IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 9, Issue 1, February- March, 2021
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

VALORIZATION OF JACKFRUIT SEEDS AND PEELS USING A BIOREFINERY APPROACH

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ABSTRACT:
Today, the rate of consumption of energy and other basic amenities like food, water, clothing, building materials, etc. is staggering. Most of the energy sources and other resources are obtained from the oil refining industry. But oil is an exhaustible source and is bound to run out in a few decades. In order to sustain the ever-increasing demand of energy and other resources, it has become imperative to search for and make use of non-conventional and sustainable sources of energy. One potential and promising source of non-conventional, sustainable form of energy is biomass.

Waste fruit peels from the food processing industries pose an eminent problem in terms of solid waste management. Conventionally, the waste generated by food processing is disposed of either by incineration or land-filling. Both of these processes are harmful to the environment and not at all lucrative. The process of bioremediating waste biomass like waste fruit peels to produce a wide spectrum of economically profitable products that can be sold commercially is known as biorefining. Jackfruit is a very important tropical fruit. It is known for its delicious golden bulbs which can be eaten when ripe or processed into juices and chips.

According to scientific reports on an average every Jackfruit contains around 59% peels and 15% seeds. The present work deals with the valorization of the waste fruit peels and seeds by developing a zero waste biorefinery. The proposed biorefinery will generate various value-added products such as pectin, industrially important chemicals (organic acids, enzymes, etc.), starch, surfactants, adsorbents as well as many clean fuels such as ethanol, biodiesel, biogas and hydrogen. All of the aforementioned products will be generated using green and environmentally benign processes. It also outlines the numerous potential uses of Jackfruit peels and seeds. This work also aims at critically reviewing the laboratory scale procedures and attempts to fill in the gaps to scale up the processes for industrial use.

KEYWORDS: *Jackfruit peels and seeds, biorefinery, pectin, clean fuel, green chemistry and engineering, reuse and recycle, borderless chemical engineering, etc.*

1. INTRODUCTION

Jackfruit (Artocarpus heterophyllus), locally known as nangka, is a tropical plant species belonging to the family Moraceae and order of Rosales. Jackfruit is the largest tree-borne fruit in the world, typically ranging from round-cylindrical to pear-shaped, 60–90 cm in length and 25–50 cm in diameter. The trees thrive well under warm and humid climate, ideally in the temperature range from 25 to 30 C, with a height from 15 to 20 m. The leaves are oblong or elliptic in shape, with a length of 10–15 cm and dark green in color. A mature tree produces 700 fruits annually, with each fruit weighing about 23–50 kg (Ghosh et al., 2000). Jackfruit tree is a multi-purpose plant with a variety of applications. Apart from the use as table fruit, jackfruit is popular in several culinary preparations as cooking dishes, pickles, chutney, jam, jelly, cakes, chips, paste, and available as the ingredients of ice cream, candies, desserts and beverages. The seeds can be eaten boiled, roasted, salted as table nuts, or blended with wheat flour for baking. (Foo et al., 2012).

According to the National Horticulture Board, India produced 1.8 MT of Jackfruit in 2016-17. Considering that nearly 74% of this amount is discarded as food processing waste, our nation is facing a grave problem in terms of solid waste management. Methane generated from the uncontrolled decomposition of such waste is the leading cause of global warming. Waste on such a huge level cannot be incinerated without emissions either. Fruit peels are powerhouses of many important chemicals, which need to be harnessed properly.

A biorefinery, is a well-organized system of valorizing such waste substances from the food processing industry and converting them to commercially viable and profitable products. The current study will deal with the valorization of waste Jackfruit Peels and Seeds in detail.

2. PROPOSED BIOREFINERY

First, we consider the biorefinery based on Jackfruit Seeds. Around 15% of the Jackfruit's mass is constituted of its seeds. These seeds are rich in polysaccharides and starch that can be processed into quite a few products. In this study, we begin with the microwave-assisted extraction of oil from these seeds using Methanol as a solvent. The purified oil is further used for Biodiesel production and the raffinate of extraction is further sent for thorough washing followed by drying to reduce its moisture content to 15% and grinding. This well ground powder is then used for further processing. Some part of this powder is sent to the Starch manufacturing unit, where it is soaked in $NaHSO_3$ and it is first hydrolyzed in order to saccharify the polysaccharides into simple reducing sugar which can be consumed by microbes to yield the desired products. After hydrolysis, the feed is again divided into 3 main streams: Bioethanol production, Lactic Acid production and Biosurfactant production. Bioethanol is obtained by the fermentation of the substrate using *Saccharomyces cerevisiae* (baker's yeast). The yield and quantity can be seen in the table that follows. In Lactic Acid production a special strain of *Streptococcus equinus* is used along with some amount of Methanol to boost the yield. This sums up the process flow for Jackfruit seed based Biorefinery.

Next, we have a biorefinery based on the peels of Jackfruit. The initial pretreatment steps remain the same. The treated stream is divided into 2 separate streams. The first stream enters the Pectin extraction unit where water is used as a solvent. This extraction process is microwave assisted and thus gets completed in a lesser processing time reducing energy consumption and preventing the thermal degradation of pectin that takes place through the conventional method. It is also reported that the use of microwaves alters the cellular structure of the substrate and enhances its reactivity with other reactants. The depectinized mass is sent to the hydrolysis unit, where it undergoes hydrolysis. The hydrolysate goes to Bioethanol production unit. As in the case of Jackfruit Seeds, *S. cerevisiae* is used for the fermentation. It is used due to its higher tolerance to alcohol and sugar concentration. The fermentation broth is filtered (centrifugal vacuum filter) and distilled to obtain ethanol with 99% purity. The residue of the filter is sent to Anaerobic Digestion unit, where it undergoes fermentation for second time.

The microbial colony for this digestion is isolated from cow dung through multiple heat treatments and pH adjustments. The products gas from this process consists of biohydrogen with undetectable amounts of methane and a few other benign volatile compounds. This process is chosen over conventional biogas production, because methane is a leading cause for Global Warming, whereas Hydrogen is a clean fuel. The product of hydrogen consumption is water.

The effluent from the water blanching step of the Jackfruit peels can be studied, characterized and can be used to produce a wide range of antioxidants, bactericide, fungicide, etc. since the peels of Jackfruit possess many different compounds like, alkaloids, saponins, tannins, phenols and flavonoids to name a few.

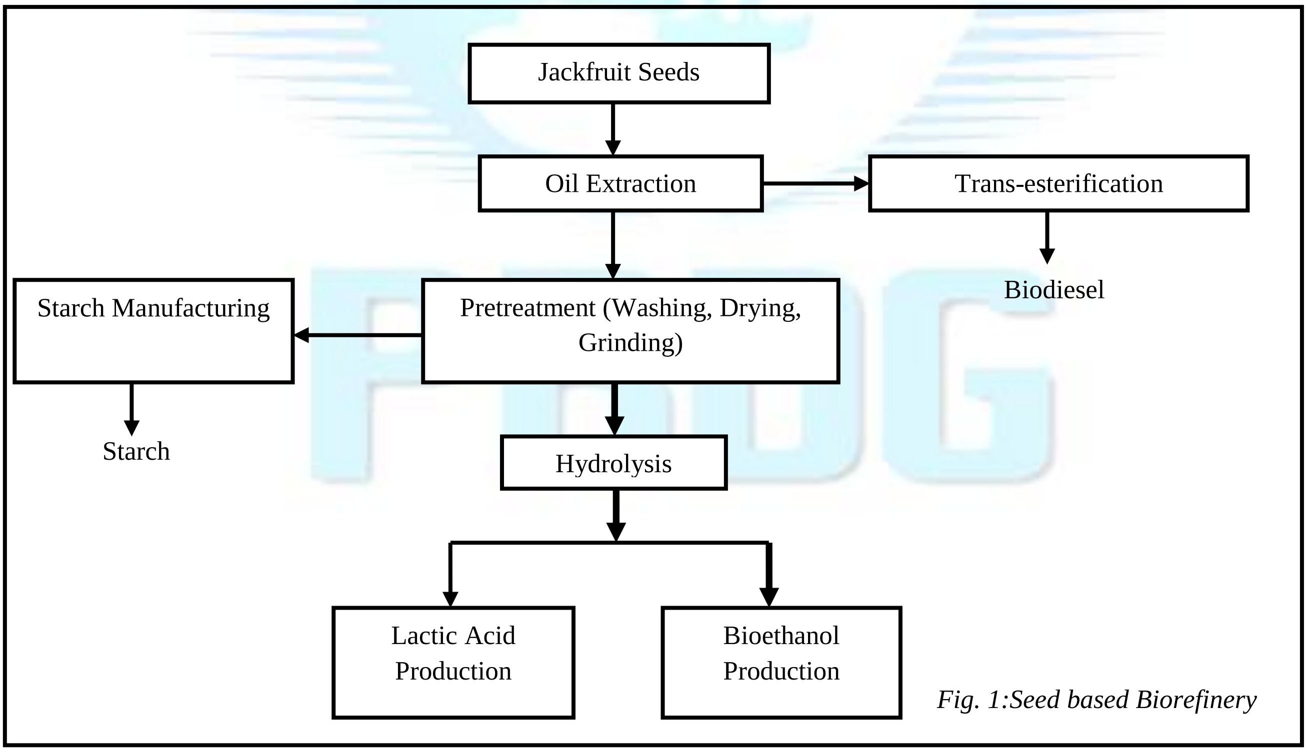

Fig. 1:Seed based Biorefinery

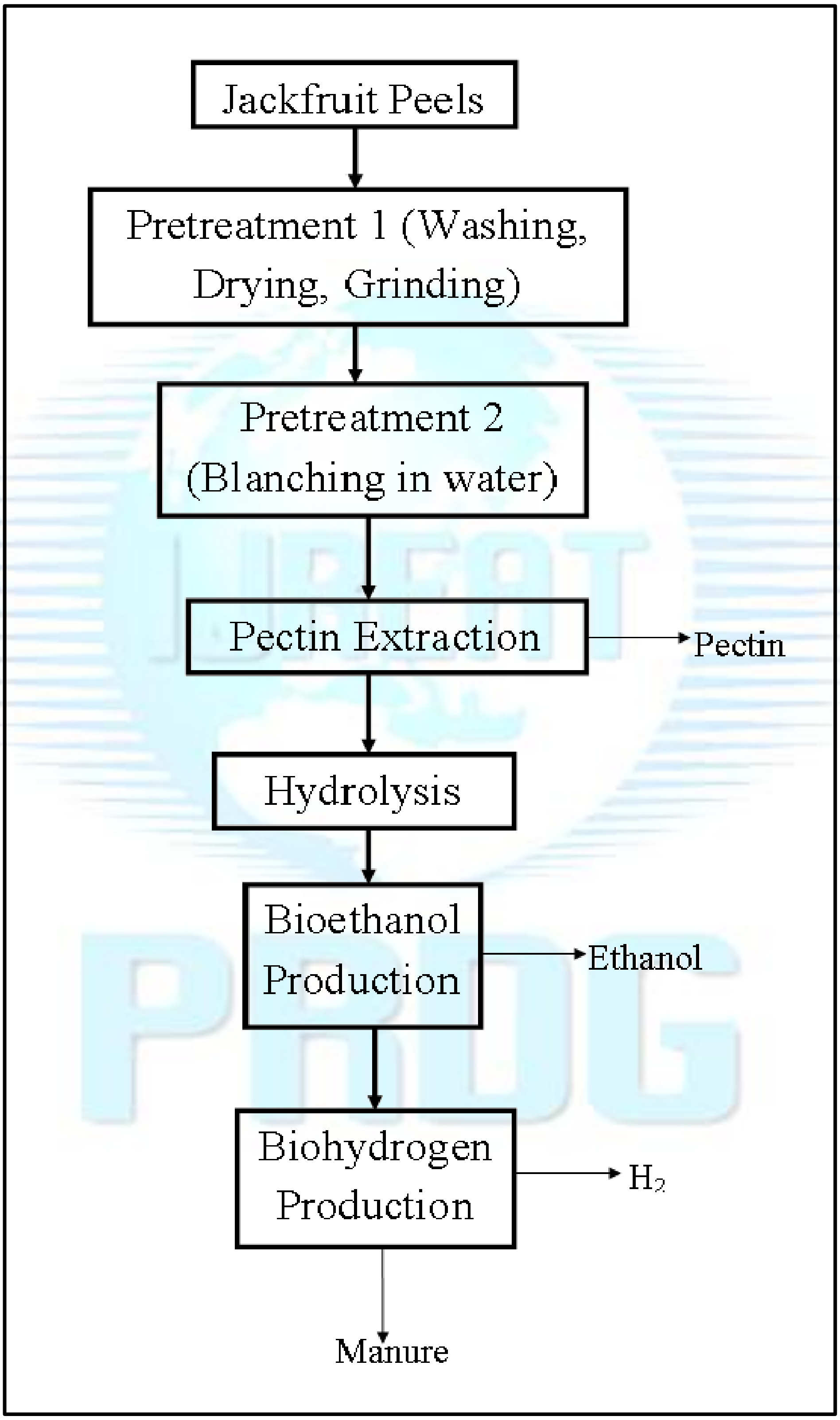

Fig. 2: Peel based Biorefinery

3. PRELIMINARY MASS BALANCE AND RAW MATERIAL-PRODUCT TRADE OFF CALCULATION

A preliminary raw material v/s product cost and selling price profitability analysis has been carried out hypothetically. One of the major costs in Biochemical processes which render them too expensive for commercialization is the cost of the substrate. With the use of readily and cheaply available Jackfruit Seeds and Peels as the substrate for fermentation and other biological transformations, we are cutting down on this major expense, thereby, making our process economically viable. Since, Jackfruit Seeds and Peels are inherently nutritious, we save a lot of money in terms of expensive nutrition media too. Plenty of other options are available in the market for synthesizing the biorefinery, but the aforementioned methods have been chosen due to the abundance of relevant data available in literature and profitable outcome obtained. A table summarizing the Mass Balance and Cost Estimation Calculations has been included below.

According to the calculations, it can be seen that, a profit of nearly 2 Cr INR per Jackfruit season can be obtained from this biorefinery, on the basis of 1T of Jackfruit per cycle. These calculations have been made without factoring in the operation costs, but with a little more study, these details can be worked out too.

Table 1: Preliminary Mass and Cost Balance Calculation Summary Table

Product	Yield	Qty of Products (based on 1 Ton J.F)	Cost of Products (in INR)	Raw Materials	Cost of Raw Materials	By Products	Cost of By Products (in INR)	Total Revenue
Biodiesel	92%	41.81818182	2509.090909	Methanol, NaOH	4387.59036	Crude Glycerol	5424.107143	3545.607691
Starch	14%	21	1008	NaHSO3	840	-	0	168
Lactic Acid	54.50%	44.71725	7691.367	LAB Culture	3577.38	-	0	4113.987
Ethanol	11%	8.227438469	205685.9617	Yeast Culture	8205	-	0	197480.9617
Total			216894.4196		17009.9704			205308.5564
				Peels				
Pectin	17.63%	104.017	124820.4	Ethanol	6836.82771	-		117983.5723
Ethanol	87.60%	471.1394713	117784.8678	Yeast Culture	32273	-		85511.86782
Hydrogen	72%	21240	1274400	Cow Dung Microflora	3872.76	-		1270527.24
Total			1517005.268		42982.5877			1474022.68
							Total of both	1679331.237
							INR per year	20991640.46

4. RESULTS AND DISCUSSION:

There are a lot of other products that can be produced in a similar manner. Some of them are industrially important enzymes (like amylase, pectinase, cellulose, etc.), pigments to naturally dye fabrics, etc., polyhydroxyalkanoates (as alternatives to PET, PC and PE). The effluent from starch manufacturing stream can be used as a substrate for hydrogen production too. The lignin-based residue from most of the fermentation broths can be gasified with steam to produce Syn-Gas. We are currently following separate hydrolysis and fermentation method, instead a simultaneous saccharification and fermentation process, wherein the hydrolysis and fermentation occur within the same vessel can be followed. This method has been proven to give better yields due to the instant availability of glucose for the fermenting species. Also, the presence of ethanol in the process vessel keeps the unit sterilized for a longer duration. Due to lack of availability of data on this method for the current study, separate hydrolysis and fermentation were chosen. The hydrolysis step releases pentose sugars as well, which can be processed to platform chemicals like Furan, Hydroxymethylfuran or other derivatives of Furan. Those sugars can also be converted to Xylitol by the use of specific bacteria or to ethanol via co-fermentation using a colony of symbiotic bacteria. Supercritical fluid extraction can also be employed at the extraction steps to limit the use of harmful solvents and to get better yields. Apart from these, the various gases generated in this process (including the Syn-Gas) can be used to generate electricity using turbines and turbine generators.

The present study focuses on use of Jackfruit Peels and Seeds as a viable substrate for fermentation processes. Inclusion of data about the cell growth and production and its impact on the process parameters is another important factor in which more research needs to be done. The calculations here were carried out based on experimental results obtained by different works cited in the bibliography. The calculations follow a conservative approach and predict the costs for a hypothetical biorefinery. They do not include operation costs or transportation costs. Despite these limitations, the study proves to be feasible and adheres to the principles of green and sustainable chemistry.

5. CONCLUSION:

The current study shows a very promising process as an extension of a Jackfruit processing plant. Waste that was being disposed of uneconomically can be valorized to achieve profits through this study. Due to the unavailability of relevant data a lot of assumptions had to be made. Studies and research in this field need to be undertaken to generate standard data which can be used to make a detailed process flow diagram and cost estimates. As is evident from the preliminary Mass Balance Calculations and Product Raw Material Profitability Trade-off, the process is profitable and is bound to yield better results. The processes used are environmentally benign and an attempt has been made to make the process a zero-waste unit. Such biorefineries hold a lot of potential in countries like India, where almost 1,740 tonnes of Jackfruits are produced annually out of which 74% (w/w) is discarded as waste. This can offer a permanent to solution to the fuel crisis that India is currently facing due to fluctuations at the global level and make it Energy Independent. This initiative is the best example of the 'Make in India' initiative.

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