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Research Article

Development and Evaluation of a Biodegradable Plant Pot from Carica papaya Agricultural Waste for Circular Economy and Sustainable Agro-entrepreneurship

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Abstract: *Malaysia is facing the growing environmental issues of food waste, significantly from agricultural by-products such as papaya peels and seeds, posing a notable challenge to sustainability. Simultaneously, the gardening sector produces large amounts of plastic pollution mainly through its extensive use of polybags. The BioPaya Pot addresses both critical problems by transforming fruit waste into biodegradable, eco- friendly plant pots, offering a groundbreaking alternative to plastic containers. Made from reused papaya waste, the BioPaya Pot incorporates organic binders such as glycerine and agar to form a flexible and durable material. As the pot decomposes, it enriches the soil with essential nutrients like calcium, magnesium, and phosphorus, promoting healthier plant growth without chemical fertilizers. This product serves two purposes by decreasing food waste while creating an eco-friendly alternative to plastic waste. The BioPaya Pot illustrates the principles of a circular economy, by repurposing agricultural waste into a valuable product. Its production fosters the development of green entrepreneurship and holds significant potential for expanding sustainable practices within the horticultural and urban agriculture sectors. The innovation targets gardeners, farmers, and environmental advocates, with benefits that include reducing landfill waste, promoting soil health, and minimizing plastic pollution. By revolutionizing the gardening industry, the BioPaya Pot has the potential to create lasting environmental and economic impact, fostering a cleaner, greener future.*

1. INTRODUCTION

According to TheStar (2024), food waste makes up the largest contributor of the waste composition, amounting at 31% which nearly one-third of all waste. Followed by plastic, comprising 22% accounting for over one-fifth of the total waste. Together, food waste and plastic make up 53% of the total waste. This highlights the need to address this environmental threat. Among the contributors

to this problem is agricultural waste, specifically papaya peels and seeds, which are discarded in large quantities. Despite their potential nutritional benefits for soil, the by-products remain underutilized and contribute to landfill overflow, which leads to soil degradation, methane emissions, and economic loss for farmers. At the same time, the gardening industry continues to depend heavily on plastic plant pots and polybags, which are non-biodegradable, petroleum based and result to long- term environmental pollution. As these plastic pots accumulate in landfills and ecosystems, it releases harmful microplastics that can accumulate in soil, affecting root growth and the plant's ability to absorb water and nutrients, worsening Malaysia's sustainability challenges (Li et al., 2022).

The demand for sustainable and biodegradable gardening solutions has been growing in recent years due to increasing awareness about plastic pollution and soil degradation (Vaish, 2024). Nevertheless, despite the availability of biodegradable alternatives like recycled paper pots, coconut coir pots, and clay pots, these options present significant limitations in terms of soil-enhancing properties, cost, and scalability (Howell, 2024). As a result, gardeners and farmers continue to struggle with a lack of affordable and effective eco-friendly alternatives, highlighting a crucial gap in the market for a biodegradable planting pot that does not only decompose naturally but also enriches the soil with essential nutrients. One of the major limitations with existing biodegradable pots is their high cost, which makes it inaccessible to a wide consumer base especially small-scale farmers and urban gardeners. For instance, coconut coir pots are biodegradable and widely used, but it is expensive to produce. This is due to processing and treatment cost before it is moulded into pots. Similarly, clay pots, while it is natural and reusable, it is heavy, fragile, and costly which makes it impractical for large-scale use. Recycle paper pots, on the other hand, is one of the alternatives but lack of durability and highly susceptible to moisture and damage, causing it to degrade prematurely before fulfilling its function (Gupta et al., 2023). Beyond cost and durability, another significant problem with the current biodegradable pot options is its lack of soil-enhancing properties. Most biodegradable pots are designed to simply decompose without adding any significant nutrients to the soil, limiting their contribution to the soul fertility and plant health (Fuentes et al., 2021). These limitations leave gardeners and farmers to rely on synthetic fertilizer which can harm the environment over time.

In addition, Malaysia has been facing a persistent challenge in managing its fruit dumping issue, driven by market fluctuations and strict cosmetic standards in the industry (Abd Ghafar & University of Technology Malaysia, 2017). Farmers are often faced with oversupply issues, where fruit production exceeds consumer demands, which contributes to surplus produce that cannot be sold profitably. Simultaneously, a significant portion of fruits and vegetables are discarded solely due to minor cosmetic imperfections, despite being perfectly edible and nutritious (Durai, 2021). These two factors combined leads to a large-scale fruit dumping, causing both economic losses for farmers and significant environmental impacts. The overproduction of fruits is a continuous issue, particularly during peak harvest seasons when supple exceeds demand. When this happens, prices drop significantly which making it difficult for farmers to sell their produce at a profit. Some fruits like durians, papayas and bananas are at risk to market saturation. This will force the producers to discard large amounts of surplus fruit that cannot be stored or exported efficiently (Ttn, 2020). This highlights the urgency to develop a sustainable, cost-effective, and soil-enhancing alternative that not only addresses plastic pollution concerns but also repurposes food and agricultural waste into value-added products.

The BioPaya Pot is an innovative, biodegradable plant pot made from papaya waste. It is designed to overcome these pressing environmental issues. By repurposing papaya peels and seeds, integrated with organic binders such as glycerine and agar, this eco- friendly alternative provides a dual benefit. It reduces food waste by transitioning discarded agricultural by-products into practical, high-value gardening product. In addition, it enhances soil fertility by naturally decomposing and releasing essential nutrients like calcium, magnesium and phosphorus which eliminates the need of synthetic fertilisers (Dahunsi et al., 2021). Moreover, depending on the soil type, papaya peels may help

adjust soil pH due to their natural alkaline properties (Jariwala, Hiral & Syed, Huma., 2016). Additionally, by integrating circular economy principles, the BioPaya Pot transforms waste into opportunity. It provides a marketable, scalable, and sustainable alternative to plastic plant pots and polybags. This innovation does not only align with the UN Global Sustainability Goals (SDGs) which are Industry, Innovation and Infrastructure, responsible consumption and production and decent work and economic growth, but also creates economic opportunities for farmers, environmentalists, and the gardening industry. With its potential to revolutionize gardening practices, the BioPaya Pot represents a breakthrough in waste management, sustainability, and eco-friendly product innovation, shows a step forward towards a greener, cleaner and more responsible future.

The primary aim of this study is to examine the feasibility and impact of utilizing *Carica papaya* waste in the development of a biodegradable planting pot as a sustainable alternative to conventional plastic containers. Specifically, the objectives of this research are as follows:

i. To assess the environmental attitudes of farmers, gardeners, and nursery owners toward sustainable agriculture.

ii. To evaluate their perception of a biodegradable plant pot prototype made from papaya agricultural waste.

iii. To examine their intention to adopt the product for future use.

2. METHODOLOGY

2.1 Research Design

This study employed a quantitative, cross-sectional survey design to investigate user perceptions, environmental attitudes, and behavioural intention to adopt the BioPaya Pot—an innovative biodegradable planting container developed from Carica papaya agricultural waste (Creswell, 2014). This design was chosen due to its ability to systematically collect data from a defined population at a single point in time, offering valuable insight into early-stage user attitudes and potential market response. The study is grounded in the New Ecological Paradigm (NEP) framework, originally developed by Dunlap et al. (2000), which served as the theoretical lens for evaluating pro-environmental worldviews among respondents. The NEP is widely recognized for its effectiveness in measuring ecological consciousness and sustainability orientation, making it an ideal fit for assessing the social acceptance of green innovations such as the BioPaya Pot.

2.2 Sampling and Participants

A purposive sampling technique was employed to ensure the inclusion of respondents with relevant knowledge and hands-on experience in agriculture. The sample comprised 30 individuals, equally divided into three groups: 10 farmers, 10 gardeners, and 10 nursery owners, all based in Seri Iskandar, Perak. These participants were selected for their regular use of planting containers and their potential as early adopters of sustainable agricultural technologies. Their direct involvement in cultivation and plant care made them ideal evaluators of the BioPaya Pot's practicality, usability, and environmental value (Etikan et al., 2016).

2.3 Research Instrument

Data collection was conducted through a structured questionnaire, developed based on literature related to environmental attitudes, innovation adoption, and sustainable product usability. The instrument consisted of six sections:

- Section A: Demographic information (e.g., age, gender, occupation, years of agricultural experience)
- Section B & C: Environmental attitudes, assessed using the New Ecological Paradigm (NEP) scale developed by Dunlap et al. (2000)
- Section D: Evaluation of product usability and user experience with the BioPaya Pot
- Section E: Behavioural intention to adopt and recommend the product
- Section F: Open-ended responses for qualitative feedback and improvement suggestions

The NEP scale items assessed dimensions such as ecological concern, anti-anthropocentrism, balance of nature, and limits to growth—critical themes in understanding sustainable behaviour. All quantitative items were rated on a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). The questionnaire's reliability was verified with a Cronbach's Alpha score of 0.81, indicating high internal consistency and statistical validity (Tavakol & Dennick, 2011).

2.4 Product Description and Materials

The prototype of the BioPaya Pot was developed through a process of biomaterial formulation and manual fabrication. The core ingredients included:

- Papaya agricultural waste, specifically peels, stalks, and fibrous material, sourced locally from discarded fruit waste
- Natural starch-based binders, serving as eco-friendly adhesives to maintain the pot's structure
- A manual moulding and heat-pressing process to shape the pot into a compact, plan table form

Each prototype was tested for form stability, biodegradability, and nutrient retention capacity. During the survey, participants were either physically handing in the product or shown high-resolution images and videos illustrating its design, texture, and application in real planting scenarios. This ensured that all respondents had a clear understanding of the product before rating its usability and potential.

2.5 Data Collection and Analysis

The survey was distributed using a hybrid method: printed questionnaires for in-person sessions and Google Forms for remote responses. Data collection was completed over a two-week period. Ethical considerations were followed, and all participants were informed of the voluntary and anonymous nature of the study.

Quantitative data were processed using SPSS version 26.0. Descriptive statistics (frequencies, percentages, and mean scores) were computed to summarize demographic information and assess general attitudes and behavioural trends. In addition, correlation analysis was conducted to test the relationship between respondents' environmental attitudes (as measured by the NEP scale) and their intention to adopt the BioPaya Pot. This approach aligns with behavioural intention models such as the Theory of Planned Behaviour (Ajzen, 1991), which posits that attitudes strongly influence the likelihood of adopting sustainable behaviours.

The combination of theoretical grounding, relevant participant sampling, and robust analytical tools ensures that the methodology effectively captures both the social and practical dimensions of the BioPaya Pot as a sustainable innovation.

Table 1. Demographic Profile of Survey Respondents.

Demographic Variable	Category	Frequency (n)	Percentage (%)
Occupation	*Farmers*	10	3.33%
	Gardeners	10	3.33%
	Nursery Owners	10	3.33%

Years of Experience	*Less than 3 years*	9	30.0%
	3 – 5 years	12	40.0%
	More than 5 years	9	30.0%
Familiarity of Biodegradable Products	*Yes*	26	86.7%
	No	4	13.3%
Gender	*Male*	11	36.67%
	Female	19	63.33%

3. FINDINGS

This section presents the core findings of the study, derived from the survey responses of 30 participants comprising farmers, gardeners, and nursery owners. The analysis focuses on three key areas: environmental attitudes (based on the New Ecological Paradigm framework), product evaluation, and behavioural intention to adopt the BioPaya Pot. The results are presented using descriptive statistics and interpreted based on mean score values using a 5-point Likert scale.

3.1 Environmental Attitudes (NEP Framework)

Respondents demonstrated a remarkably strong pro-environmental orientation. The belief that sustainable agriculture is essential for protecting the environment scored a mean of 4.52, while the sense of personal responsibility to reduce plastic use in farming practices scored 4.47. These high mean values reflect a community deeply concerned with environmental issues and receptive to alternative solutions such as biodegradable planting containers.

The overall environmental concern score—averaged across all NEP items—was 4.52, indicating a Very High level of ecological awareness among the target group. This is consistent with prior literature affirming that farmers and agro practitioners are increasingly embracing sustainable practices (Dunlap et al., 2000). Such attitudes lay a strong foundation for the acceptance of eco-friendly agricultural innovations like the BioPaya Pot.

3.2 Product Evaluation

The BioPaya Pot received positive feedback from users across several key usability criteria. Respondents found the product to be practical and functional, with a mean score of 4.31, and strong enough to support plant growth, which was rated at 4.36. Importantly, the pot's ability to biodegrade naturally and enrich the soil was perceived as one of its greatest strengths, earning a mean score of 4.53, categorised as Very High.

These findings affirm that the product is not only environmentally sustainable but also agriculturally effective, meeting the core needs of plant growers. The pot's dual functionality—as both a planting container and a source of organic nutrients—sets it apart from traditional biodegradable alternatives that do not offer additional soil enrichment.

3.3 Intention to Adopt

Respondents showed a strong willingness to adopt the BioPaya Pot in their personal or commercial gardening practices, with a mean adoption intention score of 4.24. Notably, purchase intention if affordably priced was rated even higher, at 4.41, reflecting Very High commercial potential. This suggests that while eco-consciousness plays a role, affordability and perceived value are key factors in driving real-world adoption.

These findings support the Theory of Planned Behaviour (Ajzen, 1991), which posits that favourable attitudes toward a behaviour significantly increase the likelihood of intention and eventual action. The results also confirm a positive correlation ($r = 0.69$, $p < 0.05$) between environmental attitudes and adoption intention, reinforcing the idea that those who care more about the environment are more likely to adopt green innovations.

3.4 Summary of Quantitative Results

Table 2. Summary of Survey Findings on BioPaya Pot.

Section	Statement Summary	Mean Score	Interpretation
Environmental Attitudes	*Sustainable agriculture is essential*	4.52	Very High
	Personal responsibility to reduce plastic use	4.47	Very High
	Overall environmental concern score	4.52	Very High
Product Evaluation	*Practical and functional to use*	4.31	High
	Strong enough to support plant growth	4.36	High
	Decomposes naturally and improves soil	4.53	Very High
Intention to Adopt	*Willingness to adopt in practice*	4.24	High
	Purchase intention if affordably priced	4.41	Very High

The data clearly indicate that the BioPaya Pot is well-received by key agricultural stakeholders, not only because it aligns with their ecological values but also because it functions effectively and holds strong market potential. The pot's ability to integrate into existing farming practices without compromising on performance or cost is a major advantage. These findings validate both the technical feasibility and the commercial viability of the product, supporting its readiness for further development, protection under MyIPO, and eventual market introduction.

4. DISCUSSION

The BioPaya Pot is a revolutionary innovation that converts agricultural waste into a sustainable, biodegradable planting pot, providing a unique approach to waste management, soil enrichment and plastic-free gardening. Unlike conventional biodegradable pots made from materials like recycled paper, coconut coir, or bamboo, the BioPaya Pot is the first known plant pot to combine papaya peels and seeds, making it a groundbreaking solution in the agricultural and gardening sectors.

Table 3. Comparative Analysis of Biodegradable Pots

Pot Type	Biodegradability	Nutrient Value	Moisture Resistance	Cost-Effectiveness	Aesthetic Appeal
Plastic Pot	No	No	Yes	Yes	Yes
Paper Pot	*Yes*	No	No	Yes	No
Coir Pot	*Yes*	No	Yes	No	Yes
BioPaya Pot	*Yes*	Yes	Moderate	Yes	Yes

4.1 Dual Functionality of the BioPaya Pot

This novel approach does not only address food waste and plastic pollution issue but also introduces a dual-function product. It also serves as both a biodegradable plant container and natural soil enricher. While most of the existing biodegradable pots simply decompose over time without providing additional benefits, the BioPaya Pot enhances soil fertility as it breaks down, releasing calcium, phosphorus and magnesium which are essential nutrients for plant growth (Dahunsi et al., 2021). This organic soil fertility reduces the reliance on synthetic fertilizer, which promotes a more sustainable and natural practice to plant cultivation.

Another unique feature of the BioPaya Pot is its use of natural binders which is agar and glycerin. These ingredients provide durability and moisture retention without depending on synthetic chemicals (Houthuijs & Houthuijs, 2023). Many biodegradable pots such as recycled paper pot face limitations like weak structural integrity or premature disintegration when exposed to moisture (Gupta et al., 2024). The BioPaya Pot overcomes these problems by maintaining optimal durability while ensuring complete decomposition over time. This innovation ensures that farmers and gardeners have access to a functional and sustainable planting solution that does not cause environmental harm.

4.2 Significant Impact

One of the notable contributions of the BioPaya Pot is its role in minimizing food waste, specifically fruit dumping from market oversupply and cosmetics imperfections. Papaya peels and seeds are often discarded as agricultural waste. The BioPaya Pot repurposed these by-products into a biodegradable, nutrient-rich pot, preventing them from rooting in landfills and releasing methane emissions which is the major contributor to climate change (Methane | Vital Signs – Climate Change: Vital Signs of the Planet, n.d.).

The BioPaya Pot goes beyond the conventional planting pots that simply hold soil. It actively enriches the soil by releasing nutrients as it decomposes. Papaya waste is naturally rich in calcium, phosphorus and magnesium which are the vital nutrients that support plant root growth as well as plant metabolism and soil health. By reintroducing these vital nutrients to the soil, it minimizes the need for synthetic fertilizers, which can cause water contamination, and soil degradation. For farmers, the innovation of BioPaya Pot open an opportunity to improve soil quality naturally, which results in superior yield production and healthier crops. The BioPaya Pot fits the global trend for sustainable agriculture by supporting organic farming methods and waste management in agricultural production.

Agricultural waste is often viewed as a financial loss in which farmers struggling to find profitable solutions to repurpose rejected fruit or surplus produce. The BioPaya Pot transforms these wastes into economic opportunities by turning discarded papaya peels and seeds into a marketable product. Fruit suppliers and farmers can sell their agricultural waste to manufacturers as raw material. This will create an additional source of income. Additionally, as the demand for biodegradable and eco-friendly products continues to increase, the BioPaya Pot taps into growing green economy, offering businesses with a sustainable and profitable alternative to plastic pots (Statista, 2024).

4.3 Opportunities for Product Enhancement

To improve the BioPaya Pot and maximize its environmental and commercial impact, several key strategies should be implemented.

4.3.1 Enhancing Product Durability and Composition

While the BioPaya Pot is designed to be biodegradable, ensuring a balance between structural integrity and decomposition is crucial. Research should be conducted on incorporating additional organic binders or coatings that prolong the pot's lifespan without compromising its ability to

decompose naturally. By enhancing durability, the product can cater to a wider audience, including commercial farmers who require reliable planting solutions. Further testing on decomposition rates in various soil conditions will also help refine the product and optimize its performance in different environments (Lemco, 2024).

4.3.2 Development of a Multi-Purpose Biodegradable Pot with Pest-Repelling Properties

While the BioPaya Pot already serves as an eco-friendly alternative, its functionality can be expanded by integrating natural pest-repelling agents. Studies have demonstrated that papaya contains bioactive compounds such as alkaloids and flavonoids, which exhibit antimicrobial and insect-repelling properties (Sharma et al., 2020). By adding neem extracts or citronella-infused binders, the pot can further prevent pests like aphids and fungal infestations, reducing the need for chemical pesticides. This improvement aligns with organic farming principles and could appeal to gardeners seeking holistic plant protection. Moreover, incorporating essential oils with antifungal properties, such as thyme or eucalyptus, could enhance the pot's resilience against microbial degradation, extending its usability period before decomposition begins (Nazzaro et al., 2017).

4.0 Economic Feasibility and Market Readiness

BioPaya Pot has significant potential for commercialization across various stakeholders. The target market includes home gardeners and urban farmers seeking sustainable solutions, agricultural businesses interested in biodegradable planting solutions, and government and non-governmental organizations supporting green initiatives (Market Expansion Report, 2023). The business model focuses on direct sales through nurseries, gardening stores, and online platforms, along with B2B partnership with agricultural businesses and urban farming initiatives. Additionally, collaborations with government and NGOs can help secure funding and support for environmental conservation programs. Marketing strategies include social media campaigns on Instagram, Facebook, and TikTok, workshops and demonstrations to highlight the benefits of BioPaya Pot, influencer and community engagement, and obtaining sustainability certifications to enhance credibility and consumer trust. However, potential challenges include concerns regarding durability, production costs, and market acceptance. Solutions such as improving the structural integrity of the pot, scaling up production to reduce costs, and educating consumers about its long-term benefits will be implemented to ensure market success.

As part of the initial commercialization strategy, the project has established a collaboration with *Ben Malek AgroFarm*, a small-scale industrial enterprise engaged in farming, livestock, and agro-based product development. This partnership provides a practical platform to evaluate the BioPaya Pot's performance and acceptance within agricultural environments. The collaboration enables field-level testing, facilitates feedback collection from practitioners, and supports the refinement of production techniques. Moreover, it offers opportunities to examine cost structures and assess consumer demand on a small commercial scale. By engaging with an established agro-industry partner, the project moves beyond prototyping, taking essential steps toward validating the product's economic feasibility and market readiness. This collaboration serves as a foundation for future scalability and provides insight into the practical challenges and potential of deploying the BioPaya Pot in the broader agricultural sector.

5. CONCLUSION

The BioPaya Pot demonstrates significant potential as a sustainable and socially impactful innovation by addressing two urgent environmental issues: plastic waste and agricultural food waste. Through the transformation of *Carica papaya* peels and seeds into a functional, biodegradable planting

container, this product not only offers an eco-friendly alternative to plastic pots but also contributes to soil enrichment through the natural release of nutrients such as calcium, magnesium, and phosphorus.

This study employed a quantitative, cross-sectional survey design grounded in the New Ecological Paradigm (NEP) to assess environmental attitudes and behavioural intention among relevant agricultural stakeholders. The results revealed very high pro-environmental attitudes, with mean scores above 4.50 for items related to sustainability awareness and ecological responsibility. Participants also gave favourable evaluations of the product's practicality, biodegradability, and potential for improving soil quality, reinforcing its dual functionality as both a planting medium and natural fertilizer.

Notably, the intention to adopt the BioPaya Pot was strong (mean = 4.24), with purchase intention at an even higher level (mean = 4.41), indicating solid market readiness—particularly if affordability is maintained. Furthermore, a positive correlation between environmental attitudes and adoption intention supports the role of ecological values in influencing sustainable behaviour, in line with the Theory of Planned Behavior (Ajzen, 1991).

The BioPaya Pot's relevance extends beyond environmental impact. It also offers economic opportunities by enabling farmers to monetize agricultural waste and giving rise to green entrepreneurship within the horticulture and gardening industries. At the social level, it encourages sustainable consumption, supports urban gardening, and fosters environmental education.

However, the path toward large-scale adoption is not without challenges. Issues related to durability in wet conditions, production scalability, and consumer awareness must be addressed. Based on the findings, future improvements should focus on enhancing product strength, extending usability, and tailoring design for various planting needs. Coupling these efforts with strategic marketing, government support, and partnerships with sustainability-focused organizations will help position BioPaya Pot as a key solution in the green product ecosystem.

With rising global demand for biodegradable and circular solutions, the BioPaya Pot stands as a viable, scalable, and research-backed innovation-one that not only promotes sustainable agriculture but also contributes meaningfully to the UN Sustainable Development Goals (SDGs), particularly in the areas of responsible consumption, climate action, and innovation for sustainability.

To fully harness the potential of BioPaya Pot, future research should explore advanced formulation techniques to enhance durability under varying climate conditions, as well as investigate its long-term effects on different soil types and crop yields. Life cycle assessment (LCA) studies and economic feasibility analyses would further strengthen its viability for mass production and export. As the demand for eco-friendly solutions continues to grow, stakeholders including policymakers, researchers, and industry leaders-are urged to support the development and commercialization of sustainable agricultural innovations like BioPaya Pot. By investing in green technology, we take a critical step toward a more resilient, circular, and climate-conscious future.

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