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Biodegradable Material Development from Local Resources of Kish Island: A Sustainable Approach to Airline Food Packaging

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Abstract

The aviation industry generates significant packaging waste, highlighting the urgent need for sustainable material alternatives. This study aimed to identify and develop biodegradable food packaging materials derived from indigenous resources on Kish Island as a context-specific solution for airline catering. Initially, a theoretical framework was established through a review of sustainable design principles, environmental challenges, and emerging approaches in food packaging. Semi-structured interviews with local environmental experts were then conducted to identify viable natural resources as potential substitutes for conventional plastics. Candidate materials, including algae, coral residues, palm leaves, crab shell waste, and local clay, were assessed based on biodegradability, durability, cost efficiency, production feasibility, and environmental impact. Following analytical evaluation, a composite of palm leaf fibers and local clay was selected for experimental development. Prototyping was carried out through drying, compression, and molding processes, resulting in bowl-shaped samples. Testing demonstrated favorable mechanical strength, water and grease resistance, thermal durability, and full biodegradability. Due to their natural origin and absence of petroleum-based synthetic additives, the selected materials present low toxicity potential and do not generate persistent microplastic residues, supporting their suitability for food-contact applications. The findings indicate that locally sourced biomaterials can provide a feasible, hygienic, and sustainable alternative for airline food packaging, integrating environmental responsibility with regional ecological identity and resource availability.

Keywords

Sustainability, Local Resources, Food Packaging, Biomaterial Development, Material Experimentation.

Introduction

In a hypothetical scenario, during a one-and-a-half-hour flight between Tehran and Kish Island, an airline serves meals or snacks to an average of 160 passengers. Each meal is packaged in approximately 300 grams of plastic. Assuming the airline operates only one daily flight on this route, more than 58,400 plastic packages amounting to over 17,500 kilograms of waste are used annually for this single route. Such statistics reveal the significant environmental footprint and waste crisis embedded in the aviation industry.

The aviation sector is among the world's major producers of non-recyclable plastic waste. According to the International Civil Aviation Organization (ICAO, 2023), millions of tons of in-flight meal packaging waste are generated annually, of which less than ten percent is recyclable. These wastes not only pose a serious threat to the environment but also impose substantial logistical and management costs on airlines (Lacourt et al., 2024). The limited cabin space, complex service processes, and strict hygiene requirements make packaging design a multifaceted and challenging issue within air travel.

In response to these challenges, the concept of sustainable design has emerged as an approach that aims not only to minimize environmental impacts, optimize resource consumption, and extend product lifecycles, but also to foster meaningful creation (Walker, 2006). Sustainable design succeeds when users perceive themselves as active participants in environmental preservation and experience a sense of engagement and responsibility through product use. From this perspective, the integration of contextual awareness and sustainable design principles can lead to solutions that enhance both functional efficiency and environmental consciousness (Ahmad et al., 2018).

Accordingly, the central question of this research can be framed as follows: How can indigenous materials from Kish Island be identified and developed into biodegradable compounds suitable for sustainable food packaging in the aviation industry?

Answering this question offers a new model for product design in specific ecological contexts; one that illustrates how sustainability is not merely an environmental solution, but a language connecting place, material, and form in the design process.

Literature Review and Theoretical Foundations

The review of existing literature and theoretical foundations in this study served as a crucial step in establishing the conceptual framework and guiding the design process. In the initial phase, to achieve a comprehensive understanding of the design problem, a set of key concepts was derived from the research title; namely, sustainability, the aviation industry, and food packaging design. These keywords functioned as the theoretical pillars of the study and formed the basis for searching, classifying, and analyzing relevant academic sources.

In recent decades, sustainability has become one of the central pillars of industrial design. Positioned at the intersection of science, philosophy, and ethics, its goal is to balance the needs of the present generation with the capacity of future generations to meet their own (Walker, 2006). According to Stuart Walker (2006), sustainability is not merely about minimizing environmental damage but also about creating meaning through design. Sustainable design should be culturally and contextually relevant, enhancing the quality of human life. It rests upon three core dimensions: environmental, social, and economic. The environmental dimension emphasizes reducing pollution and resource consumption; the social aspect focuses on improving quality of life and social equity; and the economic dimension underlines affordability and product longevity (Ahmad et al., 2018).

Within this framework, tools such as Life Cycle Assessment (LCA) help designers evaluate a product's environmental impact from production to disposal, enabling design decisions based on empirical data (Ahmad et al., 2018). Research suggests that more than 80% of a product's sustainability potential is determined during the design phase; hence, the selection of materials, production methods, and product form has the greatest influence on environmental outcomes (Ahmad et al., 2018). From this perspective, the designer is not merely responsible for aesthetics and functionality but also acts as a mediator balancing the relationship between humans and the environment.

The aviation industry is technologically advanced yet environmentally intensive. Commercial flights account for approximately 2.5% of global carbon dioxide emissions (ICAO, 2023), and achieving net zero by 2050 will require systemic change across the service chain. In-flight catering is a major source of waste; in 2017 alone, flights generated over 5.7 million tons of waste, largely from meal packaging (Fangzhou You et al., 2020). Consequently, sustainable design in in-flight food services is essential to reducing the industry's environmental footprint.

It is estimated that in 2021, approximately 264 million tons of paper and cardboard were used in packaging production (Lacourt et al., 2024). However, the exponential rise in plastic use over the past century has dramatically reshaped the packaging landscape. Plastics now account for 37% of food packaging materials, followed by paper and cardboard (34%), glass (11%), and metals (6%) (Lacourt et al., 2024).

What makes this trend even more concerning is the fate of these materials after use. Due to persistent challenges in collection, sorting, and recycling, less than 10% of the seven billion tons of plastic waste generated globally has ever been recycled. Approximately 19% has been incinerated, nearly 50% has accumulated in landfills, and the remaining 22% has either been improperly disposed of or directly entered natural environments (Lacourt et al., 2024).

The concept of local materials emerges in this context as a critical strategy for reducing environmental impact while strengthening cultural and economic resilience. Local materials are defined as resources that are sourced, processed, and utilized within a specific geographical region. Their use can significantly reduce transportation-related emissions, support local economies, and reinforce regional identity within product design. From a sustainability perspective, local materials contribute simultaneously to environmental, social, and economic dimensions.

Environmentally, shorter supply chains reduce embodied energy and carbon emissions. Socially, the integration of locally available materials can strengthen community-based production systems and preserve traditional knowledge. Economically, localized sourcing may reduce dependency on imported raw materials and create value within regional markets.

Food packaging design is one of the most complex fields in product design, where functionality, aesthetics, and sustainability must be addressed simultaneously. Historically, packaging has reflected both the cultural needs and technological capabilities of each era; from leaves and tree bark in ancient times to multilayer polymers in the modern age (Gupta Deduja, 2018). Today, packaging goes beyond its protective role and functions as a medium for conveying brand messaging, nutritional information, and visual identity.

The fundamental challenge in food packaging design lies in achieving a balance between durability, hygiene, and biodegradability. Innovative solutions such as active and intelligent packaging have been developed to extend shelf life and reduce waste (Han et al., 2018). At the same time, the use of local and natural materials can significantly reduce the carbon footprint associated with manufacturing and transportation.

As a Conclusion, the reviewed literature underscores the growing interdependence between sustainability, material innovation, and design practice, particularly within the aviation industry. The findings reveal that the environmental challenges of in-flight catering and packaging cannot be addressed solely through technological advancement but require a holistic design perspective that integrates ecological responsibility, material efficiency, and cultural relevance. The convergence of sustainable design principles with advances in biodegradable materials and context-sensitive approaches provides a viable framework for rethinking how products are conceived and produced in constrained environments such as aircraft cabins.

Material & Methods

This study adopts an exploratory qualitative–experimental research approach. Rather than aiming at definitive validation, the research seeks to preliminarily investigate the feasibility of utilizing indigenous materials from Kish Island for the development of biodegradable food packaging suitable for the aviation industry. In the first stage, theoretical studies were conducted on the concept of sustainability, its necessity in the aviation sector, and the main environmental and operational challenges associated with it. Subsequently, to identify the natural and biological capacities of Kish Island, semi-structured to assess the environmental potential and availability of indigenous natural resources on Kish Island for the development of biodegradable food packaging, semi-structured interviews were conducted with two environmental experts ($N = 2$) affiliated with the Kish Island Ecology Center. Participants were selected through purposive sampling based on their professional expertise in island ecology, environmental resource management, and local sustainability initiatives.

Each interview lasted approximately 60 minutes and was conducted in person. With participants' consent, discussions were documented through note-taking and audio recording to ensure accuracy in data interpretation. The interview protocol included open-ended questions addressing: (1) the types and abundance of natural resources available on the island, (2) accessibility and extraction feasibility, (3) existing or potentially implementable processing technologies, and (4) economic considerations such as estimated production costs, comparative material advantages, and environmental compatibility. The collected qualitative data were analyzed using a thematic analysis approach. Initial open coding was performed to identify recurring concepts related to material feasibility, sustainability potential, and local resource constraints. These codes were then grouped into broader thematic categories, which informed the preliminary material screening process. Rather than aiming for statistical generalization, this phase functioned as an exploratory screening mechanism to identify promising candidates for subsequent experimental investigation. In the next stage, analytical and theoretical assessments were performed on the proposed materials identified through the interviews. These evaluations focused on the materials' biological sustainability, processability, and biodegradability. The analysis was carried out based on existing scientific literature and Life Cycle Assessment (LCA) indicators to ensure that only materials that were both environmentally and economically feasible were selected.

Finally, the selected materials entered the experimental phase of testing and prototype material development. Workshop experiments included processes such as drying, compression, blending, forming, and molding to produce the primary material. At this stage, the samples were evaluated in terms of durability, moisture and oil resistance, and biodegradability, providing the basis for selecting the most suitable composition for subsequent product design applications.

Results

The table below summarizes the key thematic outcomes derived from the interviews and presents a comparative overview of the identified materials and their perceived suitability for sustainable packaging applications

Table 1: *Comparative Analysis of Indigenous Materials on Kish Island for Biodegradable Packaging Applications*

Characteristics	Local Clay	Shrimp and Crab Waste	Marine Algae	Coral and Shell Fossils	Palm Tree Fibers
Resource Availability and Abundance	Found at depths of approximately 5+ meters in local construction projects	Large quantities of crustacean and shrimp waste from Kish's fisheries industry	High abundance of marine algae along the island's coasts	Rich resources are found in the marine beds surrounding Kish Island	Abundant due to the widespread presence of palm trees and their by-products

Processing and Treatment Method	Sieving, mixing with water, and other natural additives	Extraction of chitin, deacetylation, and decarboxylation to produce chitosan	Collection, drying, and extraction of agar or alginate	Collection, crushing, pulverizing, and mixing with bio-based polymers	Washing, drying, shredding, and blending with biopolymers
Production Cost	Very low; labor and additives are the only high costs	Moderate to high, depending on production volume and processing infrastructure	High, due to the need for advanced extraction technology	Moderate, requiring specialized crushing and processing equipment	Low, due to easy accessibility and simple processing technology
Required Technology	Simple and semi-industrial equipment is sufficient	Chemical extraction tools, specialized reactors for chitin-to-chitosan conversion	Chemical or biological extraction equipment	Advanced milling and processing machinery	Shredders and pressing machines
Potential Applications	Pottery and building materials	Biodegradable films, antibacterial coatings, and food packaging applications	Transparent packaging and thin bio-films	Rigid, biodegradable containers	Simple and durable food containers
Advantages	Fully biodegradable, no industrial recycling required, inexpensive, native, and abundant	Antimicrobial properties, biodegradable, broad applications in the food and pharmaceutical industries	Innovative, biodegradable, suitable for eco-packaging	Strong, durable, and high added value	Low cost, easy processing, high availability
Disadvantages	Heavy and moisture-sensitive without stabilizers; prone to brittleness	Requires technical expertise, sensitive quality control during extraction	Complex processing, high production costs	Potential environmental damage contradicts sustainability goals	Limited to simple product forms

The Ecological Experts of Kish Island provided detailed insights regarding the type, abundance, and accessibility of materials, as well as their extraction methods, processing technologies, and related economic and environmental implications. The following section presents an analytical overview of these materials and their potential.

1. *Palm Tree Fibres*

One of the most promising local materials identified was palm tree fiber, abundantly available from date palms cultivated across Kish Island. In addition to being renewable, palm leaves and fibers can be utilized as raw material for producing simple, biodegradable packaging and containers. Once collected, these fibers can be processed through compression or blended with other bio-based materials to yield durable, eco-friendly products (Figure 1).

Figure 1: *Pruned palm fibers* (Source: Author)

Iran ranks among the world's leading producers of dates and date palms, accounting for approximately 15–20% of global palm cultivation. This industry plays a vital role in the country's agricultural economy, not only as a food source but also for its by-products: fibers, leaves, and trunks used in various industrial applications. On Kish Island, substantial quantities of palm waste are generated annually, much of which remains unused due to limited industrial applications.

a) Processing Method:
Palm fibers require simple processing steps such as collecting, washing, disinfecting, drying, and occasionally shredding. These materials can be used in the production of compressed items such as disposable food containers and packaging.

b) Production Cost and Technology:
Due to the high availability and low cost of palm fibers, collection and processing expenses are minimal. The required technology, mainly shredding and pressing machinery, is relatively simple and can be sourced or fabricated locally.

2. *Coral and Shell Fossils*

Due to its marine geography, Kish Island possesses extensive deposits of dead corals and seashells. These are considered marine waste materials that naturally accumulate in the environment.

a) Processing Method:
Coral and shell fossils can be collected, crushed, ground into powder, and used as filler material in bio-composite structures or for producing rigid biodegradable containers. However, processing requires specialized crushing and homogenization equipment, resulting in higher initial costs that may be offset by the added value of the final product.

b) Environmental Concerns:
Despite their abundance, the extraction of corals for raw material poses serious ecological risks. Coral reefs are critical habitats for marine biodiversity, and uncontrolled extraction could lead to habitat destruction, biodiversity loss, and disruption of the food chain. Moreover, corals regenerate extremely slowly, and reef recovery can take decades. Countries such as India and Sri Lanka, which historically used corals as construction material, have experienced severe coastal erosion, declining fish populations, and socioeconomic challenges in local communities.

3. *Marine Algae*

Marine algae are abundant around Kish Island, with large quantities naturally washing ashore each year. These algae represent a promising natural source for the production of biodegradable films and thin packaging materials.

a) Processing Method:

Processing includes collecting, drying, and extracting biopolymers such as agar and alginate. The main stage involves breaking dried algae into fine pieces or powder, soaking them in water or acid solutions to extract polysaccharides, heating the mixture at 80–100°C to enhance extraction efficiency, and filtering to separate the polysaccharide solution. The resulting compounds can serve as the base for producing biodegradable coatings or transparent, flexible packaging.

b) Production Cost and Technology:

The extraction of agar or alginate requires advanced chemical or biological extraction systems, which increase initial production costs. However, the ready availability of raw materials locally helps reduce logistics and material supply expenses.

4. *Crustacean Shell Waste (Shrimp and Crab)*

Chitosan is a derivative of chitin extracted from shrimp and crab shells, which is a well-known biodegradable, non-toxic, and antimicrobial material with extensive applications in food packaging, pharmaceuticals, and medical industries. Kish Island, as a major fishing and seafood processing hub in southern Iran, generates large quantities of shell waste that are currently discarded. These could instead serve as a sustainable source of chitin and, consequently, for chitosan production.

a) Processing Method:

The extraction of chitosan involves three main steps: deproteinization (removal of proteins), demineralization (removal of minerals such as calcium carbonate), and deacetylation (removal of acetyl groups to convert chitin into chitosan).

b) Production Cost:

The cost depends on the availability of raw shells, the price of chemicals used (e.g., sodium hydroxide and hydrochloric acid, typically imported), energy consumption, labor, and processing infrastructure. Establishing semi-industrial laboratories and training specialized personnel requires an initial investment, posing a key implementation challenge.

5. *Marl Clay (Local Clay Soil)*

Marl clay is a natural composite of clay, limestone, and organic matter characterized by fine texture, high plasticity, and the ability to harden upon drying, properties that make it useful in pottery and construction. It naturally occurs at a depth of approximately five meters in Kish Island's soil strata and is often exposed during local excavation and construction projects. Local artisans have long utilized this clay in pottery, indicating its quality and accessibility.

a) Processing and Production Cost:

Processing marl clay is relatively simple, involving drying, grinding, and sieving to remove impurities. Depending on its intended use, it may be combined with stabilizing additives such as plant fibers to enhance strength and moisture resistance. These processes can be conducted using semi-industrial or even manual equipment, requiring no advanced technology; an advantage for localized production. Despite its benefits, marl clay is heavier than most bio-based polymers and can pose challenges for mass transport and handling.

Theoretical Analysis of the contents of the final formula

The final composite formula was developed through iterative experimentation and theoretical analysis to achieve an optimal balance between mechanical strength, biodegradability, and environmental compatibility. Each component of the mixture was selected based on its functional contribution to the physical and ecological performance of the final material. The following section provides a detailed explanation of the role, proportion, and scientific justification for each ingredient used in the formulation (Figure 2).

Figure 2: *Composition of the Final Formula* (Source: Author)

1. *Natural Clay (70%)*

Natural clay enhances the mechanical strength and barrier performance of the composite. The mineral particles within the clay can penetrate the starch matrix and form a tortuous path that prevents the diffusion of gases and water vapor (Trigueiro et al., 2024). Moreover, clay increases the stiffness of the film and improves its hydrophobicity by reducing moisture absorption. Natural clays are non-toxic, inexpensive, and capable of forming biodegradable bio-composites (Olsson et al., 2013).

2. *Crushed Palm Leaves (10%)*

To improve mechanical properties and reduce the overall weight of the material, natural clay was partially replaced with dried and shredded palm leaves. These plant fibers act as natural reinforcements within the matrix, increasing tensile strength, reducing density, and enhancing the flexural resistance of the final product. This approach resembles the traditional Iranian method of kah-gel (straw-clay), in which straw was mixed with clay to prevent cracking and strengthen the material. The inclusion of palm leaves not only reinforces the structure but also introduces a vernacular, eco-centered approach to sustainable design, utilizing locally available organic waste.

3. *Starch (10%)*

Starch serves as the main polymeric matrix of the composite and functions as an edible, renewable, and biodegradable binder. As a polysaccharide, starch can form transparent, continuous, and tasteless biodegradable films (Trigueiro et al., 2024). Due to its abundance, renewability, and non-toxicity, starch is widely used in edible packaging. However, starch-based films are inherently brittle and moisture-sensitive; therefore, plasticizers or hydrophobic additives are required. Since starch films exhibit poor barrier properties against moisture, small amounts of coconut oil or beeswax are incorporated to enhance water resistance. During processing, starch is heated with water to achieve gelatinization, forming a cohesive film upon drying.

4. *Coconut Oil or Beeswax (5%)*

A small proportion of hydrophobic lipids, such as coconut oil or beeswax, significantly improves water resistance (Pérez Gallardo, 2015). These waxy lipids disperse within the starch matrix, forming droplets or a continuous lipid phase that repels moisture. Studies indicate that adding approximately 5% wax particles to starch films increases surface hydrophobicity and reduces water vapor transmission rates (Pérez Gallardo, 2015). In a study on blackberry coatings, higher wax content resulted in a thicker and more cohesive layer that minimized moisture migration. Coconut oil, solid at room temperature, exhibits similar behavior. Plant-derived oils enhance the water and oxygen barrier properties of films while also providing antioxidant and antimicrobial effects (Moghadas et al., 2024). The incorporation of coconut oil into starch alginate films reduces solubility and vapor permeability while improving flexibility and mechanical strength. Both additives are edible, food-safe, and approved as "generally recognized as safe" (GRAS), extending product shelf life by sealing the film's surface.

5. *Citric Acid or White Vinegar (2%)*

A small amount of acid, such as citric acid or white vinegar, is added to induce crosslinking within the starch structure and provide mild antimicrobial effects (Olsson et al., 2013). Citric acid reacts with hydroxyl groups in starch chains to form cross-links, which reduce swelling and moisture absorption under high humidity. Starch coatings treated with citric acid display lower water absorption and gas permeability. Additionally, acetic acid (the main component of vinegar) naturally reduces alkalinity and exhibits antimicrobial activity (Cagri et al., 2004). Citric acid or vinegar, when added at 2%, enhances the film's cohesion and improves its storage stability.

6. *Distilled Water (as required)*

Water functions as the processing solvent, facilitating the homogeneous dispersion and blending of all ingredients during the wet-mixing stage. In practice, starch is heated in water to induce gelatinization, after which clay and wax components are dispersed within the starch solution. During casting and drying, water evaporates, leaving behind a solid composite film. Thus, water does not remain in the final product but plays a critical role in achieving uniform dispersion and film formation under mild heating conditions.

Preparation of the final formula

1. Processing of Raw Materials:

- **a)** The clay and starch were sieved to remove coarse particles and achieve a uniform texture.
- **b)** The palm leaves, which retained some moisture after washing, were disinfected using a mild chlorine solution and then sun-dried at mild temperatures to prevent mold growth and unwanted chemical changes.
- **c)** Once fully dried, the palm leaves were shredded using scissors into fibrous pieces approximately 0.5–1 cm in length and then ground into smaller particles (Figure 3).

Figure 3: *Washing and Grinding of Palm Leaves.* (Source: Author)

- **d)** The initial dry mixture, composed of clay, starch, and shredded palm leaves, was blended thoroughly in a clean, dry container to ensure a homogeneous distribution of components.

2. Preparation of Starch Gel:

- **a)** To prepare the starch gel, 100 ml of distilled water was used for every 10 g of starch.
- **b)** The solution was heated gently (70–80 °C) under continuous stirring until complete gelatinization occurred, resulting in a transparent, viscous gel (Figure 4).

Figure 4: *Starch Gel.* (Source: Author)

3. Incorporation of Clay and Palm Leaves into the Starch Gel:

a) The powdered mixture of clay and shredded palm leaves was gradually added to the starch gel under constant stirring (Figure 5).

Figure 5: *Adding Ground Palm Leaves and Clay to Starch* (Source: Author)

b) An electric mixer was used to achieve uniform dispersion of the particles.

c) Throughout the process, the temperature of the mixture was maintained to prevent premature solidification of the gel.

4. Addition of Lipid and Acidic Components:

a) To enhance flexibility and water resistance, 5% (by weight) coconut oil was added to the mixture (Figure 6).

Figure 6: *Addition of Coconut Oil*
(Source: Author)

b) Citric acid (2% by weight) was subsequently incorporated and thoroughly stirred to complete the acidification process (Figure 7).

Figure 7: *Addition of Citric Acid*
(Source: Author)

5. Casting the Mixture into Molds:

a) For shaping, a flat mold surface coated with coconut oil was used to prevent sticking.

b) The prepared mixture was poured evenly to achieve a uniform thickness of approximately 4 mm (Figure 8).

Figure 8: *Casting the Mixture* (Source: Author)

6. Drying Process:

a) The drying process was carried out for 24 to 48 hours at ambient temperature (Figure 9).

Figure 9: *Drying the Composite in the Mold.* (Source: Author)

7. Film Removal and Kiln Firing:

a) The final film was carefully detached from the mold after complete drying.

b) To enhance mechanical strength and remove residual organic components, the molded samples were fired in a pottery kiln at approximately 200–250 °C.

c) This thermal treatment transformed the material into a hard, relatively dense structure that is safe for direct food contact, making it suitable for use as serving containers for in-flight meals.

d) The firing process not only improved the physical properties but also preserved the natural and raw aesthetic qualities aligned with the project's visual and environmental design goals (Figure 10).

The material underwent a series of performance tests to evaluate its functional and environmental properties. Table 2 presents the summarized results, indicating high overall stability, resistance, and biodegradability of the final composite (Figure 11).

Figure 10: *Containers Produced by Molding; Bowls Released from the Mold* (Source: Author)

Table 2: *Performance Evaluation of the Final Composite Material* (Source: Author)

Property Tested	Evaluation Method	Observed Result	Performance Rating
Water Resistance	24-hour immersion test	No leakage or deformation	90%
Oil/Grease Resistance	Surface absorption test	Slight absorption after 12h	70%
Thermal Resistance	Exposure to 100°C hot water	No cracking or melting observed	90%
Mechanical Strength	Manual load test (500 g weight)	No breakage, slight flexing	90%
Biodegradability	Natural composting (30 days)	80% degradation	90%
Surface Texture and Finish	Visual and tactile inspection	Smooth, natural matte surface	90%

Figure 11: *Degradation of the Bowls after 30 Days of Composting.* (Source: Author)

Conclusion

Based on the obtained results, this study demonstrates that material strategy, rather than technological substitution alone, plays a decisive role in reducing packaging waste within aviation services. The identification of palm leaves and local clay as viable resources highlights how context-based design can transform regional ecological assets into functional material systems aligned with sustainability principles.

Compared to petroleum-based plastics, the palm–clay composite presents clear advantages in biodegradability, local sourcing, and reduced end-of-life impact. Plastics persist for decades and rely on energy-intensive recycling systems, whereas the proposed bio-composite decomposes naturally without generating microplastic residues. In contrast to many industrial bioplastics that depend on imported feedstocks and controlled composting facilities, this material is derived from locally abundant resources and processed through low-energy methods. The integration of clay enhances mechanical strength and thermal resistance without synthetic additives, ensuring hygiene and non-toxicity while maintaining environmental compatibility.

Importantly, the use of clay vessels and leaf-based containers for food preservation has deep historical roots across many cultures. Reinterpreting these traditional packaging logics within a contemporary design framework reinforces the argument that sustainable innovation can emerge from vernacular material knowledge rather than purely industrial advancement. Thus, the proposed composite should be understood not as a novel invention in isolation, but as a material reconfiguration of historically proven practices adapted to modern service systems.

Although workshop-scale testing indicated promising mechanical stability and moisture tolerance, this remains an exploratory investigation. Several limitations must be acknowledged. Industrial-scale consistency, long-term durability, food-contact certification, and aviation safety compliance require systematic validation.

Future research should therefore prioritize standardized mechanical and food-safety testing, full Life Cycle Assessment (LCA) comparisons, and industrial cost–benefit analysis. Pilot implementation in airline catering systems would generate operational performance data and clarify scalability constraints.

Ethically, the research adhered to responsible sourcing principles and ensured voluntary expert participation, with minimal ecological disturbance during material experimentation.

In conclusion, while further validation is required, this exploratory research demonstrates that integrating industrial design methodologies with indigenous ecological resources can offer a promising pathway toward reducing the environmental footprint of service-oriented industries. Such approaches may contribute to the emergence of localized, circular, and climate-responsive material systems within the broader discourse of sustainable design.

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