

# Valorization of Rice Husk Cellulose for Bioplastic formulation – Processing, properties, and applications

Dhivya Gomathi.M<sup>1</sup>, Sangeetha Baskaran<sup>1\*</sup>

<sup>1</sup>Department of Biotechnology, St. Joseph's College of Engineering, Chennai, Tamil Nadu, India.

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## ABSTRACT:

The increasing environmental issues that come with traditional petroleum-based plastics have led to the pursuit of a sustainable and biodegradable alternative to plastics. Among the various renewable resources available, agricultural residues have gained increasing attention for the development of eco-friendly materials. Rice husk is produced as waste from milling, in the major rice-producing countries like India, China, Vietnam, Japan, Thailand, and Myanmar, is a potential lignocellulosic resource. It mainly consists of cellulose, hemicellulose, lignin, and significant levels of silica, which makes its use not only valuable but also complex. This review offers a comprehensive analysis of rice husk as a potential cellulose source for bioplastic production. It discusses about the structural characteristics of rice husk along with various pretreatment and cellulose extraction technologies reported in recent studies. The preparation of cellulose-based bioplastic films using suitable plasticizers and binders is also discussed. The study also focuses at how different processing conditions influence the mechanical, thermal, and functional properties of the developed materials. Also, the existing issues, such as silica removal, structural compatibility, and scalability are discussed. Future perspectives are highlighted to support further advancement and practical application of rice husk cellulose-based bioplastics.

**KEYWORDS:** Rice husk valorisation, Lignocellulose, Bio plastics, Alkali delignification, Acid hydrolysis, Nanocellulose reinforcement, Biodegradability, Mechanical properties, Sustainable packaging, Circular bioeconomy.

## I. INTRODUCTION

The intensive production and the use of petroleum-based plastics have exposed the environment to severe outcomes, such as lasting landfills, contamination of soils, and pollution of oceans. The traditional plastic is appealing in market because of their robustness, and thus they end up accumulating in the environment and pose

significant global challenges. These challenges have increased the quest to find biodegradable and sustainable alternatives that could reduce the negative effect on the environment without compromising functionality in packaging and other uses. The materials that have come up in this shift towards sustainability are bioplastics. Bioplastics are plastics that are produced using renewable biological substances such as cellulose, protein and starch. The advantage is that they are biodegradable under the certain condition [8].

Cellulose has proved to be the best biopolymer in terms of its availability, renewability, biocompatibility, mechanical strength, and structural versatility. Being the most common natural polymer on the planet, cellulose provides a great foundation point for the creation of sustainable polymeric materials [22]. Almost half of the world's population relies on rice as a diet, and with increased production, large volumes of agricultural waste are generated. Rice husk is a widely produced leftover from the rice milling process, and it typically accounts for about one-fifth of the crop's total weight. Rice husk contains cellulose, hemicellulose, lignin, and large amount of silica, which are the main structural parts of rice husk. Even though processing may be difficult because of its high silica content, rice husk still remains a potential raw material in bioplastics development owing to the large content of cellulose [2].

Rice husk has been underutilized in the past, often burned or utilized in low value products, which is a factor in resource wastage and environmental pollution. However, the increased attention to the issue of circular bioeconomy strategies has also led to its transformation into more useful products, including bioplastic films and biodegradable composites. The conversion of the rice husk into cellulose-based bioplastic offers an opportunity to convert agricultural waste into a valuable, environmentally friendly substance besides offering a sustainable alternative to the synthetic polymers [5]. This review thus provides the overall description of rice husk composition,

the methods of cellulose extraction, steps involved in film fabrication using suitable plasticizers and binders, the influence of the processing conditions on the physical, mechanical, thermal and functional properties of the developed materials, challenges and sustainability concerns related to it. This synthesis of existing literature will help to outline the value of rice husk cellulose as the available resource with the potential to improve the development of sustainable materials.

## II. COMPOSITION OF RICE HUSK

Rice husk, a leftover from rice milling, which is a valuable source of lignocellulosic biomass. It constitutes the hard outer covering of the rice grain and consists of two components the lemma and palea which are removed during the milling. About one fifth of the total weight of the harvested rice is covered by rice husk. It is abrasive, hard, water insoluble because of its structure [2].

Silica covers the outer surface and forms a thick layer of protection with fine hairs and traces of silica are in internal epidermis. Rice husk chemically consists of approximately 50% cellulose, 25%-30% lignin, 15-20% silica and 10-15% moisture. It is also characterized by low bulk density, typically ranging between 90-150 kg/m<sup>3</sup> meaning it is not easy to process or handle. Research indicates that rice husk has approximately 80% of organic material and 20% of ash [1,4]. The ash consists mostly of amorphous silica, with trace quantities of alkali oxides, alkaline earth metals, aluminium, and iron. These inorganic elements may differ significantly based on the place of rice cultivation, the soil, climate, and fertilizers or manures used. Consequently, environmental, and agricultural factors do contribute to the chemical composition of rice husk [1]. Rice husk is rich in cellulose. Cellulose is a natural polymer, which has found application in bio-based products like cosmetics, pharmaceuticals, and biomedical products because of its renewability, biodegradability, and environmental friendliness. It is made up of glucose units that are connected through the 2-1,4-glycosidic bonds and demonstrates characteristics like thermal, crystallinity and biocompatibility. Rice husks have been investigated as a source of cellulose to make cellulose nanoparticles, nanocrystals and cellulose derivatives which are applied in drug delivery systems, biomedical and other advanced materials [22].

## III. EXTRACTION AND PRETREATMENT OF RICE HUSK CELLULOSE

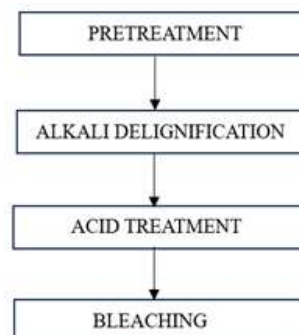


Figure 1: Extraction of cellulose from rice husk

### 3.1. Pretreatment

Rice Husk was obtained from the mills, rinsed with distilled water and left to dry in the sunlight. Then they were ground and sieved with the required mesh size [7,14,16].

### 3.2. Alkali delignification

The sieved rice husk powder was treated with the alkali for the delignification. The most used alkali for this treatment includes NaOH and KOH. The mixture was heated under the optimum temperature and time in the magnetic stirrer. Then sample was rinsed with distilled water multiple times to attain a neutral pH. Then dried in hot air oven for further treatment. This treatment removes some amount of lignin, hemicellulose, pectin, and waxes. The silica present in the rice husk gets converted to sodium silicate and removed with the solution [4,14,17].

### 3.3. Acid hydrolysis

Acid hydrolysis was performed using the mild amount of H<sub>2</sub>SO<sub>4</sub> or HCL after the alkali delignification; this improves the purity of cellulose. It affects the amorphous region of the cellulose fibre and increases the crystallinity of cellulose. The hemicellulose and silica also gets removed when treated with strong acids [4, 12].

### 3.4. Bleaching

Bleaching is performed to remove the chromophore. Sodium hypochlorite along with acetic acid or hydrogen peroxide is used for bleaching the rice husk cellulose. This removes the residual lignin and gives whitish colour to the component. The yellowish colour after bleaching indicates there is still lignin left behind in the sample [9,12,25]. Figure 1 illustrates the steps

involved in the extraction of cellulose from rice husk.

#### IV. DEVELOPMENT OF RICE HUSK CELLULOSE-BASED BIOPLASTICS

The development of cellulose bioplastics entails a mix of both conventional and novel processing methods to suit the intended structural, mechanical, and functional qualities of the final product. Solution casting is one of the common techniques of laboratory-scale manufacture, making it easier to spread cellulose or its derivatives with a uniform distribution of plasticizers and other additives, producing uniform thin films. To maximize performances of the films, more sophisticated procedures like layer-by-layer (LBL) assembly are used, in which alternated use of oppositely charged polymers creates a multi-layered structure with better barrier, mechanical, and functional properties. Extrusion on the other hand is normally used in mass production where it can offer a continuous and low-cost method to fabricate films and sheets of accurate thickness and form [15].

Further, cellulose-based coating systems are typically deposited onto substances by surface coating techniques such as dipping and spraying, allowing them to be endowed with characteristics of antimicrobial properties, waterproof performance, as well as controlled levels of gas permeability. Electrospinning processes and spray drying are new methods of fabrication that help expand the possibilities of cellulose-based bioplastics since they allow the production of micro and nano-structured materials with enhanced surface area and functionality. Also, the processes of hydrogel development and encapsulation are increasingly explored to incorporate bioactive substances into the structures of cellulose to be able to realize controlled release and greater efficacy in active package applications [15].

Rice husk cellulose is also receiving attention as a renewable resource for manufacturing biodegradable plastics. Since rice husk is an abundant agricultural by product containing a large amount of lignocellulose provides an inexpensive

source of cellulose to produce eco-friendly bioplastic films. Rice husk cellulose can be added to polymer mixtures to improve their strength, stability, and biodegradability. Rice husk cellulose-based bioplastics are made using several different techniques, including solution casting, compression molding, and melt bending. Solution casting is especially prevalent in laboratories. In this procedure polymer like starch, polyvinyl alcohol (PVA), polylactic acid (PLA) or chitosan are dissolved in water or other solvents and stirred in heat. Rice husk cellulose is then added to the polymer solution through stirring, homogenization, or ultrasonication to ensure even distribution. The blend is poured onto glass or Teflon plates and dried to form thin films [7,12,14]. To make the films less brittle and more flexible, plasticizers like glycerol or sorbitol are usually added [13,23]. Some formulations contain additives such as titanium dioxide ( $\text{TiO}_2$ ), zinc oxide (ZnO) to enhance strength, ultraviolet radiation resistance, and durability. The completed films are tested for characteristics such as tensile strength, thermal stability, water resistance, and biodegradability to determine their suitability for sustainable packaging or medical use [9,10].

Besides being directly incorporated into polymer matrices cellulose derived out of rice husk also can be modified to form value added products like cellulose acetate and carboxymethyl cellulose. These derivatives have better solubility, film forming capacities and compatibility with polymer matrices which makes them find their way in biodegradable films, coatings, and sustainable packaging materials. In addition, rice husk cellulose may be transformed into nanocellulose that has better mechanical strength, surface area, and barrier property, which can increase the overall performance of bioplastic composites. Using rice husk cellulose in bio plastics not only boosts the material's performance but also transforms agricultural waste into useful and environmentally friendly products [12,15]. The methods of preparation of cellulose derivatives and their properties shown in this table 1

**Table 1: Methods of preparation of cellulose derivatives and their properties**

S. No.	Cellulose derivatives	Methods of preparation	Properties	References
1.	Carboxymethyl cellulose (CMC)	Macerization and etherification	Increases mechanical strength, compatibility, biodegradability, water polymer solubility.	[4]
2.	Cellulose acetate (CA)	Cellulose acetylation	Improved solubility, better film formation, enhanced thermoplastic properties, and film production	[15,22]
3.	Nanocellulose	Acid hydrolysis	Good reinforcement in polymers, large surface area, high mechanical strength, improved barrier properties.	[13]
4.	Cellulose nitrate	Nitration	Gives high strength and flexibility.	[15,22]
5.	Cellulose sulfate	Sulfation	Uniformity, improved mechanical, and barrier properties.	[15,22]

## V. PROPERTIES OF RICE HUSK CELLULOSE BIOPLASTICS

### 5.1. Physical properties

The physical properties such as the thickness, density, transparency, and moisture content affect the quality of the film. Mostly in cellulose bioplastics the addition of cellulose has shown increase in the thickness and reduced the transparency of the film. In case of the nanocellulose, the dispersion was good and showed very slight increase in the thickness compared to normal bioplastic films. Addition of rice husk cellulose as bio filler was effective against the water absorption of film because of its hydrophobic nature. The cellulose reinforced plastics showed less moisture content compared to the pure one. For example the addition of the cellulose to PVA film showed increase in the thickness and density compared to the pure PVA films. The lower transparency of these bioplastics makes them suitable for packaging and protects it from the ultraviolet radiation [7,12,14].

### 5.2. Mechanical properties

#### 5.2.1. Tensile strength

Tensile strength refers to the highest stress a material can endure before fracture. Tensile strength has a great influence on the mechanical property of the bioplastic films. Generally, the incorporation of cellulose mass into the bioplastics

increases the tensile strength and reduces flexibility. In the reported study, the bioplastics prepared with the varying cellulose mass in chitosan sorbitol solution demonstrated a significant increase in tensile strength with increased cellulose mass. It increased from 0.3974 N/mm<sup>2</sup> to 2.0804 N/mm<sup>2</sup> as cellulose mass varied from 0.2g to 1g [11,12,14].

#### 5.2.2. Elastic modulus

Elastic modulus affects the stiffness of the material. The reinforcement of fillers such as cellulose and nanocellulose increases the stiffness of the bioplastics and making them suitable for the packaging materials. Conversely, it reduces the flexibility of the film. In thermoplastic starch films, the elastic modulus increased by 100% to 200% with greater cellulose fibre reinforcement such as 5 wt% and 10 wt. Compared to the unmodified starch films the flexibility was also reduced [14].

### 5.3. Barrier properties

The barrier properties involve properties such as the water vapour permeability rate. Cellulose reinforced bio plastics generally exhibited the tendency for reduced water vapour permeability. In the research carried out by Gabriel et al the incorporation of cellulose and nanocellulose to the PVA film decreased the water vapour permeability rate. The nanocellulose

incorporation significantly reduced the water vapour permeability rate compared to the normal PVA films [12].

#### 5.4. Biodegradability

Biodegradation is a very significant characteristic of bio plastics made of cellulose, especially in solutions that are aimed at environmental sustainability, in packaging. The rate and level of degradation depend on the composition of the material and the environmental factors. In short term experiments (up to 5 days) films tend to keep their integrity but gradually begin to show such changes as discoloration, surface fissures, and softening before eventually decomposing into small pieces or a paste-like substance. There has been rapid degradation in composites that contain starch-cellulose, and complete breakdown is possible in 3 to 5 days depending on the additives used. Conversely, soil burial tests have shown a slower degradation process. Pure polymer matrices like PVA usually degrade faster but cellulose, in particular, nanocellulose, increases structural integrity and extends the degradation process. Cellulose reinforced films lose approximately 40% of the original weight in 15 days and require about 45 to 60 days to be fully degraded. The retarded degradation is largely due to the presence of strong intermolecular hydrogen bonds creating a dense structure that limits absorption of water and microbial infiltrations. In general, the reinforcement with cellulose helps to create the balance between the stability of the material and biodegradation, and such bioplastics can be used in eco-friendly applications [9,12,14].

#### VI. APPLICATION OF CELLULOSE BIO PLASTICS

Cellulose and its derivatives form important materials in the development of bioplastics, especially in the development of sustainable packaging. They are popular in making the biodegradable films and coating to resist moisture, oxygen, and microbial spoilage to preserve the quality of the product and delay the degradation of the perishable food. Besides traditional packaging, cellulose based substance facilitates active packaging systems by allowing to add antimicrobial agents and antioxidants to the packaging. This restricts the growth of the microbes and oxidative deterioration enhancing the food safety and increasing the shelf life. Edible coating that is applied directly onto food to regulate the movement of moisture, gaseous exchange, and

maintain food texture and freshness also uses cellulose derivatives, e.g. carboxymethyl cellulose. These characteristics render them appropriate to fresh and minimally processed food. Moreover, cellulose strengthens bio composites, which increases mechanical, barrier, and thermal stability. It is also applied in the encapsulation system of the controlled release of active compounds in packaging. Research indicates that cellulose derivatives blend with starch and plasticizers can be used to create biodegradable films, and they are useful in food preservation including prolonging the shelf life of tomatoes. In general, bioplastics made of cellulose is a very promising and eco-friendly solution to functional package materials [4,15, 26].

#### VII. CONCLUSION

Cellulosic bioplastics produced using agro-industrial waste material such as rice husk are a sustainable and environmentally friendly alternative to traditional petroleum-based plastics. Along with the waste management concerns, the effective utilization of such biomass also contributes to the production of value-added products that correspond to the notion of the circular economy. The reviewed studies show that cellulose and its derivatives can significantly enhance the mechanical strength, barrier properties, and functional performance of bioplastic systems in terms of their addition. They also possess excellent film-forming ability. Their application in the active and biodegradable food packaging shows their ability to maintain the quality of products and increase their shelf life [22,26]. However, a number of obstacles prevent them from being widely commercialized. Chemical-intensive procedures are frequently needed for cellulose processing, especially at the nanoscale, which could rise costs and have an adverse effect on the environment. Their performance is further impacted by problems with hydrophilicity, brittleness, and inadequate long-term stability. Scaling up production methods and attaining uniform reinforcement distribution continue to be major obstacles [9, 12, 26]. Future work should focus on making the extraction and production processes simpler, more cost-effective, and environmentally friendly. At the same time, improving the performance of these materials through blending, surface modification, and the use of nanocomposites will be important. More attention should also be given to advanced applications like active and intelligent packaging, especially systems that can release functional

compounds in a controlled manner. In addition, better collaboration between researchers, industries, and policymakers, along with proper support and regulations, will be necessary to enable large-scale production. Overall, cellulose-based bioplastics have strong potential to support sustainable material development and reduce environmental impact in the future [15,22].

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