Ceylon Journal of Science 53 (1) 2024: 21-37

REVIEW ARTICLE

Potential use of plant leaves and sheath as food packaging materials in tackling plastic pollution: A Review

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Highlights

- Biodegradable packaging material is gaining attention due to health and environmental hazards owing to plastic pollution.
- Environment friendly packaging material can replace the synthetic plastics, at least partly.
- It is an age-old practice of utilizing plant parts in food packaging.
- Food packaging materials are currently being developed from variety of plant sources.
- The application of plant-based packaging materials in food industry still needs further exploration.

Ceylon Journal of Science 53 (1) 2024: 21-37
DOI: http://doi.org/10.4038/cjs.v53i1.8145

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Potential use of plant leaves and sheath as food packaging materials in tackling plastic pollution: A Review

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Received: 16.10.2023; Accepted: 28.12.2023

Abstract: Plastic pollution, mainly due to single-use food packaging materials, has become a drastic environmental issue around the world. As a consequence of their accumulation, naturally balanced ecosystems may undergo various types of vulnerabilities, and eventually, it may lead to the annihilation of flora, and fauna. Hence, there is an urgent need to find alternative ways of packaging food with environmentally friendly materials. Currently, there are considerable numbers of research being done to prove that biodegradable packaging materials can be produced from plant leaves and sheaths. However, the large-scale production and application of eco-friendly packaging materials is still a challenge and more studies are further required to accomplish it. Hence, this review is done to identify initiatives made in the field of biodegradable packaging material and directs them towards practical application. In the end, it proves that there is a huge potential to produce biodegradable packaging materials from plant sources economically.

***Keywords*:** Food packaging; Biodegradable packaging; Plant materials; Leaf; Plastic pollution; Sheath.

INTRODUCTION

Plastic pollution has become a pervasive environmental issue where inhabitants are negatively and inadvertently altering their livelihood activities. The demand and annual production of plastics have been sharply increased over the past 65 years and estimated that 8300 million metric tons (Mt) of plastics have been produced to date. As of 2015, over half (6300 Mt) of which has been discarded after a single use, around 9% of which had been recycled, 12% was incinerated, and 79% was accumulated in landfills or in the natural habitat which will take more than 500 years to decompose (Geyer et al., 2017; Verma et al., 2016).

Further, it is a known fact that the packaging industry is responsible for 90 % of the single-use plastics and which account 50% of the total plastics around the world (Geyer et al., 2017) and within this usage, the food industry accounts for more than half of the packaging market (Manalili et al., 2011).

Jambeck (2015) reported that between 4.8 and 12.7 Metric tons of plastic are released globally into the oceans yearly as mismanaged waste. In the case of Sri Lankan terrestrial and aquatic ecosystems, which have already become dumping yards and it causes to pollute as a result of mingling plastic materials. This has contributed to the Bay of Bengal's 'dead zone', an oxygen-deprived area of 60,000km^2 making it uninhabitable for many marine living organisms (Ghosh & Lobo, 2017). Thus, most of the Indian Ocean Rim Countries, like Sri Lanka, has compelled to improve the plastic management processes.

Under such circumstances, there is a pressing necessity to explore alternative means of packaging food employing environmentally sustainable materials, focusing on single-use, disposable, short-life packaging and food serving materials. As a result, the intangible impetus pertaining to food packaging has been redirected towards the utilization of plant-based materials, which possess the dual advantage of being biodegradable and enriched with antioxidants and medicinal properties (Kora, 2019). In most areas of Southeast Asia, where leaves are used in wrapping food and some leaves impart characteristic flavours to the cooked food wrapped with them (Ng, 2015). Although its complete replacement is nearly impossible to achieve with food packaging materials from plant-based agricultural resources, the use of leaves as packaging materials offers a huge opportunity for tackling environmental pollution at least partly.

According to Guillard et al. (2018), by 2050, if one in two food packs is made of such a biodegradable material, 50% of packaging waste reduction may occur which will be equivalent about to 46 million tons of plastic waste (p. 9).

The development of potentially biodegradable packaging materials as alternatives to single use plastic wrappers and service ware items is gaining attention in order to tackle plastic pollution. But, the replacing ecofriendly material should have the characteristics equal to that synthetic plastic. On this attempt bio plastics are being developed from plant sources. But most of them have Poly Lactic Acid as the base, where it needs more processing steps and these bio plastics need high temperature for composting and they make soil acidic. Also, the bio-based polymers need high investment and need more cultivation area.

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If it is possible to produce a totally biodegradable packing material with versatility and sustainability, replacing synthetic plastic is possible at least partly. In Asian culture many plant materials specially the leaves with best qualities are used for wrapping food items and for food serving. Hence developing a cheap, sustainable ecofriendly packaging material from locally available plant materials by applying simple physiochemical treatment/s and transforming them into sustainable food wrappers and serving plates will be a productive solution to replace at least half of the single-use plastic.

As a step forward in this striving path, studies are being carried out by the researchers especially in tropical and sub-tropical regions, to develop a cheap, sustainable and biodegradable packaging material from renewable edible grade plant-based materials with special concern on leaves. However, the commercial-scale production and application of eco-friendly food packaging materials that are developed from the leaves and sheath of plants are still a challenge and more studies are required to improve the versatilities and applicability of such materials. Hence, this review is done to study the evidences that prove potential of developing food packaging materials from plant sources and to identify the initiatives made in the field of plant-based biodegradable packaging material and directs the researchers towards practical application.

LITERATURE REVIEW

Negative effects of plastic packaging materials

It is imperative to employ a packaging material to encapsulate food items, as this serves to prolong their shelf life by affording a physical shield, in addition to a semi-permeable barrier from gases and water vapor. The packaging, furthermore, serves to safeguard products against physical factors and biological contaminants, hence mitigating food wastage (Shobhit & Satish et al., 2012).

Single-use plastic packages, resulting mainly from takeaway food services, need more than 500 years to decompose, and until then, they harm natural habitats and ecosystems (Verma et al., 2016). The extensive utilization of synthetic packaging materials in contemporary packaging practices has presented a significant peril to the globe, consequently leading to a decline in environmental worth. The primary ramification of this phenomenon is environmental contamination, an unfavorable outcome stemming from the improper disposal of packaging materials. The packaging materials that ultimately find their way into the oceans have caused not only the depletion of fossil fuels but also the propagation of micro-plastic pollution (Osman et al., 2018).

The disposal of synthetic packing materials into waterways results in the persistence of microplastics in the marine environment, leading to detrimental impacts on marine flora and fauna. The production of single-use packaging and serving items, such as plates, sheets, cups, and bags, relies heavily on the use of polymeric plastic compounds, including polythene, polyvinyl chloride, polyester, and polystyrene. These materials contain toxic substances, specifically bisphenol A, which can contaminate the stored food. Bisphenol A, a precursor to plastic polymers, can cause adverse health effects in humans, such as cancer, diabetes, and cardiac disease (Manzoor et al., 2022; Thushari & Senevirathna, 2020).

To solve this problem, packaging industries are now turning their interests toward developing biodegradable packaging materials with the intention of reducing plastic waste. It is believed that these biodegradable packaging materials can replace synthetic ones at a low cost, thereby producing a positive effect both environmentally and ecologically. Many types of alternative packaging materials using plant-based resources such as bioplastics and recycled leaves are being tried out because they are safe for the environment. There is an urgent need to utilize food serving materials made from plant leaves, which are biodegradable, renewable and enriched with compounds having nutritional, functional and medicinal values (Mensah et al., 2012; Khazir & Shetty, 2014).

Positive impacts of plant-based packaging materials

The leaves of a significant number of plants consist of functional compounds that exhibit antimicrobial properties. Consequently, they possess the capability to provide protection against foodborne pathogens and illnesses (Sahu & Padhy, 2013). Furthermore, the plant leaves have been found to contain a profusion of organic compounds, particularly polyphenols, which could potentially be incorporated into food products during the packing process. These polyphenolic compounds exhibit antioxidant characteristics, thereby impeding the oxidation of food components and the generation of free radicals (Somayaji & Hegde, 2016).

In South Asian nations, individuals engage in the utilization of plant foliage for food packaging as an aspect of their cultural practices. Furthermore, they hold the belief that the leaves employed for packaging exhibit medicinal properties and possess notable socio-economic significance. The protracted implementation of leaves in food packaging and serving has generated a substantial opportunity for the manufacturing technology of leaf-based plates and cups. However, not all plant materials are suitable for the production of such cups and plates. The materials utilized must possess adequate surface area, amenability, flexibility, and stability for storage. When single-use food packaging materials, such as plates and cups, are produced from plant leaves, they offer a multitude of advantages over synthetic packaging materials. Among these benefits are expansive availability and abundance, biodegradability, ease of disposal, and environmental friendliness (Kora, 2019; Sarin, 2017). In terms of biodegradability, the *Macaranga peltata* leaves, which are rich in minerals like Nitrogen and Potassium, decompose in the soil rapidly and thereby improve the nutrient content and fertility in the soil (Magadula, 2014).

Furthermore, food packaging and serving materials derived from foliage possess numerous advantageous properties, such as imperviousness to leakage and water, absence of malodorous substances, biodegradability, and safety for employment in cold storage, microwaves, and ovens. In addition, these materials are versatile, being able to accommodate both wet and dry comestibles, serving as disposable containers for the former and reusable receptacles for the latter (Kora, 2019; Shashikumar et al., 2016).

Among the various foliage employed in the creation of leaf plates, banana leaves hold a particular significance owing to the abundant presence of antioxidants, especially polyphenols, Vitamin C, and Potassium. The inclusion of hot foods on banana leaves not only imparts a desirable flavor to the food but also incorporates the aforementioned constituents (Hegde et al., 2018; Sarin, 2017).

Moreover, the plant materials used for packaging are having a major role in treating a diverse number of diseases and illnesses. They also contain many functional compounds such as Vitamins, polyphenols, tannins, alkaloids, saponins, steroids, glycosides, and many others (George et al., 2016; Orabi & Orabi, 2016). Due to the presence of these compounds, most of the plant leaves have good pharmacological and phytochemical properties such as antioxidant, anti-diabetic, aphrodisiac, antibacterial, antifungal, anticancer, anti-obesity, anti-inflammatory, antimalarial, anti-mutagenic, anti-inflammatory and many more (Bhardwaj et al., 2011; Muhammad & Mudi, 2011; Prasad et al., 2006; Sachan et al., 2014; Terças et al., 2017). Therefore, it will be an additional advantage even if the plant material is leached into the food item while packaging.

Types of plant materials used in food packing

Plant materials such as leaves, sheaths, barks, fibers, shells, and stems have been used in food packing since ancient times. Among them, the leaves are readily available and cheap and are used as wrappers for cooked foods that are quickly consumed. As a step forward in this path, plant products such as leaves, bark, and agro-based waste materials are now catching the attention of many in creating sustainable and eco-friendly packaging materials.

As far as leaf-based packaging is concerned, not all leaves are suitable for wrapping food, but the species that are being used have been tested and proven by long usage that those leaves do not contain any toxins, dyes, or irritants. But an important factor for them is flexibility, which allows them to be folded without breaking, and of course, strong water-proofing and leak-proofing quality (Ng, 2015).

The utilization of plant leaves as receptacles, drink ware, and food wrappings is an established custom in the nations of South Asia. This long-standing tradition carries with it cultural, religious, medicinal, and socio-economic significance. These materials are used with the purpose of packaging food items for extended periods, serving both solid and liquid comestibles during festivities and celebrations, or even cooking food items while enveloped within the selected plant materials. These compounds have been observed to bestow special characteristic flavors upon the food items (Mensah et al., 2012; Ng, 2015; Kora, 2019).

A very recent study conducted in Sri Lanka, and it is able to identify abundantly used plant materials such as leaves of Lotus, Kottamba, Teak, Palmyrah, Coconut, Portia, Jack, Banyan and leaves and leaf sheath of Banana and Arecanut by the people of Northern Sri Lanka for packing and serving food items (Kalina et al., 2022). In India, it is common to wrap cheese and fruit confectionery with banana leaves, corn paste or blocks of brown sugar with maize leaves, and spices with betel leaves (Fellows, 1993). There are many kinds of plant materials used in India for packing and serving foods (Metananda et al., 2023). The leaves and leaf sheath (Figure 1) which are commonly used for food packaging and serving in South Asian countries especially in Sri Lanka and India are listed with the type of food items packed in Table 1 (a, b and c).

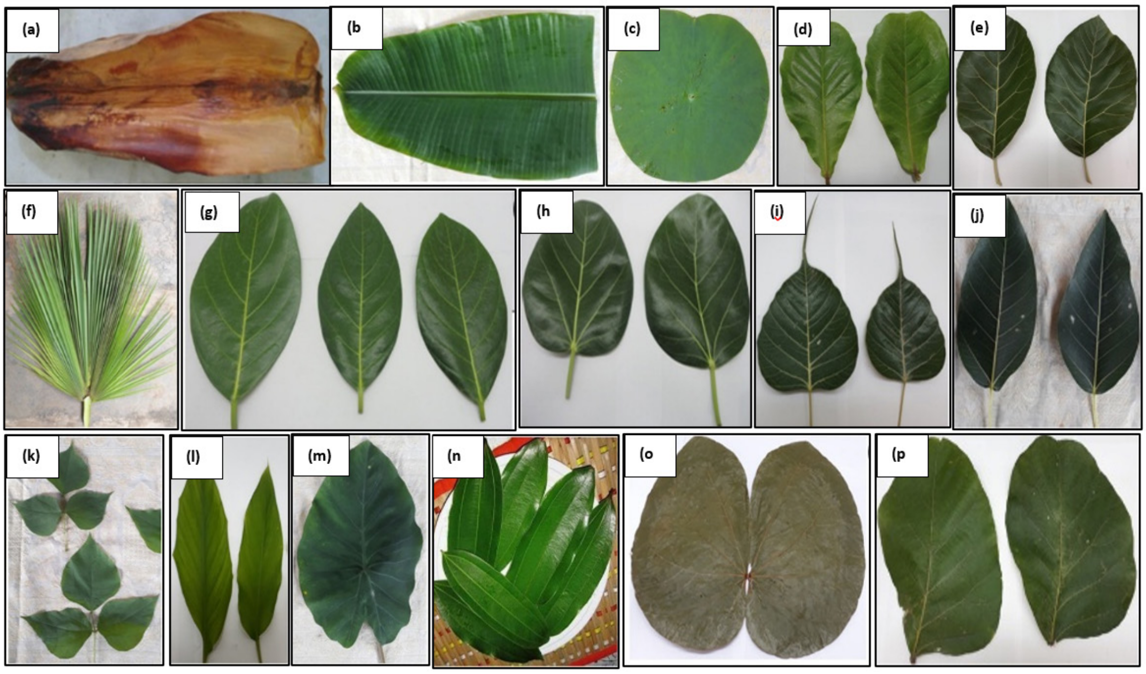

Figure 1: (a) The leaf sheath of Arecanut and the leaves of (b) Banana, (c) Lotus, (d) Kottamba, (e) Teak, (f) Palmyrah, (g) Jack, (h) Banyan, (i) Bodhi tree, (j) White fig, (k) Hyacinth bean, (l) Turmeric, (m) Taro, (n) Cinnamon, (o) Adakku and (p) Bastard teak Source: (Kora, 2019)

Table 1(a): Plant materials used for packing and serving foods in South East Asian countries.

Name of plant/ Part	Shape	Size	Food items served/ packed	References
Areca catechu **(Arecanut tree) Leaf Sheath**	Oblong	length of 65–111 cm, Width of 23–33 cm Thickness of 2.5–5.25 mm	All meals Cold and hot liquids	[Raghupathy et al., 2002]; [Shashikumar et al., 2016]
Musa × paradisiaca **(Banana) leaf**	Large Oval	2.7 × 0.6 m	All kinds of meals - Boiled, steamed, baked, roasted, and grilled foods. Multi-course meals such as rice, curries, chutney, pachadi, sweet dishes, savories, salads, cooked lentils, roasted pulses etc.	[Hegde et al., 2018]; [Mensah et al., 2012]; [Sarin, 2017]
Nelumbo nucifera **(Lotus) Leaf**	Peltate, circular, concave	20–90 cm in diameter	Cooked foods, Meat, sweets, flowers (Leaf powder acts as an oxidation retardant during the refrigerated storage of cooked food)	(Choe et al., 2011); (Hebbar, 2015)
Terminalia catappa **(Kottamba) Leaf**	Ovoid	15–25 cm long	Badam leaf kudubu, a recipe from Udupi cuisine	[Rojas-Sandoval, 2022]; [Reddy, 2022]; [Thomson & Evans, 2006]
Tectona grandis **(Teak) Leaf**	large, broadly ovate to elliptic	8–60 × 15–30 cm	Liquid food items such as soups, cereals, raita, and dhal	[Hegde et al., 2018]; [Nidavani & Mahalakhsmi, 2014]
Artocarpus heterophyllus **(Jack tree) Leaf**	Elliptical, , acutely tipped	4–25 cm in length	Steam cooked meals – Idli Baked dishes Spoon for rice starch soup, porridge	[Sidhu, 2012]

Table 1(b): Plant materials used for packing and serving foods in South East Asian countries.

Name of plant/ Part	Shape	Size	Food items served/ packed	References
Borassus flabellifer **(Palmyrah tree)** ***Leaf***	Fan shaped; rigid leaves and divided into lance shaped segments folded along the mid vein	3 × 3 m with a diameter of around 1–1.5 m	Skewed Meat and fish, Endosperm of un ripe fruit. Kernel of germinating seeds, toddy, jaggery, sugar cane, mango, coconut	[Rao et al., 2021]; [Vengaiah et al., 2017]
Ficus bengalensis **(Banyan tree)** **Leaf**	Ovate to elliptic, apex obtuse, stalked, and reticular pinnately venated	10–20 × 8–20 cm,	Serving meals	[Chaudhari et al., 2014];[Chaudhary et al., 2015]; [Kothapalli et al., 2014]
Ficus religiosa **(Bodhi Tree)** Leaf	Cordate with long tapering ends (drip tip), reticulately venated	10–17 × 8–12 cm	Serving meals	[Kora, 2019]; [Rutuja et al., 2015]
Ficus virens **(White Fig Tree)** **Leaf**	Ovate, leathery with whitish prominent mid rib	5–20 × 3–6 cm	Serving meals	[Prakash, 2019]
Ficus auriculata **(Broad leaf fig)** **Leaf**	Big, cordate, undulate, obtuse, heavily veined (5-7)	30-44 × 40-45 cm.	Serving meals	[George et al., 2016]; [Krishnan, 2015]
Pandanus amaryllifolius **(Pandan)** **Leaf**	oblong, caudate, flaccid, keeled beneath, entirely margined	25–75 × 2–5 cm.	White bread, jasmine rice, kaorimai rice, basmati rice, Idli	[Bhagya et al., 2013]; [Liew, 2013]
Lablab purpureus **(Hyacinth bean)** **Leaf**	Pinnate, trifoliate, broad oval	7.6–15.2 cm	Sweet - Prasadam	[Al-Snafi, 2017]; [Kora, 2019]
Pterospermum acerifolium **(Bayur / Dinner plate Tree)** **Leaf**	very broad, peltate, shallowly lobed, palmately ribbed,	40 × 40 cm	Serving, packaging and storing meals	[Chatterjee et al., 2012]; [Kapoor, 2017].

Table 1(c): Plant materials used for packing and serving foods in South East Asian countries.

Name of plant/ Part	Shape	Size	Food items served/ packed	References
Macaranga peltata **(Kenda) Leaf**	Peltate leaf stalk on the lower leaf surface and lamina	20–50 × 12–25 cm	Serving meals, Upma Steam-cooked sweet dishes – Ilayappam, ada	[Lekshmi-Priya, 2019]; [Shimizu-Kaya, 2014]
Curcuma longa **(Turmeric) Leaf**	Large, tufted, oblong, narrow tipped	76–115 × 38–45 cm	Steam-cooked sweet dishes	[Amit, 2022]; [Lia, 2013]; [Suryawanshi et al., 2023]
Colocasia esculenta **(Taro/ Elephant Ear plant) Leaf**	Triangular-ovate, cordate, bright green, mucronately tipped	20–150 × 24.8 cm	Steam cooking and oil frying of dishes such as patrode and alu chi wadi	[Ezeabara et al., 2015]; [Rama, 2019]
Cinnamomum malabatrum **(Cinnamon Tree) Leaf**	Three ribbed, elliptical, glabrous	10–30 × 3–9 cm	Sweet dishes – Appam	[Kora, 2019]
Shorea robusta **(Sal Tree) Leaf**	Oblong to oval	10–25 × 5–15 cm	Snacks – Boiled lentils Temple prasadam Pani puri, Prasadam	[Dash, 2015]; [Kora, 2019]
Phanera vahlii **(Addaku creeper) Leaf**	Bi-lobed	10- 46 cm long	Idli, Sweets – Jilebi, Soup, Dhal, Ice cream, Honey, Meals	[Chouhan & Saklani, 2013]; [Kora, 2019]
Butea monosperma **(Bastard teak) Leaf**	Trifoliate and Pinnate	10–15 cm long	Grilled Rottis, Grilled Bread Cooked rice, Meals Drinking Water, Chicken	[Hebbar, 2012]; [Somayaji & Hegde, 2016]

Further, many other countries of South Asia also practice the culture of packing, serving and cooking dishes by making use of plant materials. In the Malay community in eastern part of Asian continent where traditional food packaging is made from a variety of leaves and natural ingredients. The unique aspect of cakes in the Malay Archipelago is the kind of leaves which are used to wrap the sweet. For instance, banana leaves, *upih pinang*, *baharu* leaves, *ketapang* leaves, yam leaves, pandanus leaves, coconut leaves and rubber tree leaves are the most common leaf-based packaging materials. However, among these materials, banana leaves are very popular and most widely used as wrappers for some Malay food and cakes. Uniquely, each type of cake has its own packaging technique and methods, even using the same leaf as the wrapping material (Osman et al., 2018).

In Malaysia, during celebrations, they serve cooked rice in pouches made by weaving coconut or palas. The pouches are filled with rice and boiled. Cooked rice expands and becomes compressed into the shape of pouches**.** In the making of glutinous rice along with other fillings are neatly wrapped with bamboo leaves into tetrahedral, elongated and other shapes. These are boiled to cook while compressing the rice. There are many versions of this types of food in Malaysia but they are all typically wrapped in bamboo leaves (Ng, 2015).

In China, leaves of lotus, Coral tree (*M. grandifolia)* and teak are used in Chinese restaurants for serving and packing foods. Chinese serve the red oval-shaped ang koo by resting it on a piece of the banana leaf; the original purpose of the leaf may have been to prevent the ang koo from sticking to the serving plate. In posh Chinese restaurants, there is a rice dish wrapped in the leaf of the lotus. The lotus leaves impart a characteristic flavour to the rice (Ng, 2015).

In some parts of Africa, palmyrah palm leaves are used to weave boxes in which cooked foods are transported, and small banana leaf bags are used to contain coffee beans that are a traditional gift. Some of these have the potential to be developed as niche packaged products for tourist markets. Further, the teak leaves are used for packaging food products as a substitute for polyethylene and they offer a great potential to tackle environmental pollution in southern Benin. A diversified range of food is packaged with teak leaves: maize paste, bean cake, wheat paste, smoked fish, cassava cake, flat cake of groundnut, soya bean cheese, leafy vegetable, beef meat, etc. (Aoudji et al., 2013).

Other examples are green coconut palm, papyrus leaves and bamboo and rattan fibres, which are woven into bags or baskets and used for carrying meat and vegetables in many parts of the world. Fibres from kenaf and sisal plants are mainly used for making ropes, cord and string, which can be made into net bags to transport hard fruits. They can also be spun into a yarn that is fine enough to make a coarse canvas. Other examples of textile containers are woven jute sacks, which are used to transport a wide variety of bulk foods including grain, flour, sugar and salt. They are still widely used to transport fresh or dried crops, but they are being replaced as shipping containers by woven polypropylene or multi-walled paper sacks (Fellows, 1993**).**

Techniques of transforming plant materials into packaging materials

It is obviously observed that the leaves of a considerable number of plants and trees belonging to a diversified families of the plant kingdom are used in food packing and serving. The leaves are transformed into wrapping and serving materials such as single leaf plates, stitched dining leaf plates, food wraps, and food packing materials which are proved to have many beneficial properties (Sarin, 2017). The manufacturing of dining plates from leaves is feasible due to the flexible nature that the selected leaves possess. This flexibility level of leaves is effected from the type, unfurling nature, fibre content, mechanical strength and orientation of the venation (Kora, 2019).

Studies conducted on Asian culture have revealed the potential for the creation of sustainable packaging materials from plants utilizing uncomplicated processing techniques such as boiling, grilling, or steaming. In certain instances, leaves are prepared for use by being pre-softened through steaming, boiling, or grilling. Bamboo, on the other hand, is obtained from hill forests. It is crucial to note that leaves intended for use as food packaging materials must undergo boiling to effectively remove any fine bristles present on their surfaces and to ensure their cleanliness (Ng, 2015).

The production of leaf plates entails several general procedures. Firstly, the gathering of leaves, followed by manual or machine stitching and bundling for transportation. These steps culminate in the creation of thick, single-layered plates that are suitable for dining purposes. Moreover, these plates can be further processed into thicker variants through the use of heat-pressing machines, specifically hydraulic heat-pressing machines that are pedal-operated. These machines perform a myriad of functions, such as moulding, trimming, pressing, and drying. In order to render the plates impervious to water and leakage, a low-density polyethylene (LDPE) adhesive layer is inserted between the leaves and the underlying cardboard paper or leaves. It is noteworthy that the manufacturing of leaf plates is still largely conducted by small-scale and cottage industries.

Among the locally available resources, leaves from many different plant materials including the leaves of banana, teak, jack, banyan, kottamba and the leaf sheath of arecanut leaf are amenable for commercial leaf plate making. Recent studies prove that these materials have good physical properties which can be made use of when converting them into wrappers, plates and cups (Kora, 2019). The ways of utilizing or transforming the plant materials (Figure 2) for food packing and serving in South Asian countries are given in the Table 2 (a, b).

The scientific studies also prove that it is feasible to develop sustainable packaging materials from plant sources. A preliminary study explores the use of banana leaves and sheaths in making biodegradable food packaging sheets by eco-friendly methods with the use of Xylanase enzyme, immobilized in calcium alginate beads. The process involved bio-pulping, bio-bleaching and finally layering

Figure 2: (a) Machine compressed Arecanut leaf sheath plate, (b) Banana leave moulds and wrappings, (c) Application of lotus leaf for packing meat, Hand stitched dining plates made from the leaves of (d) Kottamba, (e) Teak, (f) Banyan, (g) Bodhi tree and (h) White fig, hand oven leaf basket from palmyrah leaf used for (i) storing star gooseberry fruits, (j) packing of toddy jaggery, (k) the cones used as spoons, (l) the hand stitched dining plate, (m) the hand woven baskets and (n) the steam cooking in leaf baskets of jack leaves, (o) the machine compressed cup made from the leaves of sal, (p) the hand stitched and (q) machine compressed dining plates made from the leaves of addaku, (r) the hand stitched and (s) machine compressed dining plates made from the leaves of Bastard teak, Sources: (Kora, 2019; Osman *et al*., 2018)

Table 2 (a): Ways of transforming plant materials for food packing and/or serving.

Name of plant	Ways of transformation for Food packing/ serving	References
Areca catechu	They are used for making disposable plates and cups. The naturally fallen, sheaths are collected; washed with water, soaked in hot water, and hot compressed to fabricate plates and cups.	[Dissanayake et al., 2021]; [Kalita et al., 2008]; [Shashikumar et al., 2016]
Musa × paradisiaca	Leaves are hot compressed to fabricate plates and cups. The dried leaves are used for food packing and making cups to hold liquid foods.	[Hegde et al., 2018]; [Sarin, 2017]; [Mensah et al., 2012]
Nelumbo nucifera	Steam cooking and wrapping the food ingredients	(Choe et al., 2011).
Terminalia catappa	Fresh leaves are hand hand-stitched into plates and used for serving food Wrapper during steam cooking	[Rojas-Sandoval, 2022]; [Thomson & Evans, 2006]
Tectona grandis	Fresh leaves are hand-stitched into plates and cups and used for serving food Wrapper during steam cooking	[Metananda et al., 2023]; [Ng, 2015]
Artocarpus heterophyllus	The leaves are stitched together to make round, single-use, disposable plates Used for wrapping in the form of hand-woven baskets for steam cooking Casing material for baking dishes Used as spoons for drinking kanji, a rice starch soup	[Sidhu, 2012]
Borassus flabellifer	A single young leaf which is circularly folded and secured with leaf fiber is used for packing and parcelling, Weaving the tender leaves into baskets The tender folded leaf is used for drinking liquid foods	[Rao et al., 2021]
Ficus bengalensis	The leaves are used for making disposable plates and wrapping food	[Prashanth, 2017]
Ficus religiosa	The leaves are hand-stitched into plates for serving fooz	[Kora, 2019]
Ficus virens	Leaves are used for serving food	[Elchuri, 2011]
Ficus auriculata	Plates by stitching 3 - 4 leaves together	[George et al., 2016]; [Krishnan, 2015]
Pandanus amaryllifolius	Leaves are rolled, weaved like a ribbon and made into cylindrical vessels and containers, after blanching. The cylindrical leaf moulds are used as food wraps during the steam cooking of idli. The leaves are also used for making baskets	[Bhagya et al., 2013]; [Liew, 2013]

Table 2 (b): Ways of transforming plant materials for food packing and/or serving.

Name of plant/ Part	Ways of transformation for Food packing/ serving	References
Lablab purpureus	Leaves are used for serving food	[Al-Snafi, 2017]; [Kora, 2019]
Pterospermum acerifolium	Leaves are used for making disposable plates, serving food and packaging and storing material. They are also woven into dinner plates and bowls either by stitching with twigs or molding.	[Kapoor, 2017].
Macaranga peltata	Plates made out of leaves are used for serving the meal. Wrappers for steam cooking of the sweet dishes	[Lekshmi-Priya, 2019]; [Shimizu-Kaya, 2014]
Curcuma longa	Leaves are used in wrapping foods during the steam cooking of sweet dishes	[Amit, 2022]; [Lia, 2013]
Colocasia esculenta	Leaves are used as food wraps during the steam cooking and oil frying of dishes Boiled or steamed them with tamarind during cooking as they contain calcium oxalate crystals	[Rama, 2019]
Cinnamomum malabatrum	Wrapped cones are used for steam cooking sweet dish	[Kora, 2019]
Shorea robusta	The fresh leaves are used for serving The leaves which are dried under sun are stitched together using grass stem sticks or sewing machine to produce leaf plates and leaf bowls.	[Dash, 2015]; [Arumugam et al., 2023]
Phanera vahlii	The shade dried leaves (4 – 5) are stitched by hand and machine into round plates using grass stem sticks and thread Leaves as packing material for cooked The cone-shaped leaf wraps are used during the steam cooking They are also made into cups and bowls for serving the liquid foods such as ice cream, soup and dal. Hand woven cups are used for serving honey	[Chouhan & Saklani, 2013]; [Kumar & Raju, 2022]
Butea monosperma	The plates and cups made of dried leaves are widely used for serving meals	[Hebbar, 2012]; [Rai et al., 2016]

on mould and deckle (Jeenusha & Amritkumar, 2020). Another recent research was done to develop healthy, environment-friendly, and organic packing materials based on banana leaves for food packing applications. In this study, processed dry banana leaves were stacked in various ways using corn starch to produce many samples including 2-layer, 3-layer, 4-layer, and 5-layer. When compared to a 1-layer sample, the tensile strength of 2, 3, 4, and 5-layer structures was found to be 22, 7, 42, 7, 48, and 56% higher. Without the use of any chemicals, the treated banana leaves extended their shelf life by six months, resulting in a sustainable bio-based material that can replace both paper and plastic (Arumugam et al., 2023).

Also, research on gene sequences of different varieties of banana trees was carried out in India, to identify and develop the banana varieties having desirable characteristics such as the production of a higher number of leaves within a shorter time and with good quality attributes which include soft and amenable nature and free from defects and leaf spots. The results of these researches proved that the cultivars NRCB selection-1, elaivazhai, and borkal basta are the most suitable banana varieties having desirable properties that support leaf plate manufacturing (Uma et al., 2003).

According to the findings of Manoi and his colleagues, lotus leaves known to contain anti-bacterial properties can also be utilized in producing eco-friendly food packaging. Cellulose extracted from lotus stalks by boiling in NaOH (10%) solution, can be used to make containers and coating them with a mixture of flours, TiO_2 and lotus leaf extract was found to yield the best result in increasing the tensile, tear strength and durability of the container and food can be stored longer than 24 hours in its original condition without adding preservative (Manoi et al., 2015).

Further, a study on cassava leaves indicates that, new kinds packaging sheets can be formed from cassava leaves with desirable properties, by mercerizing with NaOH. The Cassava leaves possess a desirable feature of having a waxy leaf surface which prevents the leaf from getting wet. When these leaves are subjected to a conventional mercerization treatment, they can be transformed into a sustainable packaging material. The cassava leaf sheets produced by mercerizing with a mild concentration of NaOH solution (15%) were proved to have the most preferable characteristics as a packaging material. This concentration of NaOH resulted in the packaging sheets having good tear index value, removal of toxic compound (HCN), formation of smooth sheets, low moisture absorption and hydrophobic nature. It is also mentioned that there is a huge potential for the production of these materials at a large scale due to the complete removal of HCN while considering its economic value (Sharif et al., 2014).

Further, in a study done by Aguirre and his colleagues, they developed biodegradable trays using different combinations of Cassava starch and corn husk flour with the help of a thermo-forming process. The trays developed from the blend of 85% cassava starch and 15% corn husk flour possessed promising physical and mechanical properties for the formation of biodegradable trays. (Aguirre et al., 2023). Also, it is proved that the bio-plastic films developed from cassava flour mixed with glycerol plasticizer completely bio-degraded on the 9th day of soil burial (Wahyuningtyas & Suryanto, 2017). However, this novel production process requires the utilization of natural and bio-derived resources and cost-effectiveness. In the meantime, further studies are required to confirm the above findings and their applicability.

A recent study in Sri Lanka proves that Arecanut Leaf Sheath possess mechanical properties as a raw material in the development of transparent, sustainable packaging materials for a wide array of applications. This study illustrates a possible method of developing a novel, sustainable packaging material utilizing the Arecanut leaf sheath. The developed material was coated with Carboxy Methyl Cellulose in order to improve its mechanical properties. The resultant material had a tearing strength of approximately 71% of polythene and exhibits approximately 5% elongation at failure. The bursting strength of the material was found to be three times higher (0.3 kg/cm²) than that of polythene (0.1 kg/cm²) (Dissanayake et al., 2021).

Studies on economic analysis, energy analysis and heat pressing machines for manufacturing Arecanut Leaf sheath products were done in order to find the feasibility of starting an entrepreneurial activity with Arecanut leaf sheath plates as a substitute for synthetic food serving materials. (Acharya et al., 2020; Jong et al., 2020; Kumar et al., 2019). This research indicates the rising demand for biodegradable food packing and serving materials. In a project where it aims to produce disposable takeaway food containers by using the fallen Areca leaf sheath, the sheath has a water absorption rate of 0.021g.min-1, which fulfils the purpose of disposable food packaging to contain liquid foods (Jong et al., 2020).

Furthermore, researchers have made paper materials with pineapple leaf pulp. The physical and mechanical qualities of paper made from pineapple leaf pulp were improved when it was coated with bio-coating. This was explained by the enhanced tensile strength, burst and tear resistance, and water absorbency of the materials. This finding shows that pineapple leaf pulp can be utilized to replace plastic in biodegradable packaging. As a result of this value-added utilization of natural fibers, less waste and less of it ends up in landfills (Iewkittayakorn et al., 2020).

A recent study indicated that *Caesalpinia pulcherrima* (Peacock flower) seed gum which is a rich source of galactomannan, could be used as an edible film-making material. *Caesalpinia pulcherrima* seed gum incorporated with 1.5 % of Glycerol had good physical and mechanical properties and it could be used as a potential source for the production of edible packaging film (Senarathna et al., 2022). Also, the structural modifications of galactomannan in fenugreek seed gum will lead to the development of packaging films with the required mechanical properties. (Akmeemana et al., 2023), Further, packaging films are also produced from the processing of cassava starch (Senarathna et al., 2023).

Draw backs in using plant-based packaging materials

The reviewed studies have proved the long-term usage of plant materials in food packing and also studies have proved the feasibility of developing biodegradable food packaging materials from plant sources. However, the replacing eco-friendly material should have characteristics equal to that of synthetic plastic. In this attempt, bioplastics are being developed from plant sources. But most of them have Poly Lactic Acid as the base, which needs more processing steps and these bioplastics need high temperature for composting and make the soil acidic. Also, bio-based polymers need high investment and need more cultivation area (Jeevahan et al., 2020; Mihindukulasuriya & Lim, 2014; Raza et al., 2018; Tsang et al., 2019). Hence developing a cheap, sustainable eco-friendly packaging material from these locally available plant materials by applying simple physiochemical treatment/s and transforming them into sustainable food wrappers and serving plates will be a productive solution to replace at least half of the single-use plastic.

The versatility, mechanical properties and functional properties of synthetic packaging materials are still better than the plant-based packaging materials produced so far, thus limiting their industrial applications (Da Rocha et al., 2018). The employment of plant-based materials in packaging still presents a barrier for liquid foods, and their seaming properties have limitations. The hydrophilic nature of protein and polysaccharide films results in greater permeability to water compared to synthetic films, and these also generally demonstrate weaker and less flexible structures. Consequently, the specific characteristics of the polymers utilized as building blocks determine their potential application in the packaging sector, as the safety of different products requires specific properties (Das & Chowdury, 2016; Jong et al., 2020; Khodaei et al., 2021; Wang et al., 2015).

The mechanical properties, barrier characterization, color and optical properties, water solubility, biodegradability, and sealing properties are the principal aspects that constitute the main criteria for packaging polymers in industrial production. Plant-derived packaging materials must satisfy the food packaging requirements that are applicable to traditional synthetic packaging materials. These plant-derived packaging materials must remain unaltered and operate in a safe and efficient manner until the point of disposal. Only once the intended functional use has concluded should the process of biodegradation commence. Consequently, further investigation must be conducted in order to enhance properties such as versatility, ability to be sewn, and permeability of plant-based packaging materials, so as to align them with the characteristics of synthetic packaging materials (Krochta, 2002).

The drivers that propel the market towards growth are novel advancements in packaging materials that exhibit enhanced properties, increased accessibility, and reduced costs. In addition, the escalating awareness of environmental issues and the adoption of new regulatory needs contribute to this trajectory. The development of biodegradable packaging materials derived from crops is further bolstered due to the presence of ethical quandaries pertaining to the escalation of global food prices and, indeed, the occurrence of global food shortages (Cruz-Romero & Kerry, 2009). Nevertheless, this particular trend engenders challenges in terms of material handling during the recycling process, thereby reinforcing the necessity for organic recycling as the preferred approach towards the end-of-life stage (Reichert et al., 2020).

Application in the food industry

With the rising demand from consumers for sustainable packaging materials, more stringent government regulations on plastic packaging, and ongoing technological advancements, the market for plant-based packaging is experiencing significant growth. Nevertheless, the current stage of development for the large-scale production of plant-based packaging utilizing renewable materials sourced from plants is in its infancy. The utilization of plant-based packaging extends across multiple industries. In the realm of food and beverages, for instance, it serves the purpose of preserving and extending the shelf life of perishable items such as coffee, baked goods, meats, and fish. In the healthcare sector, it plays a crucial role in safeguarding vaccines, drugs, and other medical products from contamination and tampering during their transportation and storage (Ross, 2023). The projected surge in the adoption of biopolymer-based mono films is primarily anticipated within the food and beverages industry, with a projected growth rate of 161% over a five-year period (2016 to 2021) (Reichert et al., 2020).

The functional efficacy of biodegradable materials derived from plant proteins can potentially be extended or heightened through the inclusion of additional additives or biopolymers. Plant protein-based bio-packaging materials offer significant prospects for augmenting the quality and safety of food, concurrently mitigating environmental contamination (Hadidi et al., 2022).

Certain crop-derived packaging materials, such as polylactide, are already considered viable alternatives to conventional food packaging. Conversely, other materials, like starch-based materials, necessitate further optimization to be deemed suitable for industrial packaging applications. In particular, the manufacturing of thermoformed items, such as single-use disposable cups and trays, using bio plastics, is well-suited for outdoor events. Furthermore, starch-based biodegradable polymers can be thermo-formed to fabricate trays and containers for packaging fresh and convenient food items (Cruz-Romero & Kerry, 2009).

A study was conducted where potato starch was utilized as the primary material for the development of novel packaging materials. These packaging materials, known as BIOPLAST products, are manufactured in conventional production plants established by BIOTEC GmbH & Co. KG in Emmerich am Rhein, Germany. The production of these BIOPLAST products can be tailored to contain varying levels of bio-based carbon content, which then determines the compostability of the potato starch packaging material either in an industrial or home composting setting (Reichert et al., 2020).

In a research article, it was documented that bio-based pouches made from mango kernel starch were successfully produced using a casting technique. These pouches were found to be a suitable alternative to polyethylene pouches for packaging red chili powder. The utilization of bio-based mango kernel starch pouches resulted in the preservation of the pungency and color of the chili powder to a greater extent compared to when it was stored in polyethylene pouches (Nawab et al., 2018). Thus, there is a pressing need to conduct thorough investigations on bio-based materials utilized in bags and pouches in order to generate a tangible impact on the production of more sustainable and environmentally friendly bags. To illustrate, bags designed for the containment of fruits and vegetables, constructed from the bio-plastic known as MATER-Bi, are already available in Uni coop Firenze grocery stores located in Italy. Notably, European nations have initiated the production of bio-plastic while simultaneously making substantial reductions in the utilization of disposable plastic utensils (Reichert et al., 2020).

Apart from bio-plastics, there exist Indian companies (Imarc Group) and start-up industries that engage in the production of disposable food serving materials made from banana leaves, palm leaves, and sheaths. These materials offer a viable alternative to polystyrene items, which are widely employed in the realm of food service in our daily lives. Notably, these plates possess the qualities of heat resistance, durability, freezer and microwave safety, as well as the ability to accommodate hot, cold, heavy, and messy food items with ease (Bansal, 2023).

Palm leaf tableware serves as an ecological substitute for disposable plastic, effectively mitigating the adverse effects on the environment and minimizing plastic waste. The lightweight nature of these items renders them highly suitable for various outdoor occasions, such as gatherings, picnics, and catering events. Moreover, the rustic yet refined aesthetic of palm leaf cups and plates further enhances their visual appeal, particularly in the context of environmentally-conscious gatherings and wedding celebrations. Consequently, the utilization of palm leaf tableware achieves a harmonious balance between utilitarian functionality, aesthetic appeal, and environmental accountability. Notably, these products are exported from India to numerous countries, including America, Europe, South Asia, East Asia, Oceania, the Middle East, and Africa. This signifies a significant global demand for these plates across multinational service restaurants. As time progresses, the demand for disposable plates made from plant leaves and sheaths is expected to experience a continuous upward trajectory, reinforcing the need for sustainable alternatives in the future (www.corpseed.com).

The large-scale production and application of these kinds of plant materials are still challenging phenomena. The use of plastics is widespread worldwide because of their versatility and their excellent process ability, thermal and mechanical properties (Krishnamurthy & Amritkumar, 2019). There are researches being carried out in the last two to three years in improving the properties of plant materials like arecanut sheath and banana leaves. However, the application of these types of materials in food industry may take a considerable number of years as the researches done in this area are very limited. It is therefore imperative to undertake further research in this field to enable the application of these materials in food products. Future investigations should explore the potential applications of these biodegradable trays, which could serve as packaging for fruits, vegetables, bakery products, and more. Additionally, it is essential to conduct a thorough investigation of the advantages and disadvantages associated with the use of plant-based packaging materials.

CONCLUSION

Since the production and accumulation of non-biodegradable plastic have increased drastically, replacing them at least partly with eco-friendly at the same time cheap and sustainable plant-based packing material will be helpful in saving the terrestrial and marine ecosystems from plastic pollution. Also, plant-based packing materials impart good characteristics to the packed foods, especially improving the organoleptic properties of the packed foods.

The previous both scientific and cultural studies prove that there is a huge potential to develop cheap, sustainable and biodegradable packaging materials from plant materials especially the leaves through suitable physiochemical treatments together with waterproof coatings. The food packaging industry urging for green technology as well as the customers who are becoming the victim due to the tremendous consumption of single-use plastic bags and wrapping sheets and all those who are taking steps towards the protection of the environment can make attempts to develop biodegradable packaging materials from plant sources. Hence, it is important for the scientist to focus on the area of transforming plant materials into packaging materials by improving their mechanical properties prominently and directs them towards the application in food industry.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Acharya, S., Shiwakoti, S., & Maharjan, S. (2020). Energy Analysis of Biodegradable Areca Leaf Plates Manufacturing in Nepal: A Case Study of Leaf Plus Pvt. Ltd. *Engineering, Technology and Applied Science Research*, 8(VIII), 239-244. doi:doi.org/10.22214/ijraset.2020.30860

Aguirre, E., Domínguez, J., Villanueva, E., Ponce-Ramirez, J.A., Arevalo-Oliva M.F., Siche, R., González-Cabeza, J., & Rodríguez, G. (2023). Biodegradable trays based on *Manihot esculenta Crantz* starch and *Zea mays* husk flour. *Food Packaging and Shelf Life*, **38**, 101129. doi:doi.org/10.1016/j.fpsl.2023.101129.

Akmeemana, C., Somendrika, D., Wickramasinghe, I., & Wijesekara, I. (2023). Cassava pomace-based biodegradable packaging materials: a review. Journal of Food Science and Technology, 1-22. doi:doi.org/10.1007/s13197-023-05807-y

Al-Snafi, A. E. (2017). The pharmacology and medical importance of Dolichos lablab (*Lablab purpureus*)- A review. *IOSR Journal of Pharmacy*, **7**(2), 22-30. doi:dx.doi.org/10.9790/3013-0702012230

Amit, D. (2022). Patoli Recipe Patoleo (Steamed Rice Rolls), DASSANA'S VEG RECIPES, India. Available from: https://www.vegrecipesofindia.com/patholi-recipe/ (Accessed 24th July 2023).

Aoudji, A. K.N., Adegbidi, A., Odile, D., Akpovi, R., Yao, W., & Lebailly, P. (2013, September). The teak (*Tectona grandis L.f.*) leaves marketing chain in southern Benin: part time trade, contribution to livelihoods and environmental sustainability [Paper presentation]. Fourth International Conference, Hammamet, Tunisia, *African Association of Agricultural Economists* (AAAE). doi:dx.doi.org/10.22004/ag.econ.159698

Arumugam, S., Pugazhenthi, G., & Selvaraj, S. (2023, in press). Investigations on mechanical properties of processed banana leaves for sustainable food packaging applications, *Materials Today: Proceedings*, doi:https://doi.org/10.1016/j.matpr.2023.02.256.

Bansal, S. (2023). Bamboo Plates Vs Palm Leaf Plates: Which One Is Best?. Keeo. Available from: https://www.keeo.com.au/blogs/news/bamboo-plates-vs-palm-leaf-plates-which-one-is-best (Accessed 23rd November 2023).

Bhagya, B., Ramakrishna, A., & Sridhar, K. R., (2013). Traditional seasonal health food practices in southwest India: Nutritional and medicinal perspectives. *Nitte University Journal of Health Science*, **3**(1), 30-34. doi:dx.doi.org/10.1055/s-0040-1703630

Bhardwaj, R. S., Bhardwaj, K. S., Ranjeet, D., & Ganesh, N. (2011). *Curcuma longa* leaves exhibits a potential antioxidant, antibacterial and immune modulating properties. *International Journal of Phytomedicine*, **3**(2), 270-278.

Chatterjee, P., Chakraborty, B., Nandy, S., Dwivedi, A., & Datta, R. (2012). *Pterospermum acerifolium* Linn. : A comprehensive review with significant pharmacological activities. *International Journal of Pharmacy & Life Sciences*, **3**(2), 1453–1458.

Chaudhari, S.G., Mishra, P.A., Adam, A., Chaudhari, H., Desai, J., Duvvuri, P., & Shendkar, A. (2014). A pharmacognostical and pharmcological review of *Ficus bengalensis*. *International Journal of Pharmaceutical Archive*, **3**(1), 296–301.

Chaudhary, S., Alok, S., Jain, S.K., Chanchal, D., & Dongray, A. (2015). Phytopharmacology and pharmacognostic properties of *Ficus benghalensis*-A review. *International Journal of Pharmacognosy and Phytochemical Research*, **2**(12), 560–569. doi:dx.doi.org/10.13040/IJPSR.0975-8232.IJP.2(12).560-69

Choe, J.H., Jang, A., Lee, E.S., Choi, J.H., Choi, Y.S., Han, D.J., Kim, H.Y., Lee, M.A., Shim, S.Y., & Kim, C.J. (2011). Oxidative and color stability of cooked ground pork containing lotus leaf *(Nelumbo nucifera)* and barley leaf *(Hordeum vulgare)* powder during refrigerated storage. *Meat Science*, **87**(1), 12–18. doi:doi.org/10.1016/j.meatsci.2010.08.011

Chouhan. R., & Saklani, S. (2013). *Bauhinia vahlii*: a plant to be explored. *International Research Journal of Pharmacy*, **4**(8), 5–9. doi:dx.doi.org/10.7897/2230-8407.04802

Cruz-Romero, M., & Kerry, J. P. (2009). Crop-based biodegradable packaging and its environmental implications. *CABI Reviews*, (2008), 1-25.

Da Rocha, M., de Souza, M.M., & Prentice, C. (2018). Chapter 9 - Biodegradable Films: An alternative food packaging. *In Food Packaging and Preservation*; Grumezescu, A.M., Holban, A.M., Eds.; Academic Press: Cambridge, MA, USA, 2018; pp. 307–342 doi:dx.doi.org/10.1016/B978-0-12-811516-9.00009-9

Das, M., & Chowdhury, T. (2016). Heat sealing property of starch based self-supporting edible films. *Food Packaging and Shelf Life*, **9**, 64–68. doi: doi.org/10.1016/j.fpsl.2016.05.002

Dash, D.M. (July, 2015). Mahaprasad Odisha Review. *Information & Public Relations Department, Government of Odisha Bhubaneswar* (E-magazine), Odisha Government Press, Cuttack, **71**(12), 34–39. Retrieved from https://magazines.odisha.gov.in/Orissareview/2015/July/engpdf/july%20or%202015.pdf

Dissanayake, K., Weerasinghe, D., Perera, T., Bandara, M., Thathsara, T., & Perera, S. (2021). A Sustainable Transparent Packaging Material from the Arecanut Leaf Sheath. *Waste and Biomass Valorization*, **12**(10), 1-18. doi:dx.doi.org/10.1007/s12649-021-01382-5

Elchuri, P. (2011). Uses of taking meal in the Juvvi leaves (*Ficus infectoria*), Excellent Ayurvedic Solutions. Available from: https://excellent-ayurvedicsolutions.blogspot.com/2011/10/uses-of-taking-meal-in-juvvi-leaves_27.html (Accessed 18th July 2023).

Ezeabara, C.A., Okeke, C.U., Amadi, J.E., Izundu, A.I., Aziagba, B.O., Egboka, P.T., & Udechukwu, C.D. (2015). Morphological comparison of five varieties of *Colocasia esculenta* (L.) Schott in Anambra State, Southeastern Nigeria. *American Journal of Plant Sciences,* **6**(18), 2819-2825. doi:dx.doi.org/10.4236/ajps.2015.618278

Fellows, P (1993). Packaging Materials for Food: A technical Brief, Practical Action, The Schumacher Centre, United Kingdom, 9 pages. Available from: https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/4f788680-e08c-46a8-9aed-4bf31661b3dc.pdf (Accessed 7th September 2022).

George, M., Joseph, L., & Paul, N.M. (2016). *Ficus auriculata*; A Pharmacological update. *International Journal of Current Research and Academic Review*, **4**(7), 26–31. doi:dx.doi.org/10.20546/ijcrar.2016.407.003

Geyer, R., Jambeck, J. & Law, K. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, **3**(7), e1700782. doi:doi.org/10.1126/sciadv.1700782

Ghosh, A., & Lobo A. S. (2017, January 31). Bay of Bengal: depleted fish stocks and huge dead zone signal tipping point. The Guardian. Retrieved from https://www.theguardian.com

Guillard, V., Gaucel, S., Fornaciari, C., Angellier, C.H., Buche, P., & Gontard, N. (2018). The Next Generation of Sustainable Food Packaging to Preserve Our Environment in a Circular Economy Context. *Frontiers in Nutrition*, **5**, 121. doi:doi.org/10.3389/fnut.2018.00121

Hadidi, M., Jafarzadeh, S., Forough, M., Garavand, F., Alizadeh, S., Salehabadi, A., & Jafari, S. M. (2022). Plant protein-based food packaging films; recent advances in fabrication, characterization, and applications. Trends in Food Science & Technology, **120**, 154-173. doi:dx.doi.org/10.1016/j.tifs.2022.01.013

Hebbar, J.V. (2012). Palasha: *Butea monosperma* Uses, Dose, Research . Available from: https://www.easyayurveda.com/2012/12/07/palasha-butea-monosperma-medicinal-qualities-ayurveda-details/ (Accessed 7th September 2022).

Hebbar, J.V. (2015). Lotus – *Nelumbo nucifera* Benefits, side effects, research. Available from: https://www.easyayurveda.com/2015/03/11/lotus-benefits-side-effects-research/ (Accessed 7th September 2022).

Hegde, S., Nair, L.P., Chandran, H., & Irshad, H. (2018) Traditional Indian way of eating: an overview. *Journal of Ethnic Foods*, **5**(1), 20-23. dx.doi.org/10.1016/j.jef.2018.02.001

https://www.corpseed.com/knowledge-centre/pakku-mattai-plates-manufacturing business-process (Accessed 23rd November 2023).

Iewkittayakorn, J., Khunthongkaew, P., Wongnoipla, Y., Kaewtatip, K., Suybangdum, P., & Sopajarn, A. (2020). Biodegradable plates made of pineapple leaf pulp with biocoatings to improve water resistance. *Journal of Materials Research and Technology*, **9**(3); 5056-5066. doi:doi.org/10.1016/j.jmrt.2020.03.023

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, **347**(6223), 768-771. doi:doi.org/10.1126/science.1260352

Jeenusha, K., & Amritkumar, P. (2020). Production of Biodegradable Food Packaging Material from *Musa* (Banana plant) leaves by Ecofriendly methods. *IOSR Journal of Environmental Science, Toxicology and Food Technology,* **13**(4), 1-5. doi:dx.doi.org/10.9790/2402-1404020105

Jeevahan, J.J., Chandrasekaran, M., Venkatesan, S., Sriram, V., Joseph, G.B., Mageshwaran, G., & Durairaj, R. (2020). Scaling up difficulties and commercial aspects of edible films for food packaging: A review. *Trends Food Science & Technology*, **100**, 210–222. doi:doi.org/10.1016/j.tifs.2020.04.014

Jong, O.K., Yong, T.M., & Jaafar, M.R. (2020). Production of disposable takeaway food container from areca leaf sheath (ALS) as sustainable packaging material. *IOP Conference Series: Material Science and Engineering*, **824**(1), *IOP Publishing*, Ayer Keroh, Malaysia 2020, Pp. 012014. doi:dx.doi.org/10.1088/1757-899X/824/1/012014

Kalina, S., Kapilan, R., Wickramasinghe, I., & Navaratne, S, B. (2022, February). Determination of physical properties of selected plant materials for food packaging and their development [Abstract Presentation]. International Conference on Food Research, Development and Applications*, University of Sri Jayewardenepura*, Pp.74. *Available at https://zenodo.org/records/6241801*

Kalita, P., Dixit, U.S., Mahanta, P., & Saha U.K. (2008). A novel energy efficient machine for plate manufacturing from areca palm leaf sheath. *Journal of Scientific & Industrial Research*, **67**(10), 807-811.

Kapoor, J. (2017, January 15). Kanak Champa is also popular as the 'dinner plate tree' in Punjab, and here's why. The Indian Express. Retrieved from https://indianexpress.com

Khazir, S., & Shetty, S. (2014). Biobased polymers in the world. *International Journal of Life Sciences Biotechnology and Pharma Research,* **3**(2), 35–43.

Khodaei, D., Álvarez, C., & Mullen, A.M. (2021). Biodegradable Packaging Materials from Animal Processing Co-Products and Wastes: An Overview. *Polymers*, **13**(15), 2561. doi:doi.org/10.3390/polym13152561

Kora, A.J. (2019). Leaves as dining plates, food wraps and food packing material: Importance of renewable resources in Indian culture. *Bulletin of the National Research Centre*, **43**(1), 205. doi:doi.org/10.1186/s42269-019-0231-6

Kothapalli, P. K., Sanganal, J. S., & Shridhar, N. B. (2014). Phyto pharmacology of *Ficus bengalensis*-A review. *Asian Journal of Pharmocology and Research,* **4**(4), 201-204.

Krishnamurthy, A., & Amritkumar, P. (2019). Synthesis and characterization of eco-friendly bioplastic from low-cost plant resources. *SN Applied Sciences,* **1**(11), 1432. doi:doi.org/10.1007/s42452-019-1460-x

Krishnan, B. (2015). *Ficus auriculata* – Elephant ear fig tree. Wilderness Notes, Available from: https://badrikrishnan.com/2015/11/14/ficus-auriculata-elephant-ear-fig-tree/ (Accessed 31st August 2022).

Krochta, J.M. (2002). *Proteins as raw materials for films and coatings: definitions, current status, and opportunities: Protein-based Films and Coatings*. CRC Press, Boca Raton.

Kumar, K., Patil, R., Thimmaiah, B., Manjunatha, G.R., & Sowmya, H. (2019). Eco-friendly Arecanut Leaf Sheath Products: An Economic Analysis. *Indian Journal of Ecology*, **46**(2), 431-436.

Kumar, S.S., & Raju, A.J.S. (2022). The Camel's foot climber, *Phanera vahlii* (Wight & Arn.) Benth. (Fabaceae: Cercidoideae): traditional economic uses and livelihood provider for tribals. *Species*, **23**(71), 118-122.

Lekshmi-Priya, S. (2019). All The Way from Nicobar, Kerala Researchers Root for 'Giant Leaf' to Beat Plastic. the better india, India. Available from: https://www.thebetterindia.com/169814/kerala-innovation-plastic-free-leaf-packaging-green/ (Accessed 24th July 2023).

Lia, L. (2013, November 19). Turmeric wrapped rice and banana parcels, *Hartley Botanic*, United Kindgdom. Retrieved from: https://hartley-botanic.co.uk/magazine/

Liew, P.S. (2013). *Pandanus amaryllifolius*–The only Pandanus with fragrant leaves. Tropical Biodiversity, *Word Press*, United Kingdom. Available from: https://blogs.reading.ac.uk/tropical-biodiversity/2013/01/pandanus-amaryllifolius/ (Accessed 10th August 2022).

Magadula, J.J. (2014). Phytochemistry and pharmacology of the genus *Macaranga*: A review. *Journal of Medicinal Plant Research*, **8**(12), 489–503. doi: dx.doi.org/10.5897/JMPR2014.5396

Manalili, N.M., Dorado, M.A., & Van Otterdijk, R. (2011). *Appropriate Food Packaging Solutions for Developing Countries.* Food and Agriculture Organization of the United Nations (FAO).

Manoi, T., Sonprasom, Y., Thorarit, R., & Wongthongsiri, K. (2015). Bio-based Packaging from Lotus Cellulose. Society for Science, Washington. Available from: https://abstracts.societyforscience.org/Home/FullAbstract?ISEFYears=0%2C&Category=Any%20Category&AllAbstracts=True&FairCountry=Any%20Country&FairState=Any%20State&Keywords=Biobased%20Packaging%20from%20Lotus%20Cellulose&ProjectId=12202 (Accessed 20th December, 2022)

Manzoor, M. F., Tariq, T., Fatima, B., Sahar, A., Tariq, F., Munir, S., Khan, S., Nawaz Ranjha, M. M. A., Sameen, A., Zeng, X. A., & Ibrahim, S. A. (2022). An insight into bisphenol A, food exposure and its adverse effects on health: A review. *Frontiers in nutrition*, **9**, 1047827. doi:doi.org/10.3389/fnut.2022.1047827

Mensah, J.K., Adei, E., Adei, D., Ashie, M.D. (2012). Perceptions of the use of indigenous leaves as packaging materials in the ready-to-eat corn meals. *International Journal of Biological and Chemical Sciences,* **6**(3), 1051-1068. doi: dx.doi.org/10.4314/ijbcs.v6i3.12

Metananda, A. A., Afrianto, W. F., Hasanah, L. N., Aini, Y. S., & Noorfajria, A. S. (2023). Ethnobotanical study on plant leaves for food wrapping in traditional markets of Wonosobo District, Central Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, **24**(7), 3804-3814. doi:doi.org/10.13057/biodiv/d240718

Mihindukulasuriya, S., & Lim, L.T. (2014). Nanotechnology development in food packaging: A review. *Trends in Food Science and Technology*, **40**(2), 149–167. doi:doi.org/10.1016/j.tifs.2014.09.009

Muhammad, A., & Mudi, S.Y. (2011). Phytochemical screening and antimicrobial activities of *Terminalia catappa*, leaf extracts. *Biokemistri* **23**(1), 35-39. doi:dx.doi.org/10.4314/biokem.v23i1.

Nawab, A., Alam, F., Haq, M.A., Haider, M.S., Lutfi, Z., Kamaluddin, S., & Hasnain, A. (2018). Innovative edible packaging from mango kernel starch for the shelf life extension of red chili powder. *International Journal of Biological Macromolecules*, **114**, 626–631. doi:doi.org/10.1016/j.ijbiomac.2018.03.148

Ng, C.K.C. (2015). Plant Leaves in Food Preparation and Packaging. *UTAR Agriculture Science Journal*, **1**(4), 35–39.

Nidavani, R.B., & Mahalakshmi, M.A. (2014). Pharmacology of *Tectona grandis* Linn.: Short review. *International Journal of Pharmacognosy and Phytochemical Re*search, **6**(1), 86–90.

Orabi, M.A.A., & Orabi, E.A. (2016). Antiviral and antioxidant activities of flavonoids of *Ficus virens*: Experimental and theoretical investigations. *Journal of Pharmacognosy and Phytochemistry*, **5**(3), 120–128.

Osman, M.N., Abdullah, A.F., & Gani, M.A.A.A. (2018). Sustainable Housing Landscape Concept as a Source of Wrapping Materials for Preserving Culture Activities in Malay Traditional Food. *Idealogy***,** **3**(2), 263-274.

Prakash, A. (2019). Study of morphological characters of transplanted trees with special reference to their medicinal importance. *Indian Journal of Scientific Research*, **9**(2), 21.

Prasad, P.V.V., Subhaktha, P.K.J.P., Narayana, A., & Rao, M.M. (2006). Palasa (*Butea monosperma* (Lamk.) Taub.) and its medico-history study. *Bulletin of the Indian Institute of History of* Medicine (Hyderabad), **36**(2), 117–128.

Prashanth, B.K. (2017). Banyan Tree: *Ficus benghalensis*: Uses, Research, Remedies, Side Effects. Available from: https://www.easyayurveda.com/2017/05/22/banyan-tree-ficus-benghalensis/ (Accessed 24th December 2023).

Raghupathy, R., Viswanathan, R., & Devadas, C.T. (2002). Quality of paper boards from arecanut leaf sheath. *Bioresource Technology*, **82**(1), 99-100. doi:doi.org/10.1016/S0960-8524(01)00141-9

Rai, A., Singh, A.K., Pandey, V.C., Ghosal, N., & Singh, N. (2016). The importance of *Butea monosperma* for the restoration of degraded lands. *Ecological Engineering* **97**, 619–623. doi:dx.doi.org/10.1016/j.ecoleng.2016.10.032

Rama, G. (2019). Alu Vadi / Arbi leaves Patra. Dairy free Gluten free Diet. Available from: https://dairy-free-glutenfree-diet.com/2019/07/alu-vadi-arbi-leaves-patra/ (Accessed 24th November 2023).

Rao, M. C. S., Swami, D.V., Ashok, P., Nanda, S.P., & Rao, B.B. (2021). Scope, Nutritional Importance and Value Addition in Palmyrah (*Borassus flabellifer* L.): An Under Exploited *Crop. Bioactive Compounds: Biosynthesis, Characterisation and Applications*, 207. doi.org/10.5772/intechopen.91131

Raza, Z.A., Abid, S., & Banat, I.M. (2018). Polyhydroxyalkanoates: Characteristics, production, recent developments and applications. *International Biodeterioration and Biodegradation*, **126**, 45–56. doi:dx.doi.org/10.1016/j.ibiod.2017.10.001

Reddy, D.S. (2022). Nattuvadumai paal or Indian almond milk, Paticheri. Available from: https://excellent-ayurvedicsolutions.blogspot.com/2011/10/uses-of-taking-meal-in-juvvi-leaves_27.html (Accessed 17th September 2023).

Reichert, C.L., Bugnicourt, E., Coltelli, M.-B., Cinelli, P., Lazzeri, A., Canesi, I., Braca, F., Martínez, B.M., Alonso, R., Agostinis, L., et al. (2020). Bio-Based Packaging: Materials, Modifications, Industrial Applications and Sustainability. *Polymers,* **12**, 1558. doi.org/10.3390/polym12071558

Rojas-Sandoval, J. (2022) '*Terminalia catappa* (Singapore almond)', *CABI Compendium*. CABI. doi: 10.1079/cabicompendium.53143.

Ross, L. (2023). Plant-Based Packaging: Types, Applications, and Environmental Impact. Thomas insights. Available from: https://www.thomasnet.com/insights/plant-based-packaging/ (Accessed 20th November, 2023).

Rutuja, R.S., Shivsharan, U., & Shruti, A.M. (2015). *Ficus religiosa* (Peepal): A Phytochemical and pharmacological review. *International Journal of Pharmaceutical and Chemical Sciences*, **4**(3), 360–370.

Sachan, K., Singh, P.K., Ashwlayan, V.D., & Singh, R. (2014). Evaluation of hepatoprotective activity of *Tectona grandis* Linn. *International Journal of Pharmaceutical and Medicinal Research*, **2**(3), 105–108.

Sahu, M.C., & Padhy, R.N. (2013). In vitro antibacterial potency of *Butea monosperma Lam*. against 12 clinically isolated multidrug resistant bacteria. *Asian Pacific Journal of Tropical Disease,* **3**(3), 217–226. doi:dx.doi.org/10.1016/S2222-1808(13)60044-4

Sarin, D. (2017). This is why you must eat on a banana leaf. NDTV Food Eng, India. Available from: https://food.ndtv.com/food-drinks/this-is-why-you-must-eat-on-a-banana-leaf-1793056 (Accessed 25th July 2022)

Senarathna, S., Navaratne, S., Wickramasinghe, I., & Coorey, R. (2022). Development and characterization of *Caesalpinia pulcherrima* seed gum-based films to determine their applicability in food packaging. *Journal of Consumer Protection and Food Safety*, **17**(1), 65-72. doi:doi.org/10.1007/s00003-021-01347-9

Senarathna, S., Navaratne, S., Wickramasinghe, I., & Coorey, R. (2023). Use of fenugreek seed gum in edible film formation: major drawbacks and applicable methods to overcome. *Journal of Food Science and Technology*, **60**(7), 1860-1869. doi: doi.org/10.1007/s13197-022-05465-6

Sharif, N.F.A., Razak, S.I.A., & Rahman, W.A.W.A. (2014). Cassava Leaves as Packaging Materials. *Cellulose Chemistry and Technology*, **48**(5-6), 585-590.

Shashikumar, S.D.J., Manjunatha, K., & Anantachar, M. (2016). Physical properties of arecanut sheath. *International Journal of Agriculture Sciences*, **8**(60), 3378–3380.

Shimizu-Kaya, U. (2014). Exploitation of food bodies on *Macaranga* myrmecophytes by larvae of a lycaenid species, *Arhopala zylda* (Lycaeninae). *The Journal of the Lepidopterists' Society*, **68**(1), 31-36. doi:doi.org/10.18473/lepi.v68i1.a5

Shobhit, K., & Satish, K.G. (2012). Applications of Biodegradable Pharmaceutical Packaging Materials: A Review. *Middle-East Journal of Scientific Research*, **12**(5), 699-706. doi:dx.doi.org/10.5829/idosi.mejsr.2012.12.5.63241

Sidhu, A.S. (2012). Jackfruit improvement in the Asia-Pacific region-A status report. Asian Pacific Association of Agricultural Research Institutions (APAARI). Bangkok, Thailand, pp 1–182. Available from: https://www.apaari.org/wp-content/uploads/downloads/2012/10/Jackfruit-A-Success-Story_31-8-2012.pdf (Accessed 30th December 2022)

Somayaji, A., & Hegde, K. (2016). A review on phrmacological profile of *Butea monosperma*. *International Journal of Phytopharmacology,* **7**(4), 237–249.

Suryawanshi, S., Todkar, A., Sanns, P., Thite, D., & Badhe, P. (2023). *Curcuma Longa* (Turmeric): Ethnomedicinal Uses, Chemistry, Morphology and Pharmacological Activities —A Review. *International Journal of creative Research Thoughts*, **11**(5), 34-43.

Terças, A. G., Monteiro, A. S., Moffa, E. B., Dos Santos, J. R. A., de Sousa, E. M., Pinto, A. R. B., Costa, P. C. D. S., Borges, A. C. R., Torres, L. M. B., Barros Filho, A. K. D., Fernandes, E. S., & Monteiro, C. A. (2017). Phytochemical Characterization of *Terminalia catappa* Linn. Extracts and Their antifungal Activities against *Candida spp*. *Frontiers in microbiology*, **8**, 595. doi:doi.org/10.3389/fmicb.2017.00595

Thomson, L. A. J., and Evans, B. (2006). "*Terminalia catappa* (tropical almond)," *Species Profiles for Pacific Island Agroforestry,* **2**, 1-20.

Thushari, G. G. N., & Senevirathna, J. D. M. (2020). Plastic pollution in the marine environment. *Heliyon*, **6**(8), e04709. doi:doi.org/10.1016/j.heliyon.2020.e04709

Tsang, Y.F., Kumar, V., Samadar, P., Yang, Y., Lee, J., Ok, Y.S., Song, H., Kim, K.H., Kwon, E.E., & Jeon, Y.J. (2019). Production of bioplastic through food waste valorization. *Environment International*, **127**, 625–644. doi: dx.doi.org/10.1016/j.envint.2019.03.076

Uma, S., Selvarajan, R., Sathiamoorthy, S., Ramesh Kumar, A., & Durai, P. (2003). Evaluation of banana germplasm for the leaf industry and for suitability to different growing environments in India. *Plant Genetic Resources Newsletter*, **134**, 26–32.

Vengaiah, P. C., Murthy, G. N., Sattiraju, M., & Maheswarappa, H. P. (2017). Value added food products from palmyra palm (*Borassus flabellifer* L.). *Journal of Nutrition and Health Science*, **4**(1), 1-3. doi: 10.15744/2393-9060.4.105

Verma, R., Vinoda, K.S., Papireddy, M., & Gowda, A.N.S. (2016). Toxic pollutants from Plastic waste-A Review. *Procedia Environmental Sciences*, **35**, 701–708. doi:dx.doi.org/10.1016/j.proenv.2016.07.069

Wahyuningtyas, N., & Suryanto, H. (2017). Analysis of Biodegradation of Bioplastics Made of Cassava Starch. *Journal of Mechanical Engineering Science and Technology*, **1**(1), 24–31.

Wang, L., Campanella, O., Patel, B., & Lu, L. (2015). Preparation and sealing processing of sodium alginate based blending film. *Mathematical Problems in Engineering*, **2015**, 895637. doi:doi.org/10.1155/2015/895637