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NATURAL BAST FIBRES AS SUSTAINABLE SUBSTITUTES FOR SYNTHETIC PLASTIC: A LIFECYCLE AND SOIL DYNAMICS ANALYSIS

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ABSTRACT

Conventional synthetic packaging materials, especially low-density polyethylene (LDPE) plastics, pose critical dangers to global ecosystems due to extensive fossil fuel consumption, substantial high carbon footprints and prolonged decomposition periods. This review assesses the ecological and commercial feasibility of natural bast fibres, particularly Jute and Mesta, as sustainable and biodegradable alternatives. By utilizing data from long-term agricultural studies and comparative lifecycle evaluations, this paper consolidates the carbon dynamics, soil restoration capabilities, and byproduct utility of natural fibre cropping systems.

The results indicate that raw jute cultivation sequesters an impressive 4.88 tonnes of CO_2 for every ton of fibre produced. Incorporating jute into a Jute-Rice-Wheat rotation creates a net carbon sink (1.45 to 3.33 Mg C ha^{-1}), enhancing soil organic carbon by 26% over a span of 40 years and improving the overall soil quality index by 45.1%. Additionally, natural fibre crops produce zero waste, creating circular loops; their woody sticks yield rapid biomass (98 kg day^{-1} ha^{-1}) suitable for second-generation bioenergy production or conversion into agricultural biochar, which can sequester up to 60% of CO_2 emissions.

When transformed into consumer products, Jute and Mesta carrier bags significantly surpass 100-micron single-use LDPE alternatives. They decrease Global Warming Potential from 39.40 kg CO_2 eq. to under 0.75 kg CO_2 eq., eliminate over 96% of terrestrial ecotoxicity, reduce cumulative energy demand and biodegrade safely within 90 days. Ultimately, shifting to natural bast fibre infrastructure establishes a scalable, ecologically viable framework capable of mitigating greenhouse gas emissions, regenerating soil quality and replacing hazardous synthetic plastics.

***Keywords* :** Bast fiber, Synthetic Plastic, Soil Dynamics.

Introduction

Natural fibre crops are versatile, biodegradable and relatively inexpensive substitutes for polythene. Natural fibre crops have high ecosystem service value in addition to commercial value. These natural fibre crops can contribute to GHG mitigation because of their capacity to remove carbon from the atmosphere and to store it; fully biodegradable fibre material to replace environmentally harmful polythene bags, plastics and synthetics; and their by-product can be a substitute for wood for manufacturing paper-pulp, thereby reducing anthropogenic pressures on forests. Thus, indirectly these fibre crops are helping to make a clean and green world by saving forests and mitigating climate change by additional CO_2 sequestration through saved forests.

Natural fibre-based ecosystem service values

a) Carbon sequestration (to protect carbon stocks with CO_2 capture and storage)
b) Renewable bio-mass for nitrogen mineralization and maintenance of soil quality
c) Jute, Mesta and allied fibre (JAF) carrier bags as an alternative to plastic in India.

Carbon flow by Natural fibre crops

1. Approximately 4.88 tons of carbon dioxide gets sequestered per ton of raw jute fibre production which is much higher than many tree species (Rajgopal and Sanyal, 2012).

2. On average, the manufacturing of one tonne of synthetic fibre products has an impact of 1.7 tonnes CO_2-eq (PwC 2012). On the other hand, the emission of GHG in the use of natural fibre crops usually ranges between 0.5 and 0.7 tonnes of CO_2-eq per tonne of natural fibre.
3. The impact of artificial fibre production on climate change is three times higher than the impact of natural fibre production.
4. Primary energy for producing artificial fibre accounts for 35 GJ t^{-1} of fibre, which is seven times higher than the primary energy of bast fibre use (Haufe and Carus 2011).
5. The carbon footprint of bast fibres was found to be 20–50% lower than that of synthetic or artificial fibres.

Table 1 : Carbon footprint of the four most important natural bast fibres

Crop	CO_2-eq t^{-1} of fibre
Jute	566
Mesta (Kenaf)	520
Flax	445
Sunhemp	423

Table 2 : Potential of carbon sequestration of field crops under various cropping system

Cropping system	C sequestration potential (Mg C ha^{-1})
Jute-rice-wheat	1.45 – 3.33
Maize-soybean-wheat	0.43 – 3.82
Rice-wheat	0.41 – 1.87
Soybean-wheat	0.40 – 1.67

(Singh, 2017)

Jute-based cropping systems in alluvial soils agro-ecosystems act as a net C sink, and the average SOC density has risen from 18.18 t ha^{-1} in 1972 to 22 t ha^{-1} in 2016. On an average, the critical C input was estimated to be 5.30 tonne C ha^{-1} $year^{-1}$. (Singh *et al.* 2019).

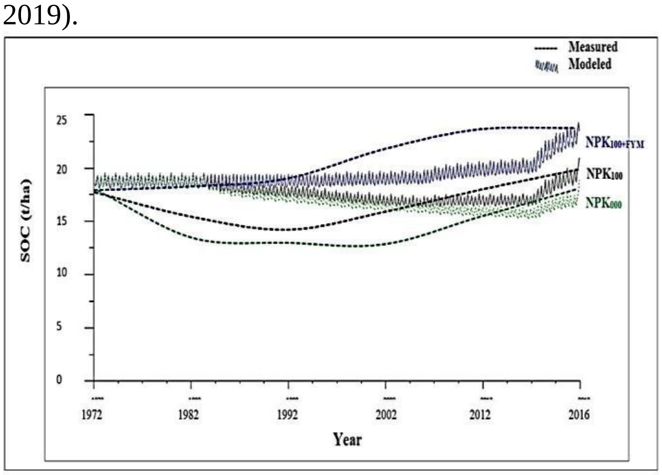

Fig. 1 : Carbon sequestration under jute-rice-wheat cropping system

In the jute crop, a daily potential biomass production of 49.7 gm day^{-1} has been reported (Palit 1993). On average, 0.97–2.8 t ha^{-1} of jute above- and below-ground biomass (leaves, stubbles, and roots) is added to soils under jute cultivation each year (Singh *et al.*, 2019). Inclusion of jute crop in cropping system provides a very good opportunity for returning biomass to the soil as well as total potential primary productivity and increased carbon sequestration (Singh, 2017).

A higher value of the carbon management index (CMI) in the jute-rice-wheat system was observed as compared to agro-forestry, sugarcane, and maize-wheat systems (Fig. 2). This is attributed to more carbon input being provided by the jute-based cropping system than other farming systems.

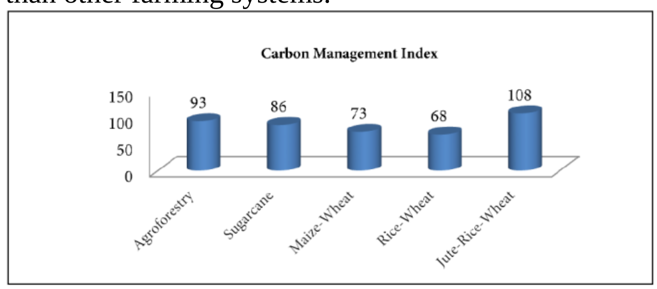

Fig. 2 : Jute-Rice-Wheat agro-ecosystems exhibit greater carbon rehabilitation than agro-forestry, sugarcane and maize-wheat and rice-wheat (LTFE Project, ICAR, 2019)

Soil quality improvement by fibre crops based cropping system

1. Natural bast fibre crops are a huge source of renewable bio-mass and carbon sequestration. Jute and Mesta crops shed about 15 tonnes of green leaves per hectare, which helps in the maintenance of soil fertility. It has been estimated that one hectare of Mesta produces 3.5-7.0 t of green leaves and roots (Rahman *et al.*, 1995; Gani *et al.*, 1999)
2. In an ICAR-CRIJAF long-term fertiliser experiment study, it was observed that adding jute leaves, stable, and roots under 100%NPK+FYM during 40 years of jute-rice-wheat cropping system increased soil organic carbon content by 26% (Singh *et al.* 2019).
3. In another study, a soil quality change of 45.1% was observed for a jute-rice-wheat cropping system and 18.7% for a rice-wheat-fallow cropping system (Mandal *et al.*, 2005).
4. This indicates that the inclusion of jute crops in the cropping system plays an important role in improving the soil quality index (Fig. 2).
5. The incorporated organic matter through the decomposition of jute leaves together with the chemical nutrients improved both the physical and fertility status of the soil.

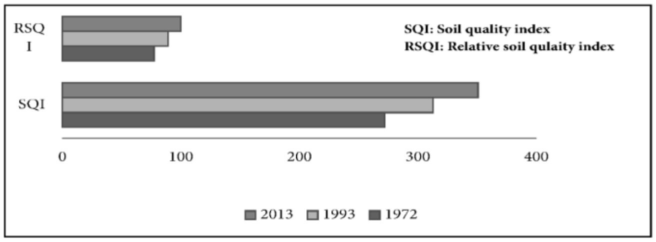

Fig. 3 : Soil quality changes under jute-rice-wheat cropping system in alluvial soils (Singh *et al.* 2017)

Mesta and jute stick as source of bio-char

The biomass production of Mesta and jute is approximately 98 kg day^{-1} ha^{-1}, which is faster than the biomass production of other woody plants (28 kg day^{-1} ha^{-1}). A large percentage of the total output of jute growers is jute sticks, i.e., the woody core of jute plants left after the fibre is taken away on completion of retting, which is the major agro-residue. Jute stick, a woody biomass, accounts for approximately 40% of the green plant, with an annual production of 4.0 million tonnes (Nayak *et al.* 2013). Jute sticks are good sources of charcoal, and approximately 15-20% biochar or activated charcoal can be produced from jute sticks. Biochar is carbonised organic material with high porosity that brings about changes in physical, chemical, and biological soil functions. Photosynthetically fixed atmospheric CO_2 stabilised in biochar may thus act as a direct carbon sink and help to mitigate climate change. Therefore, jute sticks are also good sources for charcoal, and about 60% of CO_2 emissions can be sequestered by the use of biochar in agriculture.

Mesta and jute stick as source of bio-energy

Mesta (Kenaf) crop is good source of lignocellulosic feedstock for second-generation bioenergy (bioethanol, biohydrogen) production. (Saba *et. al.,* 2015). Mesta is currently used as a biofuel in China and the United States. (Singh, 2013). The National Biofuel Policy, 2020 thrusts on the use of lignocellulosic biomass or agricultural/ municipal wastes for bioethanol production.

Structurally, Mesta fibre comprises of cellulose (58-63%), hemicellulose (18-21%) and lignin (12-14%) and stick has cellulose (40-48%), hemicellulose (18-22%) and lignin (21- 24%) (Satya and Maiti, 2013). This enriched structural composition makes jute a suitable feedstock for bioethanol production.

Jute and Mesta (kenaf) carrier bags are waste free future and an alternative to plastic

Increasing demand for natural fibre (jute/mesta) made shopping carry bag materials has given rise to various issues relating to their disposal as well as to the overall environmental footprint and sustainability of the packaging materials.

Every year, approximately 500 billion to 1 trillion plastic bags are used worldwide, emitting tonnes of CO_2 into the atmosphere. Many of these bags eventually make their way into rivers and oceans, killing thousands of animals and marine life and leaching into our own food chain at some point. The fact that a single polythene bag may take over a thousand years to decompose compounds the problem.

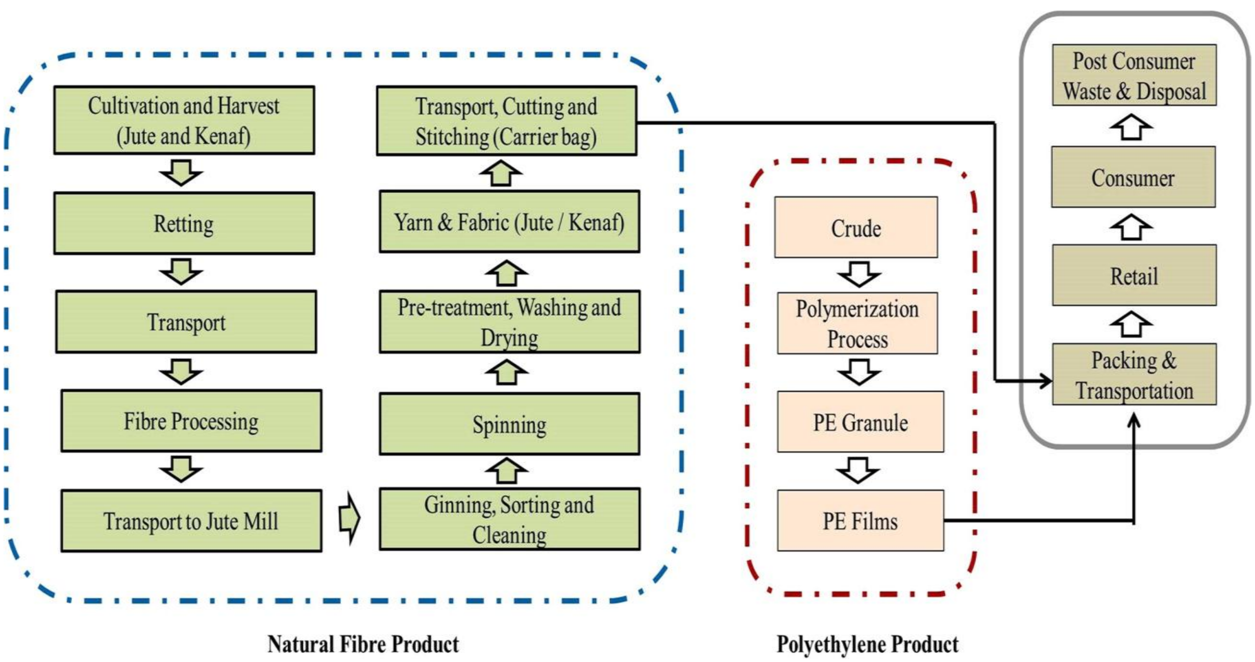

Fig. 4 : Scheme of natural fibre and LDPE carrier bags

Table 3 : Volume, weight, usage, cumulative energy demand, and water consumption for each carrier bag used in the study

Packaging item	Polythene carrier bag (100 micron)	Jute/Mesta (Kenaf) carrier bag
Weight per bag (g)	6.04	240
Capacity per bag (litre)	14	14
No. of uses per bag	1	>30
Cumulative energy demand (MJ kg^{-1})	150	105
Water consumption (m^3 water kg^{-1})	3.07	2.23
Degradation period	>100 years	<90 days

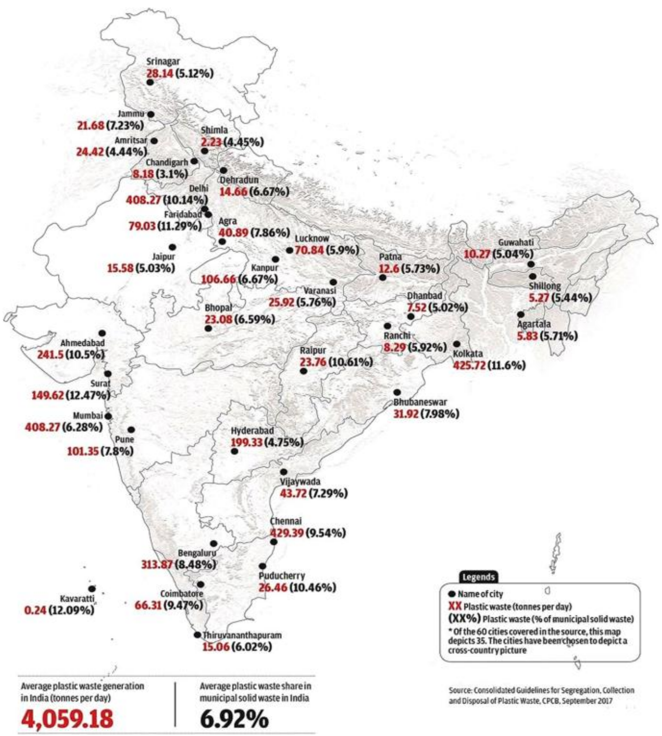

Fig. 5 : Per day production of plastic wastes in Indian cities

Table 4 : Quantitative results of environmental impact categories evaluated for each carrier bag

Impact category	Single-use LDPE carrier bag (100 micron)	Jute carrier bag	Mesta (Kenaf) carrier bag
Abiotic depletion-fossil fuels (MJ kg^{-1})	1580.74	10.27	8.27
Terrestrial ecotoxicity (kg 1,4-DB eq.)	153.00	5.86	4.51
Photochemical oxidation (kg C_2H_4 eq.)	30.75	2.89	2.93
Acidification (kg SO_2 eq.)	110.00	48.70	48.50
Eutrophication (kg PO_4 eq.)	71.50	14.93	14.72
Global warming-GWP100a (kg CO_2 eq.)	39.40	0.7247	0.7449

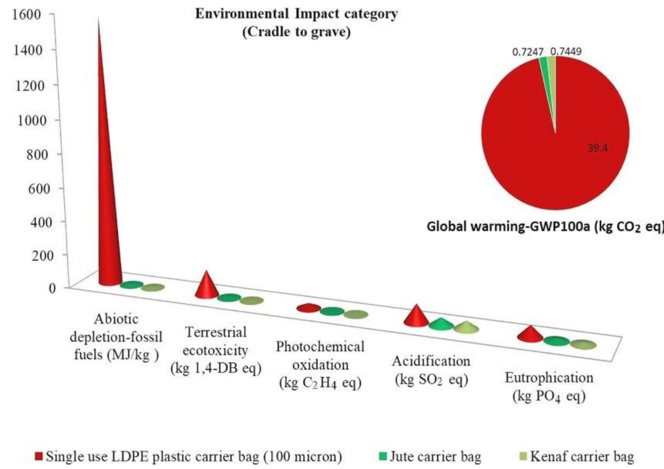

Fig. 6 : Environmental impacts from Mesta (kenaf), jute and polythene carrier bag production

Conclusion

Natural bast fibre crops such as Jute and Mesta offer an economically and ecologically sustainable solution to climate and plastic crises. They act as dual-action systems, functioning as massive carbon sinks and restoring depleted soils through organic biomass returns shedding up to 15 tonnes of green leaves per hectare.

Carrier bags made from natural fibres vastly outperform low-density polyethylene (LDPE) across all environmental metrics. They lower Global Warming Potential (*GWP100a*) and terrestrial ecotoxicity to fractions of plastic levels, consume less energy during processing, and safely biodegrade in under three months.

The lifecycle of these crops produces no waste. Byproducts like woody sticks, traditionally treated as refuse, can be used as feedstocks for second-generation biofuels or converted into biochar to lock captured carbon into the soil for long-term storage.

Shifting to natural bast fibre networks is an essential, scalable framework for mitigating greenhouse gases, repairing soil infrastructure, preventing microplastic pollution, and driving industries toward a sustainable future.

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