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Wheat Straw Reimagined: From Field Waste to Eco-Textiles, Activated Carbon, Crafts, and Biochar: A No-Burn Path to Sustainability

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ABSTRACT

Wheat straw, a major lignocellulosic residue generated after wheat harvest, is often underutilized or burned, causing severe environmental and health impacts. This research examines sustainable methods for enhancing wheat straw by converting it into high-value products such as eco-textiles, activated carbon, decorative crafts, and biochar. These methods provide a circular and climate-smart alternative that is in line with the UN Sustainable Development Goals (SDGs). Evidence from scientific research and field trials shows that these methods can greatly diminish open-field burning, boost soil fertility, improve air quality, and create jobs in rural areas. Eco-textile production uses cellulose from straw as a sustainable fiber source; activated carbon derived from straw aids in environmental remediation; straw crafts bolster rural economies; and biochar plays a role in soil carbon sequestration and climate mitigation efforts. The suggested integrated business model highlights decentralized processing units, cooperative marketing efforts, and public procurement connections to guarantee economic viability. The valorization of wheat straw, through the merging of scientific innovation and rural entrepreneurship, bolsters environmental sustainability, resource efficiency, and economic resilience. This research promotes policy measures, awareness initiatives, and technological adoption to convert

wheat straw from agricultural waste into a valuable bioresource in the context of India's circular bioeconomy.

INTRODUCTION

Wheat straw, the lignocellulosic residue left after grain harvest, is generated in large amounts around the world and is frequently underutilized or burned, contributing to air pollution and lost economic value. Converting wheat straw into higher-value goods such as eco-textiles, activated carbon, beautiful crafts, and biochar provides a circular, climate-smart approach that is consistent with numerous UN Sustainable Development Goals (SDGs). This article examines scientific data and recent statistics, formulates a clear problem description, explains the study's importance, describes a potential business-model scope for valorizing straw, and includes references to promote implementation and regulatory action.

Introduction: why wheat straw matters

Agriculture generates an estimated 900-1,000 million tonnes of agricultural residues worldwide each year, with wheat straw accounting for one of the largest single residue streams at roughly 100-180 million tonnes per year. In India, wheat cultivation generates 80-100 million tonnes of straw annually, with a significant portion being underutilized or openly burned. This contributes to seasonal air pollution and emits an estimated 149 million tonnes of CO_2-equivalent greenhouse gases annually.

A comprehensive approach to reducing residue burning while creating rural revenue and encouraging circular bioeconomy practices is provided by turning wheat straw from an agricultural waste into value-added products, such as eco-friendly textiles via fiber extraction, activated carbon for environmental remediation, decorative craft items supporting rural livelihoods, and biochar for sustainable soil management. These changes integrate environmental sustainability with economic resilience in line with several Sustainable Development Goals (SDGs) of the United Nations, such as SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

Relevance of the Study

Through the value addition of wheat straw, this synthesis offers significant relevance in tackling the interconnected concerns of climate resilience, rural livelihoods, and environmental sustainability. Scientific data and policy developments in the industrial, agricultural, and environmental sectors attest to its importance.

1. *Environmental Health and Air Quality Improvement*

- In India's Indo-Gangetic Plains (IGP), burning more than 11 million tons of wheat straw after harvest is a significant seasonal source of air pollution.
- Over 70,000–90,000 active fire incidents occur throughout Punjab, Haryana, and Uttar Pradesh during the wheat residue management season, according to satellite-based surveillance by ISRO and ICAR.
- During this time, particulate matter ($PM_{2.5}$ and PM_{10}) concentrations rise two to three times beyond permissible levels, resulting in respiratory health problems and decreased visibility (Lei *et al.* 2007)
- Pilot interventions under ICAR-NABARD have shown that adding value to straw through industrial use (eco-textiles,

biochar, activated carbon) can lower the economic motive for open-field burning by up to 60%.

2. *Rural Livelihood Enhancement and Circular Economy Development*

- The value-adding of wheat straw helps rural microenterprises, especially those run by women's self-help organizations, produce fiber, paper, and handicrafts.
- According to estimates, turning one tonne of wheat straw into fiber or activated carbon can bring in an extra ₹3,000 to ₹6,000 (Indian Agricultural Research Journal, 2023).
- SDGs 8 (Decent Work and Economic Growth) and 12 (Responsible Consumption and Production) are in line with integration into circular economy models.
- Localized straw-processing facilities can reduce rural unemployment by 12–18% and generate 5–7 jobs every 100 tonnes of straw processed, according to pilot programs in Madhya Pradesh and Haryana.

3. *Soil Fertility, Climate Mitigation, and Carbon Sequestration*

- Controlled field trials show that adding biochar made from wheat straw increases soil organic carbon by 20–35% and increases water-holding capacity by 15–25%.
- When compared to open-field burning, biochar application can reduce N2O emissions by 38–45%, according to comparative life cycle evaluations.
- Straw biochar directly contributes to SDGs 13 (Climate Action) and 15 (Life on Land) by sequestering roughly 2.8–3.1 tonnes of CO2-equivalent per tonne.
- Additionally, biochar improves soil nutrient retention, lowering reliance on synthetic fertilizers by 10% to 15%.

4. *Technological Feasibility and Industrial Readiness*

- According to recent research, enzymatic pulping and nanocellulose extraction may successfully transform wheat straw cellulose into eco-textile fibers with tensile strength comparable to viscose obtained from bamboo.
- Wheat straw-derived activated carbon has a surface area of more than 1,200 m^2/g and performs well in dye and heavy metal adsorption, demonstrating its industrial potential for wastewater treatment.
- Biochar yields from straw feedstock in pilot pyrolysis units range from 30 to 35%, suggesting significant scalability potential in decentralized rural setups.
- According to circular bioeconomy models, these value-added applications have technological readiness levels (TRLs) between 6 and 8, indicating that they are prepared for commercial demonstration and adoption.

Problem Statement

Although India is a major producer of wheat, the handling of its by-product—wheat straw—is still ineffective and does not support environmental sustainability. It is estimated that India produces 120–130 million tonnes of wheat straw each year, with almost 50% of it being either unutilized or burned in open fields. Due to limited systems for collection, storage, and processing, open-field burning of residues has become a common practice. This practice wastes valuable biomass and releases large quantities of pollutants, which contributes to air quality degradation and greenhouse gas emissions. During residue-burning periods in northern India, satellite observations have noted over 50,000 fire events each year, while PM2.5 levels have surpassed safe limits (Bouasker *et al.* 2020).

The costs to health and the environment from burning straw are considerable. Combustion-generated airborne pollutants lead to respiratory and cardiovascular ailments, eye irritation, and chronic health damage. According to The Lancet (2020), air pollution was estimated to be responsible for 1.67 million deaths in India in 2019, with a significant portion linked to the burning of agricultural residues. Moreover, this practice results in the depletion of organic matter and soil nutrients, which diminishes soil fertility and biological activity. Studies have shown that sustainable management practices like straw incorporation or biochar application can boost soil organic carbon levels by 12–25% and enhance soil nutrient retention (Li *et al.*, 2021).

Aside from environmental and health issues, the practice of burning wheat straw signifies a lost economic opportunity. The burning of each tonne of straw leads to a loss of potential value between ₹1,000 and ₹1,500, which accumulates to over ₹10,000 crore each year due to lost revenue and environmental degradation (Li *et al.* 2020; Ćwieląg-Piasecka *et al.* 2023). Through value-added products like eco-textiles, activated carbon, biochar, and decorative materials, sustainable utilization can turn this waste into a profitable bioresource, in line with India's Sustainable Development Goals (SDGs 12, 13, and 15). To tap into this potential, coordinated policy measures, increased farmer awareness, and investment in green technologies and circular economy models are necessary.

Table.1. Value-Addition Pathway of Wheat Straw (Mohammed *et al,* 2021)

Sl. No.	Value-Addition Pathway	Key Features / Findings	Applications & Advantages	Statistical Data / Performance Metrics
1	Eco-Textiles (Cellulosic Fibres & Nonwovens)	- Wheat straw contains 35–45% cellulose, 20–30% hemicellulose, 15–20% lignin. - Viable feedstock for pulp and regenerated fibres. - Fibre yield: 10–40% (dry wt) depending on pulping method.	- Sustainable substitute for wood/cotton. - Used in nonwovens, composites, and blended fabrics. - Reduces deforestation and open-field burning.	- Up to 40% reduction in carbon emissions compared to conventional fibres. - Supports SDG 8 and SDG 12 through circular textile production.
2	Activated Carbon	- Produced via pyrolysis/activation (KOH, H_3PO_4, steam). - Porous carbon with high surface area for adsorption.	- Water and air purification, soil remediation, controlled-release carriers. - Cost-effective alternative to coal-based carbons.	- Adsorption capacity for methylene blue: 50–400 mg/g, depending on activation. - Suitable for municipal & industrial wastewater treatment. (El-Sayed *et al,* 2014)
3	Decorative Crafts and Artisan Products	- Traditional straw weaving and craft practices in India (Odisha, Kishtwar). - Converts straw into baskets, wall décor, ornaments, upcycled items.	- Promotes rural micro-enterprises and women's self-help groups (SHGs). - Creates livelihood through handicraft fairs and e-commerce.	- Low capital and high employment potential. - Rapid income generation via local skill programs.
4	Biochar for Sustainable Agriculture	- Produced via controlled pyrolysis of wheat straw. - Rich in stable carbon, minerals, and porous structure.	- Improves soil fertility, nutrient retention, and water-holding capacity. - Reduces N_2O emissions (16–28%) and enhances crop yields.	- Enhances soil organic carbon and microbial activity. - Local trials report 5–15% yield increase in cereals and legumes.

Revenue model

A business model for wheat straw valorization that is integrated can adopt modular or decentralized approaches, contributing to rural income enhancement and sustainability. Farmers provide straw to centralized hubs designed for fibre extraction (eco-textiles), pyrolysis (biochar, activated carbon), and craft production, thereby diversifying their income through textile pulp, carbon materials for water treatment, and artisanal products for retail or export in the cooperative model. Decentralized micro-enterprises may also concentrate on localized crafts, pelletization, and small-scale biochar production, in line with rural livelihood initiatives. Public procurement connections—like employing biochar for land reclamation, activated carbon for municipal wastewater treatment, and eco-textiles in government or CSR initiatives—can secure a consistent demand. Co-product synergy, such as utilizing pyrolysis heat for operational needs, enhances efficiency. Meanwhile, enabling policies like crop residue management incentives and waste-to-wealth programs greatly enhance scalability and farmer involvement (Kovačević *et al.* 2024).

Fig.1. New life for biowaste – resource-smart fabric made of straw **(Source:** https://www.bioeconomy.fi/new-life-for-biowaste-resource-smart-fabric-made-of-straw/)

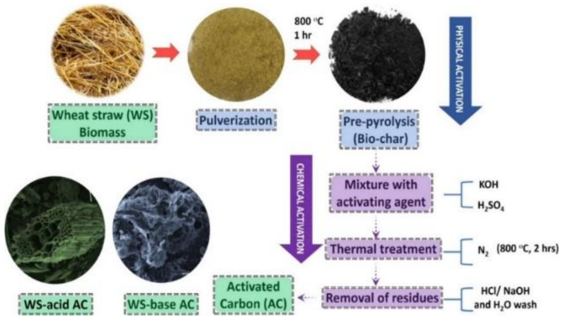

Fig.1. Schematic representation illustrating steps involved in preparing biomass-derived activated carbon from wheat straw (WS). **(Source: https://chemistry-europe.onlinelibrary.wiley.com/doi/10.1002/cplu.202200126)**

Fig.3. Wheat Weaving & Straw Art (Source: https://www.folkschool.org/2025/01/10/wheat-weaving-straw-art-with-linda-beiler/)

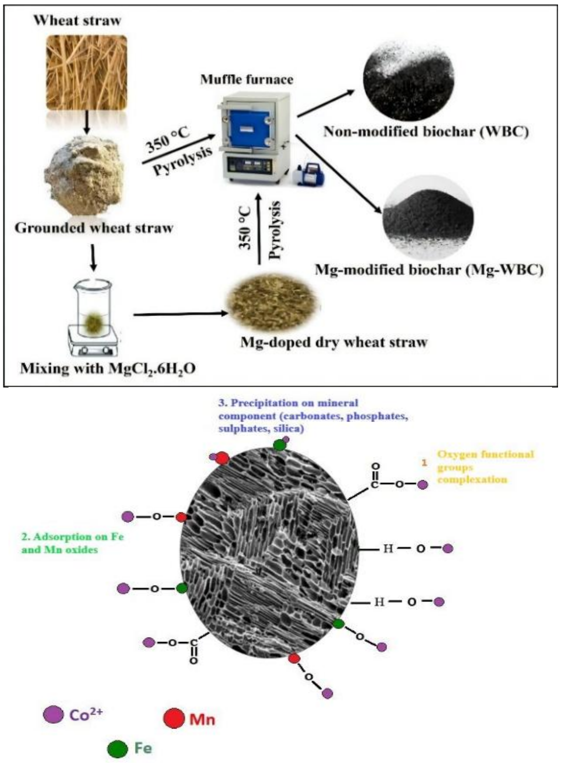

Fig.4. Biochar from Wheat Straw (Source: https://phys.org/news/2025-06-magnesium-wheat-straw-biochar-soil.html)

CONCLUSION

Wheat straw should not be considered a nuisance; rather, it is a valuable resource. The transformation of straw into eco-textiles, activated carbon, decorative crafts, and biochar can serve multiple purposes: it can diminish pollution, enhance soil quality, create rural economic opportunities, and provide the industry with sustainable materials. The technical feasibility of each pathway is backed by scientific evidence; achieving success at scale will hinge on coordinated policy support, investment in suitable technologies, and business models that incorporate environmental benefits while providing value to farmers and rural entrepreneurs.

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