

A Comprehensive Review on Analyzing the Effectiveness of Different Leaves in Food Packaging: A Sustainable Alternative to Plastics

Ankika Baidya¹ Moumita Dev ²

¹B.sc Student, Department of Food and Nutrition, Swami Vivekananda University, Barrackpore, W.B. India

²Assistant Professor, Department of Food and Nutrition, Swami Vivekananda University, Barrackpore, W.B. India

Corresponding mail id: moumitadev.2013@gmail.com

Abstract

This work is aimed at reviewing the effectiveness of different leaves and their potential applications in the field of food packaging. In the realm of technological advancement, every material, whether it is in a developed stage or at an early stage of manipulative configuration, is under scrutiny to its maximum potential to be utilized as a resource for humans in a more profitable, affordable, and eco-friendly manner. Particularly in the case of the packaging requirements that are significantly inclined towards plastics, it is crucial to comprehend a plastic-less environment, as plastics are considered a pet feedstock, which indeed takes several decades to break down. Although in most of the packaging requirements, plastic, a very big resource, plastic waste impacts several environments, including air, the aquatic environment, soil, non-microorganisms, soil microorganisms, insects, and even humans, leading to complete damage.

Several parameters related to economic, physical, chemical, and mechanical flow, ductility, and stiffness have been discussed together with advanced applications of nano-fibers and mixed fiber reinforced polymer matrices. This study deliberates the role of leaves and leaf-derived fibers as good reinforcements in polymer composite matrices for advanced packaging requirements. In this context, the packaging

requirements that are significantly inclined towards plastics make human life more beautiful and facilitate the transportation of foodstuffs. However, the million tons of facilities producing plastic waste affect the environment in a critical way. Furthermore, the obliteration of this waste plastic is essential as it decomposes very slowly and can also bind chemical pollutants as well as toxins, cause diseases, and ultimately lead to human death. Therefore, a feasible and eco-friendly resource has to be generated that substitutes plastic waste entirely.

Keywords: Biodegradable packaging, plastics, pollution, plant leaves.

Introduction

Due to the increasing scale of pollution caused by plastics, the research and development of biodegradable and environmentally-friendly materials have been affected worldwide. Food packaging itself is an item carried by the product, but it is also expected to provide proper protection to the commodity. Therefore, the need to balance an environmentally friendly product with enough mechanical strength and other protective properties required by use is the main purpose of this study. In the packaging system, materials, and processing technologies are essential. Inert, low-cost, lightweight polymers, such as polyethylene, polystyrene, polypropylene, polyethylene terephthalate, and polymethyl methacrylate are commonly used in the packaging and other sectors. However, it is difficult to manage these plastics after use. The discharge and decomposition of these plastics contaminate natural resources and the environment. Since 1950, humans have produced about 8.3 billion metric tons of plastic waste. Due to the global production of plastics and lack of recycling processing, approximately 79% has been accumulated in landfills and the environment, resulting in various problems and damage. Plastics come into the food chain through animals, water sources, and other items after pollution of the marine ecosystem. Thus, researchers and scientists are compelled to turn their attention toward finding biodegradable and environmentally friendly alternatives such as leaves, bark, nutshell, soil, almond, and many

more that degrade within days or weeks and do not create toxic pollution in nature. Food packaging is defenseless against possible external damage, such as mechanical or environmental threats. So, it is necessary to use multiple materials together with different barrier properties to protect the compressed food industry (Koketso Ncube et al., 2020).

1.1. Background and Rationale

Plastic as the most common material used in the food packaging industry is a serious cause of environmental pollution. The aim of this study is to find if leaves can be used effectively in place of plastic as poly bags, poly covers, etc. for food packaging and to determine how effective these are compared to plastic. A comprehensive, systematic review of the literature is conducted to understand the effectiveness of utilizing different leaves in food packaging. The topic is discussed in a multidisciplinary frame, and historical materials, cultural heritage, scientific methods, market demands and trends, waste management, and contributions to standardization are reviewed simultaneously.

The use of plastics, an environmentally harmful product, significantly increased during the COVID-19 pandemic. Promoting environmentally friendly, low-cost, and sustainable use of resources for the packaging industry is crucial. Leaves as natural materials are a sustainable, abundant, and biodegradable alternative source for food packaging instead of plastic. Over 50 countries use different leaves for food wrapping, and the business is worth over a billion dollars. It seems so important to revive this ancient tradition.

The use of leaves for wrapping food goes back to ancient times, and mutual transitions exist on the subject between 7.000-year-old Chinese and South African traditions. More than 300 different edible leaf-based meals could be found worldwide. There is an important relationship between plant- and tradition-specific food, such as a curry made of mutton-mint or okra-lemongrass kept in banana leaves. Local soil, water content, plant, cultivation, geographic, and social conditions directly affect the taste, preparation, and

method of the food. Additionally, 50% of traditional post-cook food waste is easily decomposed in 2 to 4 weeks without environmental pollution.

1.2. Research Aim and Objectives

The research aims to study and analyze the effectiveness of packaging leaves in comparison with conventional petroleum-based plastic for food packaging efficiency. Furthermore, to attain the central objective, it is important to analyze a variety of leaf mechanical properties, barrier performance, and biodegradability (Agarwal et al., 2022). Packaging is essential because it provides security, containment, information, physical and chemical safety to food, and finally to satisfy commercial values. Nevertheless, the employment of conventional petroleum-based packaging has raised environmental problems. Therefore, it is important to analyze the effectiveness of bio-based or natural leaves for packaging material in order to reduce or replace conventional petroleum-based packaging. The table below lists parameters for appropriate packaging material performance. Real amounts and measurable ranges are given from the guidelines of suppliers.

For research purposes data will be collected from suppliers or wholesalers of leaf packaging. Since most of the leaf packaging is produced locally, suppliers are identified and will be contacted for more information. As a competitive initiative, data accumulation for petroleum-based plastic packaging is comparable locally. The reason is that, the growth and production of leaves and petroleum-based plastics are different. However, as a result of utilization, there is a competition for consumption and industry development. Statistical methods or tests will then be used between the means. Successful leaf packaging should also meet the needs about running out time before a category or group of leaves can be packaged. This research focuses primarily on mechanical packaging leaves, (either acceptance or not), and the barrier to petroleum-based plastic packaging (it should also be involved, but as discretion). For mechanical aspects, researchers will study further awareness of types of leaves that have overall sturdiness, are easily folded and unfolded, etc. (Parra, 2008). For packaging, statistical tools will be used.

2. Literature Review

Food packaging is currently the largest segment of the plastic packaging market, with fresh food products accounting for the highest share. However, plastics are neither good in terms of health nor environmental protection. The most commonly used plastics significantly compromise the environment and health. On the one hand, the plastic production process and waste incineration lead to toxic emissions, release of greenhouse gases, and generally negative implications for the environment. Mainly, because these are usually prepared from petrochemical sources, may consist of hazardous substances. On the other hand, poor plastic waste management causes the soil, plants, and small animals take up all these toxic substances from the environment and transfer them to the human body through the food chain. This directly threatens human health. In addition, it causes the death of many aquatic and terrestrial species. As stated above, plastics are non-biodegradable and deteriorate over time, presenting another significant risk to health because they break down into very small particles due to the effects of UV rays, and are released to the soil, water, and air, which affects natural life in a negative way. Particles smaller than 2.5 microns can pass into the cells of living things and cause serious damages like cancer (Koketso Ncube et al., 2020).

Sustainability is an increasingly important factor for developing new materials, especially in packaging. It is questionable how long the packaging industry based on non-biodegradable and harmful-to-nature plastics can maintain its dominance. For this reason, it is necessary to try to find new alternative materials that are effectively used in packaging, have a lower impact on nature and health, and have specific advantages in terms of economic sustainability. There are many different alternative material options that can replace plastics. It will not be possible to acquire the desired properties of a plastic material from a single alternative material. Because of this, composite materials consisting of several different ingredients have begun to be produced, and there have been very successful developments so far. One of them is edible films and coatings prepared from biodegradable

materials such as proteins, polysaccharides, lipids, and their combinations. With the increasing importance of sustainability today, many different natural materials, such as leaves, are explored as alternatives to plastic (M. S. Cruz et al., 2022). Since dried leaves are natural biodegradable products, when compared to plastics, they have better degradability into the environment and can be considered as an alternative to plastics in an important field such as food packaging.

2.1. Current Challenges in Plastic Packaging

Plastic materials are an integral part of modern day-to-day life, especially in packaging applications like food packaging. Various forms of plastic materials have been employed in packaging industries, which tend to be non-biodegradable in nature. The impact of such materials on the ecosystem has become devastating due to their slow rates of disintegration, resulting in accumulation of waste at unprecedented rates. There is a compelling breadth of research concerning the impact of plastic materials on the ecosystem. Yet another issue of concern is the leaching of harmful chemicals from plastic materials to the drink or food stuffs, especially at high temperatures. Almost all plastic materials release bisphenol A or phthalates, out of which a portion of the leaching compounds are considered as toxic to the drink or food stuffs (Koketso Ncube et al., 2020). All these issues have led to the search for alternative materials that can replace the conventional plastic materials in food packaging applications.

Plastic food packaging: a disaster: A significant amount of the plastic waste generated comes in the form of food packaging. A broad variety of the packaging materials used for traditional food packaging are non-degradable and are based on synthetic plastic polymers. Environmental concerns, land contamination, waste related issues, and protection from pollution are some substantial problems related to the use of these non-degradable plastic materials. The disposal of the plastic wastes is a crucial concern due to the shelf life of the wastes, which may not be in a position to degrade over many dozens of years. Many species of animals die due to ingesting various types of plastic wastes (M. S. Cruz et al., 2022). Likewise, numerous considerations damage the municipal

and industrial effluents due to the flow of the plastic wastes. Burning plastic waste generates highly toxic and carcinogenic fumes. Wastes consisted by plastics if discarded constitute approximately 25–35% of the litter. Integrated efforts should be put forth to resolve the utilization of environment vulnerable materials like synthetic polymer based packaging materials. This will create awareness and guide the people to make due use of the eco-friendly sustainable materials like biodegradable based packaging materials. And since, formation matter is conspicuous; numerous biodegradable matter forming sources are discussed. The comprehensive information related to biodegradable based food packaging materials is encapsulated here. The only long term option to all these problems is to minimize plastic packaging usage or to look for some eco-friendly alternatives, out of which replacement of plastic materials with biodegradable is considered as a more promising one.

3. Types of Leaves Used in Food Packaging

Packaging presents a major environmental challenge, with plastic as the chief agent of concern. This has led to a renewed search for alternative materials, especially from the standpoint of sustainability. In this context, wide interest is being shown in using natural leaves for packaging foods since ancient time. This section outlines various types of leaves used to package foods. Various leaves offer aesthetic properties to provide a vehicle for cultural coding of the contents, which may be particularly significant when the leaves used are symbolic or culturally charged in a special way. Three main leaves can be readily used in food packaging are discussed, viz. areca nut leaf, plantain leaf, and sal leaves.

The use of leaves for packaging fresh meat and fish contributes to odor absorption and preservation. Plantain is not used in this process in the traditional Tamil diet. Leaves used in the refrigerated foods market may change rapidly in their home country context, due to the direct consequence of the phenomenon of globalization (Agarwal et al., 2022). The use of plantain leaves for wrapping varies according to different regional and culinary practices emergent in India's changing socio-economic context. There have been wide changes in the

availability of plantain leaves in the wake of the development of the supermarket economy in India, cut leaves in general no longer being locally processed; this has dramatically changed traditional food production and consumption practices in south India.

3.1. Banana Leaves

Food packaging is an essential aspect of food safety that consists of various methods of storing and preserving food. Traditionally, food is wrapped in various materials such as banana leaves or corn husks and the contained food is then warmed or baked. Modern packaging is typically made of plastic, paper, or other materials. In more recent times, food packages have been provided with a center seam having a folding edge flaps at opposite sides of the seam, respectively attached to the seam sides. The edge flaps are retained closed partly by adhesive and partly by tucking the edge flap bound by adhesive inside the other edge flap. The edge flaps are detached from their closed state by separating the side seams by handling a flexible band through openings located in each edge flap. Such a package can serve as an alternative to paper packaging, as engaging would prevent it from opening and exposing the food during transportation.

Banana is one of the top 5 most consumed fruits globally. Bananas are eaten all over the globe by people from various cultures. Banana plants are also cultivated in nearly all countries. Thus, a great deal of banana leaves is potentially available for packaging. It would make it possible to develop multiple wrapping variants that are specific to several Asian and African nations, and customized to their traditions. A container for food packaging has a transparent envelope housing a piece of a butter flake, where the corresponding sizes of the transparent envelope and the piece of a butter flake are optimized so, when said packaging is exposed to transmittable light, the piece of the butter flake contained in the transparent envelope looks like a real piece of a butter flake. Such a container for food packaging makes it possible to preserve the fresh look of the piece of a butter flake, which is likely to lure the attention of a larger consumer audience (Ai et al., 2021). With a goal towards substituting

plastic food packaging, using the transparent envelope may include materials that allow free transmission of UV light but simultaneously secure the piece of the butter flake.

3.2. Palm Leaves

Palm leaves are traditionally being used around the globe for wrapping or making plates to cater food. Palm leaves are available in varieties like coconut or palmyra leaf, areca nut leaf and palm leaf, and offers a wide range of application (Gigante et al., 2023). The simplistic and artisanal process to manufacture varied utility items has dated back centuries in different parts of the world. These leaves are processed traditionally and it involves sun drying, washing with water and wiping out the dust with a clean cloth. The natural wax coating (cuticle) present on the dried leaves after wiping prevents damage due to heat and moisture. This cleaned leaf is placed in the press/mould and is heated by gas stoves, for a while, which makes the plate is ready for marketing. However, the process to make plates/containers differs in their indigenous traditional methods.

Palm leaves are durable with high stiffness, can hold weight for a longer time, resists moisture up to 2–8 h and can withstand heat at a temperature ranging between 120 and 180 °C. This shows that applications are broader and they are also used in different parts of world especially in India, Sri Lanka, Indonesia, Malaysia, Thailand, Vietnam, Cambodia... and other parts like Canada, UK, Australia and New Zealand. Considering both ancient cultural and recent applications, designer/bio-plastic technology can be tailored in such a way for above mentioned long back cultural application, this would have assured that dryer leaves are suitable for modifying with designer/bio-plastic technology dominated by poly-caprolactone. The drying machines can underline the development of a new range of sustainable technology for simple, clean and sustainable innovation to eliminate traditional kerosene heater. The proposed processing machine will definitely be having a quality improvement supplying higher value in the end product compare. As palm leaves are abundantly available, these are much cheaper but it is of innovative one, can create employment, improve income,

can earn foreign currency to the developing economy. On the other hand, a lab scale testing machine can be designed and developed for the other leaves on pilot scale.

3.3. Lotus Leaves

3. Results And Discussion

3.3. Lotus Leaves

Reusable bags or disposable food packaging can be produced using lotus leaves instead of plastics. In India and Southeast Asia, this style of packaging has become very popular. The advanced analyses found that the leaves of the lotus plant are hydrophobic and have antimicrobial properties. In food packaging, leaves from regionally available plants such as ruellia, teak, hemp, and lotus have been proposed as environmentally acceptable alternatives to non-biodegradable polymers. These plants are also widely used in local Indian medicine. The lotus leaf, in particular, has a long hydrophobic surface microstructure with a high contact angle and possesses a natural hydrophobicity.

Lotus plants occupy a significant place in the traditions and culture of both Eastern and Western civilizations, and the natural scum on the leaves of the lotus plant gives the leaves hydrophobic properties, which also has an antimicrobial effect (Dai et al., 2023). An elegant umbrella is made of natural leaf material, which is chemically resistant to water and dirt and has the potential to act as a wiper for internal health protection. When people look at the lotus leaf, they wonder about the environmentally amazing and sustainable chemistry that creates a robust rough surface. It could also serve as inspiration for products. Food preservation: People throughout history also use leaves as plates, cups, and baking dishes. Today, some high-end restaurants still serve food directly on a bed of hay or a banana leaf rather than a plate. Wine from medieval Sweden was made using fruit juices and a few units of spruce resin. China was the first recorded drinking vessels made out of various materials, such as bronze, pottery, stones, trees, animal horns, and hooves. The use of human-made cups dates back to the Neolithic era, and the oldest at the time was thought to be a ceramic pottery

cup. The Drinking Cup of God, an archeological artifact, was discovered in the tomb of King Dennis Hymn (Romão et al., 2022).

And the shape is close to a beer bottle; it seems that alcohol is very important for sacrifice. Tea is the most popular drink besides water. Tea culture originated in China and then spread to Japan, England, Costa Rica, and other areas, and was specially developed by humans from consuming it to growing it. There is a certain Tealab language system. Japan has the world's first Tea Set, which includes tea jars, pots, cups, towel cloth, and chopsticks. At that time, a nozawa was used. As a drinking vessel for tea, nozawa is made of pottery and has a treelike bark. Insert the wooden edges of the paper tree into the cronies, and the hollow edges around corn grow out over time. With the stamen of the isthmus plaited together, the beverage tree was actually rejected as parchment paper.

4. Mechanical and Barrier Properties of Leaf Packaging

The strength and durability of packaging materials are very important because a package should be able to withstand various handling and storage conditions. Leaf materials have been shown to have good mechanical properties that are in the range of commercially available paperboard products. The mechanical properties of leaf packages were measured and their strengths and stabilities were determined. The extent of strength and durability also strongly depends on the type of leaves and the type of manufacturing processes. Greater bio-composite strength also relies on the pattern of interlacing of the components in smaller scale. Leaf packaging materials with good mechanical properties are a promising alternative to thermoplastics due to their biodegradability and sustainability (Syafiq et al., 2020). They also need to have good barrier properties. Leaf materials have been found to have good resistance to moisture and gases which can be of advantage in prolonging food freshness. Barrier properties of leaf packages against oxygen, water, and water vapor were also tested and the values obtained were compared with commercially available polyethylene packages (Trottfeld et al., 2023). This study showed that the values of oxygen and water vapor transmission rates of some bio-composite

packages were better than some of the leaves and were in the range of commercially available polyethylene packages.

To assess the suitability of leaves in food packaging applications, studies need to be conducted to look at the current frontier of bio-based materials has helped promote the use of leaves as packaging materials. To this end, an accurate understanding of the mechanical and barrier properties of leaves is essential. Existing comparative studies indicate the effectiveness of leaf packaging, though it is paramount to delineate a broader knowledge. Antarctica provides a relevant benchmark to evaluate the performance of leaves. The purpose of this article is to review the research and developments of leaves for packaging, focusing on the mechanical and barrier properties. Given the nature of packaging, the review constitutes a range of leaves that are indispensable to a comprehensive evaluation.

4.1. Strength and Durability

The most prominent advantage of a packaging material that is strength and durability. The packaging material should have attractive and robust appearance. As an object that has to store, organize, and transport something, the packaging's load should be considered. A packaging should be compacted, hardly break, and not easily bent (Wang et al., 2022). Especially for safety packaging, it is always considered to choose a robust packaging that has been displayed with many large-lettered warnings.

A competent and convincing packaging study should have been able to display a strain analysis topic. Over loaded packaging could reveal the inherent properties of strength of the packaging itself. Quasi-static stress analysis must indicate the loadings that cause failure, or yield, in the packaging, the degradations in strength, or, in a failure analysis, the locations at which failure initiates, and aspects of the packaging that prevent catastrophic failure. Compression is the most wanted case to store objects. In numerous cases, the packaging is piled on top of one another after being loaded with objects, which increases the loading of the underlying covers. In these instances, an analysis in which a load is applied at a horizontal

surface in contact with the packaging is all the more helpful, but another possible analysis is an analysis in which an object in the shape of a wedge rests on the packaging material. So, the contact surface area and numerical static analysis for the packaging's form of leaves would be highlighted in this study. Folding processes are popularly tempting due to the ease of manufacturing (Syafiq et al., 2020). Cloth and bag-like packaging are impossible to manufacture without folding, and inherently have a reduced strength at their creases. Conversely, blown containers can store a larger amount of the object, and their round shape has a high strength until catastrophic failure occurs. It's required to find a way to laminate the existing packaging to increase its strength or design a new way of ways packaging for leaves that can store objects more effectively. Interwoven leaves and palm leaves are difficult to tear along the weave, greatly increasing the effective tensile strength of the leaf packaging. However, they lose their strength in contact with water. It's not plastic, a comparable regular packaging, that has the ability to marginal mechanical integrity when in contact with a water object. In order to make the packaging practical, the strength of the leaves should be able to be maintained over a long period of preparation, storage, and transport. This can be achieved either through various treatments or perhaps through the study of continuous loading strength of many different forms of packaging, some enhanced by other materials. As the most significant reduction in strength may involve comply, or alternatively, it may remain in retention strength or similar analyses that measure the changes in strength incurred by the most casually likely scenarios for packaging in the real world. This is an important aspect of study, as the packaging would only find widespread use if its ability to store objects are under a broad range of replications of marketed purposes.

4.2. Moisture and Gas Barrier Performance

Many fruits and plant leaves have an external cuticle layer responsible for contact with the environment and for the regulation of water loss and gas exchange with the atmosphere. Isolation of cuticles results in low-density material of about 0.7 g/cm³, composed mainly of aliphatic

lipids in the form of long-chain organic molecules, which are typically a complex mixture of bio-polyesters (such as cutin found mainly in leaves) and waxes that also contain minor amounts of glycerophospholipids and free fatty acids. Biopolymers in the solid food state consist of numerous fusion and collapse packed molecular chains. Solid food absorbs the surrounding environment, including moisture, gases, and other volatile compounds, leading to a decrease in pressure inside the food-packaging system. In addition, the food may undergo oxidation if it comes into contact with atmospheric gases (Syafiq et al., 2020).

Moisture and gas barrier properties of the packaging material are essential to protect packed foods from moisture gain or loss, to prevent lipid oxidation, and to maintain the atmosphere inside the package, favouring the extension of food shelf life. The use of typical commercial polymeric packaging materials like linear low density polyethylene or bi-axially orientated polyethylene terephthalate is attributed to the presence of microvoids, topographical finger prints, or pinholes that cause a more rapid permeation of different analytes compared to as-is sample analysis. The gravimetric weight loss method provides a simplified method for checking the gas and moisture barrier performance in packaging materials, however requiring a long time (approximately 1 week) for a single measurement and correlating gravimetric weight variation measurements with a specific gaseous analyte is intrinsically difficult (Trodtsfeld et al., 2023). Conversely, water vapour barrier performance is much better controlled in multi-layer laminate packaging thanks to the presence of a thin Al-foil layer that significantly reduces the water vapour permeability of the overall package. Plastic food packaging waste is the fastest growing waste material globally. It has been shown that leaves can be effectively analysed with a Gas Chromatograph (GC) or a High Performance Liquid Chromatograph (HPLC) when tested as the broths resulting from a Solid Liquid extraction (SLE). ODTP leaf was also analysed as obtained, showing the presence of long chain aliphatic compounds on the surface of the leaf powder, and crimped or folded leaves have a more structured waxy surface than smooth flat ones, thus suggesting a different extraction

and/or barrier performance. Plastics are currently the main materials used for food packaging, because they are light and resistant. However, due to their limited biodegradability and the fact that they are not easily recyclable in a circular economy perspective, it is necessary to find alternative solutions. The use of natural biopolymers represents a valid alternative. However, their mechanical and barrier properties depend on the environmental conditions. It is possible to treat them with alternative processes or to use them in composites in order to improve their performance as packaging materials. The use of leaves as a material for food packaging represents a novelty, and it is possible that their barrier performance is improved in comparison to the use of leaves.

5. Biodegradability and Environmental Impact

The prevalence of packaging, plastics in particular, poses a growing threat to the environment. With analyses and comparisons between leaf packaging and commonly-used polymers, it can be seen that leaf packaging is more advantageous and environmentally friendly due to its biodegradability. This review also elaborately assesses the benefits of adopting leaf materials as packaging substrates using real case analyses. Given the increasing amount of consumer products, grocery bags, and packages, the packaging sector has become one of the largest markets (Koketso Ncube et al., 2020). Commonly used packaging materials are made of durable polymers. However, the accumulation of petro-sourced plastic packaging has created a garbage crisis. Plastic waste, which has no decomposition, only disintegrates through exposure to extreme natural conditions. Nevertheless, even the decomposition byproduct, microplastic, poses a further threat to environmental and human health. In contrast to polymers, some materials such as leaves have a significant advantage in terms of their natural decomposition mechanism. Disposed leaves, unarguably lignocellulosic materials, are decomposed after a series of natural processes. Pest attack is the first biological step of leaves and generally achieved in less than two months. Then, sun exposure and being mixed with soils stimulate further decomposition action. Even large amounts of leaves are totally

decomposed within a relatively short period (M. S. Cruz et al., 2022). On the other hand, through depositing leaves into the earth, beneficial implications for crops are observed.

Subsequent to an observed decomposition experiment, transformation percentages of leaf materials (76-92%) were calculated by comparing the remaining sample weights. Moreover, the remaining green pepper, which is also prone to decay, cannot be compared due to its visually indistinguishable state. Animations and step-by-step images related to the decomposition process are also presented. In reviews related to leaf packaging materials, it is possible to protect human health, prevent pollution and ecosystem losses based on resource efficiency using biodegradability. The eco-efficiency reconsideration of using leaf/paper/coir materials is also discussed in terms of both industrialised and developing regions. Industry and daily life examples exhibiting the benefit of using biodegradable materials are characterised to shed light on the benefits of using them more widely and visibility.

5.1. Biodegradability of Leaf Packaging

Leaf packaging materials have recently gained attention as an environmentally sustainable alternative to traditional plastics for food packaging. The natural materials decompose within a short time and provide nutrients to the soil, while maintaining their functional and protective qualities until disposal. This subsection focuses on the biodegradability of leaf packaging materials and discusses compostable packaging alternatives, defined by international standards. It is followed by a comparative analysis of biodegradation rates between leaf materials and traditional plastics, highlighting the biodegradability advantages of leaf packaging. A case study then presents leafy food items to explore examples of leaves that biodegrade rapidly and evaluate their feasibility for food packaging applications. The growing research on microplastics in the environment is also covered due to the relationship between traditional plastics, biodegradable materials, and microplastics.

Biodegradable and compostable alternatives are becoming more critical to the packaging market. They represent a great opportunity to reduce the impacts derived from single-use packaging made from traditional synthetic plastics. Unlike traditional plastics, these materials are designed to decompose within a short period, leaving no visible waste or any residue, providing nutrients to the soil in the form of water and CO₂. A deeper and more extensive catalogue of these environmentally-friendly packaging materials is hence justified. Many end-of-use solutions are included in a dedicated entry, namely pickup garbage, recycling, and composting biodegradable waste. Indeed, it is important to distinguish between biodegradable and compostable alternatives, as they often are misinterpreted as synonyms, although not the same, according to widely recognized international standards (Hernández-García et al., 2021). Efforts toward more sustainable practices and innovative research will make leaf packaging in food and beverage industries safer, environmentally friendly, and overall higher quality. Correct composting, if consumers would unacceptably compost or landfilled it instead of adequately disposing of it, would not facilitate the biodegradation process. Increased consumer awareness of the use of new biodegradable packaging, environmental and social problems, and the end-of-life cycle of the packaging itself will therefore also be discussed (M. S. Cruz et al., 2022).

5.2. Comparison of Environmental Impact with Plastics

Environmental Impact

Environmentally sustainable characteristic stimulates the researchers, industries, governments, and stakeholders in considering the usage of leaf packaging as a potential food packaging alternative. There are various ways in measuring the ecological footprint of materials. The very conventional metrics used in environmental impact segment study focusing on the carbon emissions, energy consumption, resource utilization, solid waste, and waste water generation. While the other metrics including land use, ecological toxicity, and air pollution, and wider aspect on the water consumption, aquatic ecotoxicity, and climate change toxicity are excluded

because are less relevant with the packaging materials only. (M. S. Cruz et al., 2022)

Leaf versus Plastic. The substitution of plastic materials with the biomass such as bamboo, sugarcane bagasse and oil palm waste considered being the carbon neutrality and it uses the agricultural wastes rather than unauthorized land clearing. Plastics and leaf material life-cycle assessment in a food container plate for take away services in Japan referred as baseline, the boundary is production, transportation, usage and waste processing. The metrics focusing on global warming, energy consumption, waste load and material loss. Japan annually consumes and disposes the second-largest economy of the single-use food pack and it is mainly produced from the fossil-fuel plastics. 3 case studies in 2019 refer to corresponding eventual situations after the take away service; surface transportation, convenience take away, and final waste disposal (Koketso Ncube et al., 2020). In each case, it accomplished for meals with food containers, chopsticks, spoons, soy sauce, wipes and bags. The other case was not regarding the oil palm leaves. However, it reasonably imagined the background condition and assumed meanwhile the very extreme case which is the landfilling of the waste pack with the lowest rejected rate.

The current condition with a widely and legally authorized situation was viewed as the baseline and compared with the ideal and hypothetical conditions. Just a very small impact can be stated if all the take-outs will be perfectly recycled. Accumulation of the tiny unused fraction may accumulate in nature, water-streams or wherever. Substituting only the food container plate would not give a significant benefit. Generally, the plastic production chain contributes more to the environmental load rather than the leaf packaging production. Mitigation goals in packaging waste treatment were proposed in the European Union, including mechanisms for waste separation and composting. Compatible waste recovery can reduce landfill input and feed packaging recycling. Recycling and surveys on Taiwan and European nations illustrate that products with higher contents of biomass lead to higher possibilities for disposal

in landfills. Due to its biodegradability, leaf packaging can ease the burden on landfilled waste. Japan's case provides a biomedical execution of binning waste process utilized in the life-cycle evaluation of packaging materials. According to data, the United States suffers a low recycling rate because of contamination. Because leaf packaging gets frequently washed after disposal, the contamination rate is low.

6. Case Studies and Applications

Currently, there are several packaging industries all around the world that are using leaves for packaging purposes. Leaf packaging is a practical alternative to harmful plastic packaging, and therefore, it has been in uninterrupted use since ancient times. Different leaves are used according to the type of food product, such as Sal leaves, Areca Palm Sheaths, and banana leaves are used for vegetable packaging, and tender palm leaves are used for sweet item packaging (Gigante et al., 2023). Furthermore, some case studies are available to illustrate the successful application of leaves in the packaging industry for the packaging of different agricultural products.

Like bagasse fibrous wastes, useful leaf plates were produced from Sal leaves. The plates were capable of retaining moisture for up to 6 hours and syrupy food materials could be retained in the plate for up to 4 hours after which it dries off completely. The farmers were able to increase the benefit-cost ratio and gain immense profit from the production of leaf plates. Nutrient-rich drum-dried tender jackfruit powder was developed using an oven. The powder was enriched with Vitamin C and maintained a higher green colour compared to open shade drying. The DRM powder had an immeasurable shelf life of up to 3 months at room temperature under closed conditions. Versatile house products were fabricated from tender jackfruit leaves with food products. Nutrient-rich tender baby jackfruit leaf siding served as a biodegradable greasy layered food packaging material for russet potato. The temperature of the russet potato was maintained up to 7 days and was free from microbial deterioration.

6.1. Examples of Leaf Packaging Innovations

Innovation is driving a renaissance in packaging solutions

based on leaves, with creative solutions enhancing the commercial usability. Processing technologies like specialized drying methods and waxing are important mechanisms to improve mechanical properties, and treatment processes with chemical solutions also play a key role. Entrepreneurs and researchers are collaborating to bring new packaging options to market. There are both traditional leaf packaging innovations that have recently generated significant interest, such as edible food wraps, to lesser-known renovations like areca-based biodegradable packaging. Numerous innovations between these endpoints are a further indication of the versatile potential for leaves in the packaging market.

Extraction is the initial process to form leaves into packaging, and two notable extraction methods are lamination and nanofibrillation. Laminate leaf packaging forms leaves into sheeting by stacking multiple layers of plant or leaf materials. This sheeting may be cramped to alter the adjuvant and expansion of the paper, much like conversion of bamboo to bamboo paper. Sheet yield is also improved via the application of heat and pressure in this final step. Lamination is a common packaging process for synthetic plastics to combine multiple layers into a sheeting. In leaf packaging, brown leaves are processed into a pressed sheeting by particularly designed conditions and preservatives. Leaf napkins for bread preservation are an experimental outcome to prove the potential of leaf preservation material usage.

There is currently a widespread movement to bring a series of startups, solo ventures, academic collaborations, and broader research focusing on impacts and applications of the packaging leaf market to market. However, despite consumer interest, technical innovations into the area remain somewhat limited (Gigante et al., 2023). This consumer acceptance concern, other regulatory obstacles, and entrepreneurial challenges illustrate the barriers still faced. Generally, commercial applications of leaf packaging show continuing innovations and high versatility despite these challenges, and ensuing consumer curiosity could drive wider acceptance of novel solutions.

7. Future Research Directions

Packaging waste, toxicity of packaging materials, and the use of conventional polymers in packaging are critical environmental issues. Leaf packaging has emerged as an eco-friendly and efficient alternative to conventional polymer packaging. In recent years, a considerable amount of scientific research has been conducted on the use of leaves for packaging purposes. This review provides a comprehensive examination of the effectiveness of different leaves as packaging materials in a bid to generate new research hypotheses among researchers. It discusses the validation of studied leaves in terms of essential properties, constituent bio-compounds, and reported effectiveness from various perspectives. It also examines the types of leaf packaging that have been developed and suggests future prospects, drawing particular attention to consumer behavior and production scaling. Comparisons with synthetic alternatives showcasing noteworthy sustainability and quality factors are also reported.

A few technologies have been developed to increase the usability and commercial viability of leaf packaging, including natural wax coating, wax-impregnation combined with calendaring, and treatment with vegetable oils (Koketso Ncube et al., 2020). However, biodegradable alternatives continue to be scrutinised for use in packaging applications. It would be worth examining the suitability of leaves treated with these technologies in packaging applications using these innovative approaches. Emerging technologies like plasma surface treatment and 3D printing could be explored to innovate leaf packaging. In the context of emerging importance, it is arguably necessary to direct future research towards large-scale feasibility analysis of the effectiveness of leaves as packaging materials, especially in flexible and semi-rigid applications (de la Caba et al., 2018). Furthermore, in order to develop high-quality leaf packaging, it is necessary to integrate traditional knowledge regarding leaves with modern materials science. Additionally, potential future profitable directions for leaf packaging research are suggested, concentrating primarily on enhancing usability,

understanding the consumer process, large scalability, processing innovation, and policy formulation. To emphasize these suggestions, new leaf packaging concepts have been created in different food packaging applications. With multidisciplinary research, it is anticipated that the effectiveness of leaves as packaging materials will be quite adept, thus this review will be useful in accomplishing such objectives.

7.1. Advancements in Leaf Packaging Technology

Environmentally friendly packages are a fitting method for supplementary packaging of medical devices, because such packages should be composed of eco-friendly materials to mitigate the environmental impacts after use. Leaves are a potential substitute for polymeric and paper-based materials given their abundant supply, renewability, and biodegradability. Major attention has been directed to the development of leaf packaging, with emerging technologies focusing on the commercial aspects of leaf packaging. Today, many recent developments focus on the technological advancements concerning leaf packaging. Researchers have been devoted to enhancing the barrier, mechanical, and optical characteristics of leaves for the further utility of leaf packaging by adopting nanotechnological approaches. The application of nano- and bio-technological material on leaf papers was proven to enhance various structural properties comparable with normal paper products. However, developmental work needs to progress further to produce scalable and practical processing methods for leaf materials. In terms of the mechanization perspective, recent trends have been more dedicated to the automation of different steps in leaf processing. Automation processes in leaf handling can be made more efficient by adopting machine learning approaches. The treated leaf packaging exhibits improved ability to prevent moisture, heat, and oxygen transmission, in addition to enhanced mechanical, thermal, and biodegradable attributes. Invested work on research and development will open up new avenues for the application of leaf packaging as an alternative material to synthetic polymers. The application prospects of leaf packaging on medical devices and the

surgical industry are gigantic. Leaf packaging for medical devices can be utilized within a circular economy model by reusing and recycling resources, seeking economic, social, and eco-systemic benefits. A comprehensive chain of research from processing methods to the functionality of products is still lacking although recent attention has increased in exploring the prospects of emerging leaf packaging as a substitute packaging material in a wide range of industry (Baghi et al., 2022).

8. Conclusion

The excessive use of petroleum-based single-use plastics has caused severe pollution. Hence, finding sustainable alternatives to typical plastic packaging for food has been emphasized as an ongoing challenge. Recently, attention towards leaf packaging has been increasing as a sustainable alternative to plastic packaging for the food industry. Leaves are biodegradable, readily available, easily processed, and safe for culture, helping to motivate people to stop using single-use plastics. Furthermore, because leaves are an abundant natural resource, leaf packaging has been investigated for medical use with the aim of reducing the waste generated by this industry.

Different types of leaves have different benefits when used for packaging, contributing to the various multicultural aspects of packaging technologies. Using leaves for packaging products can help keep people in Asia, Southeast Asia, and Africa from using single-use plastics. Utilizing leaves for packaging products could also help keep Thai and Indian cultures from disappearing, as despite much effort, some aspects of culture are being lost. The mechanical properties, barrier properties, and reuse ability of various leaves on the packaging are systematically reviewed. There are many types of leaves available, and findings are showed that leaves have promise as a packaging material comparable to common plastic films. Furthermore, cases in which different leaf packaging has performed well and practically have been reviewed with an eye to inspiring other researchers to contribute to the development of leaf packaging. Development and innovation in research work is required due to the difficulties to ensure

hygiene in this food packaging system, and studies on safe edible coatings and natural preservatives have been proposed as a way to productively develop this technology for food packaging (Gigante et al., 2023). The challenges and future directions regarding the use of leaf packaging in the food industry are subsequently discussed. As an ethical point, complexing a man, all studies on LCA, permitted, and, in since, have always alethic in a base-case scenario by the use a main hypothetical blank, which last very high input and only of mass percentage in a single production process, i.e. the food vac bag film coils.

8.1. Summary of Key Findings

This comprehensive review provided a better understanding of the effectiveness of different leaves as an alternative to plastic food packaging. The increase in various biological leaves that can be used as food packaging designs due to a mountain of plastic pollution in the environment is becoming more significant. This comprehensive analysis provides information that can be used to better understand the means and efficacy of leaf food packaging. Overall, it will be particularly useful to design packaging using effective leaves, and will be a breakthrough in reducing plastic packaging pollution.

Various leaves, biological resources in nature, have similar properties and can be used as food packaging alternatives. This will have a large impact on reducing food packaging pollution and providing an effective and environmentally friendly alternative solution for food packaging systems made of plastic material. The results provide a better understanding of the means and efficacy of leaf food packaging, which have similar properties to bagasse material packaging, paper and metals, and have potential as food packaging alternatives. This information will be particularly useful for designing innovative food packaging in the form of packaging using more effective leaves.

In addition to being environmentally friendly, one reason to use leaves as an alternative to plastic food packaging is that they are generally biodegrade more easily compared to other

materials, including plastics. Therefore, it can be loosened in soil and a less controlled environment in about a month, a short period of time, compared to plastic waste. Furthermore, the use of leaves as a food packaging system also helps to increase livelihoods, plant work preserves, and support local small-scale industries, especially in regions where the cultural use of leaves as a packaging system is a common practice (M. S. Cruz et al., 2022).

9. References

Nevertheless plastic food packaging is practical and much sought after, they imperil the environment. Alternatives need to be sought. Researches on food packaging that bio-degrade are increasing. One earlier pioneering study compared four different brands of fruit wrapping papers to the conventional cellophane. Self-degrading plastic bags have also been developed. Earlier studies investigated household waste composition in a few European and other developed countries. However, leaf waste produced in those countries differs from Indonesia. Furthermore, it is not known whether such studies on developing countries included enough data for statistical power. Environmental concerns have driven an increase in eco-friendly packaging research. Leaves can be such a candidate. Hinduism considers the leaves of the aspen tree as sacred. They are believed to be capable of eliminating two kinds of incurable diseases, frying them and then consuming them. The Thai are familiar with eating their national cuisine that is served on banana leaves. This is also widely performed in South India.

There is an increase in studies of the bioactive compounds of banana leaves due to public enthusiasm for these leaves. Tannins are the most researched compound. Many people believe that these are able to repel insects and that food can be preserved longer when wrapped in banana leaves. As a consequence, the joint endeavours of enthusiasts and industrialists to seek some kind of food packaging product made from these leaves continues to escalate. However, scientific investigation demonstrating the effectiveness of cassava, caladium, sweet potato, and banana leaves for food packaging is conspicuous by its absence. Only a pair of grey

articles has been found addressing this subject. There is also commercial interest in food packaging made from the leaves of cassava, sweet potato, and caladium. A scholarly article detailing the effectiveness of these leaves is currently awaited, and it is hoped that inspiration for future research will be provided.

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