

Recent bio-emerging strategies

for paddy straw degradation under sustainable agriculture development

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The world is mired with increasing agricultural waste and resulting pollution due to its inadequate management. Paddy straws, which contribute heavily to the country's total agricultural waste, are alternatively a source of energy and important nutrients when appropriately disposed. The recent advances towards the same have been mostly in the direction of generation of renewable energy; however, another eco-friendly approach is the in situ or on-field decomposition of these residues, which are rich in lignocellulose. This is possible via biodegradation of these components using consortia of beneficial microorganisms. This article discusses the advantages, mechanisms and microorganisms that can be and are being used for similar purposes.

Keywords: Biodegradation, Environmental pollution, Paddy straw, Sustainable Agriculture

The staggering rise in global population, which the UN predicts to be 10.4 billion by the end of the decade, calls for an exponential increase in global food demand and production. The amount of agricultural waste that results from the increased production is one constant that goes along with it. Rice is one of the most predominantly grown crops in the world, second only to corn in terms of production, with Asia being its largest producer (about 90% of all rice grown worldwide). In India alone, paddy accounts for about 45% of all total crop production, covering an area of over 10 Mha. The growth of rice is accompanied by a large amount of waste in the form of paddy straws, which are not readily decomposed in soil by virtue of their composition. These paddy straws are rich in (a) cellulose (32–47%), (b) hemicellulose (19–27%) and (c) lignin (5–24%), which makes their biodegradation in soil significantly slower and difficult. One conventional method employed for its quick removal has been to burn the resulting waste on the agricultural land (*in situ* burning) because it is easier,

less time-consuming, economical and requires no investment. It has been known till 2020 that about 90 to 140 Mt paddy straw is annually burnt in India. This approach, however, has been criticized for its unsustainability, damage to flora and fauna, loss of nutrients in the form of loss of soil organic carbon (SOC) and, in the long run, the increased global carbon dioxide emissions adding to the imminent global climate crisis.

Regarding the loss of SOC alone, the burning of paddy straw causes a deficit of 3850 million kg organic carbon, 59 million kg nitrogen, 20 million kg phosphorus and 34 million kg potassium annually. The United States Environmental Protection Agency (USEPA) estimates the global emission percentage from the agriculture sector to be over 20% of total greenhouse gas emissions, which translates to over 8 billion metric tonnes of CO₂ equivalent. When equated with the drastic rise in global temperature and the detrimental effect of climate change, these numbers make this practice even more unconscionable. Another

deteriorating effect of *in situ* burning is seen on human health because of the release of toxic carcinogens on combustion, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzodioxins (PCDDs). About 0.05% of total greenhouse gas production in India is attributed to the burning of paddy straws.

The last decade has seen significant progress, and a number of studies aimed towards developing utilization methodologies and new technologies to reduce and manage the waste resulting from paddy, are focused on biodegradation. Biodegradation is defined as a natural process that involves the breakdown of organic matter into simpler compounds like carbon dioxide or water. Although the process is mostly natural, it can be speed up and regulated using a microorganism which is selective for the substrate or by using a consortium, i.e. a group of compliant microorganisms that show synergism in their metabolism towards a substrate. Most of the studies in this regard focussed on

the high fibre content of paddy and its potential use as a renewable source of energy in the wake of depleting fossil fuels; however, they looked over the economic feasibility of these options as the straws were under-utilized because only a part of them could be useful, generating new pollutants. This was especially true in the case of paper production using paddy straws which, being low in fibre content when compared to wood, lowered its use value in papermaking.

Another use of paddy straws was suggested in biorefineries which refers to the co-production of transportation biofuels, bioenergy and marketable chemicals from renewable biomass sources. The use of paddy straws, a 2nd generational biomass for producing biofuel- a renewable and clean energy source- has seen significant research because of its high lignocellulosic content and wide distribution. However, the environmental and agricultural impacts of it are still under scrutiny. The removal of crop residues raises concerns since the removal of these residues affects vital processes like soil organic matter turnover, soil erosion, crop yields, N₂O emissions from soils, the major one being the depletion of soil organic carbon (SOC). SOC is responsible for increasing water retention in soil, improving soil structure, reducing the rate of water evaporation from soil and theoretically improving the crop yield. The primary source to enrich the SOC is the retention of crop residuals in the field itself, and this holds not just for paddy but all the major grains like corn and wheat. Hence, while the production of phenols and other biofuels from paddy straw might be an economical and environment-friendly alternative to burning the residues, but they are not completely harmless or without consequences and keeping in mind the disadvantages associated with these methods, a labour-intensive and environment-conscious alternate is needed for the adequate utilization of paddy straws. Therefore, an *in situ* approach for biodegradation is considered the most beneficial

approach towards managing agricultural waste resulting from paddy straw.

Steps involved in the biodegradation of paddy straw

Lignin degradation: Lignin degradation is the essential first step in the process because lignin is the material that is responsible for holding cellulose and hemicellulose together, acting as an adhesive and preventing the enzymatic hydrolysis of the entire lignocellulosic mass. Various enzymes, including laccases, lignin peroxidases, manganese peroxidases, bring about lignin degradation. The oxidation process leads to the breakdown of lignin into aromatic compounds like syringaldehyde, ferulic acid and vanillin. These are further decomposed to produce methane, carbon dioxide, organic acids and water.

Cellulose degradation: Cellulose is another cell wall component which is resistant to enzymatic hydrolysis. A number of enzymes are required for the effective breakdown of cellulose, and enzymatic hydrolysis is influenced by different characteristics of the cellulose, like particle size, surface area, polymerization, and degree of crystallinity. These enzymes, collectively called cellulases, comprise endoglucanases, exoglucanases and β -glucosidase. Hydrolysis of cellulose results in the formation of cellobiose and glucose as intermediates which are readily used up by the indigenous soil microbial communities as a source of energy.

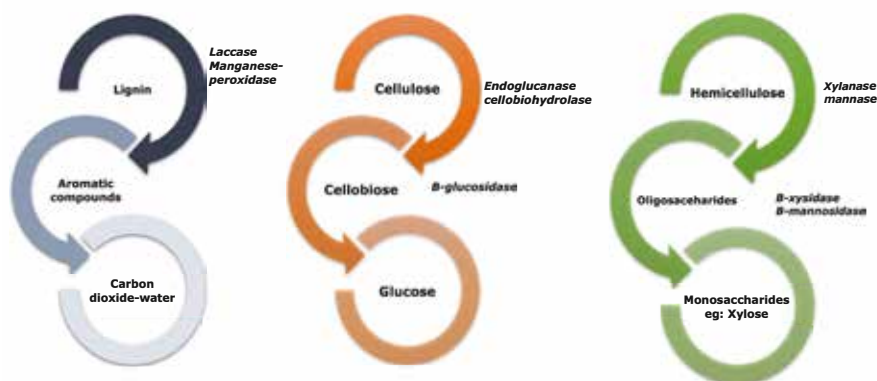
Hemicellulose: The breakdown of hemicellulose involves the synergistic action of various

enzymes, including endo-1, 4- β xylanase and exo-1, 4- β -xylosidase. The former of the two cleaves the chain internally, while the latter causes the release of monomer sugars and debranches the enzymes responsible for the cleavage of side chains associated with the oligosaccharides. The microbial hydrolysis of hemicellulose produces soluble monosaccharides and uranic acid, which are further used by microorganisms for metabolism and are converted to carbon dioxide, organic acids and water.

Factors affecting the degradation of lignocellulosic biomass:

Temperature and pH: Both properties are essential for effective degradation of lignocellulosic biomass as they affect the degradation rate of the residue. Because the soil is mainly composed of mesophilic organisms with a small number of thermophiles and psychrophiles, the highest rates of population growth and activity are seen in the mesophilic temperature range, i.e. 20–35°C. However, pH is also a deciding factor in the efficiency of biodegradation. Bacteria, including actinomycetes, prefer a near neutral pH (7.0–7.5), whereas fungi thrive in a more acidic pH range. Depending upon the microorganism being used, the pH of the soil can influence the degradation rates.

Soil moisture and oxygen supply: Soil moisture influences the residue decomposition by playing a role in the diffusion of soluble compounds and the mobility of microorganisms through the soil. Less amount of moisture results in significant hampering of these processes, whereas extremely dry conditions



may also lead to the death, of microbes. On the other hand, a low oxygen concentration in the soil negatively affects the growth of obligate aerobes and also impacts the metabolism of various microbial species.

Quality of the residue: The quality of residue is governed by the nutrient content present and is called high-quality residues when the nutrient content is high, which basically refers to a high Carbon-Nitrogen ratio (20:1 and 30:1). These high-quality residues are easily degraded as compared to their low-quality counterparts owing to the increased functionality of microorganisms. Another such parameter is lignin which can be used to predict the rate of degradation.

Soil organic matter: The contents of soil govern the soil's indigenous microbial flora because they depend solely on its nutritional value for their survival. This soil organic matter is also responsible for providing suitable soil environments to these biodegrading microorganisms, which is why it is advised to add inorganic nitrogen to the soil after residue incorporation.

Lignocellulose decomposing microorganisms

Several microorganisms have been reported and are used for their lignocellulose degrading properties to generate carbon dioxide and water as end products. These microorganisms include bacteria, fungi, archaea and algae which employ different mechanisms for desired breakdown involving a number of enzymes with oxidative properties. While most of these microorganisms operate under aerobic conditions, significant studies have been made into anaerobic pathways of degradation. Bacteria involved in residue decomposition can oxidise lignin and spread across actinobacteria, alpha-proteobacteria and gamma-proteobacteria. The application of bacteria is specifically intriguing because they cannot only degrade the lignocellulosic biomass but also help in biological nitrogen fixation. Bacteria capable of aerobic breakdown of cellulose include

Pseudomonas, *Klebsiella* and *Bacillus*. They secrete exoenzymes and these exoenzymes, enabling them to use cellulose as an energy source. The enzymes cellulase and laccase have also been identified in the genera *Clostridium*, *Cutrobacterium*, and *Flavobacterium*. Actinomycetes or Actinobacteria invade the cellulosic material, quite similar to fungi, and produce enzymes to accelerate the fate of degradation like manganese peroxidase and xylanase. The major genera include *Streptomyces*, *Nocardia*, *Rhodococcus* and *Microbispora* etc.

Filamentous fungi with plant cell wall degrading properties are substantial in degradation. Their filaments provide access to deeper parts of the biomass, and these fungi use a wide variety of extracellular enzymes with diverse catalytic activities to hydrolyse lignocellulose. The action of these enzymes is selective but also very rapid and expensive at a large scale. Ascomycete fungi, also known as the soft-rot fungi, which include *Aspergillus*, *Trichoderma* and *Neurospora* etc., act on the polysaccharide layer of the surface layer of plants and then proceed to degrade lignin by the production of laccase. The most efficient decomposition of lignocellulose is seen in the case of white-rot fungi, which include *Phanerochaete sordida*, *Phanerochaete chrysosporium*, *Phanerochaete carnosa* and *Botrytis cinerea*.

There have been several successful efforts in similar direction lately which have led to development of various effective lignocellulolytic microbial consortia in India and around the globe. Most notable of these include the capsule based consortium developed by the ICAR- Indian Agricultural Research Institute, New Delhi. Similarly, Biocompost developed by ICAR which consists of *Trichoderma viride*, *Aspergillus niger*, *Pleurotus florida* and *Phanerochaete chrysosporium*. Another example would be TNAU Biomineralizer consortium, which utilises bacteria, fungi, and actinomycetes for degradation of biomass.

A new decomposer consortium containing *Aspergillus awamori* and *Paecilomyces fusisporus* as cellulose decomposers, *Pseudomonas striata* and *Bacillus polymyxa* as phosphate solubilisers, and *Azotobacter chroococcum* as nitrogen fixer, is said to enrich the soil with essential nutrients and has been developed by ICAR-IISS, Bhopal. Similarly, efficient microorganisms consisting of *Candida tropicalis* (Y6), *Lactobacillus* sp., *Streptomyces globisporus* (C3), *Phanerochaete chrysosporium* (VV18), and Pusa compost inoculum have shown rapid decomposition of paddy straw.

Way forward

The use of microorganisms for environment friendly approaches from agriculture to plastic degradation to petroleum degradation is being widely accepted and touted as the novel means towards sustainability. These methods, although in place, need certain refinement and widespread application and research to be perfect however; their advantages are significant and have the potential to change the outlook on agricultural waste degradation, as we know it by being adapted as regular means.

SUMMARY

In the wake of the increasing global climate crisis and exponential rates of rise in population, the need for proper utilization of agricultural waste is also imperative. While most of the conventionally applied methods, like burning, contribute to an already dilapidated state of the environment, the utilization of this biomass for the generation of methane and other biofuels is also not completely without consequences. These methods not only leads to loss of SOC, but also take away the much-needed nutrition from the soil. These circumstances make *in situ* residue retention and subsequent biodegradation the most beneficial method for managing waste from paddy straws.

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