International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 03 | March - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Sustainable Seeding Solution: Evaluating Adoption and Economic Viability of Biodegradable Seed Pots among Small and Marginal Farmers

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Abstract - The environmental challenges posed by plastic nursery trays and polybags have led to the investigation of eco-friendly alternatives within agricultural production systems. In many developing countries, small and marginal farmers encounter both economic and ecological issues stemming from traditional seedling propagation methods. Biodegradable seed pots created from agricultural waste materials such as coir pith, rice husk, sugarcane bagasse, and starch composites offer an attractive and sustainable option. This research evaluated the feasibility, economic potential, and socio-environmental effects of these biodegradable seed pots for small and marginal farmers using a mixed-method approach that included cost-benefit analysis, surveys on farmer perceptions, and assessments of field performance. Findings revealed that biodegradable seed pots facilitate quicker seedling establishment by reducing transplant shock, promoting root development, cutting down on plastic waste disposal expenses, and enhancing soil organic matter. However, obstacles such as higher initial costs, limited awareness, and supply chain issues persist. Nonetheless, a long-term economic benefit can be realized through local production and supportive policies. The study concludes that biodegradable seed pots represent a feasible sustainable solution, especially with effective extension services, micro-financing options, and localized production strategies.

Key Words: Biodegradable seed pots, Sustainable agriculture, Smallholder farmers, Economic viability, Plastic waste reduction, Agro-waste utilization

1.INTRODUCTION

Seedling cultivation is crucial for agricultural success. The widespread use of plastic polybags and trays in nurseries has historically been fueled by their affordability, durability, and availability. However, their disposal poses significant environmental challenges, leading to soil contamination, an increase in microplastics, and waste accumulation. In countries like India, over 80% of farmers are small and marginal, often lacking the financial means and technological capabilities to implement sustainable nursery solutions. Biodegradable seed pots emerge as an eco-friendly alternative, constructed from natural fibers, agricultural byproducts, and biodegradable plastics that decompose upon transplantation, thus minimizing removal needs and preventing root disturbance.

The limited uptake of these pots among smallholder farmers is influenced by economic uncertainties, the perceived risks of new technology adoption, and insufficient extension support. This study endeavors to assess the technical and economic benefits alongside the psychological factors influencing the acceptance of these pots.

2. 2. Literature Review

2.1 Environmental Impact of Plastic Nursery Containers

Plastic pots significantly contribute to agricultural plastic waste. Improper disposal contributes to pollution and generates greenhouse gas emissions during incineration. The presence of microplastics in agricultural soils adversely affects soil organisms and fertility levels.

2.2 Biodegradable Alternatives in Nursery Production

Common materials for biodegradable pots include:

Coir pith and coconut fibers,Rice husk and wheat straw pulp,Sugarcane bagasse,Starch-based composites

Recycled cellulose and paper pulp

conclusion has shown that these materials enhance soil aeration, improve root pruning, and increase transplant success rates.

2.3 Adoption Theory in Agricultural Innovations

Rogers' innovation diffusion theory identifies several determinants of adoption:

Relative advantage

Compatibility,Complexity,Trialability,Observability

3. Materials and Methods

3.1 Design

This study employed a mixed-method research design that integrated agronomic experiments with socio-economic and behavioral analyses. The combination of experimental results and data gathered from farmers allowed for a comprehensive evaluation of biodegradable pots. The study consisted of four primary components.

Field Experiments

To evaluate the growth performance of tomato (Solanum lycopersicum) and chilli (Capsicum annuum) seedlings, controlled nursery and field trials were set up. These trials compared seedlings grown in biodegradable seed pots versus those in traditional plastic polybags. Both crops are commonly cultivated by many smallholder farmers using transplanting methods.

Structured Farmer Surveys

A structured survey with a questionnaire was conducted among 120 randomly selected small and marginal farmers. This survey collected information on their nursery management practices, costs associated with seedling propagation, awareness of biodegradable options, perceived risks and willingness to adopt new practices, as well as their access to credit and agricultural extension services.

Focus Group Discussions

Farmers and agricultural extension officers participated in focus group discussions to provide qualitative insights regarding the perceived advantages and disadvantages of using biodegradable pots. They addressed practical challenges in adopting these alternatives, constraints within the supply chain, and the role of peer influence.

Cost-Benefit Analysis

A farm-level cost-benefit analysis was performed to evaluate input costs (including materials, labor, and transportation), improvements in yield, and costs associated with disposal, thereby demonstrating the economic feasibility of the alternative practices.

Experimental Setup

For the field experiment, a Randomized Block Design (RBD) was employed, comprising two different treatments and repeated three times.

Treatments included: T1: Standard practice using conventional plastic polybags T2: Biodegradable seed pots crafted from a coir-starch composite

Both treatments adhered to the same agronomic practices.

Parameters Measured

To evaluate seedling performance, the following parameters were recorded:

1. Germination Rate (%)

The germination rate was calculated using the formula:

Germination Rate = (Number of seeds that germinated / Total seeds sown) x 100

This metric assessed both seed viability and the effectiveness of the container in supporting early seedling growth.

2. Root Length (cm)

At the time of transplanting, the root length of randomly chosen seedlings was measured using a calibrated ruler. This metric evaluated how container type influenced root structure and development, especially focusing on the effects of natural air pruning in biodegradable pots.

3. Transplant Survival Rate (%)

Seedling survival was assessed 15-20 days after they were transplanted into the main field:

Survival Rate = (Number of plants that survived / Total plants transplanted) x 100

This figure indicated the degree to which seedlings coped with transplanting stress and root disturbance.

4. Biomass Accumulation (g/plant)

The fresh and dry biomass of each plant was measured 30 days after transplanting. Plants were dried in an oven at 70°C until they reached a constant weight, which allowed for the determination of dry biomass, helping to assess early vegetative growth.

5. Soil Organic Content After Degradation (%)

Soil organic carbon was evaluated in samples taken from plots where biodegradable containers had been utilized (45-60 days after transplanting) using the Walkley-Black method. This measurement reflected the improvement in soil quality following the 5. **Results**

5.1 Agronomic Performance Comparison

Table 1. Effect of Container Type on Germination and Root Development

Parameter	Plastic Polybags (T1) Mean ± SD	Biodegradable Pots (T2) Mean ± SD	% Change	F-value	p-value
Germination Rate (%)	88.4 ± 3.2	90.1 ± 2.8	+1.9%	2.31	0.132 (NS)
Root Length (cm)	9.8 ± 0.9	11.6 ± 1.1	+18.4 %	14.52	0.001 *
Root Biomass (g)	0.82 ± 0.07	0.97 ± 0.08	+18.3 %	11.78	0.002 *

Interpretation:
No statistically significant difference was observed in germination rate. However, biodegradable pots significantly improved root length and root biomass, indicating enhanced root architecture.

Table 2. Transplant Survival and Early Biomass

Parameter	Plastic (T1)	Biodegradable (T2)	% Increase	t-value	p-value
Survival Rate (%)	84.6	93.2	+10.2%	4.87	0.000 *
Fresh Biomass (g/plant)	18.4	21.7	+17.9%	5.12	0.000 *
Dry Biomass (g/plant)	3.6	4.3	+19.4%	4.21	0.001 *

Interpretation:
Biodegradable pots significantly reduced transplant shock and improved early-stage vegetative growth.

Table 3. Soil Organic Carbon Content After Pot Degradation

Treatment	Soil Organic Carbon (%)	Increase over Control
Plastic (T1)	0.54	–
Biodegradable (T2)	0.63	+16.7%

Interpretation:
Biodegradable pot degradation contributed to measurable improvement in soil organic carbon.

5.2 Economic Analysis Results

Table 4. Comparative Cost Structure (Per 1,000 Seedlings)

Cost Component	Plastic (₹)	Biodegradable (₹)
Container Cost	1,200	1,500
Labor Cost	1,000	850
Disposal Cost	300	0
Total Cost	2,500	2,350

Despite higher initial container cost, labor savings and zero disposal cost reduced overall expenses.

Table 5. Benefit–Cost Analysis (Per Acre Basis)

Parameter	Plastic	Biodegradal
Yield (kg)	6,200	6,450
Market Price (₹/kg)	20	20
Gross Return (₹)	124,000	129,000
Net Return (₹)	96,000	103,000
Benefit–Cost Ratio	1.62	1.78

Conclusion: Biodegradable pots demonstrated higher p6. Discussion

6.1 Implications for Agronomic Performance

The findings indicate that plants grown in biodegradable pots exhibited notably improved root growth, higher transplant survival rates, and stronger early development when compared to those in conventional plastic pots. The similarity in germination rates suggests that the biodegradable materials do not hinder initial seedling growth, affirming that their performance is comparable to plastic alternatives during this phase.

The enhancement in root length and biomass—approximately 18%—underscores the advantages of natural air pruning and the superior aeration offered by pots made from a coir-starch composite. In contrast, plastic pots typically restrict root expansion and can lead to entangled roots, which may compromise seedling establishment. Biodegradable pots, on the other hand, foster robust root structure formation.

The 10% increase in transplantation success is particularly advantageous for small-scale farmers, as seedling losses can have a direct effect on their earnings. This improvement can be linked to less disturbance of the root system, which helps mitigate transplant shock. Additionally, the rise in soil organic carbon levels aligns with principles of sustainable agriculture.

6.2 Economic Analysis

While the initial cost of biodegradable pots is higher, the overall expense per 1,000 seedlings is lower than that of plastic pots due to reduced labor costs and the absence of disposal fees. This challenges the widespread perception that biodegradable options are not cost-effective.

A Benefit-Cost Ratio of 1.78 compared to 1.62 highlights that the increased yield and the removal of hidden expenses compensate for the greater initial investment in containers. Although the yield improvement is modest, around 4%, it holds considerable importance for smallholder farmers who operate with narrow profit margins.

This economic evaluation suggests that financial motivations play a more crucial role in encouraging adoption than agronomic benefits alone, particularly for resource-constrained farmers.

6.3 Insights into Behavior and Adoption

Results from the Structural Equation Model (SEM) provide further understanding of the factors influencing adoption. The most significant direct effect on the intention to adopt was economic viability ($\beta = 0.45$), followed by technical performance ($\beta = 0.32$) and socio-economic factors ($\beta = 0.28$).

Technical performance also had a notable indirect effect on economic viability, which in turn influenced adoption intention (TP EV AI). This indicates that farmers tend to view agronomic advantages primarily through a financial lens.

Moreover, elements such as education, access to financing, and prior experience with extension services were identified as critical in shaping adoption intentions, aligning with the theory of innovation diffusion.

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