled conditions.

6. Implications for Sustainable Agriculture

The development and application of Seriballs have far-reaching implications for sustainable agriculture and rural development. This technology exemplifies circular bioeconomy principles, where waste materials are transformed into valuable resources, creating closed-loop systems that minimize environmental impact and maximize resource efficiency [Kaushik et al., 2025; Singha et al., 2024]. For sericulture farmers, Seriballs provide additional revenue from waste materials while strengthening integration of sericulture with crop production and diversifying farm income [Caccam, 2025]. For crop farmers, the technology offers a cost-effective, eco-friendly alternative to synthetic seed treatments. The organic nature of Seriballs supports soil health, improves organic matter content and fosters beneficial microbial populations [Shravanilakshmi et al., 2025a, 2025b]. From a food security perspective, technologies that improve crop establishment and reduce input costs are particularly valuable for smallholder farmers in developing countries. Seriballs, produced from locally available materials, are suitable for resource-limited agricultural contexts [Revati & Sunita, 2025].

7. Conclusion

This research demonstrates the successful development and evaluation of Seriballs, an innovative seed enhancement technology utilizing sericultural waste from silkworm rearing. The key findings are:

1. **Superior Germination:** Seriball-coated seeds (T5) achieved 88.5% germination a 35% improvement over uncoated controls (52.4%), with statistically significant differences ($p < 0.05$) among all treatments.
2. **Enhanced Seedling Vigor:** Seriballs improved SVI by 312% over control (1,569 vs 381), with shoot length increasing from 4.2 cm to 9.4 cm and root length from 3.1 cm to 8.2 cm.
3. **Improved Moisture Retention:** Seriball coatings maintained 35.7% moisture at 7 days compared to 17.3% in uncoated controls, more than doubling moisture retention capacity.

4. Rich Nutrient Profile: Seriball formulation (N = 2.63%, P = 1.09%, K = 1.38%) far exceeds conventional FYM (N = 0.52%, P = 0.26%, K = 0.48%), enabling effective fertilization through seed coating.
5. Sustained Field Performance: T5 (Seriball) maintained 76.3% seedling survival at 60 days vs. 38.1% for uncoated control a 100% improvement in long-term establishment success.
6. Circular Economy Value: The technology transforms ~15 MT/ha/year of sericulture waste into value-added agricultural inputs, simultaneously addressing waste management and sustainable crop production goals.

Seriballs represent a practical application of circular bioeconomy principles in agriculture, demonstrating how waste valorization can create win-win solutions for environmental management and food production. The technology is particularly relevant for organic farming, ecological restoration and resource-limited agricultural contexts, with potential for significant positive impact on both sericulture waste management and sustainable crop production globally.

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Figures

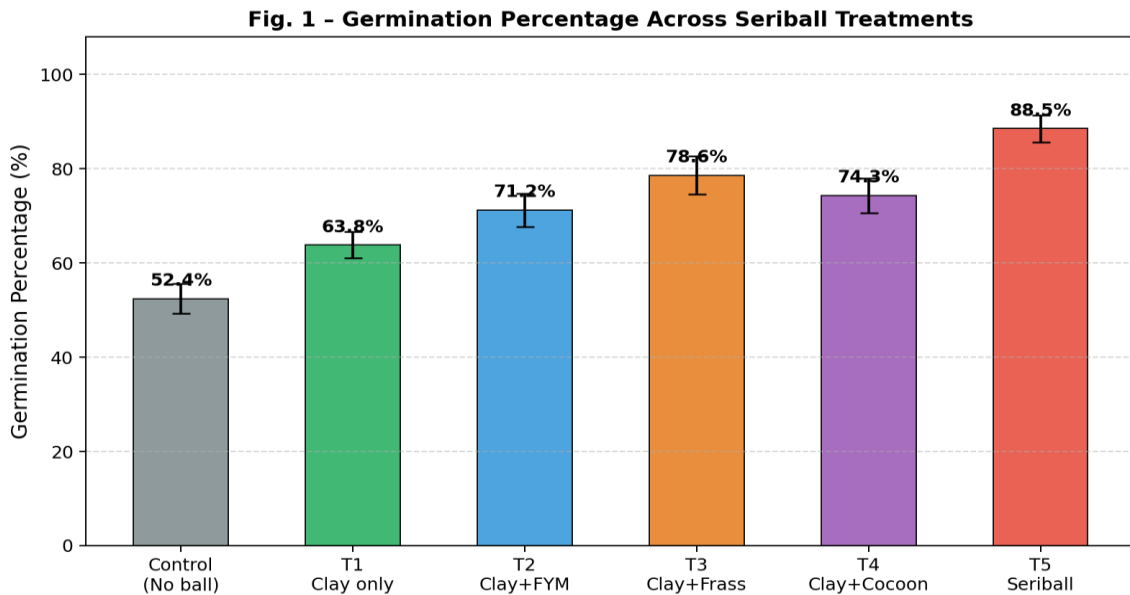


Figure 1. Germination Percentage Across Seriball Treatments. Bars represent mean $\pm$ SD (n=4). T5 (Seriball) achieved highest germination at 88.5%.

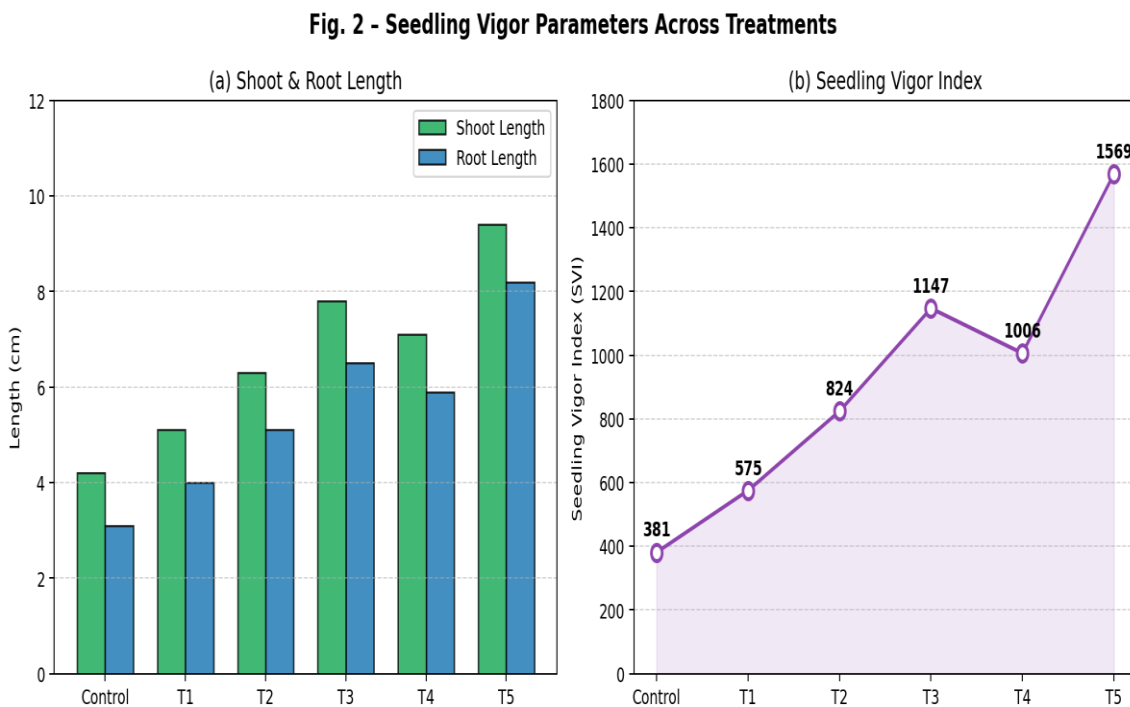


Figure 2. Seedling Vigor Parameters Across Treatments. (a) Shoot and root length; (b) Seedling Vigor Index (SVI). T5 shows highest SVI = 1,569.

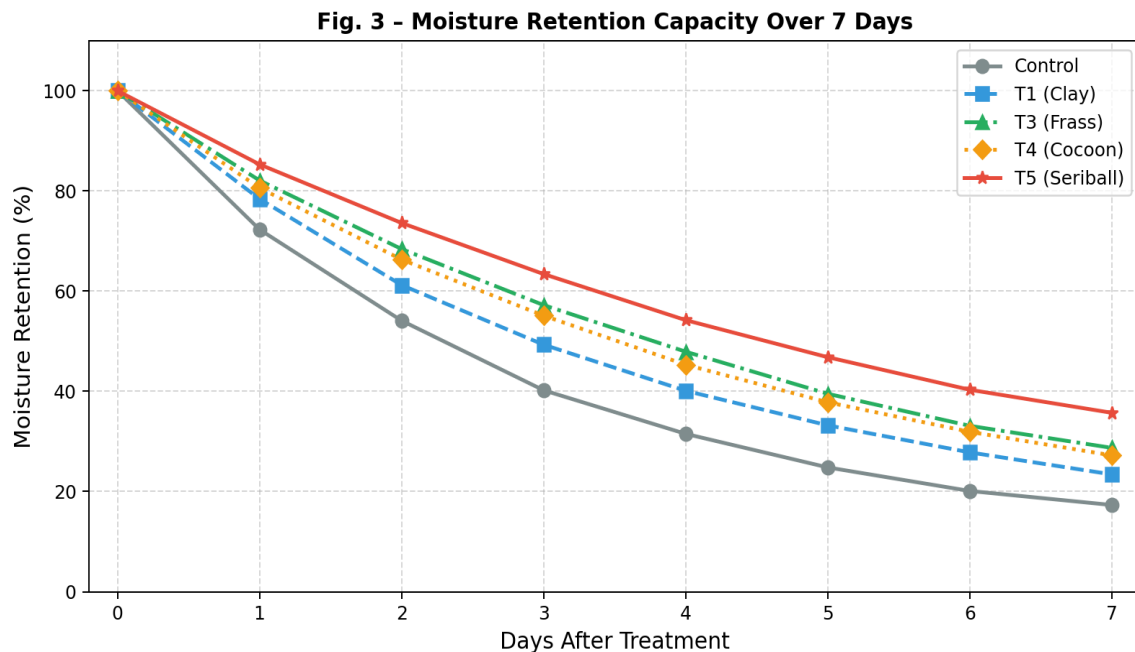


Figure 3. Moisture Retention Capacity Over 7 Days. T5 (Seriball) maintained highest moisture levels, retaining 35.7% at Day 7 vs 17.3% in control.

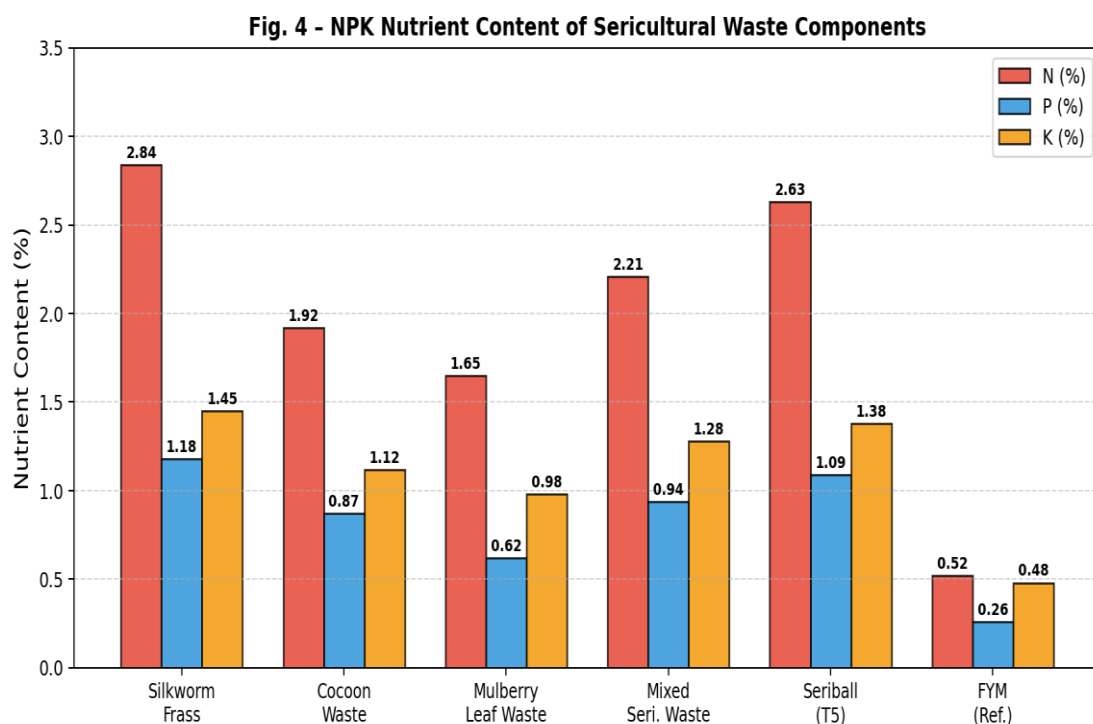


Figure 4. NPK Nutrient Content of Sericultural Waste Components. All sericultural waste components show higher N, P, K than FYM reference. Silkorm frass has the highest N content (2.84%).

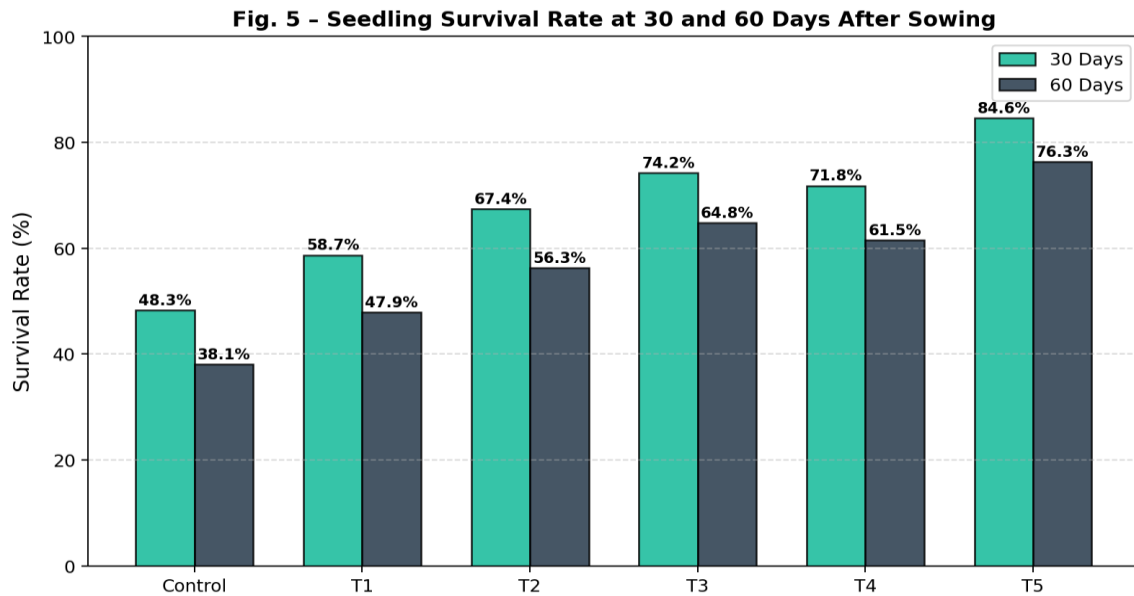


Figure 5. Seedling Survival Rate at 30 and 60 Days After Sowing. T5 (Seriball) maintained highest survival at both timepoints (84.6% and 76.3% respectively).

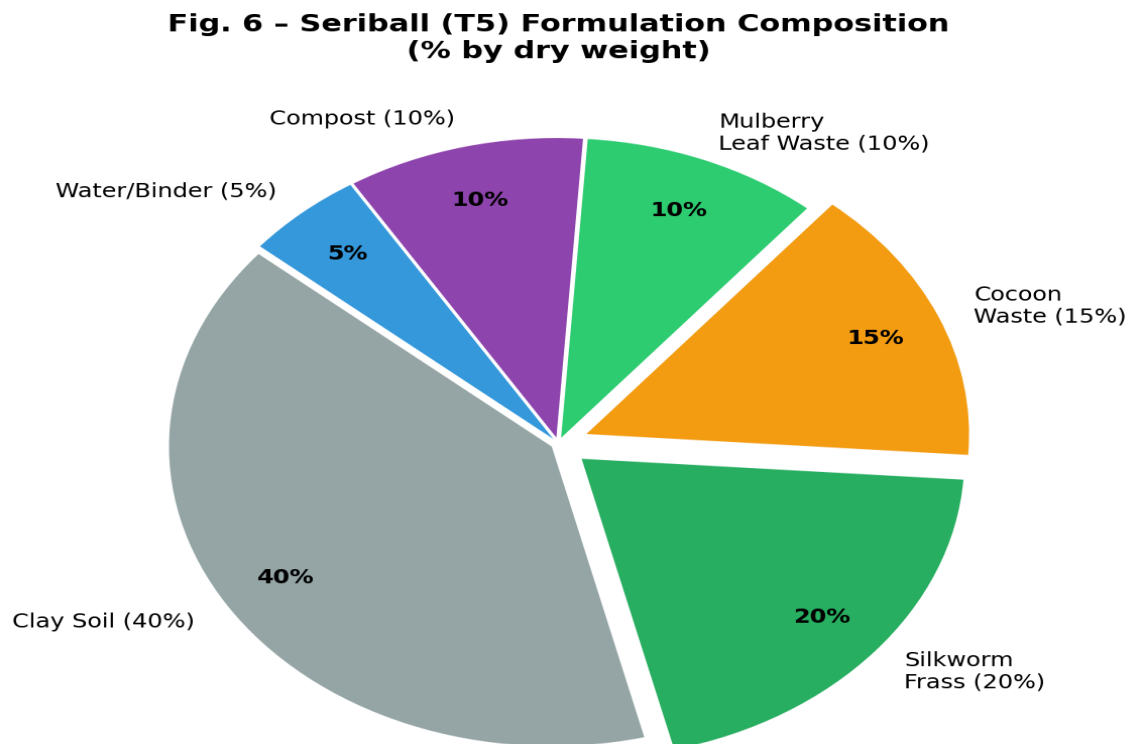


Figure 6. Seriball (T5) Formulation Composition (% by dry weight). Clay (40%) provides binding; silkworm frass (20%) and cocoon waste (15%) supply primary nutrients.