



Production of bioplastics and sustainable packaging materials from rice straw to eradicate stubble burning: A Mini-Review

Sain Mukul

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Abstract

India is the second-largest producer of rice, which plays an important role in the GDP of the nation, but the burning of rice straw is one of the most severe issues, which the country is facing. The government has tightly regulated this practice, and the farmers are usually advised to incorporate the residue in the soil, but this management option is minimal because of its slow degradation properties in the soil and may also foster rice diseases. A lot of lab-scale and commercial research studies have been conducted on rice straw-based nanocomposites, but rice straw-based bioplastic is a much superior latest technology that is not much explored. Only a few researchers have worked on making biodegradable bioplastic packaging materials from rice straw. The developed technology not only eradicates the pollution problems caused because of stubble burning but also resolves the problem of synthetic plastic packs, which is another major issue worldwide as 40% of the total plastic is used in food packaging. The current study is aimed to explore the feasibility of this agricultural residue to get converted into useful biodegradable packaging materials that can work for agroecological and sustainable development.

Key Words: *Antimicrobial, Bioplastic, Pollution, Rice Straw, Stubble Burning, Sustainable Packaging*

Introduction

India ranks second in terms of rice production all over the world, with an annual output of 117.47 MT (Bureau, 2020). Rice production plays a vital role in the economy of the country, but on the other hand, waste straw management is a huge problem resulting in environmental pollution and soil infertility. Most of the stubble burning incidents are reported in North India, among which more than 80% are found in Punjab state (Rai, 2019). The ban on field burning and providing subsidies for purchasing straw management equipment are still unsuccessful to take off expectedly as the management of straw is a very tough task because of its slow degradation properties. Waste straw incorporation in the soil, although enhances the soil nutrients for the next crop but also promotes crop diseases (Hrynychuk, 1998). Farmers practice field burning, as this is a fast and economical method that also removes disease organisms but produces a massive amount of greenhouse gas (GHG) emission. The field burning results in a generous

amount of SO₂ and NO_x emissions contributing to 3.3 kg of SO₂ eq./ton straw resulting in chronic respiratory conditions and air pollution (Gadde *et al.*, 2009; Sain, 2019). Synthetic plastic, which is used for a wide range of applications, is a grave global issue because of environmental pollution and major health hazards for humans as well as other living beings (Bilo *et al.*, 2018). Even then, plastic production has been rapidly increased since the 1950s. The reason behind this is its low cost and versatile applications (Ritchie and Roser, 2018). Around 40% of the total plastic is used for food packaging materials like plastic bottles, cups, trays, films, sheets, etc. (Elhussieny *et al.*, 2020) but synthetic plastics are found carcinogenic and remain as such without degradation resulting in poor management and ecological imbalance; badly affecting the oceans, soil fertility, animals, and all the living beings (Teuten *et al.*, 2009). Because of this, oceans are hugely affected, containing a vast mass of plastic debris, creating a devastating effect on marine life. The yearly input of marine debris into the oceans was reported by the US Academy of Sciences to be around 6.4 million tons, and another 8 million items are projected to enter marine bodies

Author's Address

Department of Agricultural Engineering, Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab, India
E-mail: mukulsain95@gmail.com

daily through different sources (UNEP, 2005, Macfadyen *et al.*, 2009).

Paddy straw has the potential to produce biodegradable plastic packs, which can provide a sustainable solution for straw management and synthetic plastic without polluting Mother Nature. Waste rice straw contains a reasonably high amount of cellulose (32%-47%), hemicellulose (19%-27%), and lignin (5%-24%) (Garrote *et al.*, 2002; Saha 2003). The abundant amount of cellulose present in rice straw can be used to produce biodegradable plastics or bioplastic packaging materials. Following studies are reported to overcome the stubble burning and synthetic plastic problems in a very uplifting way:

Application of rice straw for producing biodegradable packaging materials

Production of bioplastic packaging materials using rice straw

In recent years, a few research studies have been conducted to produce sustainable bioplastic materials for packaging purposes. Pratiwi *et al.* (2017) produced bioplastic packaging materials from rice straw cellulose to replace the non-biodegradable conventional plastics. The bioplastic was produced by using the phase inversion method with different ratios of chitosan and rice straw cellulose (chitosan: cellulose; 3:10, 4:10, and 5:10). The various physical and mechanical characteristics like density, water absorption, tensile strength, modulus of elasticity, and elongation at break were calculated, and it was found that higher chitosan content had higher density, i.e. bioplastic 5:10 had a higher density as compared to other two samples. The tensile strength, modulus of elasticity, and elongation at break was found highest in 4:10 bioplastic. In contrast, the water absorption was more elevated in 3:10 bioplastic in comparison to the rest of the two samples. Most importantly, the results showed that rice straw-based bioplastic had much higher water absorption than that of conventional synthetic plastics which was desirable as higher water absorption helps in easy degradation. Table 1 shows the detailed characteristics of bioplastic with different chitosan-cellulose ratios and various traditional plastics. The

attributes of developed bioplastic were found comparable to that of various synthetic plastics, as shown in Table 1. Bilo *et al.* (2018) produced rice straw-based bioplastic using a novel technique. In this study, a Naviglio extractor was used for the synthesis of samples, which were then dissolved with the help of trifluoroacetic acid (TFA) for solubilising the cellulose with another organic matter present in the rice straw. This was a time-efficient, and low-cost method as TFA could be quickly evaporated and collected for the synthesis of other raw samples. Also, the produced bioplastic had desirable mechanical characteristics. It was found that the strength of bioplastic in dry state was comparable to that of polystyrene, whereas the properties of cast bioplastic in its wet state were similar to that of polyvinyl chloride (PVC). The elongation at break and tensile strength of produced bioplastic was 6.1% and 45 Mega Pascal (MPa) in the dry state and 63% and 10 MPa in the wet state. Also, the produced bioplastic was utterly biodegradable, which degraded in the soil within 105 days. Elhussieny *et al.* (2020) used the waste rice straw for producing biodegradable food packaging packs. In this study, the chitosan was extracted from shrimp shell waste, whereas cellulose and rice straw fibres were extracted from rice straw waste. Adding 25% of rice straw cellulose and 35% of nano rice straw fibres improved the thermal, mechanical, and biological characteristics of chitosan films. The attributes like fracture strength, young's modulus, and yield strength in produced bioplastic were found higher as compared to that of unreinforced materials and Egyptian synthetic plastic bags. As reported in these experimental studies, these bioplastics have high mechanical performance and degradation properties. Based on these studies, bioplastics are reported much more suitable as compared to synthetic plastics. Table 2 shows the generalised comparison between conventional synthetic plastics and bioplastics based on various studies.

Use of rice straw-based cellulose nanocrystals in bioactive films for better preservation of food products

Lu and Hsieh (2012) prepared cellulose nanocrystals (CNC) from rice straw by utilising

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series of treatments. Firstly, sodium chloride was used, followed by glacial acetic acid and cellulose was separated from straw by further treating it with potassium hydroxide. Also, hydrolysis of the resulting material was done with sulphuric acid at 45°C for 30 and 45 min (named as CNC30 and

Table 1. Comparative properties of rice straw-based bioplastics and synthetic plastics (adapted from Pratiwi *et al.*, 2017; Pandey *et al.*, 2010).

| Properties | Bioplastic | | | PLA | PCL | PBSA | PBAT | PP | PET |
|------------------------------|------------|--------|-------|------|------|------|------|-----------|-------|
| | 3:10 | 4:10 | 5:10 | | | | | | |
| Density (g/cm ³) | 0.76 | 0.956 | 1.139 | 1.25 | 1.11 | 1.23 | 1.21 | 0.90 | 1.37 |
| Water absorption (%) | 154.65 | 119.21 | 93.87 | 172 | 177 | 330 | 550 | 0.01 | 0.15 |
| Tensile strength (MPa) | 4.2 | 13.8 | 4.1 | | 14 | 19 | 9 | 24.7- 302 | 45.52 |
| Elongation at break (%) | 235.5 | 316.5 | 140.5 | 9 | >500 | >500 | >500 | 21-220 | - |
| Modulus of Elasticity (MPa) | 1.8 | 10.5 | 2.6 | 2050 | 190 | 249 | 52 | 1430 | - |

PLA - Poly Lactic Acid, PCL - Poly (ϵ -caprolactone), PBSA-Poly Butylene Succinate Adipate, PBAT- Poly (butylene adipate-co-terephthalate), PP- Polypropylene, PET- Poly ethylene terephthalate

Table 2: Generalised difference between conventional synthetic plastic and rice straw-based bioplastic (Sain, 2019; Elhussieny *et al.*, 2020; Kalita, 2019).

| Conventional synthetic plastics | Rice straw based Bioplastics |
|---|---|
| Petroleum based | Cellulose based |
| High energy consumption during production | 48% lower energy consumption than conventional synthetic plastic |
| Contains toxic chemicals | No toxic chemicals |
| High mechanical, thermal strength and stability | Equally stable |
| More than 500 years | Around 105 days along with the production of methane which can be used as kitchen gas |
| Cannot retain the original flavour and scent of stored food | Preserve the original flavour and scent of stored food |

CNC45 respectively). The yield obtained was 36%, and the length of CNC30 obtained was longer (270 nm long, 30.7 nm wide and 5.95 nm thick) in comparison to that of CNC45 (117 nm long, 11.2 nm wide and 5.06 nm thick) as given by the transmission electron microscopic (TEM) analysis. The crystallinity index for CNC30 and CNC45 was found to be 86% and 91.2%, respectively, than the

cellulose obtained from rice straw (61.8%). It was also reported that these fibres exhibited stability in terms of their structure and can bear intense shaking and stirring.

The extracted nanocrystals can be added to composite films in order to produce bioactive packaging films, which enhance the yield, mechanical as well as thermal strength, and



crystallinity index for better antimicrobial and antifungal properties; beneficial for its uses in multiple sectors such as food, dairy, and livestock industries. Xu *et al.* (2018) developed value-added rice straw nanocrystalline cellulose based biocomposites. Chitosan and nanocrystalline cellulose were used as two key raw materials. These biocomposites were produced by treatment with acid hydrolysis-ultrasonic waves along with blending casting. The result showed a uniform rod-like structure of nanocrystalline cellulose, concentrated in the width distribution on the 10-15 nm range and length of several hundred nanometres. The produced biocomposites were thermally stable and had strong water absorption with high clarity. Beside, Perumal *et al.* (2018) reported the formation of bio-based nanocomposite films by a casting method, mixing polyvinyl alcohol/chitosan with cellulose nanocrystals (CNC) obtained from rice straw. Acid hydrolysis method was used in the isolation of CNC, and its characterisation was done for various parameters. The reported particle size was around 15nm with rod-shaped structure. Tensile strength and thermal stability of films were increased with the addition of variable concentrations of CNC's to polyvinyl alcohol/chitosan. Antibacterial tests showed that these films displayed impeccable antibacterial and antifungal properties, which is highly beneficial for the food processing industry.

Initiatives taken in India to convert the rice straw into biodegradable cutleries along with farmers' profitability

In India, bioplastic production using rice straw is very lesser-known. Other than this, Bio-Lutions, a Hamburg, Germany based company, working in Ramanagara, Bangaluru, introduced a completely new material 'Plantio' to replace the paper and plastic. 'Plantio' is made of waste crop residue or field waste, like rice straw. Bio-Lutions is producing completely natural fibre-based packaging packs and microwaveable tableware, suitable for greasy and moist food contact. Also, it does not need time-consuming cellulose extraction from rice straw. The bio-lutions team in India purchases the waste residues from the farmers and

converts it into useful packs so that farmers get profit from the straw waste (Sain, 2019).

Some Indian entrepreneurs, companies, and researchers are also working to use the waste rice straw efficiently and cost-effectively to eradicate the stubble burning and petroleum-based packaging materials. Kriya Labs, founded by three IIT Delhi graduates in 2017, worked for the value addition in rice straw to resolve the pollution problems caused by stubble burning. They used a novel method for pulping of the straw and converting it into biodegradable cutlery, crafty items, tableware, and secondary packaging materials. The startup company pays Rs. 3 per kg of rice straw, which encourages the farmers to stop the field burning (Balaji, 2019).

Scientists from IIT-Guwahati produced low-cost bio-based biodegradable plastic (Sain, 2019). The produced cutlery is not only biodegradable, but its degradation also adds nutrients to the soil. Earlier, the institute had been produced around 7-8 kg of bio-based degradable plastics at one go (Kalita, 2019). For a commercial pilot plant, IIT-Guwahati has collaborated with Numanligarh Refinery Limited (NRL) (Barrett, 2019).

Conclusion

Bioplastic production is limited because of a lack of awareness and proper processing setups. All over the globe, very few experimental studies have been conducted to convert waste rice straw into biodegradable bioplastics. This article has discussed the various research studies for the production of rice straw-based bioplastic packaging materials so that the technology can be widely adopted especially in India, to eradicate stubble burning and synthetic plastics. Proper management and value addition to this so-called waste can give environmental and economic benefits.

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