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Where there is space for every dream

Value-added products from Agri-waste

A comprehensive handbook on using Agri-waste as a raw material for useful applications

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Transforming lives through translational research

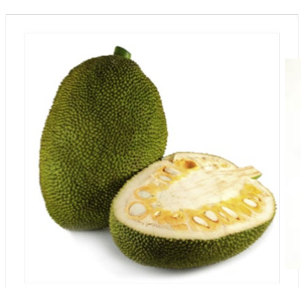
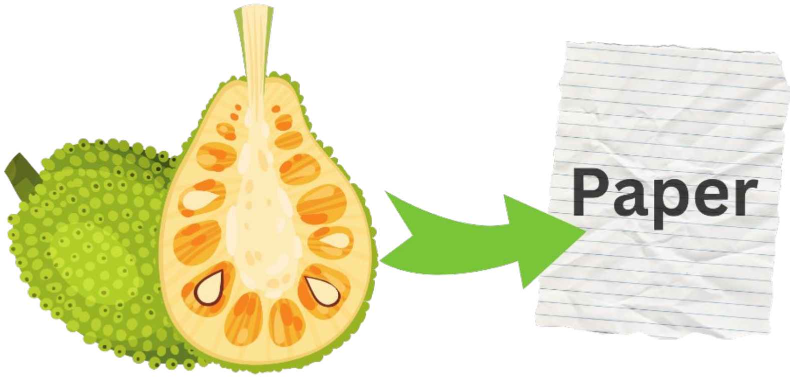



Table of Content

A. PAPER FROM JACKFRUIT WASTE



1. Introduction

1.1 Jackfruit: Botanical description

Jackfruit (*Artocarpus heterophyllus*) belongs to the Moraceae family, a reasonably large tree with the largest fruit among edible fruits. The jackfruit tree originates from Southeast Asia and is renowned in numerous tropical and subtropical nations. It thrives in the humid and warm climates typically found on hill slopes**.** The jackfruit is predominantly propagated from seeds and is characterized as a highly heterozygous and cross-pollinated crop. This leads to significant variation within the population concerning yield, fruit size, shape, quality, and time to maturity. The genus *Artocarpus*, a member of the Moraceae family, is part of the tribe Urticales. This family includes economically important species. *Broussonetia species are grown in the Asian tropics for paper pulp, while the bast of Artocarpus elasticus and other Artocarpus species are used locally as fiber for rope and paper. In contrast, other members of the Moraceae family, like species of fig from the genus Ficus, yield significant fruits for human consumption in tropical regions.*

The fruit mainly consists of three regions: the fruit axis, the persistent perianth, and the actual fruit. The axis, or core of the fruit, is non-edible and rich in latex due to the presence of laticiferous cells holding the fruit together**.** Jackfruit is considered a research-worthy species because of its potential use in nutrition and ability to increase local incomes, mainly when grown in agroforestry and home garden systems. It is sometimes highly valued locally and becomes valuable when introduced to other parts of the world, where it can be cultivated in suitable climates. The juicy pulp of the ripe fruit is eaten fresh or preserved in syrup and has excellent potential for preparing food items like jam, jelly, and value-added products due to its pectin content. Jackfruit rinds are important by-products that comprise more than 25.3 of the total weight of fruit. Preliminary studies reported that this part of jackfruit is sub-classified based on its fat content, protein content (low protein), fiber content (high fiber), and mineral content. Jackfruit rags, which include perianths of unfertilized fruits, have been generally processed to produce paper due to their higher fiber content.

1.2 Jackfruit waste and its importance

Jackfruit waste refers to the parts of the jackfruit that are typically discarded after consumption or unfit for consumption, such as rinds, seeds, peels, rags, and sometimes even the core. Despite being considered waste, these parts of the jackfruit can be repurposed in various beneficial ways: Nutritional value, Culinary uses, Animal feed, Biogas production, Composting, Industrial uses

Despite this, Jackfruit waste holds potential beyond culinary uses, extending into sustainable fabric and textile production and other innovative applications such as Fiber Extraction, Alternative to Leather, Dye Production, Biodegradable Packaging, Bioactive Compounds, and alternative papers.

1.3 Alternative Papers from Agro Waste

In the search for long-term solutions, alternative papers made from agricultural waste are emerging as a promising option. Traditionally, paper production relied primarily on wood pulp, contributing to deforestation and environmental deterioration. However, researchers and inventors increasingly use agricultural by-products to develop environmentally friendly paper substitutes.

In the world of sustainable materials, jackfruit fibers are emerging as a promising component for alternative papers. Jackfruit, a tropical fruit known for its vast size and fibrous texture, produces strong and long-lasting fibers that may be turned into environmentally friendly paper.

2. Jackfruit wastes that could be used as a primary fibre component of paper

- Peel
- Rag
- Leaves

2.1 Jackfruit peel

Jackfruit peel is the most abundant waste produced from jackfruit processing, which is already used as fertilizer or discarded. Still, it also has the potential to make biofuel, papers, paints, optics, and environmental remediation. According to research, jackfruit peel contains functional ingredients like steroids, saponins, glycosides, triterpenoids, alkaloids, tannins, and higher levels of phenolics and flavonoid content rich in carbohydrates and proteins. Calcium is abundant in the peel. The peel contains 15 to 16% of pectin, making it a good source of polysaccharides. As an emulsifier, stabilizer, and binding agent, pectin is vital in food, cosmetics, and pharmaceuticals. The various compounds from the peel extract are helpful in the textile, paper, and biofuel sectors. Studies have found that the jackfruit peel is a good source of cellulose, which has more potential than the commercially produced cellulose used in food and pharmaceutical industries.

2.2 Jackfruit Rag

Jackfruit rags are long filament-like structures that encircle the fruit's bulb and are typically discarded as garbage. They account for around 25% of the fruit weight and are high in cellulose, protein, reduced sugar, and pectin.

Jackfruit rag, a natural fibre formed from the inner bark of the jackfruit tree, has extraordinary characteristics that have been used for ages in various cultural contexts. This fibrous substance, recognized for its strength and durability, is traditionally treated by stripping and sun-drying the bark, which is then meticulously hand-cleaned to assure purity. Jackfruit rag is used in a variety of customary crafts and is used daily. Craftspeople incorporate this fibre into robust textiles, such as rugs and mats, prized for their toughness and rustic appeal. In addition, the fibres can be used to make ropes and twines, which are essential for daily use in rural areas and for agricultural activities where durability is a top priority.

2.3 Jackfruit Leaves

Jackfruit leaves are famous for their great size, brilliant green color, and exceptional fibrous characteristics. These leaves are made of strong, resilient fibers that have long been used in various cultural applications. Jackfruit leaf fibers are primarily used in handicrafts and traditional arts. Artisans employ these fibers to make baskets, mats, and other household products, demonstrating their versatility and sturdiness. Also, the fibers from jackfruit leaves are used to make ropes and twines due to their strength. Because of their strength and flexibility have long been used in rural communities to bind bundles, secure thatched roofs, and even make fishing nets. This natural material is an environmentally friendly alternative to synthetic fibers, aligning with sustainable practices.

Beyond their practical usage, jackfruit leaf fibers have potential industrial applications. Research is being conducted to determine their usefulness in papermaking processes, as their strength may improve the durability and quality of paper products. Furthermore, the fibers have intriguing qualities for composite materials, helping to drive advancements in sustainable construction and manufacturing.

Overall, the fibrous properties of jackfruit peel, rag, and leaves exemplify nature's ingenuity, offering a renewable resource that combines strength, flexibility, and eco-friendliness in various traditional and modern applications.

3. Significance

The potential for jackfruit waste to transform the paper industry with sustainable alternatives makes it an organic option for paper in manufacturing processes. Deforestation and environmental degradation are frequently the results of resource-intensive procedures used in traditional paper production. The goal is to address these environmental issues and help develop paper options that are more environmentally friendly by investigating jackfruit waste as a potential material. We have several benefits from using jackfruit waste as an alternative, such as

Sustainability: Jackfruit waste provides a sustainable and environmentally beneficial alternative to conventional Paper, repurposing a waste product that would otherwise be thrown away.

Biodegradability: Jackfruit waste is likely more biodegradable than regular resources, which reduces environmental impact and trash generation.

Renewable Resource: Considering jackfruit as a renewable resource and using its waste to make Paper conforms with a circular economy approach emphasizing resource efficiency.

Local Sourcing. Jackfruit is commonly grown in tropical areas. Using its waste for Paper could promote local sourcing and reduce transportation-related carbon emissions.

4. Manufacturing process:

1. Collection and Preparation of Raw Materials

- **Jackfruit Rag:**

Collection: Collect the fibrous strands (rag) surrounding the ripe jackfruits' seeds.

Cleaning and Chopping: Clean the rag to remove any dirt or debris. Chop or shred it into smaller pieces to facilitate the pulping process.

- **Jackfruit Leaves:**

Collection: Gather fresh jackfruit leaves and clean them.

Processing: Remove the midribs and cut the leaves into smaller pieces. Leaves can be used either fresh or after drying, depending on the paper-making process chosen.

- **Jackfruit Peel:**

Collection: Collect the outer peel of ripe jackfruits.

Processing: Clean and chop the peel into pieces similar to the rag.

2. Pulping

Pulping is breaking down raw materials into a pulp that can be used to make paper. There are two main methods:

Mechanical Pulping: This involves grinding or chipping the materials to separate the fibres physically.

Chemical Pulping: Uses chemicals to break down lignin and separate fibres more effectively. Standard methods include sulfate (kraft) pulping or soda pulping.

Mechanical and chemical pulping might be used to obtain a suitable pulp consistency for jackfruit rags, leaves, and peels.

3. Paper-Making Process

Once the pulp is prepared, the paper-making process proceeds as follows:

Mixing: The jackfruit rag, leaves, and peel pulp are mixed with water to create a slurry.

Formation: The slurry is poured onto a screen or mesh to form a sheet of paper. Water drains through the screen, leaving a mat of fibers on the surface.

Pressing: The newly formed sheet removes excess water and consolidates the fibers.

Drying: The pressed sheet is dried using air drying or heated rollers to remove the remaining water and solidify the paper.

4. Finishing

After drying, the paper may undergo additional processes:

Calendering: Smoothing the paper by passing it through rollers.

Cutting: Cutting the paper into sheets or rolls of desired sizes.

Packaging: Packaging the finished paper for distribution.

5. List of machinery requirements for paper manufacturing with capacity and Cost

Machinery	Capacity (Tonnes per day)	Cost (in INR)
Raw material Chippers	10	5 lakhs
Pulping Machines	20	15 lakhs
Digesters	**20**	**20 lakhs**
Washers	**20**	25 lakhs
Bleaching Equipment	20	50 lakhs
Refiners	10	20 lakhs
Paper Machine and parts	20	2 crores
Fourdrinier Machine	20	1 crore
Press Section	20	50 lakhs
Dryers	20	20 lakhs
Calendars	**20**	50 lakhs
Reel and Winder	**10**	25 lakhs
Coating Machines	20	50 lakhs
Slitters and Rewinders	20	25 lakhs

6. Market study and scope

In India, few alternative papers cost similar to the conventional papers in the market but with the advantages of more sustainability and eco-friendliness; still, there is much demand and need for sustainable and alternative papers produced from Agro-waste in the worldwide market. Currently, no companies are manufacturing papers from jackfruit waste worldwide. So, this can be a fresh and open concept for any start-up to take over the business in India and worldwide.

B. Value-added Products from Poultry Feather Waste

1. Introduction:

Feathers a by-product of poultry production have several valuable uses across various industries. some producers raise poultry specifically for their feathers. Chicken feathers can be transformed into various valuable products across multiple industries both decorative as well as useful products. Chicken feathers have 92% keratin that can be a good source of peptides, amino acids, and minerals and are used to produce nitrogen-rich organic fertilizers, enhancing soil health in agroindustry and animal feed supplements. Feathers which have keratin a durable protein is used to produce biodegradable plastics, cosmetics, and medical products like wound dressings. Apart from these the textile and fashion industry utilizes feathers for decorative items, as well as lightweight, insulating stuffing for cushions and bedding. Their unique structure makes them suitable for filtration systems, effectively removing heavy metals and contaminants from water and air. Feathers also find applications in the paper and packaging sector, being processed into strong, lightweight feather fibre paper. In construction, feathers contribute to the creation of lightweight composites and insulating materials. Lastly, feathers can be harnessed for bioenergy production through processes like pyrolysis or gasification. These diverse applications not only add economic value to chicken feathers but also promote sustainability by reducing waste and utilizing renewable resources.

1.1 Poultry Feather Waste Generation

On average, feathers constitute about 5-7% of a chicken's total body weight. India produces approximately 4.5 million metric tons of broiler meat annually. Karnataka is among the top states in broiler production. it is estimated that the state contributes significantly to the overall national production.

1.2 Value-added products generated from polutry feather

S. No	Products
1	Organic fertilizers
2	Animal feed supplements
3	Biodegradable plastics
4	Cosmetics
5	Wound dressings
6	Stuffing for cushions and bedding
7	Filtration systems
8	Paper and packaging material
9	Decorative items

2. Biodegradable material alternates to plastics

Presence of keratin in the waste chicken feathers can be used to produce bio plastic. Keratin is a fibrous protein in structural material making up hairs, claws, feathers and the outer layer of the skin. Keratin is a non-burning hydrophilic and bio degradable which is can be applicable via chemical processing. Extraction of keratin from waste chicken feathers can be converted into a useful product.

2.1 Manufacturing process

- Wash the collected feather samples in water & neutral soap solution Followed by treating it with sodium chloride (NaCl). By this the excess amount of blood was removed and the pH of
  raw material was neutralized to 7.
- Dry the chicken feather in hot air dryer and finely chop to a powdery state.
- Add 5g of chopped chicken feathers to 100ml of 0.5M sodium sulphide (Na_2S) and 2M of sodium hydroxide (NaOH).
- Keep this solution in for stirring in shaker incubator for two hours at room temperature

- Centrifuge the sample 10,000 rpm for 5 minutes
- Extract the supernatant carefully and transfer it to a fresh container.
- Add 2N of HCl slowly until the pH of the extract is 4.2.
- Transfer the extract to a dryer plate and keep in hot air oven at 50ºC for one hour
- The product obtained will be a thin layer of bio-plastic

2.2 Equipment required

S. No	Equipment	Purpose	Price (₹)	
1	Milling Machine	To powder the feathers	₹ 40,000	
2	Shaker incubator	Incubation and shaking	₹ 30,000	
3	Industry grade centrifuge	Separation of substance	75,000	
4	Industrial grade hot air oven with trays	for drying	250 per piece	

5	Plastic crates	Storage, transport and treatment	₹ 3,000	

2.3 Consumables required for kg of feather

S. No	consumables	purpose	Price
1	Industrial Grade Soap solution	Initial treatment to neutralise the pH	₹ 150/ 50 Litter
2	Industrial Grade Powder Sodium Chloride	Initial treatment to neutralise the pH	₹ 30/ Kilogram
3	sodium sulphide (Industry grade)	Extraction of keratin	₹ 48/ Kg
4	sodium hydroxide (Industry grade)	Extraction of keratin	₹ 59/ Kg
5	HCl (Industry grade)	Extraction of keratin	₹ 18/ Kg

Ref: Industrial Waste Management Association, Tamil Nadu

3. Keratin-based cosmetic products from chicken feathers

Keratin-based cosmetic products derived from chicken feathers represent a sustainable and innovative approach in the beauty industry. Chicken feathers, a by-product of the poultry industry, are rich in keratin—a fibrous structural protein known for its strength and protective qualities. The process begins with collecting and thoroughly cleaning the feathers to remove impurities. The keratin is then extracted through chemical or enzymatic treatments, followed by purification to ensure it is safe for cosmetic use.

These keratin extracts are incorporated into a variety of cosmetic products. In hair care, keratin is used in shampoos, conditioners, and hair masks to strengthen hair, improve elasticity, and reduce frizz. In skincare, keratin-enhanced creams, lotions, and serums are designed to boost hydration, improve skin texture, and promote a healthy appearance.

3.1 Manufacturing process

- Soak feathers in detergent for overnight to remove all the impurities and then in petroleum ether for 2-3 hr
- Dissolve the pre-treated feathers in 0.2M of NaOH solution and keep for overnight incubation at 50^0C and continuous shaking at 150 rpm.
- Filter the solution to remove insoluble residues
- Neutralize the filter solution using 2N HCl. Filter and lyophilise the precipitates of for future use.
- Dialyse the keratin solution against the distilled water (5L). Collect the dialysed solution after 48 hours and store in a container.

(A): Feathers soaked in detergent; (B): Feathers soaked in petroleum ether; (C): Drying of feathers in sunlight; (D): Stored clean feathers in plastic bags

Ref: Provided below

300 grams of Chicken Feather yields around 60-70% of keratin

3.2 Materials Required

S. No	Material	Purpose	Price
1	Petroleum ether	pre-treatment	₹ 85/ Litre
2	sodium hydroxide (Industry grade)	Extraction of keratin	₹ 59/ Kg
3	HCl (Industry grade)	Extraction of keratin	₹ 18/ Kg
4	Dialysis membrane	Extraction of keratin	₹ 5000

3.3 Formulation of Keratin Shampoo

S. No	Material	Amount	Price
1	Dialyzed Keratin	10 ml	
2	Sodium Lauryl Sulphate	0.5gm	₹ 145/ Kg
3	Gaur gum	1 gm	₹ 135/kg
4	Glycerol	10 ml	₹ 60/ Kg
5	Propylene Glycol	1 ml	₹ 800/ Kg
6	Citric Acid (3%)	As per the need	₹ 215/ Kg
7	Distilled Water	As per the need	₹ 150/ Litre

3.4 Equipment's required

S. No	Equipment	Purpose	Price (₹)	
1	Shaker incubator	Incubation and shaking	₹ 30,000	

2	Plastic crates	Storage, transport and treatment	₹ 3,000	

Ref: Megha Sharma, Formulation of keratin-based cosmetic products from chicken feathers, Project thesis submitted to Department of Biotechnology and Bioinformatics, Jaypee University of Information Technology, Waknaghat, 2023.

4. <u>Pillow and bedding material from chicken feathers</u>

4.1 Manufacturing process

- Sort the feathers to separate the desirable down feathers (small, soft feathers found under the tougher exterior feathers) from the less desirable ones.
- The feathers are washed thoroughly to remove dirt and other impurities with mild soap solution and disinfectant. Adding a small amount of fabric softener during the washing process can enhance the softness
- Dry the feathers thoroughly using the dryer and grade the feathers as per quality. Down feathers are usually preferred for bedding and pillows due to their softness and insulating properties.
- Feathers can be blended with synthetic fibres to enhance certain properties like firmness or durability.
- The processed feathers should be stored in a controlled condition to maintain dryness and cleanliness.

4.2 Material Required

S. No	Consumables	Purpose	Price
1	Industrial Grade Soap solution	Initial treatment to neutralise the pH	₹ 150/ 50 Litter

2	Fabric softener (Industry grade)	To soften the feathers	₹ 1890/5 Litre
3	Disinfectant solution	To remove the microbes	₹ 2464/Litre
4	White Polyfill Fiber	To enhance firmness	₹ 155/ Kg

4.3 Equipment Required

S. No	Material	Purpose	Amount	
1	Hot Air Dryer Oven for Industrial use	Drying	₹ 90,000	
2	Industrial-grade hot air oven with trays	Drying	250 per piece	
3	Milling Machine	To powder the feathers	₹ 40,000	

5. <u>Paper and packaging material</u>

5.1 Manufacturing process

- Treat the chicken feathers with aqueous solutions of SDS (1gm/40L) in a big container. Agitated the sample at 500 rpm using an industry-grade stirrer for 30 min
- Purify the treated feather by rinsing it in distilled water for 10 minutes and then dry using an industry-grade drier
- Mill the feathers using a heavy-duty milling machine to make it into a powder form

- Prepare the suspensions of feather pulp mixtures by adding water and defibrillating in a disintegrator
- Prepare the sheet of the suspension using a hand sheet former machine
- Dry the sheets on a hot plate provided in the hand sheet former machine

Ref: Tesfaye T, Sithole B, Ramjugernath D, Chunilall V. Valorisation of chicken feathers: Application in paper production. Journal of cleaner production. 2017 Oct 15;164:1324-31.

5.2 Material Required (for 1 kg of untreated feather)

S. No	Material	Amount
1.	SDS	₹ 52/Ltr

5.3 Equipment required

S. No	Material	Purpose	Amount	
1	Stirrer Storage Tank	Cleaning	₹ 70,000	
2	Hot Air Dryer Oven, For Industrial use	Drying	₹ 90,000	
3	Heavy Duty Milling Machine	Powder the feathers	₹ 40,000	
4	Disintegrator Dissolver mixer, Capacity (Litre): 500 L	To mix the components	₹ 2,00,000	
5	Hand Sheet Former	Sheet Making	₹ 80,000	

C. Coconut Shell Oil

1. Introduction

The coconut tree (*Cocus nucifera*) is a member of the palm tree family. The term coconut can refer to the whole coconut palm, the seed or the fruit, which botanically is a drupe, not a nut. They are ubiquitous in coastal tropical regions and are a cultural icon of the tropics.

The coconut tree provides food, fuel, cosmetics, folk medicine and building materials, among many other uses. Coconuts are distinct from other fruits because their endosperm contains a large quantity of clear liquid called' coconut water' or 'coconut juice'. Mature, ripe coconuts can be used as edible seeds or processed for oil and plant milk from the flesh, charcoal from the hard shell and coir from the fibrous husk. Dried coconut fruit is called the copra, and the oil and milk derived from it are used in cooking, frying, and soaps and cosmetics.

The coconut tree grows up to 30 meters tall and can yield up to 75 fruits per year. Plants are intolerant to cold and prefer copious precipitation and full sunlight. In 2022, about 73% of the world's supply of coconut was produced by Indonesia, India and the Philippines.

1.1 The fruit

the coconut fruit is a drupe. Like other fruits, they have 3 layers: the exocarp, mesocarp and endocarp. The exocarp is the glossy outer skin, usually yellow-green to yellow-brown in color. The mesocarp is composed of a fibre called the coir, which has many conventional and commercial uses. Both the exocarp and mesocarp make up the husk of the coconut, while the endocarp makes up the hard coconut shell. The endocarp is thick and has three distinctive germination pores on the distal end, two of which are plugged, while one is functional.

1.2 Production by country

Indonesia is the world's largest producer of coconuts, with gross production of 15 million tonnes.

The Philippines is the world's second-largest producer of coconuts. It was the world's largest producer for decades until its production declined due to ageing trees and devastation of typhoon.

Indonesia overtook it in 2010. It is still the largest producer of coconut oil and copra, accounting for 64% of global production.

Traditional areas of coconut cultivation in India are the states of Kerala, Tamil Nadu, Karnataka, Puducherry, Andhra Pradesh, Goa, Maharashtra, Odisha, West Bengal and Gujarat and the islands of Lakshadweep and Andaman and Nicobar. Kerala has the largest number of coconut trees in production per hectare, and the coconut tree is the official state tree of Kerala.

Sri Lanka is the world's fourth-largest producer of coconuts and is the second-largest producer of coconut oil and copra, accounting for 15% of the global production. The production of coconuts is the primary source of Sri Lanka's economy, with 12% of cultivated land and 409,244 hectares used for coconut growing.

1.3 Uses

The coconut palm is grown throughout the tropics for decoration and culinary and non-culinary uses; virtually every part of the coconut palm can be used by humans in some manner and has significant economic value. Coconut versatility is sometimes noted in its naming. In Sanskrit, kalpa vriksha is the tree that provides all life's necessities. In the Philippines, the coconut is commonly called the ‘tree of life’.

The coconut shell is likewise the primary contributor to the nation's pollution problem, as solid waste in the form of shells involves an annual production of approximately 3.18 million tonnes. It also presents serious disposal problems for the local environment, which is an abundantly available agricultural waste from the local coconut industries. Coconut shells, being a difficult and not quickly degrade material if crushed to the size of sand, can be a likely material to substitute sand. Currently, coconut shells have also been burnt to produce charcoal and activated carbon for food and carbonated drinks and filtering mineral water use. The chemical composition of the coconut shell is similar to wood. It contains 33.61% cellulose, 36.51% lignin, 29.27% and ash 0.61%. In many countries where abundant coconut shell waste is discharged, this waste can be used as potential material or replacement material in the construction industry. This will receive the dual advantage of reducing the monetary value of construction material and being a means of disposing of waste.

Pyrolysis is a thermal conversion process for turning biomass into more valuable products like bio-oil. Bio-oil is a dark-coloured liquid fuel that smells like smoke that is condensed from pyrolysis. It vapours products from ingredients containing lignin, cellulose, hemicellulose, and other carbon compounds. Bio-oil consists of carbon, hydrogen and oxygen with little nitrogen and sulfur. The sulfur and nitrogen components of the bio-oil can be eliminated because of their little impact towards bio-oil performance. The largest organic components in the bio-oil are lignin, alcohol, organic acids and carbonyls. These carbonyls make bio-oil an environmentally friendly fuel, potentially have a greater caloric value other than oxygen fuels (such as methanol) and are only slightly lower in caloric value than diesel and other light fuel oils.

The biomass used to produce bio-oil can be obtained from agriculture, forest, plantation, industrial and household waste. Tropical countries like Indonesia generally have abundant biomass resources. Biomass raw materials are potentially used for making bio-oils, such as durian leather, oak, corn cobs, powder/ sawmills, wheat bark, jatropha, fruit pulp, and coconut shells.

Coconut shell waste caused many problems in waste management that usually had been left to rot, stacked and burned. This handling will have a negative impact on the environment. One alternative that can be taken to overcome those problems is to convert it into a valuable product with applicative and cheap technology so that the results are easily applied to society.

Coconut shells are widely used for enriching plotting soil or covering plants as much in a garden setting. The dried coconut shells contain polyphenols and organic acids. Coconut shell liquid smoke contains phenolic compounds such as phenols, guaiacol, etc. This coconut liquid smoke is not toxic, is safe, and is used to preserve fish.

Coconut shell oil has antimicrobial activity; this oil contains alkaloids, carbohydrates, saponins, phenols, flavonoids, amino acids, tannins, proteins, terpenoids, oxalate, carboxylic acid, quinines and glucosides.

2. <u>Pyrolysis bio-oil:</u>

Bio-oil, or pyrolysis oil, is a liquid product produced by pyrolysis: rapid heating and rapid quenching of organic material in a low-oxygen atmosphere. Liquified biomass is more easily pumped and stored and is more compatible with chemical modification, processing, or extraction. This bio-oil is a liquid emulsion of oxygenated organic compounds, polymers and water. It contains up to 40%oxygen by weight and has properties that are dissimilar to petroleum oil, including that it is immiscible with petroleum oils, contains water, often in the range of 20-30%, has a lower heating value than petroleum oil, is acidic, unstable especially when heated, has a higher density than water and often contains solid inorganics and carbon char.

2.1 Characteristics of Bio-oil:

Crude pyrolysis oil is dark brown and approximates biomass in elemental composition. The liquid is formed by the fat's pyrolysis, which is rapidly heating and quenching biomass in inert or oxygen-deficient atmospheres. This freezes the intermediate decomposition products of hemicellulose, cellulose and lignin. Thus, the liquid contains many reactive species, contributing to its unusual attributes.

Pyrolysis oil is composed of a complex mixture of oxygenated hydrocarbons with an appreciable proportion of water from the original moisture and reaction product. The amount of water depends on how the pyrolysis oil is produced, but it is typically in the range of 20- 30 wt- %. Solid char may also be present. Pyrolysis oil can be considered a micro-emulsion in which the continuous phases is an aqueous solution of hemicellulose decomposition products that stabilizes the discontinuous phase of pyrolytic lignin macro-molecules through mechanisms such as hydrogen bonding. Some important characteristics of this liquid are summarized in the table below:

Analysis	Bio-oil
C, dry (wt%)	50 – 60
H, dry (wt%)	6 – 7
O, dry (wt%)	35 – 40
Nitrogen (wt%)	< 0.4
Sulfur (wt%) Water (wt%)	< 0.05 20 to 30
Solids (wt%)	0.01 to 0.1
Ash (wt%)	0.01 to 0.2
Stability	Unstable
Viscosity @40C	15 – 35
Density @15C	1.10 – 1.30
Flash point (°C)	40 – 110*
Pour point (°C)	-9 to -36
LHV (MJ/kg)	13 – 18
pH	2 – 3
Boiling Range	Decomposes

Biomass pyrolysis oil contains several hundred different chemicals in widely varying proportions, ranging from formaldehyde and acetic acid to complex high molecular weight phenol, anhydro-sugars and other oligosaccharides. The liquid has a distinctive odour- an acrid, smoky smell, which can irritate the eyes if exposed for a prolonged period to the liquids. The cause of this smell is the low molecular weight of aldehydes and acids present in the oil. The liquid is corrosive and should be handled with care, as some biomass pyrolysis oils are suspected of causing genetic defects and cancer.

As the pyrolysis oil constitutes intermediate, reactive decomposition products, it is generally not stable with time. While some bio-oils have been successfully stored for several years in normal storage conditions, they change slowly with time; most noticeably, viscosity gradually increases. Condensation reactions of the reactive components cause the ageing and can also lead to phase separation of the oil. Furthermore, the oil cannot be completely re-vaporized once it has been recovered from the exit gas of pyrolysis. If the liquid is heated to 100° or more, it rapidly reacts and eventually produces a solid residue of 50 wt% of the original liquid and some distillate containing volatile organic compounds and water.

Pyrolysis liquids can tolerate the addition of some water, but there is a limit to the amount of water which can be added to the liquid before phase separation occurs; in other words, the liquid cannot be dissolved in water. It is mostly miscible with polar solvents such as methanol, acetone, etc., but immiscible with petroleum oils.

The density of the liquid is very high at around 1.2g/ml compared to the light fuel oil at around 0.85g/ml. this means that the liquid has about 42% of the energy content of fuel oil on a weight basis but 61% on a volumetric basis. This has implications for the design and specification of equipment, such as pumps and atomizers in boilers and engines.

2.2 Manufacturing process

- Coconut shell collected from various sources is dried for two days and then crushed using a Jaw crusher.
- Broken coconut shell is then passed through a roll crusher and a ball mill to produce fine particles.
- An earthen/ steel feed is fed with coconut shell powder and kept on an electric furnace at 610°C.
- The fumes that rise from the furnace pass through a tube surrounded by a coolant (ice water), which cools the fumes and results in the collection of oil droplets in a beaker.

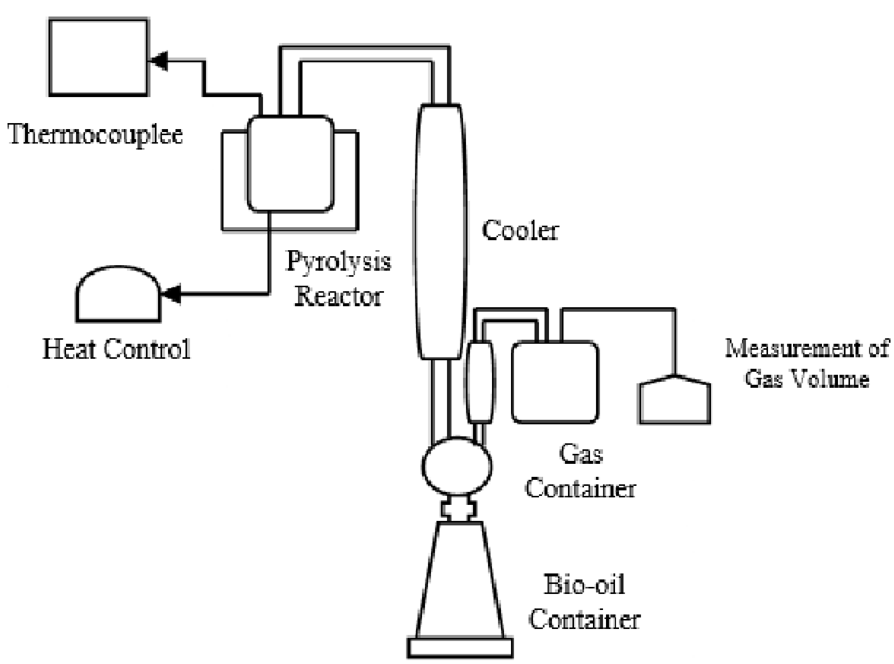


Figure: Schematic representation of methods of bio-oil production setup

Yield: 1 kg of coconut shell powder can yield up to 600 ml of Bio-oil.

2.3 Purification of bio-oil

Distillation of crude bio-oil should be done at 80°C and 120 °C for purification.

The remnant coconut shell charcoal could be used as raw material for the production of activated carbon and activated charcoal.

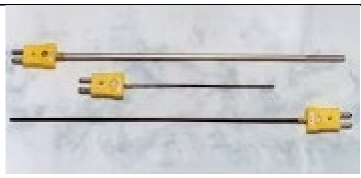
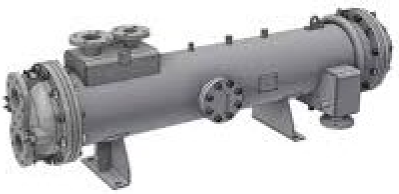
The remnant is ground and sieved until 200 mesh of particle size was obtained. Next, the sample in powder form is washed with 40% hydrofluoric (HF) to remove the impurity compound of the sample.

The sample is cleaned using a hotplate stirrer by adjusting the sample ratio, and HF was 1:3 and heated at 45˚C for 3 h. The sample should then be washed with deionized water until the pH value of the solutions is between 6 and 7 and dried in an oven at 110 °C for 12 h.

2.4 Synthesis and activation of activated carbon

The remnant product in the pyrolysis plant is activated by using sodium hydroxide (NaOH), zinc chloride ($ZnCl_2$), and phosphoric acid (H_3PO_4) activating agents with a ratio between sample and activator of 1:4 and heated at 85˚C for 2 h, then drying it at 130˚C for 3 h. After activating, the sample is then washed with 1 M hydrochloric acid (HCl) and deionized water until pH 7 is obtained, then dried in an oven at 110˚C for 12 h.

2.5 Equipment list and cost

Instrument name	Cost (in Rupees)	
High-temperature thermocouple probe	Rs. 5,000/-	
Pyrolysis plant	Rs. 30,00,000/-	
Steam Condenser	Rs. 1,50,000/-	
Automatic water chiller	Rs. 1,50,000/-	

Bio-oil container- Glass bottle (1Ltr)	Rs. 40/ piece	

2.6 Commercially available Pyrolysis units

Description	Cost (In Rs.)
Small skid-mounted pyrolysis plant (100kg/day)	25Lakhs-40 Lakhs
9000 kg Pyrolysis Plant with Oil Separator	~55 lakhs

2.7 Potential suppliers to India

Supplier	State/ Country
DOING Holdings Co., Ltd	China and Nigeria
Beston group	China
Niutech Environment Technology Corporation	China
Divya International	Ahmedabad, Gujarat
Pyrocrat Systems LLP	Navi Mumbai, Maharashtra
S. K. Engineers	Surat, Gujarat
Shree Balaji Engineering	Surat, Gujarat
Anjali Exim	Surat, Gujarat
Kingtiger Environmental Technology	International, with operations in India
Ecostan India Private Limited	Ludhiana, Punjab

2.8 Current Availability in India

Product	Cost	State
Aravind herbal labs- “CHIRATTAI THYLAM”-30ml	Rs. 75/-	Tamil Nadu

2.9 Cost /Day Analysis

Details	Cost
Coconut shell waste (per 100kg)	Rs. 1,100/-
Electricity consumption	Rs. 2,000/-
Heating fuel (Coal/Tire oil/LNG)	Rs. 1,500/-
Manpower (avg. 3)	Rs. 3,000/-
Total	Rs. 8,000/-

D. Ethylene Extraction from Banana Peel

1. Introduction:

Bananas are among the most produced, traded and consumed fruits globally. More than thousand varieties of bananas exist in the world, which provide vital nutrients to populations in producing and importing countries. The most traded variety is the Cavendish banana, which accounts for just under half of global production at an estimated annual production volume of 50 million tonnes. Bananas are particularly significant in some of the least developed and low-income, food-deficit countries, where they can contribute not only to household food security as a staple but also to income generation as a cash crop. The largest producers for domestic consumption are India and China.

Fruit ripening is the set of processes that occur from the later stages of growth and development until the fruit is ready to be consumed. Fruit ripening results in changes in fruit quality characteristics. The firmness of the fruit flesh typically softens, the sugar content rises, and acid levels are reduced. Aroma volatiles are released, and the true flavour of the fruit develops. The colour of fruit typically darkens, the skin and flesh soften, and the green background colour fades.

During the year 2023, the volume of bananas produced across India was estimated to be around 34.9 million metric tons. During the same period the leading producers of bananas were Tamil Nadu, Maharashtra, and Gujarat.

2. State-wise production data for banana

Sl.no	State	Production (in 1000 tonnes)	Total share (%)
1	Andhra Pradesh	5,838.88	17.99
2	Maharashtra	4,628.04	14.26
3	Gujarat	3,907.21	12.04
4	Tamil Nadu	3,895.64	12.00
5	Karnataka	3,713.79	11.44
6	Uttar Pradesh	3,391.01	10.45
7	Bihar	1,968.21	6.06
8	West Bengal	1,147.79	3.54
9	Assam	1,108.00	3.41
10	Chhattisgarh	585.52	1.80

India stands first in banana consumption, with an annual estimated consumption rate of 20.5 million tons. The banana peel makes up 35% of the fruit and is usually discarded or used as fodder for animals. The most important varieties of banana cultivated in India includes cultivars like Dwarf Cavendish, Robusta, Monthan, Poovan, Nendran, Red banana, Nyali, Safed Velchi, Basrai, Ardhapuri, Rasthali, Karpurvalli, Karthali and Grand Naine etc.

2.1 Manufacturing Process

Raw material collection

Collect the banana peel from local vendors', banana distributors, and banana chip makers. Collect the peel in dry polythene bags and transfer it in cold conditions (<20°C, and do not close the bags completely allow little ventilation to avoid dissociation of ethylene gas).

Cleaning the banana peel

Clean the collected banana peel with Luke warm water and give a bath in 5 ppm hypochlorite solution for 5 min. Wash the chlorinated peel with running water to remove the traces of hypochlorite. Once cleaned sort the peel according to colour, tenderness and freshness. Avoid using foul smelling peel.

Ethylene production

Collect all the air-dried banana peels and put them in an ethylene gas production chamber and create a vacuum by removing all the air through suction pumps fitted on the sides of the ethylene production cylinder (Note- presence of oxygen in the cylinder oxidizes ethylene gas into CO_2 and H_2O decreasing the efficiency of the ethylene production). Keep the reactor to run for about 24 hours (time can be decided based on the quality of the banana peel).

Selection and processing criteria for the raw material

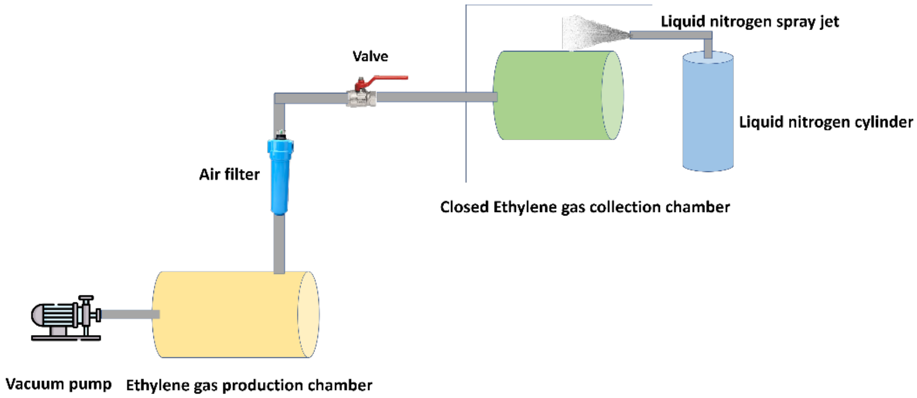
Colour/ texture	Time in reactor
Green and hard	48 hours
Green and mushy	24 hours
Yellow and bit hard	24 hours
Yellow and mushy	24 hours
Blackened	12 hours

Collection of ethylene gas

The ethylene gas produced is collected in the gas collection cylinders due to a negative pressure gradient. Fit the ethylene chamber in a cold chamber to condense the ethylene gas produced. Store the liquified gas in a temporary storage unit.

Filling and distribution

Based on the consumer demand fill the ethylene containers accordingly (industrial scale or small-scale distribution). Store it in in cool and dark environment if required.



General working flow for ethylene gas production plant

3. Capital investment for the plant

Sl. No	Requirement	Quantity	Cost	Distributors
1	Hypochlorite solution	Depend on requirement	16 Rs/L	Chemtex Speciality Limited
2	Single stage 3 Phase Vacuum Pump	1	₹ 25,000/ Piece	Alpha Vacuum Technology
3	Cast Carbon Steel Gate Valve	1	₹ 750/ Piece	Torrential Agro Products Pvt Ltd
4	Industrial Vacuum Tank, 1000 L	1	₹ 45,000/ Piece	Alisha Pneumatics India Private Limited
5	Plastic crates	50	₹ 600/ Piece	Sunshine Plasma Crafts
6	Customized 3meter diameter welded cylinders	2	₹ 1,00,000/piece	Axetronic Industries LLP
7	Stainless Steel Dura Cylinders for Liquid Nitrogen,	1	₹ 50,000/ Piece	Abhijit Enterprises
8	Stainless Steel Empty Gas Cylinder, 47 L, 50 KG	10 (storage)	₹ 15,000/ Piece	Mars Gas Company

3.1 Ethylene yield and revenue (Domestic market)

1 kg of banana peel puts out 0.5 ethylene gas per second, and would take 23 minutes to fill 1 L container.

1 tonne will yield 1000 L liquified ethylene gas at an estimated time period of 23 min. if a company process 10 tonnes of banana peel it will yield 10,000 L ethylene gas. The estimated price for 1 L ethylene container 300 Rs.

The per day revenue will be 3,00,000 Rs. Which can be increased with increased raw material processing.

The marginal profit vary according to the approach (small or large scale industry)

3.2 Export value (international market)

Currently the ethylene gas is exported to Bangladesh, Nepal, United Kingdom, Ethiopia and Tanzania. It can be extended to some other countries to fetch higher revenue.

3.3 Expenses

- Buying equipment- 6 lakhs to set up the ethylene production plant (one-time investment)
- Servicing charges (annual)- 2 lakhs
- Labour expenses (annual)- 18 lakhs
- Raw material procuring (per day) – 10 Rs/ kg, i.e. 10,000 per 1 tonne
- Distribution- 20,000 Rs per day
- Miscellaneous (packing materials and for liquid nitrogen)- 25,000Rs per day
- Per day profit (considering all the produced materials are sold out)- 1lakhs (for large scale industry) and 25,000-50,000 for small scale industries

3.4 Applications

- Fetch high international market with organic name tag
- Can be used for any of the fruits since ethylene can trigger ripening process regardless of the host
- Many of the requirements for setting up the plant are coming under long term investment sector so from the second year the profit margin will be high
- Requires less manpower