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Valorisation of Paddy Straw into Biodegradable Packaging Film

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Nowadays, the alternative to plastic packages is in demand due to their non biodegradability. They also cause pollution and harmful effects to the environment. Extensive efforts have been made recently to replace plastics with biodegradable materials. The packaging films are in trend but, often they had been manufactured using synthetic polymers. There is a need for natural polymers like chitosan, starch, gelatin etc. Chitosan is usually obtained from aquatic animals, insects, fungi etc. The natural sources for starch are cereals, root crops, legumes etc and gelatin is a protein derived from collagen, which is found in the skin, bones and connective tissues of animals. Stubble burning is a major issue where the paddy straw is been burnt in the fields and used as feed for animals. They are not disposed in a proper way which causes air pollution, greenhouse gas emission and soil health degradation. There is a need to mitigate this problem by converting them into usable products. Paddy straw contains starch and cellulose in abundance in view of this they had been used for the preparation of biodegradable films.

Extraction of starch from paddy straw

Starch extraction from paddy straw can be achieved through various methods such as acid hydrolysis, enzymatic hydrolysis, alkaline hydrolysis and physical processes.

1. In acid hydrolysis method, paddy straw is treated with acid usually sulphuric acid or hydrochloric acid to break down the cellulosic and hemi cellulosic components, leaving behind the starch. The process involves soaking the straw in dilute acid, followed by heating to facilitate hydrolysis. Afterward, the mixture is neutralized and starch is separated from the residue.
2. Enzymatic hydrolysis utilises enzymes to break down starch into simpler sugars. Paddy straw is first ground then mixed with water and enzymes. The mixture is allowed to react under specific conditions, facilitating the hydrolysis of starch. After enzymatic treatment, starch is separated from the rest of the solids.
3. Alkaline hydrolysis involves treating paddy straw with alkaline solutions to disintegrate the structure and release starch. The process includes soaking the straw in alkaline solution followed by heating. After hydrolysis, the mixture is neutralized and starch is separated.
4. Physical processes, such as grinding and milling can be employed to disrupt the structure of paddy straw and release starch granules. These methods are often combined with other treatments such as chemical and enzymatic to enhance starch extraction efficiency.

Extraction of Cellulose from paddy straw

Cellulose extraction from paddy straw typically involves a series of steps to break down the complex structure of the straw and isolate the cellulose fibres. Paddy straw is collected and cleaned. It is then shredded into smaller pieces for the need of subsequent processing. Then delignification will be carried out and it's a process of removing lignin for the easy access of cellulose fibres. Delignification can be performed using various methods like chemical, enzymatic and oxidative treatments. Some of the delignification agents are sodium hydroxide, sodium sulphite, sodium chloride etc. After delignification, pulping need to be done to break down the structure further. Pulping can be done mechanically or chemically. The pulped material is then subjected to fractionation to separate the cellulose fibres from other components such as hemicellulose and lignin. This can be achieved through processes like filtration, centrifugation or sedimentation. Purification is done further to remove residual impurities and chemicals from the cellulose. The extracted cellulose fibres are dried and depending on the intended application, additional processing steps such as bleaching, refining or surface modification may be carried out to enhance the properties of the cellulose.

Methods for preparation of film

The various methods used for preparation of film are solution casting, extrusion, compression moulding and electrospinning Siqueira et al. (2021)

1. Solution Casting: This method includes solubilisation, casting and drying. First, the starch is gelatinised, forming a solution and some additives can be added. The casting technique consists of pouring the filmogenic solution onto plates like teflon plates, petri dishes or acrylic plates, wherein the film thickness is controlled based on the mass of the film forming solution. Then, the drying is conducted at room temperature or at a controlled temperature with drying time varying generally between 6 to 48h.
2. Extrusion: Extrusion is a continuous and dynamic process where, the material enters a fixed barrel and is conveyed until it exits the barrel, passing through a die which shapes the material The conveyance is generally made by rotating screws. The material undergoes several unit operations, such as mixing, heat exchange, melting, shear and pressure drop inside the barrel. The continuous sheet of film is formed and cooled to solidify.
3. Compression Moulding: In this method, first the biodegradable material is heated until it softens and then placed into a mould cavity. Then, pressure is applied to the mould, the material will be compressed into the desired shape. The mould is then cooled to solidify the material and to form the film 4.
4. Electrospinning: In electrospinning, a high voltage is applied to a polymer solution causing it to form a jet that is stretched and collected on a grounded substrate as nano fibres.

Fabrication of film

The starch and cellulose extracted from paddy straw using different methods is used to prepare the biodegradable film with varying fillers and polymers. Bio-nano composite film can also be prepared from starch and cellulose extracted from paddy straw with different polymers such as chitosan, poly lactic acid, gelatin etc as they provide good barrier and mechanical properties. The choice of fabrication method influences the dispersion of fillers within the polymer matrix and consequently, the properties of the resulting films. Optimization of processing parameters is essential to achieve homogeneous dispersion and maximize the reinforcement effects of fillers.

Potdar et al. (2023) prepared the biodegradable film with polyvinyl alcohol, paddy straw and starch blend as matrix. The dried and shredded paddy straw was first treated with alkali at different concentrations at 55 °C for 4 h. It was filtered and then dried. In 200 mL of water, 10% of starch (w/w basis) was added, mixed with a stirrer and heated to constant temperature of 60 °C, followed by continuous stirring for 4 hours to obtain a clear solution. The polyvinyl alcohol solution was prepared separately and it is heated as well as stirred thoroughly for 4 hours. The two solutions were then mixed in different proportions. The treated paddy straw was first ground, then dispersed in the solution containing polyvinyl alcohol and starch in different proportions with polyethylene glycol as plasticizer mixed thoroughly and cast in flat plastic trays. It undergoes drying and then sheets were peeled off, cut to size and characterized.

Freitas et al. (2021) worked on the improvement of the physical properties of the starch based films by incorporating the cellulose microfibers obtained from the paddy straw. Starch based films were prepared by melt blending and subsequent compression moulding using 30 wt% of glycerol as plasticizer with respect to the total starch mass. The cellulose microfibers were incorporated at 1, 3 and 5 wt% by melt mixing. The resultant materials were finally shaped into films by thermo compression and were characterized.

Benefits of film

The cellulose nanocrystals have gained interest primarily in the nanotechnology field due to its high mechanical strength, aspect ratio, thermal and barrier properties. They consist of highly crystalline rod like particles with a high specific area with diameters ranging from 1 to 100 nm and the length from 10-100 nm. Additionally, cellulose contains abundant hydroxyl groups on their surfaces, making them hydrophilic nanomaterial. The cellulose film production reduces dependence on synthetic polymers and contributes to sustainable resource management. Cellulose film derived from paddy straw is biodegradable in nature, which reduces environmental pollution and waste accumulation Zhang et al. (2020). They are generally considered safe for use in food packaging applications. Unlike some synthetic packaging materials, they are less likely to leach harmful chemicals into food products Qiang et al. (2019). They also have low density, good compatibility and excellent mechanical properties Freitas et al. (2021).

The paddy straw contains starch, albeit in smaller quantity so, addition of fillers to starch based films improves mechanical properties, such as tensile strength, elongation at break and puncture resistance. Fillers also enhance barrier properties by reducing water vapour permeability and oxygen transmission rate, making the films suitable for food packaging applications. Moreover, the incorporation of fillers can enhance thermal stability and provide antimicrobial properties, extending the shelf-life of packaged products Sodhi et al. (2019).

Conclusion

The increasing demand for biodegradable packaging had risen up due to the harmful effects of plastic packaging. Stubble burning had been a threat to the environment as burning of straw leads to emission of greenhouse gases which tends to cause global warming. In order to overcome this problem, paddy straw is been used to prepare biodegradable films. The cellulose and starch obtained from paddy straw has good mechanical, thermal and physical properties. Since, they had been implemented in laboratory scale their usage is limited so studies need to be carried out to expand their availability in large scale.

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