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Research on jute (*Corchorus olitorius* and *C. capsularis*) and kenaf (*Hibiscus cannabinus* and *H. sabdariffa*): present status and future perspective

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ABSTRACT

About 5 million people get employment in raw jute (jute and kenaf) farming, trading and industry though the crop occupies only 0.55% of the gross cropped area of the country. The productivity of jute had doubled from 1.10 tonnes/ha during 1947 to about 2.24 tonnes/ha in 2006–07 made possible through development of high-yielding varieties and improved production technologies though the acreage remains stagnated around 0.80 million ha. Significant improvement in fibre quality has been attained during this period. The changing climate coupled with variable soil conditions had often exposed the crop to more biotic and abiotic stresses which are affecting the yield and fibre quality and is also creating considerable regional disparity in yield level of the crop. Stiff competition from low-cost synthetic fibres is compelling us towards product diversification and value-addition for which improvement in quality attributes is of paramount importance. This review, attempts to summarize the achievements made in jute and kenaf research and also strive to highlight the constraints faced by the raw jute sector along with its possible mitigation options.

Key words: Fibre yield, Jute, Kenaf, Fibre quality

Raw jute [jute (*Corchorus olitorius* L. and *C. capsularis* L.) and kenaf (mesta or roselle) (*Hibiscus cannabinus* L. and *H. sabdariffa* L.)] occupying only 0.55% of the cropped area, provide livelihood to 5 million people in farming, industry and trade involving 4 million farm families, 0.25 million industrial workers and 0.5 million traders in India. Raw jute farming alone supports about 10 million man-days of employment. During 1950–51, jute and kenaf together occupied 0.57 million ha with production and productivity of 3.31 million bales and 1.04 tonnes/ha and the corresponding figures for 2006–07 are 0.9 million ha, 10.4 million bales and 2.24 tonnes/ha, respectively (www.agricoop.nic.in, 2008). Significant increase in production and productivity were the result of advent of high-yielding varieties of the crops along with improved production technologies and appropriate policy interventions. India's export market share is estimated at around 30% of the global market valued at Rs 12 000 million. Incidentally, India earned Rs 1 200 crores as foreign exchange by exporting jute goods during 2005–06 as against Rs 233 crores in the early 1960s (Saha and Hazra 2008).

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Adoption of high-yielding and premature flowering resistant varieties of jute along with judicious crop husbandry were the key factors for doubling the productivity over a period of 50 years. Moreover, the crop duration has also been brought down from 5 to 4 month, which enabled jute to be fitted in multiple cropping sequences. Jute varieties, especially of 1970's, helped salvage this crop, otherwise it would have been in oblivion. A comprehensive review of the results of jute and kenaf (mesta/roselle) on different aspects is lacking. This review aims at providing the achievements in the jute and kenaf research and also brings to fore the constraints identified in the raw jute sector to make it viable globally.

Origin and distribution

Commercial jute cultivation is mainly restricted between 80°18′E–92°E and 21°24′N – 26°30′N in the Indo-Bangladesh sub-continent. Other major jute- and kenaf-growing countries are China, Thailand, Myanmar, Indonesia, Brazil and Nepal. Africa and Indo-Myanmar region were accepted as the primary and secondary centres of origin, respectively, for *C. olitorius,* while Indo-Myanmar region including South China has been considered as the centre of origin for *C. capsularis* (Kundu 1951). Only 10 species of *Corchorus* out of 210 available globally were recorded in India including the 2 cultivated species *C. capsularis* and *C.*

olitorius, and the remainder are wild (*C. aestuans* L., *C. depressus* Stooks L., *C. fasicularis* Lam., *C. psuedo-olitorius* Islam and Zaid, *C. tridens* L., *C. trilocularis* L., *C. urticifolius* Lam., and *C. velutinus* Her.) (Mahapatra *et al*. 1998). *C. aestuans* was the most dominating species, followed by *C olitorius, C. capsularis, C. tridens*, *C. trilocularis* and *C. fasicularis*.

Varietal development

Varietal developments in jute were initiated in the early part of 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**.** Plant height and basal diameter, having high correlation with fibre yield were identified as criteria for selection**.** Development of *C. capsularis* varieties, like 'JRC 321' and 'JRC 212' and *C. olitorius* variety 'JRO 632' increased the fibre yield from 1.0 to 1.25 tonnes/ha during the sixties (Saha and Hazra 2008). White jute varieties occupied more than 80% of the jute-growing areas till early seventies 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 a paradigm shift in jute farming with *tossa* replacing the other jute types in entire India. These *olitorius* varieties (particularly 'JRO 524') enabled jute to be juxtaposed in the multiple cropping sequence 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 wider adaptability to varied agro-climatic situations and made possible the jump in average fibre yield to 2.3 tonnes/ha at national level (Tables 1–4).

The genetic base of our elite jute and kenaf varieties is quite narrow. The 12 *C. olitorius* and 13 *C. capsularis* varieties released till 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 2 899 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 higher degree of drought tolerance and *C. trilocularis* showed significant level of tolerance to water stagnation. *C. urticifolius* and *C. psuedo-capsularis* exhibited resistant reaction to all diseases except soft rot and anthracnose, respectively. *C. psuedo-capsularis* gave 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* (Palve *et al*. 2004). Country-wise availability of trait-specific germplasm of jute had been enlisted in details by Mahapatra and Saha (2008). The germplasm available in CRIJAF Gene Bank are in the process of rigorous multi location field screening and are being used in the breeding programme.

Physiology

In general, *C. olitorius* is more responsive to short light period for flowering compared to *C. capsularis* and the critical photoperiod for flowering was observed to be 12.5 hr. The dry matter production potential of jute has been estimated as 25–30 g/m^2/day at 90–95% light interception level which represents the radiation-use efficiency of 2.89–3.50 g/MJ (Palit 1993) though the overall radiation use efficiency of the crop remains at around half of its maximum potential (Palit 1999). Higher rectangularity (nearly 4.5) in jute due to wider row and closer plant spacing leads to asymmetrical leaf area distribution over the field and poor radiation-use efficiency at early growth stage (Palit and Bhattacharya 1987). The leaf angle of cultivated jute ranges from +31° to –22° indicating the broad planophile canopy with drooping lower leaves. The initial leaf area development is slow but the leaf area index increases rapidly thereafter exceeding 4 at 40 days after sowing, 6 at 60 days after sowing and finally around 4 at harvest (110–120 days after sowing) (Palit and Bhattacharya 1982, 1987). Similarly, the crop growth rate increases slowly (about 0.5–0.7 g/m^2/day) during initial stage of growth (10–20 days after sowing) and thereafter increases exponentially, the average value over the growth period being 15 g/m^2/day (Palit 1993). White jute varieties showed higher growth rate compared to *tossa* jute varieties at the early stage, while the latter surpassed the former at the later stage (Gopalkrishnan and Goswami 1970). Under polyhouse condition, the relative water content (RLWC) in *capsularis* leaves was more than that of *olitorius* leaves both under wet and dry soil moisture regimes (Mitra *et al*. 2004). *C. capsularis* roots penetrated to a soil depth of 15–20 cm with extensive lateral branching, but *C. olitorius* possesses deeper tap root system with lesser lateral spread making the former more adapted to low-lying situation (Kar and De Sarkar 1961). Contrary to this, higher root depth in *capsularis* varieties was also observed by Mitra *et al.* (2004) at the early stage of crop growth. Goswami and Saha (1969), using P^{32} tracer, found that the root of both the species penetrated up to 60 cm soil depth or more with the lateral roots confined mostly to 10 cm. Application of N up to 90 kg/ha increased the root weight and number of secondary and tertiary roots/plant (Gupta and Dargan 1972). White jute showed better seed germination and higher transpiration rate compared to *tossa* jute under salinity stress. The wild species,

Table 1 Characteristic features of improved varieties of *white* jute (*C. capsularis* L.) in India

Variety	Developing Institute	Year of release	Parentage	Days to 50% flower	Optimum sowing time	Significant attributes	Average fibre yield (tonnes/ha)	Areas recommended
'JRC 321' (Sonali)	CRIJAF, Barrackpore, West Bengal	1954	Selection from indigenous type Hewti	120 –130	February to late March	Pods non-shattering type, produce finest quality fibre (1.5 tex); suitable for jute-cotton blended yarn and fabric	2.0 – 2.5	Suitable for low lying flood prone areas of North Bengal, Assam and Bihar
'JRC 212' (Sabuj Sona)	CRIJAF, Barrackpore, West Bengal	1954	Selection from indigenous type	150 –160	Mid-March to mid-April	Pods non-shattering type	2.5 – 2.8	Suitable for medium and uplands of entire *capsularis* belt
'JRC 7447' (Shyamali)	CRIJAF, Barrackpore, West Bengal	1971.	x-ray derivative of 'JRC 212'	150 –160	Mid-March to mid-April	Pods non-shattering type; responds to higher N dose	2.8 – 3.0	Suitable for medium and uplands of entire *capsularis* belt
'J'RC 4444' (Baldev)	CRIJAF, Barrackpore, West Bengal	1980	'JRC 212' × 'D 154'	150 –160	Early March to mid-April	Pods non-shattering type	3.0 – 3.2	Suitable for Orissa
'UPC 94' (Reshma)	Jute Research Station, Bahraich, Uttar Pradesh	1983	'JRC 321'× 'JRC 212'	130 –140	Late February to late March	Pods non-shattering type	2.5 – 2.7	Suitable for medium and uplands of entire *capsularis* belt
'Padma'	CRIJAF, Barrackpore, West Bengal	1983	'JRC 6165' × 'JRC 412'	140 –150	Late February to late March	Pods non-shattering type	2.5 – 2.8	Suitable for *capsularis* belt particularly the low lying flood prone areas of North Bengal, Assam and Bihar
'KC 1' (Jaydev)	Jute Research Station, Kendrapara, Orissa.	1992	Gamma-ray derivative of 'JRC 4444'	140 –150	Early March to mid-April	Pods non-shattering type	2.6–3.3	Suitable for Orissa
'JRC 698' (Shrabanti)	CRIJAF, Barrackpore, West Bengal	1999	Multiple crosses involving 13 parents.	120 –130	Mid-March to mid-April	Pods non-shattering type, fine quality fibre	3.0 – 3.5	Suitable for *capsularis* belt particularly the low lying flood prone areas of North Bengal, Assam and Bihar
'Bidhan Pat 3'	BCKVV, Kalyani, West Bengal	2000	'D 154' × 'D 18' (mutant)	110 – 115	Early March to early July	Pods non-shattering type; suitable for paper-pulp industry, can be harvested in 110 days	2.5 – 2.7	Low-lying flood-prone areas

(Contd . . .)

(Table 1. Concluded)

Variety	Developing Institute	Year of release	Parentage	Days to 50% flower	Optimum sowing time	Significant attributes	Average fibre yield (tonnes/ha)	Areas recommended
'Bidhan Pat 1'	BCKV, Kalyani, West Bengal	2001	Gamma-ray derivatives of 'D 154'	65 – 70	Early March to early August	Pods non-shattering type; can be harvested in 60–65 days	1.3 – 1.4	Low-lying flood-prone areas
'Bidhan Pat 2'	BCKV, Kalyani, West Bengal	2001	'D 154'× 'D 18' (mutant).	90–95	Early March to early July	Pods non-shattering type; can be harvested in 90–100 days	2.0 – 2.3	Low-lying flood-prone areas
'JRC 80' (Mitali)	CRIJAF, Barrackpore, West Bengal	2005	'CIN 114'×'JRC 321'	110–120	Mid March to early April	Pods non-lodging type; can withstand drought at early stage and waterlogging at later stage of growth	3.0 – 3.5	North Bengal, Assam, Uttar Pradesh

Source: Modified from Mitra *et al.* (2007)

viz *C. siliquosus*, *C. tridens* and *C. trilocularis* were reported to be more resistant to salinity than the cultivated species (Kar and De Sarkar 1957).

The leaf area index, leaf area duration, crop growth rate and biomass production of roselle were highest with closer spacing and increased N application, but net assimilation rate decreased with increase in N rate (Krishnamurthy *et al*. 1994a). The leaf area index, light interception, radiation use efficiency and biomass production of kenaf was found more affected by moisture stress than nitrogen shortage in Australia (Muchow 1992). The dry matter accumulation in leaf, bark, stick and root of kenaf was found maximum during 75–100 days (Ahmad *et al*. 1995). Roselle can withstand drought better than kenaf and both the species are susceptible to water logging.

Production technology

Sowing of *olitorius* jute in mid-April and harvesting it at 120 days after sowing, in general, recorded maximum fibre yield. Premature flowering resistant varieties, advanced or delayed the sowing of both *capsularis* and *olitorius* jute without much effect on fibre yield. In *olitorius* and *capsularis* jute, the optimum seed rate for fibre crop was 4–6 and 6–8 kg/ha, while the same for seed jute were 3–4 and 4–5 kg/ha when sown in mid-May to mid-June. In case of kenaf and roselle, maximum fibre yield is realized in May-June sowing with optimum seed rate of 11–13 and 13–15 kg/ha, respectively, under rainfed condition (Mitra *et al*. 2006). Seedling emergence, seedling vigour and seed yield was found to be positively correlated to seed size in jute (Bhattacharjee *et al*. 2000) and in kenaf (Paul 1993).

The results of All India Network Project on Jute and Allied Fibres trials revealed that optimum row spacing for *C. olitorius* and *C. capsularis* were found to vary between 22–25 cm and 25–30 cm, respectively, in different jute-growing states, while spacing of 25–30 cm between rows and 7–10 cm between plants were found optimum for kenaf and roselle (Mitra *et al*. 2006). Closer spacing produced higher biomass in roselle (Krishnamurthy *et al*. 1992) and significantly higher fibre yield of kenaf (Manzanares *et al.* 1997). Maximum seed yield was observed in jute with spacing of 40–45 cm×10 cm and a seed rate of 2–2.5 kg/ha when the crop was sown on mid-May to mid-June while in mesta, crop sown during end May to end June gave maximum seed with 40 cm×15 cm spacing and seed rate of 5–7 kg/ha (Mitra *et al*. 2006).

Promising location-specific cropping sequences identified through extensive trials under AINPJAF are listed on the next page.

Mixed cropping of jute, red amaranth (*Amaranthus tricolor* L.), white amaranth (*Amaranthus* sp.) and summer raddish (*Raphanus sativus* L.) produced 3.6 tonnes jute fibre, 1.9–2.9 tonnes red amaranth (at 21 days after emergence), 0.7–0.9 tonnes white amaranth and 0.57–0.9 tonnes summer

Land situation	Crop sequences	Location
Rainfed uplands	Jute–lentil, jute–blackgram, jute– greengram, jute–toria	North and South Bengal,
	Jute–blackgram–toria/wheat, jute–rice–toria, jute–toria	Assam
	Jute–mustard–cowpea	Orissa, Bihar, Uttar Pradesh
	Mesta–horsegram	Andhra Pradesh, Tamil Nadu
Irrigated uplands	Jute–rice–potato, jute–rice–vegetables, jute–rice–mustard	North and South Bengal, Assam Katihar, Bihar
	Jute–rice–potato/wheat/peaJute–rice–wheat, jute–radish	
	jute–onion, jute–berseem	
Rainfed lowlands	Jute–rice–lentil	Bengal, Bihar, Orissa, Uttar Pradesh

Source: Mitra *et al*. (2006)

raddish/ha under irrigated condition and fetched additional net returns of around Rs 4 000/ha (Ghorai 2007).

Around 80% of the total jute area of our country is under rainfed condition, while the remainder is in low-lying areas (Basu 1997). Jute crop is exposed to deficit water stress during the early phase of growth due to the uncertainty and poor distribution of rainfall. Young jute seedlings tend to wilt and flower early when subjected to low humidity (19% or below) and soil moisture (< 20%) (Patel and Mandal 1983). The critical water potential for germination of *C. olitorius* and *C. capsularis* seeds were found to be – 0.3 and – 0.5 Mpa, respectively, and the latter required lesser time (10 hr) than the former (18 hr) to germinate (Palit and Bhattacharya 1981). In its early growth stage, *C. capsularis* was found to withstand natural drought better than *C. olitorius*. The *capsularis* varieties subjected to acute moisture stress at early stage under field condition at Jhargram, West Bengal, gave 54–89% more plant height and accumulated 67% more biomass compared to *olitorius* ones, but the growth difference narrowed down at the later stage as *oltorius* picked up growth with time. In seed jute, the yield loss was to the tune of 69–78% as water stress significantly affected the yield-attributing characters in both *capsularis* and *olitorius* jute (Mitra *et al*. 2004). Imposition of waterlogging in jute under pot condition reduced plant height, basal diameter, leaf retention, photosynthetic rate, nutrient absorption and also the beneficial microbial population (Ghorai *et al*. 2005) and provision of drainage led to 2–3 fold increase in fibre yield of jute (Ghorai *et al*. 2003). Jute and mesta varieties of shorter duration suitable for early or late sowing had already been developed at CRIJAF which enabled the crop to escape both deficit and excess moisture stress. Still it is essential to determine the stage-specific water requirement of the crop and to ascertain the climatic risk involved in getting it, so that suitable mitigation options can be developed.

The jute tracts of India comprise nine agro-climatic zones based on the rainfall pattern and soil types. The soils are mostly colluvium, red and lateritic, calcareous and sandy loam to clay loam in texture. The alluvial soils of West Bengal, Assam, Bihar and Orissa are dominant in illitic clay, mostly acidic to neutral in reaction, low to medium in available N, medium to very high in available P, medium in K content and the organic carbon content varies between 4.2 and 12.0 g/kg. The red and laterite soils cover parts of Birbhum, Bankura, Midnapore and Purulia districts of West Bengal; Nagaon and south of Kamrup in Assam and Kendrapara of Orissa. These soils are dominated by kaolinite, rich in Fe and Al leading to high P fixation, mostly of poor fertility status and frequently suffer from moisture stress. Calcareous soils are found in parts of Bihar and Uttar Pradesh and the soils are characterized by high *p*H (7.5–8.5), high P fixation and low fertility status (Saha *et al*. 2008).

The nutrient uptake by 'JRO 632' *olitorius* jute producing 3.1 tonnes/ha of dry fibre was to the tune of 65 kg N, 52 kg P_2O_5, 163 kg K_2O, 128 kg CaO and 33 kg MgO/ha, while the same for 'JRC 212' *capsularis* jute producing 2.0 tonnes/ha of fibre was 84 kg N, 37 kg P_2O_5, 117 kg K_2O, 120 kg CaO and 49 kg MgO/ha, respectively. The nutrient requirement/kg dry fibre was 2.06 kg N, 1.66 kg P_2O_5, 5.18 kg K_2O, 4.70 kg Ca and 1.04 kg MgO in *olitrius* jute and in *capsularis* jute it was 3.14 kg N, 1.50 kg P_2O_5, 7.97 kg K_2O, 4.99 kg Ca and 2.15 kg MgO respectively (Mandal *et al*. 1976). The ratio between shoot growth and N, K uptake increased from 1.2: 1 at 45 days after sowing to 2.3: 1 at 105 days after sowing (maturity), whereas the ratio remained constant through out the growth for P uptake (Ahad 1988).

Nitrogen deficiency reduces the plant height as well as basal diameter in jute plants. The response of *tossa* jute to applied N varied from 30 kg N/ha at Nepal (Deo 1978) to 60 kg N/ha at Kendrapara, Orissa (Nayak *et al*. 1996). White jute (*C. capsularis* L.), on the other hand, responded up to 80 kg N/ha at Barrackpore, West Bengal (Anonymous 1976). Seed yield of jute increased significantly in *capsularis* up to 60 kg N/ha (Ray *et al*. 1995) possibly due to increased proportion of bolder seeds in the seed lot (Bhattacharya *et al*. 2000).

Maximum 10–12% of fertilizer P is utilized by the jute plants, thereby indicating the preference to soil P (Ray and Sinha 1973). The critical limit of soil P for jute has been estimated as 24 kg P_2O_5/ha (Goswami *et al.* 1971). The Fe-P was found to be the main source of P supply to jute (Ahad and Debnath 1989) while Doharey *et al*. (1980) reported that Al-P was major source of P in jute in neutral clay alluvial soil. The jute crop did not respond to applied K in the same

Table 2 Characteristic features of improved varieties of *tossa* jute (*C. olitorius* L.) in India

Variety	Developing Institute	Year of release	Parentage	Days to 50% flower	Optimum sowing time	Significant attributes	Average fibre yield (tonnes/ha)	Areas recommended
'JRO 632' (Baisakhi *Tossa*)	CRIJAF, Barrackpore, West Bengal	1954	Selection from indigenous type	130–140	Mid-April to end-April	Suitable for late sowing, pods shattering type	3.0 – 3.2	Medium and uplands of entire *olitorius* belt
'JRO 878' (Chaitali *Tossa*)	CRIJAF, Barrackpore, West Bengal	1967	'JRO 620'× 'Sudan Green'	180–200	Mid-March to end-April	Suitable for early sowing, pods non-shattering type, better fibre fineness and fibre strength	3.0–3.2	Medium and uplands of entire *olitorius* belt
'JRO 7835' (Basudev)	CRIJAF, Barrackpore, West Bengal	1971	'JRO 632' × 'Sudan Green'	180–200	Mid-March to end-April	Pods non-shattering type, withstand waterlogging to some extent at later stage	3.2 – 3.4	Medium and uplands of entire *olitorius* belt, not suitable for high rainfall areas
'JRO 524' (Navin)	CRIJAF, Barrackpore, West Bengal	1977	'Sudan Green' × 'JRO 632'	180–200	Mid-March to end-April	Suitable for early sowing, pods non-shattering type, fairly tolerant to yellow mite and root rot disease and drought, most widely cultivated	3.4 – 3.6	Medium and uplands of entire *olitorius* belt
'TJ 40' (Mahadev)	BARC, Trombay, Maharashtra	1983	Selection from inter-mutant cross.	140–150	Mid-April to end-April	Pods non-shattering type	3.0 – 3.5	Suitable for Orissa
'JRO 3690' (Savitri)	CRIJAF, Barrackpore, West Bengal	1985	'Tobacco Leaf '× 'Long Inter-node'.	130–140	Mid-April to end-April	Pods non-shattering type; better fibre quality	3.0 – 3.3	Medium and uplands of entire *olitorius* belt
'KOM 62' (Rebati)	Jute Research Station, Kendrapara, Orissa.	1992	Gamma-ray derivative of 'JRO 878'	135–145	Mid-March to late-April	Pods non-shattering	3.0 – 3.5	Suitable for Orissa
'JRO 66' (Golden Jubilee *Tossa*)	CRIJAF, Barrackpore, West Bengal	1998 days	Multiple crosses involving six parents	145–155	Mid-April to early May	Suitable for late sowing; pods non-shattering, fibre quality good (TD2 grade)	3.5 – 4.0	Medium and uplands of entire *olitorius* belt

(Contd . . .)

(Table 2 Concluded)

Variety	Developing Institute	Year of release	Parentage	Days to 50% flower	Optimum sowing time	Significant attributes	Average fibre yield (tonnes/ha)	Areas recommended
'JRO 8432' (Shakti)	CRIJAF, Barrackpore, West Bengal	1999	'IC 15901' × 'Tanganyika 1'	170–180	Mid-March to Late-April	Pods non-shattering type, resistant to pre-mature flowering	3.5 – 4.0	Medium and uplands of entire *olitorius* belt
'JRO 128' (Surya)	CRIJAF, Barrackpore, West Bengal	2002	'TJ 6' × 'Tanganyika 1'	170 – 180	Mid-March to end-April	Pods non-shattering type, resistant to pre-mature flowering	3.2 – 3.8	Medium and uplands of entire *olitorius* belt
'S 19' (Subala)	CRIJAF, Barrackpore, West Bengal	2005	('JRO 620' × 'Sudan Green')× 'Tanganyika 1'	170 – 180	Mid-March to end-April	Pods non-shattering type	3.5 – 4.0	Medium and uplands of entire *olitorius* belt
'JBO 2003 H' (Ira)	CRIJAF, Barrackpore, West Bengal	2007	('JRO 632'× 'Sudan Green')× 'Tanganyika 1'	170–175	Mid-March to end-April	Pods non-shattering type, resistant to pre-mature flowering; fibre quality TD2 grade	3.5–4.0	Suitable for entire tossa jute belt
'JRO 204" (Suren)	CRIJAF, Barrackpore, West Bengal	2007	'IDN/SU/053'× 'KEN/DS/060'	180–190	Early March to end-April	Pods non-shattering type, resistant to pre-mature flowering; finer fibre (2.38 tex)	3.6–4.0	Suitable for entire tossa jute belt
'AAOJ 1' (Tarun)	AAU, Jorhat, Assam	2007	'Tanganyika 1'× 'JRO 640'	120–125	Mid-March to end-May	Pods non-shattering type, resistant to pre-mature flowering	2.8–3.0	Suitable for entire tossa jute belt

Source: Modified from Mitra *et al*. (2007)

Table 3 Improved varieties of roselle (*Hibiscus sabdariffa* L.) in India

Variety	Developing Institute	Year of release	Parentage	Days to 50% flower	Sowing time	Area of adoption	Average fibre yield (tonnes/ha)
'HS 4288'	CRIJAF, Barrackpore, West Bengal	1967	'RT 1'×'RT 2'	170–180	Mid-April to mid-May	West Bengal, Assam, Tripura and Bihar	2.0–2.2
'HS 7910'	CRIJAF, Barrackpore, West Bengal	1977	'HS 4288'× 'RT 1'	170–180	Mid-May	West Bengal, Assam, Orissa and Bihar	1.0–2.0
'AMV 1'	ANGRAU, Amadalavalasa, Andhra Pradesh	1966	Pure line selection from local type	180–200	Mid-April to early-May	Andhra Pradesh, Orissa	1.5–1.6
'AMV 2'	ANGRAU, Amadalavalasa, Andhra Pradesh	1982	Pure line selection from local type	180–200	Early-May	Andhra Pradesh, Orissa	1.7–1.8
'AMV 3'	ANGRAU, Amadalavalasa, Andhra Pradesh	1989	'AMV 1'× 'ER 79'	180–210	End-April to early-May	Andhra Pradesh, Orissa	1.8–1.9
'AMV 4'	ANGRAU, Amadalavalasa, Andhra Pradesh	1991	'AMV 1'× 'AS 163'	180–200	May	Andhra Pradesh, Orissa	2.0–2.2
'GR 27'	CRIJAF, Barrackpore, West Bengal	2007	Mass selection of an exotic germplasm ('RIJ 012')		May–June	Andhra Pradesh, Tamil Nadu, Orissa, Bihar, West Bengal	2.7–3.0

Source: Modified from Mitra *et al*. (2007)

Table 4 Improved varieties of kenaf (*Hibiscus cannabinus* L.) in India

Variety	Developing Institute	Year of release	Parentage	Days to 50% flower	Sowing time	Area of adoption	Average fibre yield (tonnes/ha)
'HC 583'	CRIJAF, Barrackpore, West Bengal	1967	Selection from exotic germplasm (Nigeria)	160–180	End-April	West Bengal, Assam and Orissa	2.5–3.0
'AMC 108'	ANGRAU, Amadalavalasa AndhraPradesh	1982	Selection from local bulk collection	150–160	Mid-April to May	Andhra Pradesh, Bihar and Orissa	2.5–3.0
'MT 150'*	CRIJAF, Barrackpore, West Bengal	2005	Pure line selection from exotic germplasm (Nigeria)	160–180	Mid-April to mid-May	West Bengal, Assam, Tripura, Bihar Orissa and Andhra Pradesh	2.5–3.0

Source: Modified from Mitra *et al*. (2007) *This variety has been released for production of paper pulp

extent compared to N and P, particularly in the alluvial tracts, as these soils are dominated by illite which lead to higher availability of K (Mandal *et al*. 1979).

In the sulphur-deficient soils, application of 1 kg sulphur was found to produce an additional fibre yield of 18 kg/ha in Bangladesh (Hussain 1990) and 21 kg/ha at CRIJAF, Barrackpore, West Bengal. The critical limit of soil available S was estimated to be 8.5 ppm SO_4–S (Saha *et al*. 1998).

Application of magnesium increased the fibre yield of *tossa* and white jute significantly up to 40 kg MgO/ha in Assam (Kumar and Borthakur 1980), while the response to applied Zn and Mn was up to 4 and 5 kg/ha, respectively in alluvial clay loam soil.

In roselle, response to N ranged from 40 kg N/ha at Amadalavalasa, Andhra Pradesh (Naidu *et al*. 1996) to 100 kg N/ha in vertisol at Honnaville, Karnataka (Krishnamurthy *et al*. 1994b). In kenaf, the crop responded to applied N up to 75 kg N/ha (Reddy and Rao 1971) in India or even up to 180 kg N/ha in China (Huang *et al*. 1994). Roselle responded to the applied P up to 20 kg P_2O_5/ha at Amadalavalasa, Andhra Pradesh (Naidu *et al*. 1996), while the response to K was observed up to 40 kg K_2O/ha at Dharwad, Karnataka (Mansur *et al*. 1993) and up to 300 kg K_2O/ha in China (Huang *et al*. 1994).

Organic matter as well as soil microbial biomass carbon (SMBC) is considered as the important indicators of soil quality and is essential for achieving a sustainable production system. Inclusion of jute in most of the cropping systems showed an increase in soil organic C as well as improved microbial and enzymatic activity of the soil possibly because jute, in its life-cycle, adds about 15 tonnes green leaves to the soil/annum which finally adds around 53, 9, 58, 22 and 15 kg/ha of N, P, K, Ca and Mg and considerable amount of organic matter to soil. Long-term fertilizer trial in jute – rice – wheat cropping sequence on new gangetic alluvial soil at Barrackpore, West Bengal, revealed that application of 100% fertilizer NPK alone based on soil test values increased the available N, P and K of soil significantly over initial value after 10 cropping cycles (Mandal *et al*. 1985), but with a declining trend in soil organic C (Mandal *et al*. 1984). The soil organic C, total N as well as soil mineralizable N showed an increasing trend after 29 years of continuous cropping only when farmyard manure was applied along with NPK (Saha *et al*. 2007)**.** Similarly, jute–rice–rice system maintained better organic C status as well total P in soil than rice–rice–fallow sequence (Sadanandan and Mahapatra 1972, 1975). In soybean–jute–rice sequence, the net gain of total N was 27 kg/ha, while in fallow–jute–rice system total N showed a deficit balance in Bangladesh (Patwary *et al*. 1989). Continuous cultivation of rice–jute–rice led to deterioration of soil structure which, however, was found to improve slightly with the inclusion of groundnut in the sequence and the exchangeable K in soil was found to increase (Sadanandan and Mahapatra 1974 a,b).

In jute-growing soils of West Bengal, urease and alkaline phosphatase activity was significantly correlated with organic carbon, fungal and bacterial population, while acid phosphatase activity was significantly correlated with organic P content (Tarafdar *et al*. 1981). Combined application of farmyard manure and fertilizer N increased the activity of acid phosphatase, alkaline phosphatase, dehydrogenase in soil, and dry matter production, fibre yield and P uptake by both *capsularis* and *olitorius* jute (Tarafdar *et al*. 1989). In mesta, maximum enzyme activity was observed in rhizosphere during 20–30 days crop age (Tarafdar and Roy 1981). Significant increase in plant height, dry weight, chlorophyll and N content in *olitorius* jute was observed in single inoculation with *Azospirillum* (Mishra *et al*. 1989) as well as combined inoculation with *Glomus macrocarpum* and *Azospirillum brasilense* (Bali *et al*. 1991). The combined inoculation also showed significant antagonistic effect on *Fusarium solani*. Location-specific fertilizer prescription equations were developed for jute and mesta-based cropping systems in varied agro-ecosystems and the targeted yield for jute (3.0 tonnes/ha), mesta and their component crops like rice (4.0 tonnes/ha), pulses, etc. could be achieved with fertilizer application based on soil test-targeted yield equations along with 5 tonnes farmyard manure/ha.

The source as well as method of application of the fertilizer, alike other crops, certainly had a significant effect on productivity of jute and mesta. Slow release N fertilizers were found more effective in increasing jute yield than urea (Sarkar *et al*. 1987) and cut down the N requirement for subsequent rice crop and the response of jute to N source was in the order of urea super granule = neem coated urea> wax coated urea> urea (Sarkar 1990). Split application of nitrogen or foliar application recorded significantly higher dry matter and fibre yield (Gupta and Bhattacharya 1981) and seed yield (Bhattacharya *et al*. 2000) of jute. Placement of P at 10 cm depth in soil recorded significantly higher fibre yield in both *olitorius* and *capsularis* jute (Sinha and Saha 1973). Split application of potash in two equal doses (basal and 3–4 weeks after sowing) resulted in better fibre yield, K uptake and K-use efficiency in jute (Maitra *et al*. 1999)**.**

Jute crop suffers from heavy weed infestation during the early stage of its growth, which significantly reduces the fibre yield. The magnitude of yield loss ranged between 52 and 55% in *C. capsularis* and 59–75% in *C. olitorius* (Sarkar *et al*. 2005). Weeding alone incurred about 35% of total cost of cultivation in jute (Saraswat 1980) and manual energy requirement for weeding in jute (543 MJ/ha) was 4.5 times more than that for land preparation (Borkar *et al*. 1999). As many as 190 different species of weeds belonging to 37 families were identified through an extensive survey on weed flora associated with jute in five major jute-growing states of India, namely, West Bengal, Bihar, Assam, Orissa and Uttar Pradesh. The dominant weeds were mostly annual grasses and also sedges, like *Cyperus* sp. It was also observed at Barrackpore that weed population in jute field may reach up to 90% (Ghorai *et al*. 2004) or even up to 98% (Sarkar *et al*. 2005) if not attended properly. The growth of weeds in jute field showed a sigmoidal pattern and maximum dry biomass weight of grassy weeds was observed at 87 days in *C. olitorius* and at 112 days in *C. capsularis* jute (Sarkar and Bhattacharya 2005). The critical period of crop-weed

competition in jute was found to be between 15 and 60 days after sowing (Gogoi and Kalita 1992).

Maximum control of weeds was achieved with hoeing at 15 days after sowing and two hand weedings at 3rd and 5th week after sowing at Kalyani, West Bengal (Prusty *et al*. 1988) while mixed cropping of red amaranth (seeding @ 10–30 kg/ha) with jute resulted in 22–25% more suppression of weed biomass as compared to two hand weedings coupled with an additional return of Rs 3 853/ha (Ghorai 2007). Mulching with paddy straw @ 10 tonnes/ha reduced the weed biomass by 68–82% as compared to two hand weedings (Ghorai *et al*. 2004). Weed suppression by soil solarization was found non-remunerative due to higher cost of polythene (Ghorai 2007). Better weed control in jute was observed with pre-emergence application of fluchloralin @ 1.0 kg ai/ha, followed by one hand weeding at 28–35 days after sowing (Rajput 2000) or with pre-plant soil incorporation of trifluralin @ 0.75 kg ai/ha 1 day before sowing (90% control of grassy weeds and some broadleaf weeds up to 35–42 days after sowing without any residual toxicity in soil) (Sarkar *et al*. 2005) or with pre-emergence application of S-metolachlor @ 0.5 kg a.i./ha (better control of sedges) (Sarkar 2007). Post-emergence spray of quizalofop ethyl 5% EC (40–50 g a.i./ha) + adjuvant @ 1 ml/litre of water at 15–21 days after emergence controlled the grassy weeds very effectively (Bhattacharya *et al*. 2004, Ghorai *et al*. 2004). In jute seed crop, higher net return was realized with the application of herbicides like sethoxydim (Rs 8 400/ha) and oxyfluorfen (Rs 7 800/ha) as compared to two hand weedings (Rs 7 750/ ha) (Dey *et al*. 1998). Maximum fibre yield and net returns in roselle was observed with three hand weedings (3, 5 and 7 weeks after sowing (Naidu *et al*. 1994). The trials under AINPJAF, CRIJAF revealed that application of fluchloralin @ 1.0 kg ai/ha at 1–3 days before sowing or pendimethalin @ 0.75 kg ai/ha at 1 day before sowing, followed by one hand weeding at five weeks after sowing gave better weed management in mesta (Mitra *et al*. 2006). Bhattacharjee *et al*. (1988) reported that fluchloralin @ 2.0 kg ai/ha gave better weed control in *H. sabdariffa* in light-textured soil.

Though chemical weed control has been proved to be very effective, it should be advocated very carefully considering the texture and moisture content of the soil, as there had been contradictory results regarding the effect of herbicides on the beneficial microbes in soil. Smothering the weeds through intercropping or mixed cropping may be a suitable alternative as it showed comparable economics to chemical method and did not exhibit any negative impact on soil microbes.

Pest management

Major pests of jute and their management: The intensive cultivation of high-yielding, fertilizer-responsive cultivars of jute brought forth the problem of insect pests and mites. A few relatively less important pests turned to be major ones. Semilooper *Anomis sabulifera* Guenee, stem-weevil *Apion corchori* Marshall and yellow mite *Polyphagotarsonemus latus* (Banks) are the major pests of jute. The yield loss due to *A. sabulifera* (Noctuidae: Lepidoptera) has been estimated at up to 50%. It not only defoliates, but also feeds on the pods of seed crop. Among the limited number of *white* jute cultivars screened for resistance to semilooper, 'NDC 8812' and 'NDC 9801' were reported to be moderately resistant (Prasad *et al.* 2004*)*. Though several parasitoids, such as *Sisiropa formosa, Trichologa sorbilans, Litomastix* sp.*, Mesochorus* sp. were recorded on semilooper, the mass multiplication technique has not been perfected yet. Sisalana oil and herniarin, a constituent of *Herniaria glabra* (Family: Illecebraceae) exhibited heavy knockdown effect coupled with high insecticidal activity against the larvae of semilooper (Mallick 1989b, Mallick and Banerji 1989). Development of insecticidal formulations from these promising botanicals is in progress at CRIJAF. Endosulfan (0.07%), carbaryl (0.1%), cypermethrin (0.03%) were reported to be effective in managing the semilooper. Though the stem weevil *Apion corchori* Marshall is a pest on both the species of *Corchorus, C. capsularis* suffers more than *C. olitorius.* The insect exists throughout the cropping season and it damages the early-sown crop sometimes to such an extent that hardly any fibre can be obtained. Among the white jute cultivars, 'NDC 8812' and 'NDC 9801' were observed to be resistant to *A. corchori* (Prasad *et al.* 2004). *Entedon manilensis* Crawford was reported to be the most efficient among the parasitoids recorded. Endosulfan (0.075%), carbofuran (1 kg ai/ha) and cypermethrin (0.03%) were found effective in managing the stem weevil (Das *et al*. 1995). The hidden nature of the pest, which precludes the contact from insecticides, necessitates transgenic jute with coleopteran specific *cry* genes (Ramasubramanian and Ghosh 2008). Yellow mite (*Polyphagotarsonemus latus*) is one of the most destructive pests of jute (Pradhan and Saha 1997). *Tossa* jute suffers more due to yellow mite infestation as compared to white jute. The quality of the fibre was also found to be deteriorated due to the attack of yellow mite. The fibre strength was 12.13 g/tex in the infested plants as against 15.43 g/tex in the healthy plants (Pandit *et al.* 2002). 'JRO 524', 'JRO 7835' and 'JRC 212' were reported to be least susceptible, while 'JRO 878' was observed to be highly susceptible. Insecticidal interference is required as soon as the population crosses the economic threshold level of 110 mites/leaf (preferably in the second unfolded leaf) (Das *et al.* 2002). Endosulfan (0.04%) twice at fortnightly intervals was found to be the most effective and economical (Das and Singh 1985 a, b). Hairy caterpillar (*Spilosoma obliqua* Walker) was once considered as a sporadic and irregular pest on jute, but nowadays it is a regular and major pest on jute. Endosulfan was reported to be effective in reducing the incidence of hairy caterpillar under field condition (Hath and Chakraborty 2004). *Myllocerus discolor* Boheman causes considerable damage to *tossa* jute by defoliating the crop. Unopened tender apical leaves are the first choice of attack by *M. discolor*. No variety

was found to be resistant to grey weevil. 'JRO 7835' was observed to be the most susceptible variety (Mallick 1995a). Among the insecticides tested, two rounds of cypermethrin at 15 days interval was found most effective, followed by oxydemeton methyl (0.05%) carbaryl (0.1%) and endosulfan (0.075%) (Mallick 1989a, 1995b). Endosulfan was reported to be more effective against all the major pests of jute and hence being used extensively in the jute-growing tracts. This may lead to the development of resistance to endosulfan. A detailed investigation on status of susceptibility of the jute pests to endosulfan from different parts of the India is required to prevent/delay the development of resistance, if any. It is the ideal time to get the susceptible population for generating baseline susceptibility data to other insecticides with novel modes of action. This will also help to phase out the insecticides for which resistance has been built up, and thus the expenditure on ineffective insecticides by the resource poor jute farmers may be minimized (Ramasubramanian 2007).

Major pests of mesta and their management: Mesta suffers due to ravages caused by a number of insect pests. Spiral borer *Agrilus acutus* Thunb, mealy bug *Maconellicoccus hirsutus* (Green) and flea beetle *Nisotra orbiculata* (Motsch) are the major pests of both kenaf (*Hibiscus cannabinus*) and roselle (*Hibiscus sabdariffa*). Carbofuran @ 1 kg/ha was observed to be very effective in managing the spiral borer. Swabbing the stem with methyl demeton (2.5% @ 20 ml/ plant) at a height of 45 cm above the soil surface can also take care of this pest. The kenaf variety 'MT 150' and the roselle variety 'RT 1' were found to be the least susceptible to *A. acutus* (Das *et al.* 1999). In the Caribbean sub-region, the introduction of *Cryptolaemus montrouzieri* from India resulted in very good control of hibiscus mealy bug, *M. hirsutus*. It has been a tremendous success in all crops with the exception of *Annona muricata* and *Hibiscus sadariffa* (Kairo *et al.* 2001). It is a challenge rather than opportunity for the entomologists working on mesta mealy bug to rectify the lacunae in release technology and make it successful in roselle also. It is unfortunate that the potential of indigenous *C. montrouzieri* has remained untapped or under-utilized against the mesta mealy bug *M. hirsutus* in India. Flea beetle, *Nisotra orbiculata* (Motsch) [= *Podagrica orbiculata* (Mots.); *Podagrica bowringi* Baly] (Curculianidae: Coleoptera) attack commences with seedling stage and ceases just before harvest. Week-old seedlings are highly susceptible to this pest and hence resowing is warranted frequently. The possibilities of exploring the entomogenous fungi *Beauveria bassiana* (Balls) Vuill and *Metarhizium anisopliae* (Metsch) need to be studied on priority basis as the natural mortality of *N. orbiculata* was recorded up to 87% by the earlier workers (Pandit and Pathak 2000).

Disease management

Major diseases of jute and their management: Stem rot caused by *Macrophomina phaseolina* is an economically important disease of jute. Anthracnose is of regular in occurrence, especially in *capsularis* belt. Black band, soft rot and Hooghly wilt are the diseases of minor importance. In mesta, foot and stem rot caused by *Phytophthora parasitica* var. *sabdariffae,* soft rot/collar rot caused by *Sclerotium rolfsii* and yellow vein mosaic caused by geminivirus are the important diseases. *Macrophomina phaseolina* (Tassi) Goid is the causal organism of stem rot in jute, the sclerotial stage of which is *Rhizoctonia bataticola* and the perfect stage is *Orbilia obscura*. The pycnidial and sclerotial stages are primarily responsible for the disease and the perfect stage is of less important (Mandal 1990). Both *C. olitorius* and *C. capsularis* are equally susceptible to this disease. Average yield loss due to the disease has been estimated at around 10–15% (De and Mandal 2008). Six *capsularis* accessions, viz 'CIM 036', 'CIM 064', 'CIN 109', 'CIN 360', 'CIN 362', 'CIN 386' were identified as resistant genotypes against the most virulent pathotype of Shorbog, Assam (Mandal *et al.* 2000). 'OIN 107', 'OIN 125', 'OIN 154', 'OIN 157', 'OIN 221', 'OIN 651', 'OIN 853' and 'OIJ 084' were the *olitorius* accessions short listed for final confirmation as tolerant against the *Macrophomina* (De and Mandal 2008). Use of fungicides either as seed treatment or as foliar spray is the only feasible option to the jute growers for the management of the stem rot pathogen (Hembram and De 2008). Seed treatment with carbendazim @ 2.0 g/kg or mancozeb @ 5.0 g/kg or *Trichoderma viride* @ 10.0 g/kg was found effective. Foliar spraying of carbendazim (0.2%) or copper oxychloride (0.75%) may be suggested depending upon the disease severity. Anthracnose is of regular occurrence in the *capsularis* belt of India, viz. Assam, North Bengal, Bihar and Uttar Pradesh. The causal agents are *Colletotrichum corchori* for *C. capsularis* and *Colletotrichum gloeosporioides* for *C. olitorius*. *C. capsularis* is more susceptible and *C. olitorius* is rarely affected. Seed treatment with bavistin @ 2 g/kg or captan @ 5 g/kg, followed by foliar spraying of bavistin @ 2 g/litre or captan @ 5 g/litre or dithane M 45 @ 5 g/litre have been recommended under severe incidence. Black band is caused by *Botryodiplodia theobromae*. The pathogen is seed borne as well as air borne and has a very wide host range (Mandal 1990). It was a minor disease in the past, but the incidence is gradually increasing nowadays. Good agronomic practices coupled with seed treatment (carbendazim @ 2.0 g/kg or mancozeb @ 5.0 g/ kg) could reduce the incidence**.** Soft rot is a disease of minor importance caused by *Sclerotium rolfsii*. This is primarily a soil-borne fungus. Both *capsularis* and *olitorius* jute are equally susceptible. Spraying copper oxychloride @ 5–7 g/ litre of water towards the basal region was observed to contain the spread of the disease to a greater extent. Hooghly wilt is caused by *Ralstonia solanacearum (=Pseudomonas solanacearum),* while *Rhizoctonia bataticola* and *Meloidogyne incognita* facilitate the entry of the primary

pathogen (Mandal 1986). There is no report of *capsularis* jute being attacked by this pathogen so far. Potato or other solanaceaous crops in the rotation are to be avoided as far as practicable. The most effective crop rotations against this disease are jute–rice–rice or jute–rice-wheat. By adopting cultural practices, particularly appropriate crop rotation in Hooghly district, the disease has come down to 1–2% as against above 40% in the late 1980s (Mandal and Ghosh 2002). Jute crop or its wild relatives are not very much prone to the viral diseases. Jute mosaic, chlorosis and yellow vein are the viral diseases reported to occur on jute. The incidence of jute mosaic (syn. jute leaf mosaic, jute yellow mosaic, jute golden mosaic) was observed recently to the tune of 50% on 'JRC 7447' and 'JRC 212' (Ghosh *et al.* 2007b). Majority of the workers reported that the virus is transmitted by the whitefly *Bemisia tabaci* Gen. Based on symptomatology and transmission, the virus was identified as a member of *Begomovirus* under family Geminiviridae.

Major diseases of mesta and their management: Foot and stem rot is the most important disease of mesta (Ghosh 1983). It is more serious on roselle than kenaf. In severe cases, more than 40% crop loss in roselle was observed (Mandal *et al.* 1995a, b; De and Mandal 2007a). *Phytophthora parasitica* var. *sabdariffae* is the causal organism. The infected plant struggles for survival by producing secondary roots above the rotten portion of the stem. None of the cultivated varieties are resistant to the disease, but 'AMV 1', 'RT 1' and 'AP 481' were observed to be moderately resistant (Majumdar and Mandal 2000a, b). Red bristled *H. sabdariffa* lines were observed as more resistant than others (Majumdar and Mandal 1994). Seed treatment with copper oxychloride was reported to be more effective (De and Mandal 2007a, b) and reduced the incidence by 50.3 and 45.5% at 30 days after sowing and at maturity, respectively. Collar rot of mesta is caused by *Sclerotium rolfsii.* It is more prevalent in kenaf varieties than roselle. The incidence is not yet alarming (Mandal 1990, De and Mandal 2007b). Spraying copper oxychloride @ 5–7 g/litre of water, directed towards base of the plants helps in managing the disease. Yellow vein mosaic of mesta was first observed in Andhra Pradesh and then reported from West Bengal (Chatterjee *et al.* 2005) and Uttar Pradesh (Ghosh *et al.* 2007a). The yield loss due to this disease has been estimated to be 12.78–17.45% with respect to fibre yield and 18.91–23.83% with respect to seed yield. Viruliferous whitefly could effectively transmit the virus with 78–85% transmission efficiency. Three whiteflies/plant were found to be sufficient to transmit the disease. Molecular characterization revealed that two distinct *Begomovirus* complexes associated with the yellow vein mosaic disease of mesta in two different geographical locations (Northern and Eastern India) in India (Roy *et al.* 2007).

Nematode pests and their management

Root knot nematode (*Meloidogyne igconita, M. javanica)* is one of the economically important pests of jute and mesta. The average extent of damage has been estimated at about 15–20%.

Both *olitorius* and *capsularis* are susceptible to it. *Hibiscus sabdariffa* is resistant, while *H. cannabinus* is susceptible to this nematode (Laha and Pradhan 1987). Root-knot nematode facilitates entry of other bacterial pathogen *R. solanacearum* and fungal pathogen *M. phaseolina* by creating injury on plant roots and cause heavy damage. Cultural practices, like removal of stubbles, weeding, thinning, crop rotation with rice and wheat for two years could reduce root-knot nematode population in jute field.

Retting

The quality of jute and mesta fibre depend largely on the quality of retting. The jute and mesta plants when immersed in water decompose and release soluble sugar, glucosides and nitrogenous compounds (Ahmed and Akhter 2001), which boost up the growth and multiplication of retting microbes. Pectisinase, pectase and pectinase enzymes were found to be mainly responsible for decomposition of pectic substances. The efficient retting microbes were identified by different workers and some of the important ones are (i) fungus: *Aspergillus niger*, *Macrophomina phaseolina*, *Phoma* sp., *Trichoderma* sp., etc. (ii) aerobic bacteria: *Bacillus subtilis*, *B. polymixa, B. macerans,* and (iii) anaerobic bacteria: *Clostridium* sp. Chemical retting of jute/mesta plants can be done by boiling the plants with 0.5% H_2SO_4 or 1% NaOH under normal or high temperature. Ammonium and sodium sulphate were found to be suitable for chemical retting, but are costlier (Dasgupta *et al*. 1976). The effects of different factors, like age of plants, fertilizer dose, quality of retting water particularly its *p*H and temperature, use of activators, covering materials, etc. on retting process and its subsequent effect on fibre quality had been studied in details by several workers.

Availability of slow moving clean water is becoming rare in most of the jute-growing areas nowadays and hence, farmers ret the jute and mesta plants in the field or road side ditches by covering the plants with mud, banana stems, etc., which significantly reduces the fibre quality. The mechano-microbial retting technology developed at CRIJAF requires less water (25% of the conventional system), is cheaper than conventional retting and significantly reduces the retting duration. The ribbons extracted using the CRIJAF Bast Fibre Extractor can be retted in 5–7 days as against 15–20 days required under conventional retting. The extraction capacity of machine is 25 and 15 kg/machine-hr compared to 5 and 4 kg/man-hr under conventional retting system in jute and mesta, respectively. This system has been proved very effective in areas where there is shortage of good quality retting water.

Fibre quality and value-addition

Finer fibre with better yarn tenacity and regularity in *olitorius* jute was observed in plants grown under closer spacing (Pal *et al*. 1981) and lower nitrogen dose (Gupta *et al*. 1979). Application of K was found to improve the fibre quality parameters (strength, number of-fibre bundles, fibre layers, cell number/bundle, etc.) (Peng and Mo 1984). The differentiation and development of fibre cells in *C. capsularis* plants (except at basal region) was significantly influenced by the application of N, P and K, which resulted in maximum number of fibre bundles (253), single fibres (9396), single fibre diameter (15.872 µm) and thicker cell walls (4.015 µm, 13.5% more than control). Although N application favoured fibre bundle differentiations and number of single fibres, tensile strength and count of jute fibre was found more with P and K application (Zhao 1984). Ribonning, followed by retting in water with or without microbial treatment reduced the retting duration and also improved the fibre quality by at least two grades (Mandal 1986). Covering the plants during retting with mud, banana stem, etc. develop a 'steel grey' colour which reduces the quality of fibre as well as price.

Paper and pulp production

Pulp and paper industry survives on the continuous supply of cellulose raw materials. Around 35% of raw materials come from hardwood/bamboo, 30% from agro-residues, like straw and bagasse, and rest 35% from waste paper. The pulp from agro-residues is certainly of inferior quality and the growing demand of newsprint (about 8.53 million metric tonnes on 2010) cannot be met from forest resources alone due to its severe negative impact on environment. At this juncture, whole jute/kenaf plants having similar strength of hard wood has tremendous potential as raw material for pulp and paper (Sinha and Day 2008). Jute and allied fibres are rich sources of cellulose and can produce quality paper. Kenaf variety, 'MT 150' has been identified as the best paper pulp variety and the newsprint produced from 'MT 150' was found to be excellent (Sinha and Sen 2004). About 8 tonnes of paper pulp can be produced from 1 ha of mesta cultivation (Sinha and Day 2008). The biomass production in *C. capsularis* and *C. olitorius* varieties ranged from 48.1 to 48.7 and 52.8 to 55.0 tonnes/ha, which can also be successfully utilized for paper pulp. So to ensure the year-round supply of raw material to paper industry, we need to develop varieties of jute and mesta, which can be grown throughout the year. Besides, technology has also to be developed to preserve the reeds of jute and mesta for a considerable period of time free from pest and disease incidence.

Constraints faced by raw jute

Ever since jute industry began its journey, jute agricultural research has immensely contributed in all its crucial phases by developing high-yielding varieties backed by improved production technologies. Though the productivity has reached all-time high of 2.3 tonnes/ha, the area under jute and mesta has remained stagnated at around 1.0 million ha only for the last two decades. Moreover, there is still a wide disparity in the yield level of the crops between the states as well as between the agro-climatic zones of the same state. A preliminary constraint analysis on jute cultivation revealed that majority of the farmers were unaware of most of the jute production technologies developed at CRIJAF or SAUs which clearly indicates that a significant gap still exist between the reasearchers and the farmers, which has to be bridged immediately. Raw jute production is becoming more and more costly and labour intensive and about 70% of the total cost is incurred in weeding and retting. Increased cost of fertilizers, particularly phosphatic and potassic fertilizers, is creating a severe imbalance in fertilizer use in jute which is ultimately affecting fibre yield and quality. Major quantity of good quality fibre needed to produce jute diversified products (JDPs) has to be imported from Bangladesh. There is also a shortage of good quality seeds every year in the market as the share of certified seeds in jute is 35% only. Lack of grading and appropriate market system for selling the jute fibre has been expressed, by about 87% of the farmers, as the most important constraints.

Future areas of research

The severe competition from the cheaper synthetic fibres had certainly posed a severe threat to natural fibres and raw jute is no exception to that. Fortunately the biodegradability and eco-friendliness of jute and allied fibres has again attracted the consumers, who now are more concerned about the environment. So to reap the benefit of the situation, the raw jute production system should be made more remunerative and the fibre quality should be improved significantly to meet the requirement of the value added jute diversified products. To attain these targets, emphasis is to be given on the following areas of research and development in jute and kenaf (mesta and roselle):

- The acreage of jute and kenaf should be increased by providing proper support price and other incentives to farmers. The different forms of incentives as provided in Mini Mission II of Jute Technology Mission should be utilized.
- The germplasm collection of jute and allied fibre crops has to increased through exhaustive exploration within the country and abroad.
- To improve the fibre quality, particularly strength and fineness, both conventional and molecular breeding tools are to be used to develop varieties with desirable traits. Emphasis must be given on breeding varieties having tolerance to biotic and abiotic stresses. Development of transgenic plants is also an important issue.
- It is essential to identify the means as well as factors responsible for low productivity and quality and

location-specific strategies should be developed accordingly.

- Integrated management programmes for nutrient, weed and pest of jute and mesta should be developed, the essential components of which must be locally available, cheap and eco-friendly.
- Major emphasis has to be given on mechano-microbial retting technology which will produce better quality fibre using lesser quantity of water.
- Since jute and mesta are grown in rainfed condition, introduction of short-duration and high-value crops requiring less water in jute/mesta-based cropping systems will increase the net returns and will also act as insurance crops to the growers.
- Production of jute and kenaf seed can be tried in the red and lateritic belt of West Bengal, parts of Bihar and Orissa as this will ensure early arrival of good quality seed to market.
- Mechanical interventions in field operations like sowing, weeding, harvesting and fibre extraction is essential as this will reduce the cost of cultivation and will improve the fibre productivity as well as fibre quality.
- There is an urgent need to have a research – industry interface which will help the scientists to understand the requirement of fibre quality by the industry so that the research activities may be fine tuned, if needed.

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