A Systematic Overview of Research Developments in Jute and Allied Fibre Crops

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Edited by

Gouranga Kar, Arvind Kumar Singh, Subrata Satpathy, Jiban Mitra, Bijan Majumdar, Sabyasachi Mitra and Suniti Kumar Jha

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PREFACE

Research on botanical aspects, cultivation, and technology of jute and allied fibres has been going on for a long time. The first comprehensive account of these research findings was made in the form of a monograph on jute in India in 1959. Since then, significant changes have taken place in research orientation and relevance in the changing socio-economic context in terms of eco-friendliness, sustainability, renewability, global competitiveness in the WTO regime, and intellectual property protection, and novel opportunities have arisen due to the emergence of powerful catalytic tools in information technology and biotechnology, especially in the last few decades.

This book deals with the systematic overview of the recent developments on plant genetic resources in jute and allied fibres; management and its utilization; genomic resources and new paradigm in improvement of jute and allied fibre crops; breeding mesta-from conventional to 21st century applications; jute fibre quality: evaluation, grading and improvement; seed production technology of jute and allied fibres; climate smart farming of jute and allied fibres; advancement in jute retting and post-harvest management; ecosystem service values of jute and allied fibres; farm mechanisation in jute and allied fibres for small and marginal farmers; pest-disease dynamics in jute and allied fibre crops under a changing climate scenario; ICT-based pest and disease management in jute and allied fibre crops; host plant resistance to insect pests and diseases in jute; technological and economic empowerment of jute growers; and value chain development in the jute sector. This updated and comprehensive publication in book form will surely be useful to research workers, teachers, industrialists, development agencies, and students.

—Editors

JUTE & ALLIED FIBRE RESEARCH IN INDIA

CHAPTER 1

MAJOR CONTRIBUTIONS OF ICAR-CRIJAF FOR THE PROSPERITY OF FARMERS IN 75 YEARS OF INDEPENDENCE

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Introduction

The cultivation of jute in the area of the Bengal Delta has started since immemorial time. Jute played an important role in the culture and economy of West Bengal and the south-west part of Bangladesh (then India) for many centuries. The greater India was under British colonization, and the British East India Company traded jute for the first time. The company sent its first consignment in 1793, and trading continued until the 20th century. There was trading of raw jute with the Scottish jute industry in Dundee. With the success of trading raw jute, the necessity of trading jute products by adding value to raw jute was understood. With this urge, jute processing mills and factories were established. In Kolkata, the first jute mill was established in 1855, followed by the establishment of more jute mills in West Bengal during the 1900s. After the partition in 1947, the finest quality jute stocks remained in the south-west part of Bangladesh (then East Pakistan), while the jute mills that process raw jute were in West Bengal. Then, the emergence of a new jute research institute took place in India. In 1953, the Jute Agricultural Research Institute (JARI) was started in Barrackpore, West Bengal (India). In 1966, the ICJC was taken over by the Indian Council of Agricultural Research (ICAR), and the institute was renamed the Central Research Institute for Jute and Allied Fibres (CRIJAF) in 1990. The institute mainly deals with six natural fibre crops, viz., jute, mesta, sunn hemp, sisal, ramie, and flax. To carry out research on jute and allied fibres, the Institute established four research stations, namely the

Central Seed Research Station for Jute and Allied Fibres at Budbud, West Bengal (1956), Ramie Research Station at Sorbhog, Assam (1959), Sisal Research Station at Bamra, Odisha (1962), and Sunn hemp Research Station at Pratapgarh, Uttar Pradesh (1963). Besides these, the institute has nine SAU-based and six ICAR-based collaborating centres for multi-locational testing and validation of the CRIJAF technologies under the All India Network Projects on Jute and Allied Fibres (AINP on JAF).

The ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF) is one of the premier crop research institutes under the aegis of the Indian Council of Agricultural Research (ICAR), spearheading research and technology development on jute and allied fibre crops. Through systematic research and development activities undertaken by ICAR-CRIJAF on crop improvement, crop production, crop protection, and other aspects of crop management, the crop duration could be reduced to 120 days and productivity increased to more than 26 q/ha in the current year.

Jute varieties and production technologies developed by ICAR-CRIJAF have contributed a lot to achieving the landmark production of raw jute of over 100 million bales per year at present. The productivity of jute and mesta has increased by threefold since independence. This was made possible through the introduction of high-yielding varieties supported by location-specific production and protection technologies developed by ICAR-CRIJAF. Besides, the tossa jute varieties having pre-mature flowering resistance enabled the crop to fit in the intensive rice-based cropping sequence of the eastern and north-eastern parts of the country. The tossa jute (*C. olitorius*) and white jute (*C. capsularis*) varieties, released by the institute, are cultivated in 95% of the jute area in the country. These varieties are also grown in a sizable area in Bangladesh and Nepal. To date, the institute has developed 63 varieties of jute and allied fibre crops. A number of short-duration, high-yielding, and premature flowering-resistant, finer fibre varieties have been developed. During the last 10 years, 15 varieties have been released by the institute, which are 15-20% more productive and 21% finer than the older varieties. These varieties have tremendous potential for the manufacture of jute-diversified products.

Plant genetic resource activities

ICAR-CRIJAF is the National Active Germplasm Site (NAGS) for jute and allied fibre crops in India. Collection, characterization, evaluation, conservation, and utilization of jute and allied fibre germplasm are continuous activities of NAGS. At present, more than 5,500 germplasms of jute and allied fibre crops are being maintained at the germplasm unit of the institute. Out of these germplasm, 2800 are of cultivated and wild jute, which are very systematically used in the breeding program to create trait-specific variability like low-lignin fibre, resistance to biotic and abiotic stresses so that the additional demand for finer-quality jute fibres can be fulfilled for the manufacture of jute-diversified products (Table 1-1).

Table 1-1. Status of germplasm collection in ICAR-CRIJAF

Crop	No. of accession
Tossa jute (*Corchorus olitorius)*	1770
White jute (*Corchorus capsularis*)	965
Wild jute	498
Kenaf (*Hibiscus cannabinus*)	770
Roselle (*Hibiscus sabdariffa*)	988
Wild mesta	124
Sunn hemp (*Crotalaria juncea*)	197
Wild sunn hemp	114
Flax (*Linum usitatissimum*)	127
Ramie (*Boehmeria nivea*)	180
Sisal (*Agave spp*.)	76
Total	5809

Varietal developments

Varietal developments in jute and allied fibre crops were initiated in the early part of the 20th century. *C. olitorius* variety ‘Chinsurah Green’ and a *C. capsularis* variety ‘Dhaka 154 (D 154)’ were released during 1915 and 1919, respectively, through pure line selection. The development of *C. capsularis* varieties like ‘JRC 321’ and ‘JRC 212’ and the *C. olitorius* variety ‘JRO 632’ increased the fibre yield from 1.0 to 1.25 tons/ha during the 1960s. White jute varieties occupied more than 80% of the jute-growing areas until the early 1970s, as they were suitable for mid-March to mid-April sowing. Pre-mature flowering resistant tossa jute varieties, namely ‘JRO 878’, ‘JRO 7835', and ‘JRO 524', were released in 1967, 1971, and 1977, respectively, after successfully transferring the early flowering resistance gene from an exotic germplasm ‘Sudan Green’ to Indian elite varieties, ‘JRO 620’ and ‘JRO 632', resulting in a paradigm shift in jute farming with tossa replacing the other jute types in the whole of India. These olitorius varieties (particularly ‘JRO 524’) enabled jute to be juxtaposed in the multiple cropping sequences with transplanted *Aman* rice, mainly because of their shorter duration (120 days). Now a series of new *C. olitorius* varieties, like ‘JRO 66’, ‘JRO 8432’, ‘JRO 128’, ‘S 19’, ‘Ira’, ‘Suren’, 'Tarun', and *capsularis* varieties, viz., ‘JRC 698’, ‘JRC 80', are available for cultivation. These varieties have a wider adaptability to varied agro-climatic situations and have made possible the jump in average fibre yield to 2.3 tons/ha at the national level.

The genetic base of our elite jute and mesta varieties is quite narrow. The 12 *C. olitorius* and 13 *C. capsularis* varieties released to date have been developed from 14 and 24 parental accessions, respectively, while in mesta only 9 different parental accessions have been used to develop the 11 varieties released so far. CRIJAF has a collection of 2899 and 1435 germplasm belonging to jute and mesta, respectively. Many of the germplasm possess desirable traits of tolerance to biotic and abiotic stresses as well as improved fibre quality, like fineness, strength, etc. *C. depressus* exhibited a higher degree of drought tolerance, and *C. trilocularis* showed a significant level of tolerance to water stagnation. *C. urticifolius* and *C. psuedocapsularis* exhibited resistant reactions to all diseases except soft rot and anthracnose, respectively. *C. psuedo-capsularis* gave the finest fibre (0.20 tex), followed by *C. urticifolius* (0.30 tex), *C. aestuans* (0.51 tex), *C. trilocularis* (0.77 tex), and *C. pseudo-olitorius* (0.95 tex). The fibre and bundle strength, however, were observed to be very weak as compared to *C. capsularis* and *C. olitorius*. The germplasm available in the CRIJAF Gene Bank is in the process of rigorous multi-location field screening and is being used in the breeding program.

Development of a high biomass cultivar for bioethanol production: JROB-2 (Purnendu), a *C. olitorius* jute variety, was developed through the γ-ray mutation of JRO-204. It produces high biomass (60–80 t/ha) along with a high fibre yield (40 q/ha). The stem has a high cellulose content (> 650 mg/g DW), making it suitable for bioethanol production. It can substitute the ethanol demand in India by 25%.

Development of jute and allied fibre genotypes with high nutrition value: A wild jute genotype IC0621650 (WCIN 009) was identified for its high iron content in leaves (173.75 mg/kg fresh weight). Five vegetable jute genotypes were tested in the National Trial for vegetable-purpose jute. Of these, JROV-5, with a yield of 149.3 q/ha, was found to be promising with a high leafy vegetable yield. A roselle genotype, HSLC-1, with a productivity of 42.7 q/ha of fresh calyx was advanced to an adaptive trial. It also has higher mineral contents than other roselle genotypes.

Seeds of ICAR-CRIJAF varieties dominate the jute sector in India and abroad

ICAR-CRIJAF is the nodal organization for the crop improvement program of jute and allied fibre crops in the country, and the institute successfully incorporated the desirable traits in the new varieties (Table 1-2 and 1-3). A number of short-duration, high yielding and prematurely flowering-resistant Olitorius varieties (Tossa jute) were developed, which replaced the area of about 90% of the *C. capsularis* varieties (White jute) and increased the fibre yield (national average) from 11 q/ha (1960s) to 27 q/ha. Similarly, the ruling varieties of flax, ramie, and sunn hemp have been developed by the institute. Presently, 5000 metric tons (MT) of certified seeds are required to cover around 700,000 ha of area in the country, 95% of which is from ICAR-CRIJAF-developed varieties. The spread of ICAR-CRIJAF-developed varieties is not only restricted in India but also in neighbouring countries like Bangladesh (>95%), Nepal (100%), Thailand, Myanmar, and Malaysia. About 4000 MT of the ICAR-CRIJAF-developed variety (cv. JRO 524) is exported to Bangladesh every year.

Table 1-2. Crop varieties of jute and allied developed in ICAR-CRIJAF

Crop	Varieties developed
Tossa jute (*Corchorus olitorius)*	JRO-204 (Suren), JBO-2003-H (Ira), S-19 (Subala), JROG 1 (Rithika), JRO 2407 (Samapti), CO-58 (Sourav), JROM 1 (Pradip), JROMU 1, JRO 524 (Navin)
White jute (*Corchorus capsularis*)	KJC 7 (Shrestha), JRC 9057 (Ishani), JRC 517 (Siddhartha), JRC 532 (Sashi), JRCM 2 (Partho)
Kenaf (*Hibiscus cannabinus*)	JRKM 9 1 (Satyen), Central Kenaf JBMP 2, JBMP 3 (Priya), JBMP 4 (Utkarsh), Central Kenaf JRHC 3
Roselle (*Hibiscus sabdariffa*)	CRIJAFR-5 (Central Roselle Ratna), JRR 17 (Ayush), CRIJAF R-2 (Roselle Vardan), CRIJAF R-8 (Roselle Sampurna), JRHS 1
Sunnhemp (*Crotalaria juncea*)	JRJ 610(Prankur), SUIN 03(Kavita), SUIN 053 (Swastik),
Flax (*Linum usitatissimum*)	JRF 2 (Tiara)
Ramie (*Boehmeria nivea*)	R 1411 (Hazarika), R1411 (Kanai)

Table 1-3. Jute growing states in India

State	Jute variety
West Bengal	JRO-204 (Suren), S-19 (Subala), JBO-2003H (Ira), JRO-8432 (Shakti), JRO-128 (Surya), JRO-66 (Golden Jubilee Tossa), JRC-80, JRC-698, CO-58 (Sourav), JBO-1 (Sudhangshu), JBC-5 (Arpita), RRPS-27-C-3 (Monalisa)
Bihar	JBO-2003H (Ira), JRO-204 (Suren), S-19 (Subala), JRO-8432 (Shakti), JRO-128 (Surya), JRO-66 (Golden Jubilee Tossa), CO-58 (Sourav), JBO-1 (Sudhangshu), JRC-698, JBC-5 (Arpita), RRPS-27-C-3 (Monalisa)
Assam	AAUOJ-1 (Tarun), JBO-2003H (Ira), JRO-204 (Suren), S-19 (Subala), JRO-8432 (Shakti), CO-58 (Sourav), JBO-1 (Sudhangshu), JRC-698, JRC-80, JBC-5 (Arpita), RRPS-27-C-3 (Monalisa)
Orissa	JBO-2003H (Ira), JRO-204 (Suren), S-19 (Subala), JRO-8432 (Shakti), JRO-128 (Surya), JRO-66 (Golden Jubilee Tossa), CO-58 (Sourav), JBO-1 (Sudhangshu), JBC-5 (Arpita), RRPS-27-C-3 (Monalisa)

Jute biotechnology

Sequencing of the jute genome: The genome of the leading dark jute (*Corchorus olitorius*) variety JRO 524 (Navin) was sequenced in collaboration with ICAR-NIPB. The 377.3 Mbp genome contains 57,087 protein-coding genes and a large number of (1765) disease resistance and defence response genes. This would provide new insights that could help to understand bast fibre biogenesis, mechanisms of photoperiodic control of flowering, and responses to several stresses in jute to help breeding of high-yielding jute varieties.

Jute marker database: A database of a large number of molecular markers, including simple sequence repeats (SSRs), introns, and transposable element-derived markers, was developed for the easy access of jute breeders, researchers, and students. These markers were developed from the published genomic resources of jute and can be used for genetic diversity estimation of jute germplasm, marker-assisted breeding, tagging of important traits, and genetic characterizations of jute and related bast fibre plants.

Population genetic analysis of jute: Individual-based restriction site-associated DNA sequencing (RADseq) of a dark jute (C. *olitorius*) association mapping population was performed. The population was comprised of Indian and exotic fibre-type cultivars, landraces, improved lines, and varieties collected from 15 countries. The RAD analysis was able to conclusively distinguish between Indian and African populations and demonstrated that bast fibre production was artificial, while abiotic and biotic stresses were natural selection pressures in *C. olitorius* adaptation.

Viable agro-technology for crop production and ecosystem services

Crop production packages developed: Recommended crop production packages have been developed for jute and allied fibre crops and have been widely adopted among farmers in different states. The average yield of jute has improved during the last two decades, from 20 quintals per hectare in the late 1990s to 27 quintals per hectare in 2020–21.

Integrated fertilizer prescription system for nutrient management: Soil-test-based fertilizer prescriptions for jute, mesta, sunn hemp, rice, wheat, lentil, mustard, and garden pea has been developed on the alluvial soils in eastern India, taking into account the nutrient requirements and contributions of NPK from the nutrient sources (soil, fertilizer, and farmyard manure). The fertilizer prescription equations can successfully be used in the larger part of alluvial soils of eastern India as effective guides for efficient integrated nutrient management to reduce the cost of cultivation, increase fertilizer-use efficiency, and maintain soil fertility with judicious use of organic manure with chemical fertilizers. By following the ready table, farmers are saving NPK fertilizers and reducing the cost of cultivation under a jute-based cropping system.

Soil organic matter under long-term multiple cropping and fertilization: Long-term fertilizer experiments (45 years) with continuous cropping and NPK fertilizer application, either alone or in combination with FYM, maintained active and slow pools of C and N at the surface (0–15 cm depth). The pronounced effect of an integrated plant nutrient supply system on the distribution of organic matter among labile and slow pools is an indication of its greater impact on soil fertility improvement. A more efficient and integrated nutrient supply strategy is being advocated to sustain long-term productivity and soil quality under such cropping sequences.

Viable jute-based cropping systems for cereal-cropped areas: Four cropping systems (jute-rice-wheat, jute-rice-baby corn, jute-rice-garden pea, jute-rice-mustard-mung bean) were developed. Among different jute-based cropping systems, jute-rice-baby corn, jute-rice-garden pea, jute-rice-mustard and lentil have been recommended for farmers as the most viable options, as they recorded higher system productivity, water use efficiency, energy productivity, net returns, and benefit cost ratios.

Intercropping for profitability and stability in jute production: ICAR-CRIJAF has introduced non-competitive and short-duration green gram as an intercrop into sole jute to salvage the risk perturbed by monocropping. Jute intercropped with green gram registered a weed-smothering efficiency of 56 percent. Thus, higher yield and profit were realized by the farmers with the introduction of such intercropping in a jute-growing field during the summer season.

A promising approach to alleviate moisture stress for increased fibre crop production: The agronomic practices have been developed by ICAR-CRIJAF for jute and roselle production in the summer season with the aim of saving irrigation water without affecting crop productivity. The open furrow sowing with the recommended dose of NPK fertilizer and 1 or 2 lifesaving irrigations saved a significant amount of irrigation water compared to normal sowing (flatbed method) without reducing jute and rainfed roselle yield. The depth of irrigation for jute crops in row sowing compared to normal implies a significant reduction in irrigation water requirement by 40–50%. Application of sulphur helped to sustain the productivity in sulphur-deficient soils. Soil mulching further reduces weed competition and increases yield by supplying higher soil water content in dry periods after the first irrigation.

Integrated approach to weed management in jute and allied fibres: Scientists at CRIJAF developed Nail Weeder, Single Wheel Jute Weeder, and Herbicide Applicator to control composite weed flora at the early growth stages of jute and other allied fibre crops. These systems can control about 70–80 percent of the total weed flora.

Ecosystem based climate resilient agriculture

Jute plants are a huge source of renewable biomass and can sequester 3.80 t/ha of carbon from the atmosphere. Through the cultivation of jute in a 750,000 hectare area, India absorbs about 2.85 MT of CO_2 from the atmosphere every year. The CER (certified emission reduction) revenue per hectare out of jute cultivation can be up to 101 million per year, which may be shared proportionately with jute industries and farmers. The carbon footprint of bast fibres is 20–50% lower than that of synthetic or artificial fibres. The adoption of jute-based integrated soil-crop system management helped in reducing the carbon footprint by 78%. Net CO_2-eq emissions were 68% less as compared to other systems. JRO 204 and NJ 7010 cultivars of jute were found to be tolerant to high ozone concentrations (>40 ppb h) and recommended for cultivation in areas suffering from high O_3 concentrations. Sunn hemp green manure (GM) is a nitrogen (N) resource that can replace a substantial amount of chemical fertilizers (CFs) in late-summer or rainy-season field crops to meet about 50% of the N demand of the crop under integrated nutrient management. Compost from leaf litter and crop waste with effective microorganisms and sunn hemp green plants can help in reducing about 2600 g of CO_2 emissions per kg of NPK use over chemical fertilizer. The practices of crop residue retention and minimum tillage provided an increased supply of carbon and nitrogen through better biological activity in the soil. Increase in moisture availability throughout the soil profile by reducing evaporation loss, increasing infiltration, and increasing soil moisture retention.

Agro-advisories Services: ICAR-CRIJAF has provided prompt contingency plans and emergency agro-advisories during the sudden cyclone (AMPHAN and YAAS) attacks in the peak jute growing season, which saved over 100,000 hectare of jute crops that were badly affected by cyclone and post-cyclone disease problems. Agro-advisory services prepared by a multi-disciplinary team of scientists emphasizing real-time information flow on innovative and sustainable technologies, along with weather forecasts and best practices for crops, were instrumental for farmers and other stakeholders during the lockdown period. Agro-advisory released at a 7–10 day interval was made simpler with pictorial farming tips as per the phonological stage of the crop in Hindi and Bengali to cater to a larger section of the users of jute-growing states. This service has helped farmers, extension officers, and field functionaries to solve jute farming-related problems. The farmers were also responded to, and their problems related to jute farming were addressed with proper technology backstopping in time.

Farm Mechanization: The ICAR-CRIJAF has developed many farm implements for small and marginal jute and allied fibres' farming communities.

Multi-row Seed Drill: The ICAR-CRIJAF Multi-Row Seed Drill is a low-cost manual seed sowing machine. It reduces the seed rate by 50%, i.e., 3–4 kg/ha, and saves labour for weeding and thinning.

Improved Multi-row Seeder: The ICAR-CRIJAF improved multi-row seeder is a light-weight, four-row manual seed sowing machine for line sowing of jute and other small-seeded upland crops. The durable and transparent seed box facilitates the visibility of seed quantity in the box during operation. The larger ground wheels with pegs and the bearings attached to the drive shaft of the machine facilitate easy movement of the machine on tilled soil. There is a reduction of about 50% of the seed requirement, i.e., 2.8–3.0 kg/ha, against 6–7 kg/ha in the broadcast sowing method.

Nail Weeder: CRIJAF Nail weeder has been developed to weed out young composite weed flora, including germinating ones, from line-sown and broadcast field crops (jute, mesta, cereals, pulses, vegetables) since 3–7 days of crop sowing.

Single Wheel Jute Weeder: It is a manual-operated weeding device for controlling composite weed flora in line-sown upland crops. The effective field capacity (EFC) of the machine is about 0.028 ha/hr, so 35 man-hours are required for weeding a one-hectare area.

Herbicide Applicator: The ICAR-CRIJAF herbicide applicator eliminates the risk of crop damage by directed herbicide application and is effective for other crops as it has no drift hazard.

Ramie and Sisal Fibre Extractor: It is a portable ramie and sisal fibre extractor/decorticator operated by a single-phase 3-hp electric motor that is used to extract fibre from both ramie stems and sisal leaves. The throughput capacity and material capacity for sisal fibre extraction are about 330–380 kg leaves per hour and 12–14 kg dry fibre per hour, respectively.

Flax Fibre Extractor: It is a portable flax fibre extractor operated by a single-phase 1 hp electric motor that is used to extract fibre from retted and dried flax stalks. To extract fibre from a one-hectare area, it needs about 22 working days, i.e., 44 man-days, for its operation.

Pest and diseases management

Management of insect pests of jute: Based on single- and multiple-pest economic injury levels, two sprays of spiromesifen 240 SC at 0.7 ml/litre at 36 and 46 days after sowing (DAS) against yellow mite and two sprays with profenophos 50 EC were recommended at 66 and 76 DAS for hairy caterpillar and semilooper caterpillar when the mite population exceeds 42 mites/cm^2 on the second unfolded leaf and damage caused by lepidopteran pests is 10% plant damage, respectively.

Chemical control of mealybug and spiral borer in kenaf: Preventive seed treatment with imidacloprid 600 FS followed by a foliar spray of profenophos 50 EC at 2.5 ml/liter or chlorpyriphos 20 EC at 2.5 ml/liter of water is highly effective in protecting the plants against mealybug, flea beetle, and spiral borer in kenaf.

Bleaching powder as an alternative for the management of jute stems: Preventive soil application of bleaching powder at 30 kg/ha before 7 days of sowing is recommended for stem rot disease control in jute. It is attributed to increasing soil pH and direct detrimental effects on pathogens without adverse effects on beneficial microbes.

Preventive management of stem rot of jute: Sowing the jute crop in the first week of April integrated with the application of tebuconazole 25.9 EC (0.1%) as a seed treatment and foliar spray at 45 days after sowing (DAS) is effective in the management of stem rot disease, which significantly reduces the stem rot incidence and further spread of the disease until 120 DAS.

Production of disease-free quality jute seed by altering sowing dates and fungicide scheduling: Sowing of the jute seed crop during mid-August, followed by foliar spraying of carbendazim 50WP at 0.01% either at pod maturity or pod setting stage, is the most effective method for reducing the seed infection and maximizing the quality of the jute seed yield with higher viability.

Multiple pest economic injury level an indicator for pest management in jute: Based on single- and multiple-pest economic injury levels, two sprays of spiromesifen 240 SC at 0.7 ml/lit at 36 and 46 DAS against yellow mite and two sprays with profenophos 50 EC were recommended at 66 and 76 DAS for hairy caterpillar and semilooper caterpillar when the mite population exceeds 42 mites/cm^2 on the second unfolded leaf and damage caused by lepidopteran pests is 10% plant damage, respectively.

Isolation and characterization of sex pheromone components of jute semilooper: The technology for isolation, characterization, and evaluation of the female sex pheromone of the jute semilooper was standardized. The female sex pheromone of jute semilooper was isolated from the pheromonal glands of virgin females. The blend of (6Z, 9Z)-heneicosadiene and (3Z, 6Z, 9Z)-heneicosatriene in a 3:1 ratio can be effectively used as a tool for monitoring jute semilooper, which perfectly fits in the IPM of jute insect pests.

Jute retting

Microbial formulation CRIJAF SONA: The institute has developed an improved jute retting process with the microbial formulation CRIJAF SONA. This microbial formulation consists of three very efficient pectinolytic strains of Bacillus spp., which have very high pectinolytic and xylanase activities without any cellulase activity. The technology reduces the retting duration by 6–7 days and also improves the fibre quality by at least 1–2 grades. It increases fibre yield by 8–10% and provides an additional income of ₹12,000–15,000/ha. It also minimizes the water requirement by 75% and increases water use efficiency by 2 to 3 times.

Cement tank-based retting of jute and mesta with free-flowing water: To improve the fibre quality, ICAR-CRIJAF has also initiated a project named 'Cement tank-based retting of jute and mesta with free-flowing water'. Retting with free-flowing water with CRIJAF SONA will help quality jute production to become 100% self-reliant, paving the way for affordable, sustainable, and eco-friendly natural biodegradable fibre which can be used for versatile diversified applications by substituting plastics and synthetics which will facilitate the creation of a clean and green environment.

In-situ tank-based self-reliant eco-farming: The availability of water for jute retting and the high cost of transportation of jute bundles from the field to the nearest waterbody are the main constraints for jute cultivation. To create water resources, improve the fibre quality, and reduce the cost of cultivation, ICAR-CRIJAF has developed an in-situ retting tank-based self-reliant eco-farming system near the jute farm to harvest rainwater in a tank where retting can be done. It requires only 3 to 5% of one acre of land for the retting of one acre of jute plants in a staggered manner for the production of high-grade fibres. The farmers can get an additional income of ₹25000–30000 per acre by adopting such a system, besides reducing their carrying costs.

ICT-based agro support

Farmer-friendly ICT tools have been developed to disseminate the agro-advisory on mandated crops through mobile apps, WhatsApp, SMS, websites, and local media. Besides, ICAR-CRIJAF has developed several expert system apps and databases, like JAFexpert, JuteMet, JuteMarkerdb, JAF-Safe, JAF-Kisan, and CRIJAF-Advice, for obtaining and disseminating information on different aspects of cultivation, pest management, and meteorological parameters related to JAF crops.

JAFexpert: A web-based expert system containing information on the growing of jute and allied fibre crops like mesta, sunn hemp, ramie, sisal, and flax to help farmers and extension workers to effectively manage these fibre crops.

JuteMet: A web-based agro-meteorological database management system cum-agro-advisory system for management of climate data for disseminating weather-based agro-advisory services on jute and allied fibre crops to help farmers and other stakeholders. It covers the whole jute-growing area of India. The advisory contains general as well as dynamic advisory systems.

JAF-Safe: An Android-based app dealing with the identification, nature of damage, and management of insects and diseases of jute and allied fibre crops. JAFsafe makes the farmers better acquainted with the pest problems in the jute crop vis-à-vis their proper and economical management practices.

JAF KISAN: The institute has also developed the JAF-KISAN app for yield gap analysis of jute between the potential yield and actual yield.

JUTE AGRI: An Android app for the dissemination of information on the present status of the sector, improved varieties, production and protection technologies, and marketing of jute.

Value addition and value chain establishment

During the last five years, ICAR-CRIJAF has undertaken various activities, like training and demonstration programs, to strengthen the SHGs and FPOs in West Bengal. Capacity-building programs were organized for the women self-help groups formed under the Farmers' Producer Organisation (FPO). Technical support was extended to three FPOs in the North 24 Parganas, covering around 1600 farmers and farmwomen. Two self-help groups (SHGs) each from three FPOs in the North 24 Parganas were trained in the value addition of jute fibre and fabrics in order to facilitate the FPOs in building their business plans. In addition to this, necessary linkages were created with the FPO through ICAR-CRIJAF and the Farm Science Centre (KVK) for need-based technical support to the farmers' interest groups registered with the FPO. ICAR-CRIJAF has taken initiatives in developing the value chain in jute by putting special emphasis on the value addition of jute and allied fibres. Farmwomen from jute-growing areas were trained on making jute bags and fibre-based handicrafts. These farmwomen were organized into different self-help groups. The groups are further linked with the Farmers Producers Company (SAFPCL) for easy procurement of raw materials and marketing of final value-added products. The value chain is being established with the involvement of all the stakeholders, right from seed production to jute fibre based diversified products.

Jute-diversified products as alternatives to plastic and synthetics: A series of possible jute-based diversified products are identified, and the probable quantity and fibre requirement (245,000 bales) is also estimated.

These jute-diversified products can replace plastics and synthetics to a great extent. To improve the socio-economic conditions of jute farmers through value chain creation, linkages have been established with the FPO and the SAFPCL by forming the Farmers Interest Groups (FIGs).

Initiative for by-product utilization of jute and allied fibre: The jute variety (JROB-2) developed by the institute has a high biomass yield coupled with a high potential fibre yield (41 q/ha). It also has higher cellulose content in its green biomass, making it suitable for biofuel production. A project sponsored by the Department of Science and Technology (DST) on the conversion of jute biomass to biofuel showed good promise for biofuel production from JROB-2 compared to existing jute varieties like JRO 524. A kenaf variety MT 150 is ideal for paper pulp production (60 tonne green weight per ha). The newsprint produced from MT 150 is excellent in quality, even better than Russian and Canadian newsprints. On average, 8 tons of paper pulps are expected from 1 ha of kenaf cultivation. Four entries have been identified for consumption as leafy vegetables. Initial screening of methanolic extracts from jute leaves identified several health-promoting phenols and flavonoids. Transcriptome characterization and downstream analysis led to the identification of over 300 genes involved in the biosynthesis of phenylpropanoids and flavonoids in jute. The nutritive value of jute leaf may help to boost immunity. Roselle calyces can be used for different purposes, like the preparation of chutney, pickles, soup, or vegetables, in different parts of the country. Roselle juice has high medicinal value as well.

Outreach program

Different technologies, namely (i) certified quality seed of improved tossa jute variety (JRO 204), (ii) line sowing of jute by CRIJAF multi-row jute seed drill, (iii) mechanical weeding by CRIJAF Nail Weeder, and (iv) improved microbial jute retting technology using CRIJAF Sona, etc., are largely transferred among the growers of jute and allied fibres in West Bengal, Bihar, Assam, and Odisha through various schemes like the National Food Security Mission (NFSM), National Innovation for Climate Resilient Agriculture (NICRA), Scheduled Caste Sub Plan (SCSP), Tribal Sub Plan (TSP), Mera Gaon Mera Gaurav (MGMG), and the Improved Cultivation and Advanced Retting Exercise (Jute-ICARE) programs. An area of 538,000 ha was covered under JUTE-ICARE with improved production technologies, including a new variety, a seed drill, and a nail or single-wheel jute weeder. More than 1,100,000 farmers were covered under the program. Improved seeds of jute, CRIJAF SONA for retting, and small farm implements like a nail weeder, a single-wheel jute weeder, a multi-row seed drill, etc. were provided to farmers in all the jute and allied fibre crops growing states.

Human resource development and training: National and state-level trainings and farmer-scientist interactions were conducted regularly for the capacity enhancement of farmers, researchers, and extension officials of the country with the latest technical know-how. These programs cover holistic production technologies pertaining to jute and allied fibre crops. Short-duration (5 days) as well as long-duration (21 days) training programs on entrepreneurship development through diversification of jute products are also conducted on a regular basis for farmwomen of weaker sections to produce diversified products from jute fibre and market the same through a cooperative approach. The Institute has been successful in mobilizing financial support from the Directorate of Jute Development, the National Jute Board, the Jute Corporation of India, the Ministry of Agriculture and Farmer's Welfare, and the Government of India for conducting different training programs.

Field Extension Centre Model: The institute has emphasized a location-specific approach for agricultural technology promotion and adoption in improving the livelihood of the small farmers in extensive jute-growing districts of West Bengal by establishing field extension centres. The extension personnel deployed in the centres collect grassroots-level information on socio-economic status, yield gap, available resources in the villages, and the causes of low productivity at first instance. Village-level master's trainers are trained to prioritize technological solutions to augment jute productivity. This model improved the forward linkage and has reached a large number of farmers in the selected and/or adopted villages.

Significant advancements made in R&D of jute and allied fibres

1. The first fertile sexual hybrid of the two cultivated jute species from a cross between *C. capsularis,* cv. JRC 212 (♀) and *C. olitorius,* cv. JRO 524 (♂) was developed.
2. Restriction site-associated DNA (RAD) sequencing-based (1115 RAD-SNPs) population genomic analyses revealed the genetic basis of selection for geographic adaptation in tossa jute was resolved.
3. Multi-parent and advanced generation cross (MAGIC population) were developed by crossing 20 parents and advanced to ML4-RI6 (1023 MAGIC lines (MLs) representing 341 ML families).

4. Crossing barriers in inter-specific crosses in the genus *Crotalaria* were delineated.
5. The draft genome of Tossa jute (377.3 Mbp) of Olitorius cv. JRO-524 (Navin) was sequenced. This is the first whole genome sequence for a *C. olitorius* genotype derived from African jute.
6. Mitogenome sequences of cultivated jute were decoded. Mitochondrial genomes of the two cultivated species (*C. capsularis* and *C. olitorius*) were assembled, with genome sizes of 1.9 MB and 1.8 MB, respectively.
7. The bast transcriptome of jute helped to decipher lignin biosynthesis pathways. Cinnamyl alcohol dehydrogenase 7 (CAD) was identified as a promising target for developing low-lignin jute fibres.
8. Transcriptome profiling of jute hypocotyl provides the first clue as to how β-galactosidase influences hypocotyl development in a fast-growing plant.
9. De novo transcriptome assembly of the shoot-apex transcriptome of a delayed flowering mutant identified differentially regulated photoperiodic genes for short-day early flowering.
10. System productivity analyses of the jute-based cropping system established that the jute-rice-vegetable pea cropping system is a profitable and sustainable cropping system in the Indo-Gangetic plain.
11. The candidate aquaporin genes involved in fibre biogenesis and drought stress responses were identified.
12. Heat shock factor proteins involved in heat response in flax are characterized for developing terminal heat-tolerant flax genotypes.
13. With the cultivation of jute in a 750,000 hectare area, India absorbs about 2.85 MT of CO_2 from the atmosphere every year.
14. The carbon footprint of bast fibres is 20–50% lower than that of synthetic or artificial fibres.
15. Adoption of jute-based integrated soil-crop system management helped in reducing the carbon footprint by 78%.
16. JRO 204 and NJ 7010 cultivars of jute were found to be tolerant to high ozone concentrations (>40 ppb).
17. Sunn hemp green manuring can reduce 50% of the N demand of the crop under integrated nutrient management.
18. Compost from leaf litter and crop waste can help in reducing about 2600 g of CO_2 emissions per kg of NPK use over chemical fertilizer.
19. The practices of crop residue retention and minimum tillage can provide an increased supply of carbon and nitrogen in soil through better biological activity in soil.

20. Carbon and nutrient dynamics under long-term nutrient management in the rice-wheat-jute system established that jute enhances carbon sequestration in soil.
21. Transcriptome analysis of nano-formulation-treated jute helped to understand the molecular mechanism of nano-silica-based mortality in the hairy caterpillar (HC) (*Spilosoma obliqua*).
22. Genome sequencing of the fibre-retting bacterial consortium (CRIJAF SONA) allowed comprehensive genomic analyses of three bacterial strains (PJRB 1, 2, and 3) of the consortium.
23. We resolved the pectin biosynthesis pathways in jute for improving retting and fibre quality.
24. Eddy Covariance established that the jute ecosystem acts as a carbon sink and sequester of 2.68 t C/ha during a 110-day period.

FROM BREEDING TO BIOTECHNOLOGICAL ADVANCEMENT

CHAPTER 2

PLANT GENETIC RESOURCES IN JUTE AND ALLIED FIBRES: MANAGEMENT AND UTILIZATION

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Introduction

Plant genetic resources of a crop species represent its genetic variation in the form of reproductive or vegetative propagating material of landraces, wild and weedy species, wild relatives, new, extant, and obsolete varieties, special genetic stocks including DNA, pollen, and the cell having a functional unit of heredity. Having actual and potential immense value as a resource for present and future generations, these have been the foundation of the development of agriculture for the last 12,000 years. The activities in plant genetic resource management include germplasm exploration and collection for tapping genetic diversity from different sources, including the centre of origin and diversity, characterization and evaluation for estimating actual and potential value, and conservation for safeguarding and reducing genetic erosion. Its utilization leading to varietal development, prebreeding, and specific trait transfer is of great importance in crop improvement programs, particularly when broadening the genetic base through diversification in parentages of new varieties.

Jute and allied fibre crops, namely mesta (kenaf and roselle), flax, ramie, sunn hemp, and sisal, are of pivotal importance as natural vegetable fibres used in the textile, paper, and automobile industry, as convenient packaging material, and as a diversified product where jute is only second to cotton in its importance. Like food crops, fibre crops, viz., cotton, flax, and sunn hemp primarily stem from domestication by human civilizations, as evident from archaeo-botanical studies (Weber 1991, Good 2007). The association of jute with human civilization as reported by researchers

(Good 2007, Wright et al. 2012) during their archeo-botanical studies at Mesopotamia and Indus civilization sites indicates that jute fibres were also used as a textile fibre from ancient times, apart from cotton and flax. Among the fibre crops, jute and allied fibre crops are the second most produced after cotton, with around 30 million metric tons of natural fibre of plant origin produced globally. Cotton usually accounts for 80%, followed by jute contributing 10%, and allied fibres like mesta, flax, ramie, and sisal less than 1%. Thus, collection, evaluation, and conservation of the genetic resources of these crops play a vital role in developing high fibre yielding and wide-adapted cultivars and also in ensuring improved production and productivity of these fibre crops for diverse applications.

Though jute and mesta are thought to have originated in African countries, their major cultivation is concentrated in Asian countries, and most of the genetic resource management activities, including collection, conservation, and utilization, as illustrated in Fig. 2-1, are being accomplished in Asian countries (India, Bangladesh, and China).

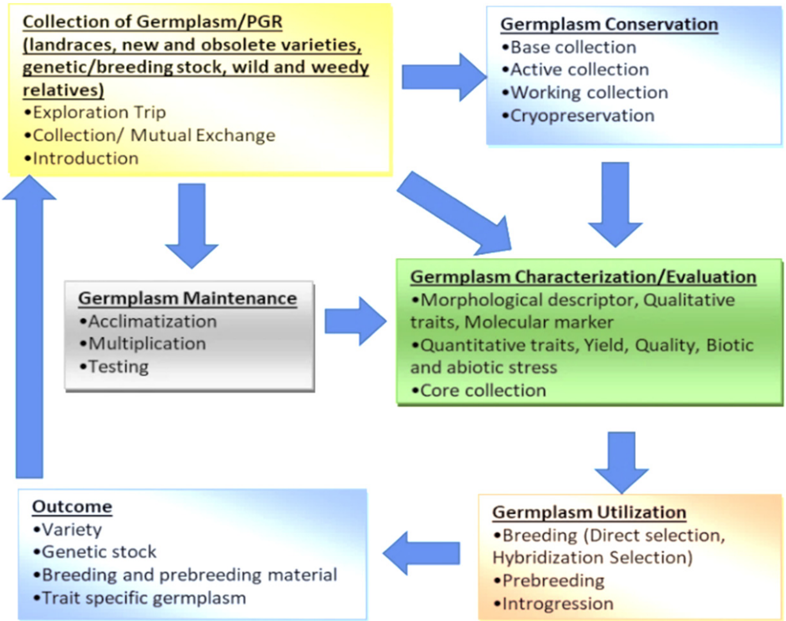

Fig. 2-1. Schemetic presentation of plant genetic resource management of jute and allied fibres

In India, ICAR-NBPGR, New Delhi, acts as a base collection centre for all the crops, including fibre crops, and ICAR-CRIJAF, Kolkata, acts as an active collection centre for jute and allied fibre crops. At present, India conserves a total of 6060 germplasm accessions of jute and allied fibre crops, followed by Bangladesh, with 5,936 species comprising 15 species of Corchorus, 22 species of Hibiscus, and 15 allied fibre species (Haque et al. 2007). However, Xiong (2008) reported that around 10,970 germplasms of bast fibres are conserved in China, out of which 1946 belong to jute, comprising 11 species.

Origin and distribution of species

Jute (*Corchorus* spp.): The Genus *Corchorus* belongs to the spermanniacea family with a chromosome number of 2n = 2x = 14 except for seven natural tetraploid wild species, viz., *C. junodii, C. pascuorum, C. cunnighamii, C. hirtus, C. argutus, C. siliquosus,* and *C. orinocensis* (2n = 4x = 28), which comprise more than 100 species distributed in the tropics and subtropics of the world. Among these, only two species, namely *C. olitorius* (tossa jute) and *C. capsularis* (white jute), are cultivated in Asian countries like India, Bangladesh, and, to some extent, China, for their importance as natural bast fibre**.** The primary centre of origin of *C. olitorius* is Africa, with India or the Indo-Myanmar region being the secondary centre of origin, whereas *C. capsularis* is reported to have originated in Indo-Myanmar, including south China (Kundu 1951). On the contrary, both species are suggested to have originated in Africa (Kundu et al. 2013). Different wild species are reported to be distributed mostly in Africa. South Africa is the richest source of diversity, with 16 species, followed by Tanzania with 13 species, Zimbabwe, Ethiopia, and Mozambique each with 12 species, and Kenya with 11 species. Zambia has nine species of the wild taxa of *Corchorus* (Edmonds 1990). In Asia, wild species are distributed in India, Bangladesh, Pakistan, Thailand, and Indonesia. In India, eight wild species of *Corchorus* (*C. aestuans, C. depressus, C. fascicularis, C. pseudo-olitorius, C. tridens, C. trilocularis, C. urticifolius,* and *C. velutinus*) in addition to two cultivated species have been reported (Mahapatra et al. 1998). *C. aestuans* is the most dominant wild species in India, distributed all over the area, followed by *C. tridens* and *C. trilocularis,* restricted to the western, central, and southern parts of the country. *C. urticifolius* and *C. pseudo-capsularis* are distributed in Tamil Nadu, while *C. pseudoolitorius* is in the western part, and *C. depressus* is in the semi-arid regions of Gujarat, Rajasthan, Tamil Nadu, and Punjab (Mathur and Sundaramoorthy 2008). Most of the wild species