Heliyon 7 (2021) e08129

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Morpho-phenetical study of high yielding tossa jute variety BJRI Tossa Pat 7 (MG-1) for bast fibre yield and qualities

Md. Mia Mukul [*], Nargis Akter, Mohammad Moinul Islam, Md. Solaiman Hossain Bhuiyan [1], Md. Golam Mostofa, Ranjit Kumar Ghosh, Chandan Kumar Saha, Md. Abbas Ali

Breeding Division, Bangladesh Jute Research Institute, Ministry of Agriculture, Manik Mia Avenue, Dhaka 1207, Bangladesh

ARTICLE INFO

Keywords:
Cellulose & lignin
Corchorus olitorius
Fiber strength
Golden fiber
Jute anatomy
Tiliaceae
Tensile strength

ABSTRACT

Background and aim of the study: Tossa jute *(Corchorus olitorius)* is a natural fibre crop produces good quality fiber having great demand for industrial uses. High yielding tossa jute variety is very important in Bangladesh.
Materials and methods: Bangladesh Jute Research Institute (BJRI) has developed a new tossa jute variety (BJRI Tossa Pat 7) through pure line selection (PLS) from another pre-released variety named OM-1 during 2017. The new variety was evaluated for fiber yield and attributing phonological traits through comparing with another pre-released variety named BJRI Tossa Pat 5 (O-795) in RCB design at six locations during 2015–2018.
Results: Distinct morphological traits i.e. ovate lanceolate glossy leaves; full green plant were found in MG-1 and stem & stipule red; ovate lanceolate leaves in O-795. MG-1 showed higher fiber yield (3.39–3.40 t ha^{-1}) where, O-795 showed 3.10–3.22 t ha^{-1} as means of their maximum performances for three years at both farmers' plots and research fields. MG-1 gave higher plant height, base diameter, fiber yield than O-795 at both research stations and farmers' fields. Even after sowing at 10–15 March, MG-1 gave late flowering; lower leaf size, leaf angle, green leaf biomass and node number; maximum inter-nodal length, bark diameter, bark thickness and fiber bundle cells; and finally golden bright quality fiber than O-795. If both varieties were sown at 2nd to 3rd week of March, and harvested at 110 days old, MG-1 gave 5–7% higher fiber yield than O-795.
Conclusion: Undoubtedly, MG-1 is a good tossa jute variety for its fiber yield and quality than pre-released varieties.
Recommendation: MG-1 having good fiber yield would be used for commercial cultivation by the farmers to contribute to the national economy.

1. Introduction

Jute is a herbaceous annual fiber crop belongs to the *Corchorus* genus and considered to be under *Tiliaceae* family for long time (Maity and Datta, 2010; Mukul and Akter, 2021), but now it belongs to the family "*Sparmanniaceae*" (JCU, 2010). Sinha et al. (2011) reported 10 jute species (2 cultivated and 8 wilds) from India where, *C. capsularis* L. and *C. olitorius* L. produce fiber of commerce from the bark of the stem (phloem fibre), and are widely cultivated in India, Bangladesh, Nepal, China, Indonesia, Thailand, Myanmar and south American countries. These two species were originated from two different geographical locations. According to Kundu et al. (2012), the dark jute (*C. olitorius* L.) had its origin in equatorial region of east Africa, but was domesticated in India. They could not support an Indo-Myanmar origin of white jute (*C. capsularis* L.), and possibly it also originated in Africa, but was domesticated in Asia. *C. olitorius* is a traditional African leafy vegetable (ALV). The two cultivated jute species contain ~70% of the neutral genetic diversity present in their wild relatives (Kundu et al., 2012). Jute plant is an extremely renewable resource because, it is totally agro-based, biodegradable, compostable, durable, reusable, nutrient supplier to soil and superior to synthetic fibers (Basu and Roy, 2008). The wild jute species are poor fibre yielder but good source of genetic material for the improvement of qualitative (stress tolerance, quality fibre) and quantitative (yield) traits in jute crops (Maity et al., 2012). Jute is considered as the second most important fibre producing recalcitrant plant throughout the world (Samira et al., 2010) and as well as in Indian sub-continent after cotton (Basu et al., 2004; Chattopadhay et al., 2010). *Corchorus* (Family: *Tiliaceae*) possessing more than 170 species are fibrous annual

* Corresponding author.
E-mail address: mukulbjribreeding@gmail.com (Md.M. Mukul).
[1] Deceased author.

https://doi.org/10.1016/j.heliyon.2021.e08129
Received 22 October 2019; Received in revised form 18 April 2021; Accepted 30 September 2021

plants distributed in warm regions throughout the world (Mandal and Datta, 2011). The largest gene bank of jute and allied fiber (JAF) crops is being maintained at Bangladesh Jute Research Institute (BJRI) in Bangladesh, with 5936 accessions comprising 15 species of *Corchorus*, 22 species of *Hibiscus* and 15 of allied genera, yet to be characterized (Haque et al., 2007).

Jute fiber is the best natural substitute for nylon and polypropylene, and used for making textile, non-textile commodities and packaging materials in the jute mills, pulps in paper industries, geo-textiles and agricultural applications (Roy, 2010). Jute plants improve soil productivity by its massive leaf dropping and root proliferation in the field. Jute is a vital crop regarding agricultural, industrial and commercial use in Bangladesh and India. These are two major jute-growing countries, contributing almost 85% of the world jute production and area cultivated (Gupta et al., 2009). Bangladesh produces around 30% of the total world production of jute and exports around 40% of its total produce as raw jute (Sheheli and Roy, 2014). Bangladesh has exported 12.97 and 8.25 lakh bales raw jute during 2017–18 and 2018–19, respectively having the export values of 12255.50 and 8590.50 million taka, respectively (Akter et al., 2020). Bangladesh ranks in first position for jute export and production among the jute growing countries of the world.

Jute is a photosensitive plant; its vegetative and reproductive growth phase depends on the day length, temperature, humidity (Khatun et al., 2009). The tossa jute (*C. olitorius*) is very susceptible to disease pests, climatic and environmental changes (Sarkar and Gawande, 2016). It is a rapid growing and photo-sensitive crop which needs more than 12 h day length (after 15 March) for its proper vegetative growth in respect of fibre production in Bangladesh (Islam and Uddin, 2019). It can be harvested within 100–120 days after sowing for economic fibre yield. For early seed production purpose, it is grown during short day (<12 h) period (September to January) for early reproductive growth escaping the vegetative growth. Jute plant consist of surface feeder tap root system having a primary root (tap root) of 10–15 cm length surrounding by numerous secondary roots, tertiary roots and rootlets which can absorb nutrients with water content from the depth of soil. The fiber materials are known as bast fiber or phloem fiber obtained from the stem and ribbon (outer skin) of the jute plant (Tanmoy et al., 2014).

The breeding of jute crop is problematic due to its narrow genetics base; jute is a self-pollinating crop having the possibility of natural out-crossing in *C. olitorius* (8–12%) than in *C. capsularis* (3–4%) (Kar et al., 2009). Jute is predominantly self-pollinated, but cross- pollination of 10–15% occurs in *olitorius*, mainly by insects. The plant height, stem diameter, leaf angle, leaf petiole-stipule, number of node and leaves, auxiliary buds, leaf structure, root systems etc. are directly involved with the fibre yield of jute plant (Maity et al., 2012). The more plant height, no branching habit, non-shattering fruits, no lodging habit are the desired morphological (Maity et al., 2012; Mukul et al., 2020a); higher bark thickness, fiber bundle cell, trapezoidal area are stem anatomical (Mukul et al., 2020b); low lignin, pectin, water contents and higher cellulose & hemicellulose content are chemical (Lazic et al., 2017); and good fiber bundle strength, fiber tensile strength, fiber cell fineness, fiber cell twisting are physical properties of jute and allied fiber crops as well as its' fiber cell (Virk et al., 2009).

The jute fiber strength, thermal conductivity, and cost are major concerns because it can be used as alternative of synthetic fiber (Islam and Alauddin, 2012). The physical properties of jute fiber are important for its textile and industrial use. Fiber strength is the strength of an individual fiber. The ability of the fibre to resist strain to the limit of rupture is called the fibre bundle strength. The jute fiber having more strength showed good use in textile production. The load required to break a specimen is termed as breaking load. Breaking load depends on fibre type, nature of fibre bonds, crystallinity, orientation etc. The ratio of load required to break the specimen and the linear density (count of that yarn) of that specimen is called tenacity or tensile strength. It is very important property of textile materials. Tyagi (2010) reported that, the extension to break the material to the initial length of that material is known as breaking extension. It indicates the length of fibre cell having fibre yarn. The fineness of jute fibre can be defined in micronaire (μg inch^{-1}) which measures the units of mass (micrograms or μg) per unit of length (inches) to assess linear density (Yang et al., 2019). Fibre length and strength relate directly and indirectly with fiber maturity and fineness. Fiber fineness affects the material's surface area, porosity, and filtration resistance, thereby indirectly determining the performance and applications of the fiber (Yang et al., 2019). Fibre fineness is important quality characteristic which indicates the spinning value of fibre. Number of the fibre in the yarn is depends on fibre fineness (Shaha et al., 2011). Moody and Needles (2004) described that, *luster* refers to the degree of light that is reflected from the surface of a fiber or the degree of gloss that the fiber possesses. The inherent chemical and physical structure and shape of the fiber can affect the relative luster of the fiber.

Khan and Khan (2015) reported in earlier, the chemical composition of jute fiber includes cellulose (61–71%), hemicelluloses (13.6–20.4%), lignin (12–13%), ash (0.5–2%), pectin (~ 0.2%), fat & wax (~ 0.5%), water soluble (1.1 %), moisture/water (~ 12.6%). Jute genotypes with thinner cell wall and lesser lignin may be utilized in breeding for improving the fibre fineness of jute (Meshram and Palit, 2013). The production of quality jute fibers influenced by soil, retting system, and jute genotype (Das et al., 2014).

Tossa jute fiber is softer, silkier and stronger than white jute (Akter et al., 2009). It can be grown during Kharif-I or summer season in Bangladesh. Tossa jute is susceptible to biotic and abiotic stresses but produce quality fiber than *C. capsularis* L. (Rahman et al., 2021). More than 80% of world jute grows in the Ganges delta of Bangladesh which has been categorized in to three areas such as- Jat area (Brahmaputra Alluvium), the Nothern area (Teesta Silt) and the Districts area (Ganges Alluvium). Market price of tossa jute fiber is higher for its better quality than white jute (Chowdhury et al., 2001). As a result, tossa jute cultivation is gradually increasing and has a great demand to the farmers in Bangladesh (NJB, 2019). In Bangladesh, not only the area under jute is declining; the crop is being pushed more and more to the marginal lands (Sheheli and Roy, 2014). Bangladesh Jute Research Institute has developed 17 tossa jute varieties during 1915–2017 (Islam and Uddin, 2019). Among these varieties, O-9897 was the mega variety which was released in 1987. These varieties gave fiber yield up to 3.0–3.20 t ha^{-1} in farmers' field. The pre-released tossa jute varieties are not tolerant to stresses. If the newly developed variety will be able to give 5–10% more fiber yield than the pre-released varieties, it will be considered as high yielding variety. For this reason, release of high yielding stress tolerant tossa jute variety is crying need of Bangladesh. This study was undertaken to evaluate or justify the newly developed high yielding tossa jute variety namely BJRI Tossa Pat 7 (MG-1) in terms of morpho-anatomical and physiological traits attributing the fiber yield and qualities, and to disseminate this high yielding variety among the farmers for commercial cultivation.

2. Materials and methods

2.1. Experimental sites

The study was conducted at six locations i.e. Manikganj [23°52′56.1″N 90°01′53.0″E], Kishoreganj [24°26′39.3″N 90°46′28.1″E], Faridpur [23°35′23.2″N 89°48′43.1″E], Rangpur [25°44′33.7″N 89°16′21.8″E], Jashore (Monirampur) [23°01′08.5″N 89°14′09.2″E], Cumilla (Chandina) [23°29′26.0″N 91°00′37.2″E] districts of Bangladesh for three fiscal years (2015–16, 2016–17, and 2017–18). The jute anatomy was carried out at laboratory of Breeding Division; and physical properties of jute fibers were tested at Textile Physics Department of Bangladesh Jute Research Institute, Dhaka (23°45′26″N, 90°22′47″E).

2.2. Plant materials

Three tossa jute varieties (Table 1) were used in this investigation where, BJRI Tossa Pat 7 (Locally known as Basantika) was studied for fiber yield and qualities against the control variety BJRI Tossa Pat 5. BJRI Tossa Pat 3 (OM-1) was used as the ancestor of BJRI Tossa Pat 7 to differentiate the characters between them.

2.3. Ancestry of MG-1 and development as a variety

The experimental jute variety BJRI Tossa Pat 7 (locally known as 'Basantika pat') has been developed by BJRI from a pre-released tossa jute variety named BJRI Tossa Pat 3 (OM-1) through pure line selection (PLS) during 2017. OM-1 was developed by BJRI through PLS method from the germplasms collected previously from Uganda. To release the MG-1 as a variety, the breeders of BJRI performed in earlier the preliminary yield trial (PYT), advanced yield trial (AYT), on farm yield trial (OYT) along with multi-location yield trial (MLT) in different agro-ecological zones (AEZs) of Bangladesh. The Distinctness, Uniformity and Stability (DUS) and Value for Cultivation and Use (VCU) tests were done with help of Seed Certification Agency (SCA) and National Seed Board (NSB) of Bangladesh. After completing these field trials and tests, the Field Evaluation Team (FET) and Seed Certification Agency (SCA) recommended this genotype for release by National Seed Board (NSB). Finally the NSB recommended and it has been released as a high yielding new tossa jute variety in Bangladesh under the proper investigation of the Ministry of Agriculture, Government of Bangladesh. According to the release information, the distinct and common characters of these varieties are as follows:

BJRI Tossa Pat 7 (MG-1): It is a segregated genotype having fast growing nature, less photosensitivity, earliness, high yielding good quality fiber, tall & cylindrical green stem-stipule, ovate lanceolate glossy smooth leaves, and bluish green seeds. The main difference between MG-1 and OM-1 are leaf shape i.e. ovate lanceolate leaves of MG-1 and ovate type leaves of OM-1. Sowing time: 15 March to 15 April; harvesting time: 110 days after sowing (DAS); flowering time: 140–145 days old. Plant height: 3.50–4.00 m; and basal diameter 15–20 mm (Al-Mamun et al., 2018).

BJRI Tossa Pat 5 (O-795): It has red/reddish stem-stipule, coppery red coloured upper surface of petiole, ovate lanceolate leaves and bluish green colored seeds. It can be sown from 15 March to 30 April and could be harvested at 110 DAS. This variety give flower at 140–155 DAS. Plant height would be 2.50–4.50 m and basal diameter 11–18.50 mm. It can produce 2.70–3.20 ton dry fiber hectare^{-1} of land. It is a quick growing red tossa jute variety having red stem, bright golden coloured fiber, slightly stress (flood/waterlog, salinity, drought, insect pests) tolerant than other tossa jute varieties (Al-Mamun et al., 2017, 2018).

BJRI Tossa Pat 3 (OM-1): Full green plant, ovate leaves with wide & glossy surface, greyish brown seeds. Traditionally it is known as Rani Tossa jute variety which can be sown from 15 March to 30 April and can be harvested at 110 DAS. It gave flower at 140–160 DAS. It can produce 2.50–2.80 ton fiber ha^{-1} in farmers' field. Especially, this variety gave no early flowering, showed long sowing time, less photosensitivity and quick growing habit, fine colour and quality fiber, and easily separable from other varieties for its deep greyish brown seeds (Al-Mamun et al., 2017, 2018).

Table 1. List of plant materials with their type, ancestry and source of collection.

Sl. No.	Varieties	Material type	Ancestry	Release year	Source
1.	BJRI Tossa Pat 7 (MG-1)	Tested genotype	PLS from OM-1	2017	Breeding Division, BJRI, Dhaka.
2.	BJRI Tossa Pat 5 (O-795)	Control	O-4 × Uganda red	2008	
3.	BJRI Tossa Pat 3 (OM-1)	Plants for PLS	PLS from accession	1995	

2.4. Experimental design

Experiments were conducted in randomized complete block (RCB) design with 3 replications keeping plot size of 13.5 m^2 (4.5 m × 3.0 m) in PYT and 10 m^2 (4.0 × 2.5 m) in AYT (Gupta et al., 2016). On farm yield trials (OYT) along with multi-location yield trials (MLT) in different agro-ecological zones (AEZs) of Bangladesh were conducted in simple design keeping unit plot of 5 decimal area near roadside having easy access.

2.5. Field preparation, seed sowing, growing and harvesting of plants

The experimental fields were prepared through ploughing, harrowing and leveling for several times; and fertilizers were applied @ Urea 100 kg, Triple Super Phosphate (TSP) 25 kg, Muriate of Potash (MoP) 80 kg and Gypsum (Sulphate) 40 kg per hectare of land. Few amounts of cow dung was previously supplied to add organic matter content in soil. Half of the urea was applied at land preparation and the rest half was top dressed at 45 days after sowing. Jute grows in hot and humid climate with temperature variation of 24–37 °C or even higher with long day length more than 12 h and in humidity conditions as high as 74%. It needs a rainfall in the range of 1000–1500 mm depending on soil characteristics and ground water. It is thermo and photo sensitive plant so it needs appropriate time for sowing and harvesting. Generally, seed germination did not occur in temperatures lower than 25 °C. However, pre-chilled seeds demonstrated a better vitality. Jute seeds were sown on 15–20 March. Plants were grown and agronomic practices were done carefully. Plants were harvested at 120 days after sowing.

2.6. Morphological study and method of data collection

After 95–100 days of seed sowing, tossa jute plants attain physiological maturity to harvest. Tossa jute plants can be harvested from 100 to 120 days after sowing (DAS). Early harvesting (110 DAS) increase the fiber quality but decrease the yield capacity; and vice versa occur in case of late harvesting (120 DAS). The leaf morphological data were recorded carefully from the standing jute plant (110 days old) attained the physiological maturity. Then, jute plants were harvested at 120 DAS and morphological data were taken. The plants were bundled according to plot with proper tagging and allowed to shedding of leaves. After shedding of leaves, the bundles were steeped in fresh water for 20–22 days, and fibers were extracted after retting. The extracted jute fibers were carefully washed in clean water, and dried on grass field or by hanging from bamboo poles. The weight of dry fibers and sticks were recorded carefully. Methods of morphological data collection were described in Table 2.

2.7. Anatomical study and method of data collection

Jute plant stem specimen need to preserve and formaldehyde acetic acid- FAA (formalin: acetic acid: alcohol•5: 15: 80) is commonly used for preservation (Frank and Perkins, 2017). The anatomical jute specimens were collected with the help of sharp knife from the base, middle and top of jute plants of each genotype at 100 days old and preserved in FAA solution (Verma, 2008). Transverse sections (TS) of 0.02 mm thin were prepared using hand operated Microtome machine (WSL Lab Microtome-modified Reichert-type) from the collected jute specimen (Mukul et al., 2020a); and mucilage substances were removed by rinsing the TS with clean water. The TS specimens were stained with 1% safranin (aqueous) solution and mounted with a drop of glycerin mixed water on clear glass slide and covered with a cover slip (Mukul et al., 2020a). Then it was observed under trinocular microscope with objectives of 4×–10× and heavy quality camera setup (SKU: Labtmc_87654). The anatomical

Table 2. Measurement of morphological traits.

Sl. No.	Characters and unit of measurement	Method of measurement
1	Leaf angle (X^0)	Using set square (90°) at petiole base between upper leaf surface and plant stem
2	Leaf petiole length (cm)	Scale (30 cm)
3	Leaf length and breadth (cm)	Scale (30 cm)
4	Leaf length breadth ratio	Leaf length divided by leaf breadth
5	Inter-nodal length (cm)	Scale (30 cm)
6	Average weight of fresh leaf laminas (g)	Radwag analytical balance (AS 220.R2)
7	Average weight of fresh leaf petioles (g)	Radwag analytical balance (AS 220.R2)
8	Green leaf biomass (g)	Average weight of 10 random green leaves
9	PP-Plant population (L ha^{-1})	Total number of plants per plot
10	PH-Plant height (m)	The average height of 20 plants selected randomly
11	BD-Base diameter or girth of the plant (mm)	The av. base diameter of 20 plants selected randomly
12	GWL- Green weight with leaves (t ha^{-1})	Total plants wt. with leaves after immediate harvest
13	GWL1- Green weight without leaves (t ha^{-1})	Total plants wt. without leaves after immediate harvest
14	FY-Dry fibre yield (t ha^{-1})	Total weight of dry fibre produced
15	STY-Dry stick yield (t ha^{-1})	Total weight of dry stick produced

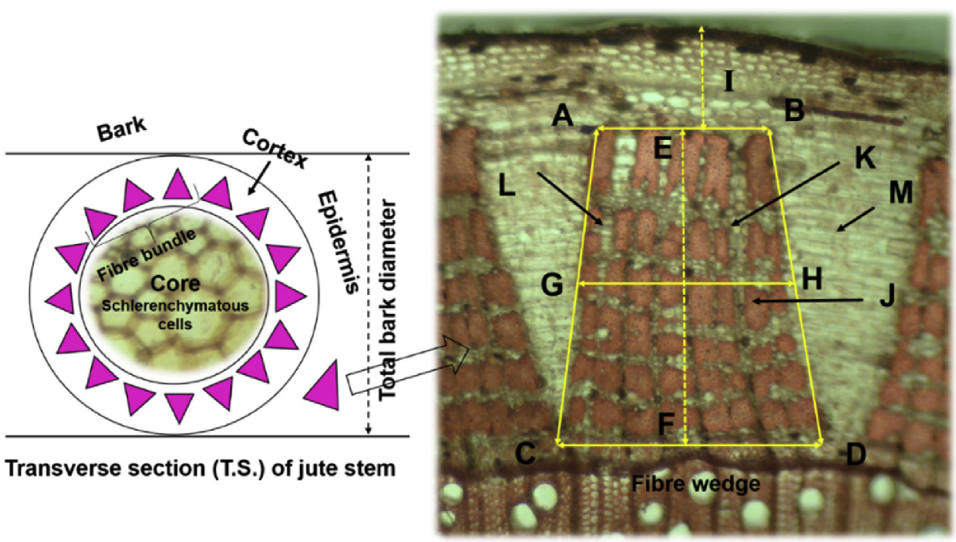
data i.e. bark diameter (mm), bark thickness (mm), height of trapezoid or fiber bundle wedge (mm), average width of trapezoid (mm), area of a trapezoid (sqmm), average number of trapezoid per transverse section (TS), total fiber bundle area per TS (sqmm) and number of bundle layer trapezoid^{-1} in the selected jute genotype were observed and recorded carefully.

Kumar et al. (2014) described that, jute fiber is known as phloem fiber containing maximum amount of cellulose (Figure 1b) which is formed beneath the epidermis and outer of cambium cell of plant. The fiber bundle is composed of many fiber cells formed a pyramid shaped fiber wedge (Figure 1a). The anatomical parameters were measured as follows:

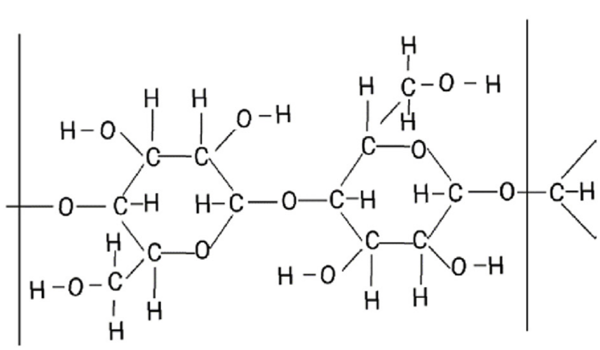
1. Bark thickness around the jute stem (Figure 1a.EF+I) was measured at four places per section with the help of centimetre scale;

2. The wedge-shaped groups formed by the layers of fibre bundles, which were separated from each other by ray cells (Figure 1a.M), were designated as 'trapezoids' (Figure 1a). The number of such trapezoids in each section was recorded;

3. In these trapezoids, the layers of fibre bundles (Figure 1a.J) are separated by the longitudinal (Figure 1a.L) and transverse (Figure 1a.K) strips of soft tissues. The gross perpendicular distance between the parallel sides of five trapezoids per section inclusive of the fibre layers and strips of soft tissues were measured. To obtain the net perpendicular distance between the parallel sides and the lengths of the bigger and smaller parallel sides only, the total perpendicular distance and length



a) Patterns of fibre cell distribution in transverse section (TS) of jute stem



b) Chemical formula of jute fibre cellulose

Figure 1. a) Exhibits the pattern of distribution of cells in cross section of jute fiber; Schematic diagram of a trapezoid and its components (AB = Average width of fiber wedge at top; CD = Average width of fiber wedge at base; GH = Average width of fiber wedge at middle; EF = Average length of fiber cell wedge; I = Difference between fiber wedge tip; EF+I = thickness of bark; J = layer of fibre bundles; K = transverse & L = longitudinal strips of soft tissues respectively; M = Ray cells separating two wedge-shaped formations of fibre bundles designated here as 'trapezoid'; b) Chemical formula of jute fibre cellulose.

occupied by the soft tissues within each trapezoid was subtracted from the gross measurements.

4. From these measurements of the trapezoids, the mean area of fibre cells in each section was computed by using the following formula:

$$\text{Area of a trapezoid (sq mm)} = \frac{1}{2} \times A \times B \quad (1)$$

$$\text{Mean area of fibre cell in each section (sq mm)} = \frac{1}{2} \times X \times Y \times Z \quad (2)$$

Where,

X = Sum of upper (Figure 1a.AB) and lower (Figure 1a.CD) parallel sides of trapezoid

Y= Perpendicular distance between the upper and lower parallel sides of trapezoid (Figure 1a.EF)

Z = Total number of trapezoids in the transverse section (TS)

5. Number of fibre bundles/trapezoid was computed by counting the bundles in five trapezoids per section and calculating means from a total of 45 trapezoids/strain.

6. Number of fibre cells/bundle was determined by counting the fibre cells in 10 bundles of each section and calculating the means from 90 bundles/strain.

7. The means, ranges, standard deviation, coefficients of variations and least significant differences were calculated for the studied anatomical characters

8. Simple Pearson correlation coefficients among the studied anatomical characters were computed.

2.8. Measurement of jute fiber quality data

Bundle strength of jute fiber: Fibre bundle strength can be measured in two methods: i) Stelo meter (strength-elongation meter) and ii) Pressley (based on pivoted beam balance). This is expressed in g denier^{-1}, g tex^{-1}, newton tex^{-1}, CN tex^{-1}, lbs mg^{-1} etc. (Roy and Bhattacharya, 2004). The single fibre strengths (gf/tex HVI strength) were graded as very strong (≥31), strong (29–30), average (26–28), intermediate (24–25) and weak (≤23; and fibre bundle strengths (gf/tex) are very strong (≥41), strong (31–40), average (21–30), intermediate (11–20) and weak (≤5.0). It is measured by the Pressley Fiber Bundle Strength Tester and Fiber Bundle Strength Tester. The jute fibre bundle strength can estimated using the formulae (eqn. iii-v) as follows:

$$\text{Pressley Index (PI)} = \frac{\text{Breaking load in pounds (lbs)}}{\text{Bundle weight in milligram (mg)}} \quad (3)$$

$$\text{Tenacity (gm / tex)} = \frac{\text{Tensile strength (gm)}}{\text{Linear density (tex)}} \quad (4)$$

$$\text{Tensile strength (g tex}^{-1}) = \frac{\text{Breaking load (in kg)} \times \text{Length of sample (in mm)}}{\text{Mass of fibers (in mg)}} = 5.36 \times \text{PI} \quad (5)$$

Values from Pressley tester means as: excellent (≥93), very strong (87–92), strong (81–86), medium (75–80), fair (70–74), weak (≤70).

2.9. Important conversion formula of fiber strength

Tenacity (g tex^{-1}) = 0.981 CN tex^{-1} = Breaking length in kilometers = 9 × tenacity in g denier^{-1} = 0.671 × breaking stress in 10^8 dyne cm^{-2}

Table 3. Optimum lusture contents for jute fiber crops (Nickerson, 1957; Bag and Ray, 1978).

Species	Lusture grade	Contrast ratio (S/D)	Lusture index (1-D/S) × 100%	Bundle tenacity g tex^{-1}
Capsularis (White)	Very high	1.60	37.5	24
	High	1.40	28.6	21
	Medium	1.34	25.4	20
	Low	1.15	13.1	16
Olitorius (Tossa)	Very high	1.77	43.5	28
	High	1.65	39.4	26
	Medium	1.55	36.5	25
	Low	1.40	28.6	18

Breaking extension of jute fiber: The elongation necessary to break a textile material is a useful quantity. The jute fibre breaking twist is generally measured by Jute yarn breaking twist tester and Single and double yarn twist tester. It may be expressed by the actual percentage (%) increase in length and is termed as breaking extension. It can be calculated using the following formula (eqn. vi).

$$\text{Breaking extension (\%)} = \frac{\text{Elongation at break}}{\text{Initial length of specimen}} \times 100 \quad (6)$$

Breaking twist of jute fiber: The twist for breaking of a yarn is called breaking twist. It also can be defined as the number of twists required to break a yarn. Breaking twist depends on the diameter of fiber and it is inversely proportional to its diameter.

That is, $T_b \infty 1/d$

Where, Tb = Breaking twist, d = diameter of fibre

Breaking twist angle: This is the angle through which outer layer of fiber are sheared at breaking. Mathematically, $\alpha = \tan^{-1}(\pi d T_b)$

Where, α = breaking twist angle, d = diameter of fiber, T_b = breaking twist per unit length

Fineness of jute fiber: It is a measure of the diameter (width) or weight per unit length of fibre filament (Bandyopadhyay and Sinha, 1968). The jute fiber fineness can be assessed by using microscope and computer having camera setup and Micronaire machine. The fineness measurement range of jute fiber is 0.6–40 dtex including fineness error of ≤±2%. Micronaire is common measurement that is used as a reflection of fibre fineness and maturity. Usually, MIC values mean very fine fiber (<3), fine fiber (3–3.9), average fine fibre (4–4.9), coarser (5–5.9) and very coarser (≥6.0) fibre. Also, fiber fineness in microns was graded as ultra-fine (<15), super fine (15–19), fine (20–26), medium (27–32), medium coarse (33–37), coarse (>37). Fibre fineness can be measure in four methods i.e. Optical, Uni-dimensional, Bi-dimensional and Air flow methods.

Breaking strength/Tensile strength: Tensile strength is measured by tensile tester of jute fibre or yarn. It is expressed as Newton m^{-2}, dyne cm^{-2} and can be estimated according to the eqn. vii.

$$\text{Tensile strength} = \frac{\text{Force equired to break}}{\text{Cross section area}} \quad (7)$$

Table 4. Physical properties of jute fiber (IJIRA, 2012; Roy and Lutfar, 2012; Pujari et al., 2014; Zakriya et al., 2015; Banerjee et al., 2015; Shahid et al., 2016; Sathishkumar et al., 2017; Khan et al., 2020).

Sl. No.	Parameters	Values	SL. No.	Parameters	Values
1.	Fiber diameter	15.9–20.7 μm	12.	Strength or Tenacity Single (gauge length – 1 cm) Bundle (gauge length – 5 cm)	30-50 gf/tex or 0.0047–0.0079 lbs/g 12-35 gf/tex or 0.0019–0.0055 lbs/g
2.	Fibre length (after carding)	2–50 cm	13.	Young's modulus	10–55 Gpa
3.	Fibre length	1.5–120 mm	14.	Breaking extension or elongation	1.0–1.8%
4.	Ultimate cell length (mm)	0.8–6.0 mm	15.	Breaking twist angle (α)	80–83°
5.	Ultimate cell breadth (μm)	5–25 μm	16.	Tensile strength	6.74 lbs or 0.31 N Tex^{-1} or 200 or 393–773 or 800 Mpa or 30.1 CN/Tex
6.	LBR: Length/Breadth ratio (Aspect ratio)	110	17.	Specific tensile strength	140–320 Mpa
7.	Cell wall thickness	3–9 μm	18.	Moisture regain at 65% RH	13.80%
8.	Fibre fineness (1 Micronaire = 0.039 Tex)	33.05–114.39 Micronaire	19.	Moisture regain at 100% RH	36.0%
9.	Lusture index (1-D/S) × 100	28.60–43.50 %	20.	Specific gravity	1.48
10.	Bulk density	0.4–1.45 g cc^{-1} or 1300–1500 kg m^{-3}	21.	Moisture regain or water absorption	12 or 13.75%
11.	Diameter	20–200 μm			

Lusture or brightness of jute fiber: The luster of a single fiber is determined by the total visual appearance of these reflections from the fiber surface. It is directly proportional to the amount of light reflected by a fiber. Luster of the fabric is the most vital point. The attraction of the fabric depends on the luster of the fabric. It is measured by fibre brightness or lusture machine. Comparatively lusture content is higher in tossa jute fiber than white jute according to previous research results (Table 3). The major physical properties of jute fiber were studied in earlier (Table 4).

2.10. Data analyses

The morphological and anatomical data were collected carefully and compiled in MS Excel program. Statistical analyses were performed using Microsoft Excel program and statistical analysis software (Statistix10.0.0.9 and OriginPro 9.1) program.

3. Results

3.1. Morphological study

3.1.1. Leaf morphology of MG-1, OM-1 and O-795

The leaf morphological data were recorded carefully at maturity stage of jute plants (Figures 2, 3, and 4; Table 5). The tested variety (MG-1) showed full green stem (Figure 2a), red stipule, ovate lanceolate glossy leaves (Figure 2b), bluish green seeds (Figure 2c), lower leaf angle (67.50°), higher leaf length breadth ratio (2.33), higher inter-nodal length (5.0 cm) and lower biomass (0.97 g) of green leaves compared to O-795 (Figure 3a,b,c) and OM-1 varieties (Figure 4a,b,c).

3.1.2. Morphological view of MG-1, O-795, OM-1

The leaves, seeds and full plants of MG-1, O-795, OM-1 were observed and plated as Figure 2.

3.1.3. Performance of MG-1 compared to O-795 for fiber yield and yield related traits at research stations

Jute plants were harvested at 120 days after sowing, and fiber yield and yield related traits were observed in field trials at six locations.

Plant population: BJRI Tossa pat 7 (MG-1) showed the highest plant population (3.96 L ha^{-1}) at Chandina station and the lowest (1.48 L ha^{-1}) at Rangpur station during 2015–16. In respect of means over year, MG-1 showed higher plant population (3.65 L ha^{-1}) with the mean of 2.88 L plant ha^{-1} (Table 6). There is no statistically significant difference between the MG-1 and O-795 for pooled mean of plant population.

Plant height: The highest plant height (3.89 m) was found in MG-1 at Faridpur station during 2017–18 (Table 6). For the means over year, the highest plant height (3.46 m) was found in MG-1 at Faridpur station compared to control variety. O-795 showed the lowest plant height (3.02 m) at Monirampur station (Figure 5).

Plant base diameter: The highest plant base diameter (22.14 mm) was recorded in MG-1 at Chandina station in 2016–17 (Table 6). For the means over year, MG-1 gave higher base diameter (18.93 mm) in the same location compared to control variety. O-795 recorded the lowest base diameter (13.78 mm) at Monirampur station (Figure 5).

Dry fiber yield: The highest dry fiber yield (3.92 t ha^{-1}) was found in MG-1 at Monirampur station during 2016–17 (Table 6). MG-1 gave the highest dry fiber yield (3.17 t ha^{-1}) in the same location compared to control variety O-795 having the lowest dry fiber yield (2.46 t ha^{-1}) at Faridpur station considering the means over year (Figure 5; Tables 7 and 8). The pooled mean over year for dry fiber yield of MG-1 (2.91 t ha^{-1}) showed statistical significant difference with O-795 (2.72 t ha^{-1}) but non-significant difference with the maximum dry fiber yield (3.17 t ha^{-1}) found in MG-1 and average dry fiber yield (2.82 t ha^{-1}) for means over year (Figure 5).

Dry stick yield: The highest dry stick yield (5.74 t ha^{-1}) was recorded in O-795 at Manikganj station and lowest (4.24 t ha^{-1}) was found in MG-1 at Rangpur station during 2015–16 (Table 6). O-795 gave the highest dry stick yield (5.35 t ha^{-1}) in the same location compared to control variety O-795 having the lowest dry stick yield (4.58 t ha^{-1}) at Kishoreganj station considering the means over year (Figure 5; Tables 7 and 8). The pooled mean over year for dry stick yield of O-795 (4.85 t ha^{-1}) showed statistically non-significant difference with MG-1 (4.86 t ha^{-1}) but significant difference with the maximum dry stick yield (5.35 t ha^{-1}) found in O-795 and average dry stick yield (4.86 t ha^{-1}) for means over year (Figure 5).

3.1.4. Performance of MG-1 compared to O-795 for fiber yield and yield related traits at farmers' fields

The morphological trait performances of studied jute genotypes leading to fiber yield were observed in yield trials at six farmer's fields near six research stations and data were recorded after harvesting of 120 days older jute plants from (Table 9).

Plant population: In farmer's plot, MG-1 gave higher plant population (4.60 L ha^{-1}) at Chandina station and the lowest plant population (0.92 L

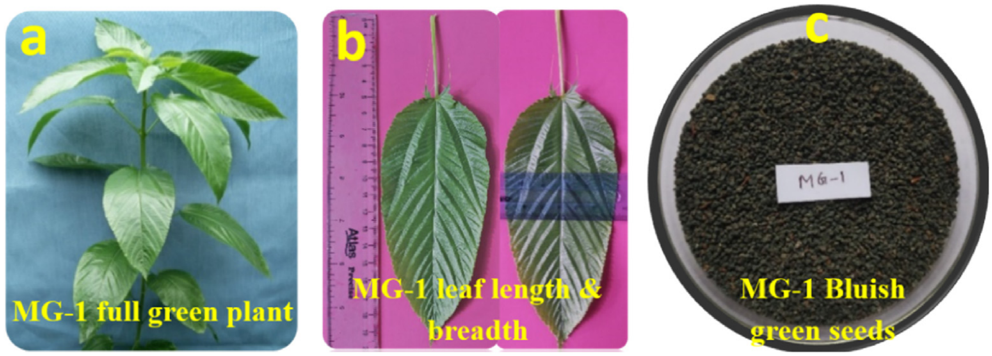


Figure 2. MG-1: a) Green plant, b) Glossy ovate lanceolate leaves and c) Bluish green seeds.

Figure 3. O-795: a) Green plant, b) Ovate lanceolate leaves and c) Bluish green seeds.

Figure 4. OM-1: a) Green plant, b) Glossy ovate leaves and c) Grey colored seeds.

Table 5. Leaf morphological characters of MG-1, OM-1 and O-795.

Genotype	Leaf angle (°)	Leaf length (cm)	Petiole length (cm)	Leaf lamina Length (cm)	Leaf breadth (cm)	Length breadth ratio	Inter-nodal length (cm)	Green leaf biomass (g)	Wt. of lea lamina (g)	Wt. of petiole (g)
MG-1	67.50c	19.17	5.43b	13.73	5.89c	2.33a	5.00a	0.97c	0.79c	0.18b
OM-1	81.83b	20.25	6.58a	13.67	7.03a	1.94b	4.75a	1.21a	0.93a	0.28a
O-795	86.17a	20.23	5.65b	14.58	6.32b	2.31a	2.97b	1.05b	0.86b	0.21b
Maximum	86.17	20.25	6.58	14.58	7.03	2.33	5.00	1.21	0.93	0.28
Range	18.67	1.08	1.15	0.91	1.14	0.39	2.03	0.24	0.14	0.10
Mean	78.50	19.88	5.89	13.99	6.41	2.19	4.24	1.07	0.86	0.21
S.E.	1.48	0.54	0.26	0.42	0.04	0.06	0.29	0.006	0.014	0.02
CV (%)	3.27	4.67	7.60	5.19	1.06	4.60	11.78	1.03	2.87	14.34
$LSD_{(0.05)}$	3.30**	1.19NS	0.58*	0.93NS	0.09**	0.13**	0.64**	0.014**	0.03**	0.04**

Note: S.E- Standard error; CV- Co-efficient of variation; LSD-Least Significant Difference; *, ** denote statistically significant at 0.05 and 0.01 probability level, resp.; NS- Non significant; the mean data in the same column with dissimilar letter indicate significantly statistical different.

Table 6. Mean performance of MG-1 and O-795 for yield and yield contributing characters at research station.

Stations	Variety	Plant population (Lha^{-1})				Plant height (m)				Plant base diameter (mm)			
		2015–16	2016–17	2017–18	Mean over year	2015–16	2016–17	2017–18	Mean over year	2015–16	2016–17	2017–18	Mean over year
Manik.	MG-1	2.06	2.80	3.20	2.69	2.67	3.40	3.70	3.26	14.65	17.84	18.80	17.10
	O-795	3.60	2.70	3.00	3.10	2.91	3.26	3.45	3.21	16.60	16.86	18.50	17.32
Kishor.	MG-1	1.66	3.80	3.40	2.95	3.42	3.20	3.55	3.39	18.06	15.03	18.81	17.30
	O-795	2.00	3.30	2.70	2.67	3.24	2.80	2.99	3.01	17.34	11.27	15.35	14.65
Faridp.	MG-1	3.10	3.70	3.60	3.47	3.10	3.39	3.89	3.46	15.40	17.68	19.89	17.66
	O-795	3.16	3.20	3.40	3.25	3.05	3.06	3.87	3.33	14.46	13.82	17.20	15.16
Rangp.	MG-1	1.48	3.30	3.20	2.66	2.99	3.37	3.62	3.33	14.41	19.20	16.16	16.59
	O-795	1.98	2.90	2.80	2.56	3.29	3.15	3.42	3.29	15.40	16.23	15.48	15.70
Monir.	MG-1	2.92	2.60	1.80	2.44	2.97	3.15	3.75	3.29	14.06	13.38	17.22	14.89
	O-795	2.12	2.40	1.80	2.11	2.83	2.91	3.33	3.02	14.31	11.42	15.61	13.78
Chand.	MG-1	3.96	2.40	4.60	3.65	3.56	3.85	2.94	3.45	16.02	22.14	18.63	18.93
	O-795	3.04	2.20	3.80	3.01	3.47	3.26	2.89	3.21	17.65	16.62	18.00	17.42
Pooled mean	MG-1	2.53	3.10	3.30	2.98	3.12	3.39	3.58	3.36	15.43	17.55	18.25	17.08
	O-795	2.65	2.78	2.92	2.78	3.13	3.07	3.33	3.18	15.96	14.37	16.69	15.67
Maximum		3.96	3.80	4.60	3.65	3.56	3.85	3.89	3.46	18.06	22.14	19.89	18.93
Mean		2.59	2.94	3.11	2.88	3.13	3.23	3.45	3.27	15.70	15.96	17.47	16.38
Range		2.48	1.60	2.80	1.55	0.89	1.05	1.00	0.45	4.00	10.87	4.54	5.15
CV%		29.72	16.91	24.27	14.79	8.39	7.94	9.77	4.20	8.64	19.08	8.40	8.89

Stations	Variety	Dry fiber yield ($t\ ha^{-1}$) during				Dry stick yield (($t\ ha^{-1}$) during			
		2015–16	2016–17	2017–18	Mean over year	2015–16	2016–17	2017–18	Mean over year
Manik.	MG-1	2.30	3.28	3.28	2.95	4.32	5.35	5.20	4.96
	O-795	2.12	3.05	3.15	2.77	5.74	5.30	5.00	5.35
Kishor.	MG-1	2.04	3.80	2.90	2.91	4.78	4.85	4.70	4.78
	O-795	1.94	3.47	2.60	2.67	4.64	4.60	4.50	4.58
Faridp.	MG-1	2.26	2.75	2.67	2.56	4.76	5.00	4.80	4.85
	O-795	2.24	2.60	2.55	2.46	4.66	4.80	4.60	4.69
Rangp.	MG-1	2.01	3.85	2.82	2.89	4.24	5.11	5.08	4.81
	O-795	1.94	3.67	2.50	2.70	4.66	4.92	4.90	4.83
Monir.	MG-1	2.34	3.92	3.25	3.17	4.46	4.94	4.99	4.80
	O-795	2.22	3.60	2.80	2.87	4.66	4.78	4.83	4.76
Chand.	MG-1	2.67	2.92	3.36	2.98	4.46	5.25	5.20	4.97
	O-795	2.42	2.85	3.22	2.83	4.66	5.00	5.08	4.91
Pooled mean	MG-1	2.27	3.42	3.05	2.91	4.50	5.08	5.00	4.86
	O-795	2.15	3.21	2.80	2.72	4.84	4.90	4.82	4.85
Maximum		2.67	3.92	3.36	3.17	5.74	5.35	5.20	5.35
Mean		2.21	3.31	2.93	2.82	4.67	4.99	4.91	4.86
Range		0.73	1.32	0.86	0.71	1.50	0.75	0.70	0.77
CV%		9.31	13.48	10.25	6.62	7.73	4.36	4.43	3.73

Note: Manik. = Manikganj, Kishor. = Kishoreganj, Faridp. = Faridpur, Rangp. = Rangpur, Monir. = Monirampur, Chand. = Chandina.

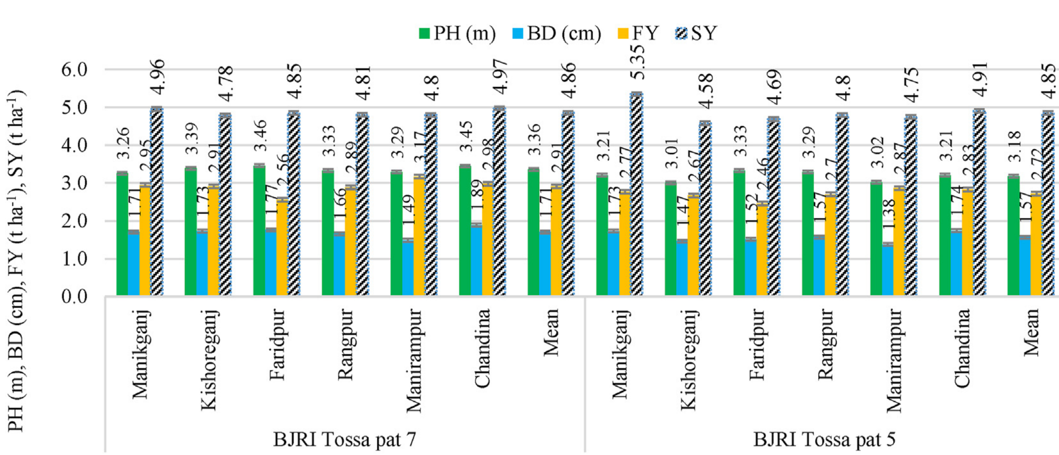


Figure 5. PH, BD, FY, SY of MG-1 and O-795 at six locations; and overall means for these traits over locations. Note: BJRI Tossa Pat 7 gave 5.52, 8.68, 7.51 and 0.21 % increase in PH, BD, FY, SY, respectively than BJRI Tossa Pat 5 at research stations.

Table 7. Effects of sowing times on plant population, plant height, and dry fiber yield of BJRI Tossa pat 7 (MG-1) at different locations.

Sowing times	Locations	Plant population (m^{-2})					Plant height (m)					Dry fiber yield (t ha^{-1})				
		Year			Mean over year	Mean for each sowing time	Year			Mean over year	Mean for each sowing time	Year			Mean over year	Mean for each sowing time
		2013	2014	2015			2013	2014	2015			2013	2014	2015		
10 March	Manikganj	29.23	29.29	33.74	30.75	32.41	2.72	2.72	2.97	2.80	2.91	2.36	2.36	2.96	2.56	2.43
	Rangpur	32.08	31.09	33.38	32.18		2.61	2.61	2.87	2.70		1.58	1.58	2.89	2.02	
	Monirampur	34.20	34.20	34.48	34.29		3.33	3.33	3.01	3.22		2.58	2.58	3.01	2.72	
20 March	Manikganj	29.35	29.35	35.47	31.39	33.36	2.88	2.88	3.34	3.03	3.14	2.51	2.51	3.26	2.76	2.81
	Rangpur	32.12	33.52	34.95	33.53		2.80	2.94	3.25	3.00		1.92	2.33	3.19	2.48	
	Monirampur	35.22	35.19	35.10	35.17		3.50	3.50	3.14	3.38		3.20	3.20	3.18	3.19	
30 March	Manikganj	30.68	31.70	34.33	32.24	33.73	2.95	3.00	3.11	3.02	3.21	2.72	3.19	3.09	3.00	3.04
	Rangpur	33.27	33.07	34.77	33.70		2.92	3.08	3.29	3.10		2.93	2.67	3.22	2.94	
	Monirampur	35.99	35.76	34.01	35.25		3.89	3.66	2.98	3.51		3.87	2.78	2.89	3.18	
10 April	Manikganj	31.70	30.68	33.19	31.86	33.39	2.96	2.90	2.89	2.92	3.09	2.78	2.68	2.74	2.73	2.76
	Rangpur	33.83	33.84	33.24	33.64		3.14	3.17	2.94	3.08		3.00	3.00	2.67	2.89	
	Monirampur	35.85	35.48	32.69	34.67		3.39	3.62	2.84	3.28		2.93	2.42	2.63	2.66	
20 April	Manikganj	30.03	30.04	32.58	30.88	32.48	2.82	2.82	2.70	2.78	2.93	2.53	2.53	2.53	2.53	2.61
	Rangpur	34.57	33.27	32.46	33.43		3.21	2.92	2.61	2.91		3.27	2.93	2.42	2.87	
	Monirampur	34.02	33.02	32.34	33.13		3.28	3.29	2.76	3.11		2.67	2.17	2.47	2.44	
Max.		35.99	35.76	35.47	35.25	33.73	3.89	3.66	3.34	3.51	3.21	3.87	3.20	3.26	3.19	3.04
Range		6.76	6.47	3.13	4.50	1.32	1.28	1.05	0.73	0.81	0.30	2.29	1.62	0.84	1.18	0.61
Mean		32.81	32.63	33.78	33.07	33.07	3.09	3.10	2.98	3.06	3.06	2.72	2.60	2.88	2.73	2.73
CV (%)		6.92	6.63	3.07	4.44	1.79	11.07	10.42	7.22	7.37	4.27	20.10	16.03	9.93	11.21	8.29

Table 8. Effects of sowing times on plant population, plant height, and dry fiber yield of BJRI Tossa pat 5 (O-795) at different locations.

Sowing times	Locations	Plant population (m^{-2})					Plant height (m)					Dry fiber yield (t ha^{-1})				
		Year			Mean over year	Mean for each sowing time	Year			Mean over year	Mean for each sowing time	Year			Mean over year	Mean for each sowing time
		2013	2014	2015			2013	2014	2015			2013	2014	2015		
10 March	Manikganj	29.10	29.20	34.10	30.80	32.22	2.72	2.72	2.95	2.80	2.88	2.41	2.01	2.90	2.44	2.32
	Rangpur	30.97	30.97	33.45	31.80		2.58	2.58	2.82	2.66		1.53	1.62	2.92	2.02	
	Monirampur	34.37	34.37	33.48	34.07		3.33	3.33	2.90	3.19		2.63	2.03	2.79	2.48	
20 March	Manikganj	29.33	29.33	35.37	31.34	33.38	2.92	2.92	3.21	3.02	3.20	2.38	2.68	3.19	2.75	2.75
	Rangpur	31.43	34.43	34.27	33.38		2.83	3.11	3.14	3.03		2.07	2.58	3.07	2.57	
	Monirampur	35.31	35.31	35.64	35.42		3.65	3.65	3.37	3.56		3.07	2.37	3.38	2.94	
30 March	Manikganj	29.93	31.87	34.17	31.99	33.37	2.93	3.04	3.03	3.00	3.18	2.67	2.90	3.05	2.87	3.01
	Rangpur	32.77	31.43	34.73	32.98		2.95	2.83	3.47	3.08		3.23	2.26	3.33	2.94	
	Monirampur	35.43	35.37	34.60	35.13		3.89	3.43	3.06	3.46		4.00	2.53	3.10	3.21	
10 April	Manikganj	31.87	29.93	33.17	31.66	33.32	3.04	2.93	2.78	2.92	3.12	2.88	2.67	2.48	2.68	2.68
	Rangpur	33.67	33.67	33.97	33.77		3.10	3.10	2.97	3.06		3.30	1.95	2.58	2.61	
	Monirampur	35.37	35.43	32.78	34.53		3.43	3.89	2.85	3.39		2.93	2.70	2.63	2.75	
20 April	Manikganj	30.87	30.87	32.40	31.38	32.49	2.96	2.96	2.51	2.81	2.95	2.69	2.59	2.38	2.55	2.56
	Rangpur	34.43	32.77	32.65	33.28		3.11	2.95	2.61	2.89		3.43	1.90	2.40	2.58	
	Monirampur	33.03	33.03	32.38	32.81		3.31	3.31	2.79	3.14		2.60	2.60	2.43	2.54	
Max.		35.43	35.43	35.64	35.42	33.38	3.89	3.89	3.47	3.56	3.20	4.00	2.90	3.38	3.21	3.01
Range		6.33	6.23	3.26	4.62	1.16	1.31	1.31	0.96	0.90	0.32	2.47	1.28	1.00	1.19	0.69
Mean		32.53	32.53	33.81	32.96	32.96	3.12	3.12	2.96	3.07	3.07	2.79	2.36	2.84	2.66	2.66
CV (%)		6.80	6.76	3.04	4.38	1.68	11.26	11.26	8.83	8.20	4.70	21.30	15.87	12.06	10.28	9.56

ha^{-1}) at Monirampur during 2016–17 (Table 9). In respect of means over year, this genotype showed higher plant population (3.40 L ha^{-1}) with the mean of 1.63 L plant ha^{-1} (Table 9).

Plant height: The highest plant height (4.46 m) was found in O-795 and MG-1 showed 4.00 m plant height at Faridpur station during 2015–16 (Figure 6). In respect of means over year, the highest plant height (3.80 m) was found in O-795 station while the MG-1 gave 3.76 m plant height at Faridpur (Table 9).

Plant base diameter: MG-1 recorded the highest plant base diameter (22.14 mm) at Chandina station during 2017–18 (Figure 6). For the means over year, it gave the highest base diameter (18.61 mm) in the same location compared to control variety O-795

Table 9. Mean performance of MG-1 and O-795 for morphological characters at farmer's field.

Station	Variety	Plant population (Lha^{-1})				Plant height (m)				Stem base diameter (mm)			
		2015–16	2016–17	2017–18	Mean over year	2015–16	2016–17	2017–18	Mean over year	2015–16	2016–17	2017–18	Mean over year
Manik.	MG-1	3.40	3.20	2.80	3.13	2.99	3.70	3.40	3.36	17.77	18.80	17.84	18.14
	O-795	3.58	3.00	2.70	3.09	2.91	3.45	3.26	3.21	16.01	18.50	18.86	17.79
Kishor.	MG-1	1.78	3.40	3.80	2.99	2.93	3.55	3.20	3.23	15.05	18.81	15.03	16.30
	O-795	1.74	2.70	3.30	2.58	2.91	2.99	2.80	2.90	14.90	15.35	11.27	13.84
Faridp.	MG-1	2.50	3.60	3.70	3.27	4.00	3.89	3.39	3.76	16.02	19.89	17.68	17.86
	O-795	2.33	3.40	3.20	2.98	4.46	3.87	3.06	3.80	17.65	17.20	13.82	16.22
Rangp.	MG-1	3.70	3.20	3.30	3.40	3.08	3.62	3.37	3.36	16.08	16.16	19.20	17.15
	O-795	3.74	2.80	2.90	3.15	3.06	3.42	3.15	3.21	15.07	15.48	16.23	15.59
Monir.	MG-1	0.92	1.80	2.60	1.77	2.87	3.75	3.15	3.26	14.06	17.22	13.38	14.89
	O-795	1.12	1.80	2.40	1.77	2.83	3.33	2.91	3.02	14.31	15.61	11.42	13.78
Chand.	MG-1	2.86	4.60	2.40	3.29	2.16	2.94	3.85	2.98	15.05	18.63	22.14	18.61
	O-795	2.73	3.80	2.20	2.91	2.37	2.89	3.26	2.84	14.90	18.00	16.62	16.51
Pooled mean	MG-1	2.53	3.30	3.10	2.98	3.01	3.58	3.39	3.32	15.67	18.25	17.55	17.16
	O-795	2.54	2.92	2.78	2.75	3.09	3.33	3.07	3.16	15.47	16.69	14.70	15.62
Maximum		3.74	4.60	3.80	3.40	4.46	3.89	3.85	3.80	17.77	19.89	22.14	18.61
Mean		2.53	3.11	2.94	2.86	3.05	3.45	3.23	3.24	15.57	17.47	16.12	16.39
Range		2.82	2.80	1.60	1.63	2.30	1.00	1.05	0.96	3.71	4.54	10.87	4.83
CV%		37.19	24.27	16.91	18.40	19.61	9.77	7.94	8.90	7.27	8.40	19.49	9.47

Station	Variety	Dry fiber yield (t ha^{-1})				Dry stick yield ((t ha^{-1})			
		2015–16	2016–17	2017–18	Mean over year	2015–16	2016–17	2017–18	Mean over year
Manik.	MG-1	2.88	3.28	3.28	3.15	5.22	5.22	5.34	5.26
	O-795	2.76	3.15	3.05	2.99	5.74	5.74	4.8	5.43
Kishor.	MG-1	2.36	2.90	3.80	3.02	4.94	4.94	4.80	4.89
	O-795	2.26	2.60	3.47	2.78	4.76	4.76	4.79	4.77
Faridp.	MG-1	2.60	2.67	2.75	2.67	5.50	5.50	5.50	5.50
	O-795	2.56	2.55	2.60	2.57	5.07	6.07	5.20	5.45
Rangp.	MG-1	2.28	2.82	3.85	2.98	3.06	5.06	4.90	4.34
	O-795	2.24	2.50	3.67	2.80	2.76	5.76	4.5	4.34
Monir.	MG-1	2.22	3.25	3.92	3.13	2.46	4.46	4.50	3.81
	O-795	2.18	2.80	3.60	2.86	2.66	4.66	4.45	3.92
Chand.	MG-1	2.61	3.36	2.92	2.96	3.96	4.96	4.6	4.51
	O-795	2.54	3.22	2.85	2.87	3.56	4.73	4.53	4.27
Pooled mean	MG-1	2.49	3.05	3.42	2.99	4.19	5.02	4.94	4.72
	O-795	2.42	2.80	3.21	2.81	4.09	5.29	4.71	4.70
Maximum		2.88	3.36	3.92	3.15 (3.39)	5.74	6.07	5.50	5.50
Mean		2.46	2.93	3.31	2.90	4.14	5.16	4.83	4.71
Range		0.70	0.86	1.32	0.58	3.28	1.61	1.05	1.69
CV%		9.04	10.25	13.48	5.75	27.81	9.42	6.97	12.20

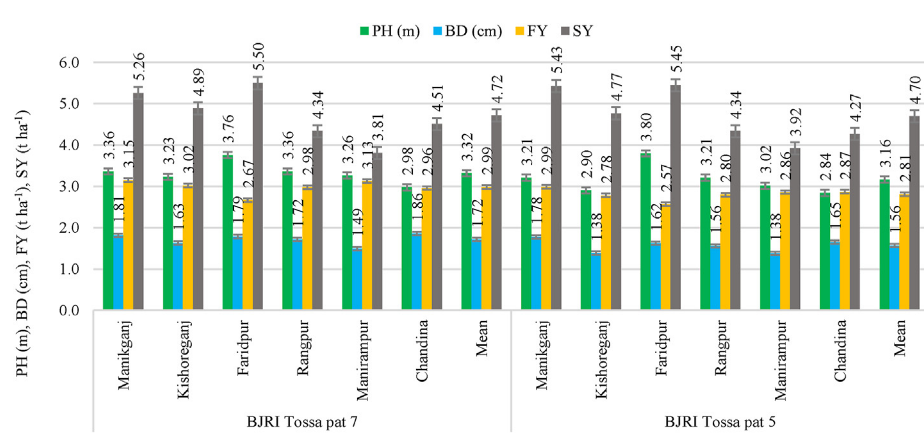


Figure 6. PH, BD, FY, SY of MG-1 and O-795 at farmers' field in six regions; and overall means for these traits. Note: BJRI Tossa Pat 7 gave 4.94, 9.40, 6.21 and 0.42 % increase in PH, BD, FY, SY, respectively than BJRI Tossa Pat 5 in farmers' field at six regions.

Table 10. Correlation coefficients among the morphological traits of jute plants at research stations (left) and farmer's fields (right).

Characters	PP (Lha^{-1})	PH (m)	BD (mm)	FY ($t\ ha^{-1}$)	SY ($t\ ha^{-1}$)
PP (Lha^{-1})		-0.08	0.55**	0.40*	0.47*
PH (m)	0.40*		0.42*	0.30*	0.48*
BD (mm)	0.33*	0.86**		0.64**	0.76**
FY ($t\ ha^{-1}$)	0.60**	0.06	0.17		0.26
SY ($t\ ha^{-1}$)	0.44*	0.09	0.38*	0.35*	

Note: PP ~ SW: see in Table 2; * & ** means statistical significance at 0.05 and 0.01 probability level.

having the lowest base diameter (13.78 mm) at Monirampur station (Table 9).

Dry fiber yield: The highest dry fiber yield (3.92 t ha^{-1}) was recorded in MG-1 at Monirampur station during 2017–18 and O-795 gave the lowest yield (2.18 t ha^{-1}) in the same station during 2015–16 (Table 9). Considering the means over year, MG-1 having the pooled mean of 2.99 t ha^{-1} yield showed the highest dry fiber yield (3.15 t ha^{-1}) at Manikganj station while the O-795 having pooled mean of 2.81 t ha^{-1} yield recorded lower fiber yield 2.57 t ha^{-1} at Faridpur station (Figure 6).

Dry stick yield: The tested variety MG-1 showed the good results for dry fiber yield than the control variety O-795 at farmers' field (Table 9). In respect of means over year, MG-1 gave higher stick yield (5.50 t ha^{-1}) at Faridpur station and showed statistical significant differences with their pooled mean over location and year; but there is no significant differences between them for the pooled mean of stick yield (Figure 6).

3.1.5. Correlation coefficients among the yield and yield contributing characters

The analyses of Pearson associations among the studied morphological traits of jute plants cultivated at research stations (Table 10, left) explored that, highly positive significant relations were found between plant height and base diameter (r = 0.86**); plant population and fiber yield (r = 0.60**); plant population gave significant associations with plant height, base diameter, stick yield; base diameter & fiber yield were significantly related with stick weight. Plant height showed non-significant but positive relation with fiber yield and stick yield, and base diameter showed similar relation with fiber yield. For the character association analyses of jute plants experimented at farmers' plot (Table 10, right), highly significant correlations were recorded for jute plant population with plant base diameter (r = 0.55**); base diameter with fiber yield (r = 0.64**) and stick yield (r = 0.76**). Non-significant and positive relation was found between fiber yield and stick yield, but negative association was recorded between plant population and plant height. The other associations were found positively significant.

3.1.6. Effects of sowing times on MG-1 and O-795

Jute seeds were sown in three stations i.e. Monirampur, Manikganj and Rangpur during 2013, 2014, 2015 at five times. The tested variety MG-1 showed higher results for plant population (3.37 L ha^{-1}), plant

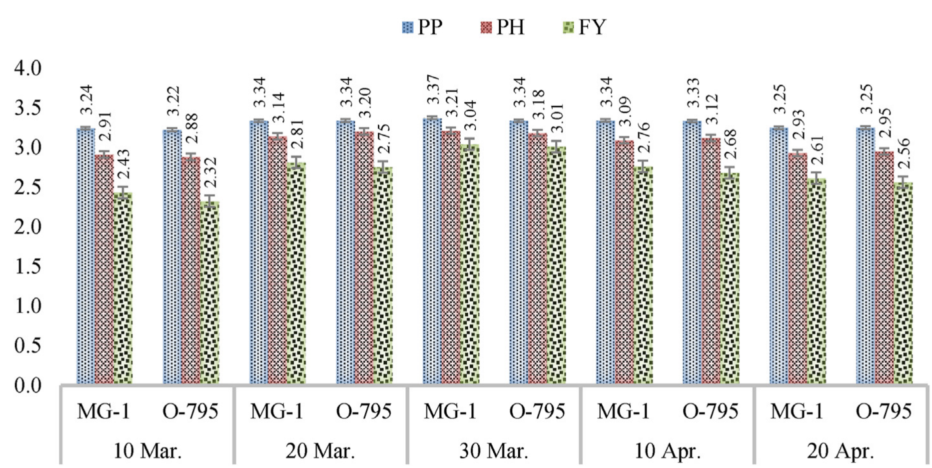


Figure 7. Mean performance of MG-1 and O-795 for plant population (PP), plant height (PH) and dry fiber yield (FY) on different sowing times.

Table 11. Anatomical observation in transverse section (TS) of jute stem of MG-1, O-795, and OM-1.

Genotypes	A	B	C	D	F	G	E	H_1	H_2	I	J	K
MG-1	7.09	0.11	0.66	0.54	0.19	0.36	0.24	11.00	3.80	66.60	9.40	40.20
O-795	6.50	0.14	0.53	0.31	0.17	0.27	0.13	5.60	4.80	33.20	7.40	34.00
OM-1	6.06	0.10	0.55	0.44	0.19	0.29	0.17	9.00	3.80	50.60	8.20	39.80
Mean	6.55	0.12	0.58	0.43	0.19	0.31	0.18	8.53	4.13	50.13	8.33	38.00
Range	1.03	0.04	0.13	0.23	0.02	0.09	0.11	5.40	1.00	33.40	2.00	6.20
S.Dev.	0.52	0.02	0.07	0.12	0.01	0.05	0.06	2.73	0.58	16.70	1.01	3.47
CV (%)	7.89	17.84	12.07	26.82	6.30	15.41	30.93	31.99	13.97	33.32	12.08	9.13
$LSD_{(0.05)}$	0.21	0.03	0.07	0.14	NS	NS	0.07	3.98	NS	23.46	1.10	NS

Note: A = Total bark diameter (mm), B = Difference between fiber wedge tip and outer bark layer (mm), C = Average length of fiber cell wedge (mm), D = Average width of fiber wedge at base (mm), F = Average width of fiber wedge at top (mm), G = Average width of fiber wedge at middle (mm), E = Total area of fiber cell, H_1 = Number of fiber cell blocks at base, H_2 = Number of fiber cell blocks at middle, I= Number of fiber cells in each block, J = Fiber cell layer in each transverse section (TS) and K = Total fiber bundle wedge/trapezoid in each transverse section (TS).

height (3.21 m), fiber yield (3.04 t ha^{-1}) compared to O-795 during 1^{st} (10 March) and 3^{rd} (30 March) sowing times. Both varieties showed nearly similar results for these traits at 2^{nd} sowing time. In respect of means over sowing time and jute genotypes, average values were accounted for plant population (3.30 L ha^{-1}), plant height (3.06 m) and fiber yield (2.70 t ha^{-1}); while the pooled mean values of MG-1 and O-795 for plant population (3.31, 3.30 L ha^{-1}), plant height (3.06, 3.07 m) and fiber yield (2.73, 2.66 t ha^{-1}) which indicate the higher ability of MG-1 for higher fiber yield even after having the plant population and plant height nearly similar to O-795 (Figure 7).

3.1.7. Anatomical study of the genotypes

The anatomy of jute plants revealed that, the TS of MG-1 showed higher bark diameter (7.09 mm), length of fiber cell wedge (0.66 mm), area of fiber cell (0.24 sqmm), number of fiber cells (66.60) and fiber cell layer (9.40) and total fiber bundle wedge or trapezoid (40.20) compared to OM-1 and O-795 (Table 11). O-795 showed higher bark thickness (0.14 mm) than MG-1 and its ancestor OM-1. In the transverse section (TS) stem, MG-1 gave good anatomical features for the distribution of fiber cells than O-795 and its ancestor OM-1 (Figure 8).

3.1.8. Anatomy of MG-1, O-795, OM-1 stem

The stem anatomy of MG-1, O-795, OM-1 were observed and plated as Figure 8.

3.1.9. Correlation coefficient among the studied anatomical characters of jute crops

Most of the studied anatomical characters of jute plants showed highly significant associations (r**) among them; where, average length of fiber cell wedge, average width of fiber wedge at middle and total area of fiber cell per TS showed significant relations (r*) with the bark thickness of jute stem. Non-significant relations were found among bark diameter with bark thickness, average width of fiber cell wedge at top and total fiber bundle wedge per TS of jute stem (Table 12).

3.1.10. Fiber quality tests

In this study, MG-1 comparatively gave higher values for brightness and breaking twist than O-795, but almost similar results for bundle strength, fiber lusture, and fiber fineness (Figure 9). In this study, intermediate type fibre bundle strengths, medium breaking twists, coarse type fiber fineness, very high lusture ratio, medium to high lusture index or brightness were found in fibre content of jute genotypes. The brightness and breaking twist were significantly different between the varieties (Figure 9).

4. Discussion

In the morphological study, MG-1 showed lower leaf angle than O-795. The lower leaf angle with plant stem resulting the lowest bending or dropping of leaf along with the lowest shading effects on plants resulting higher absorption of sunlight on leaf surface increasing photosynthesis rate as well as enhanced plant growth and development (Kriedeman et al., 1964). Chlorophyll are important leaf pigments involved in light use efficiency. The levels of chlorophyll in the *C. olitorius* were higher than other leafy vegetables (Bouayed et al., 2011). The amount of light energy falling upon the foliage of a plant community is frequently the environmental factor that limits the growth rate of that plant community (Donald, 1961). In this study, MG-1 showed the lowest leaf angle than O-795 and OM-1 resulting the possibility of higher light absorbance capacity for more photosynthesis as well as more food production and fiber yield. According to Verhagen et al. (1963), there are two factors influencing the photosynthetic rate of individual leaves within the canopy are (i) the disposition of leaves in relation to the incident light, and (ii) the optical properties of the leaves themselves. Both of these factors will influence the proportion of the light incidence that is reflected, absorbed, and transmitted.

The new variety MG-1 gave higher LBR-leaf length breadth ratio (2.33) than O-795 (1.94) indicating the possibility of lower leaf biomass, leaf angle and higher light absorbance and maximum plant population per unit area leading to higher fiber yield content. Ultimately, fiber yield will be increased for the plants having lower LBR and leaflet angle. The LBR of jute leaf depends on the length and width of leaf lamina which indicates the leaf area. The more length and minimum width of jute leaf causes decrease in leaf angle and increase in LBR (Ngomuo et al., 2017). The decrease in leaf angle increase the light incidence followed by increasing photosynthetic rate, growth, development and plant population per unit area of jute crop. Similar reports were described by Sarlikioti et al. (2011) in tomato.

The inter-nodal length is responsible for the variation of jute fiber quality (Maity et al., 2012). The lowest inter-nodal length or maximum number of node in jute stem causes more knot in jute fiber cell, tear up of jute fiber and ultimately deteriorate the fiber quality (Tanmoy et al., 2014). On the other hand, the minimum number of node or maximum inter-nodal length of jute plant increase the fiber quality without tearing of the cell (Paridah et al., 2011). MG-1 stem showed lower number of node as well as higher internodal length indicating the possibility of good fiber quality.

Jute plants have sun leaves at top and shade leaves under the sun leaves. The sun leaves get maximum sunlight and contains many stomata, two layered palisade and compact spongy layer of leaf lamina, compact cells of the mesophyll of midrib, compact parenchyma cells of the cortex of the stem, and larger vacuole in the pith of the stem than shaded jute leaves (Silverio, 2015). The lowest biomass of leaf is desired for jute crop. The jute leaf biomass depends on the weight of leaf lamina and petiole. The more leaf biomass or weight causes more dropping of leaves as well as more leaf angle resulting the shading effects on other leaves or plants, and limits the photosynthetic rate, plant population per unit area (Ngomuo et al., 2017). The lowest leaf angle and leaf biomass; highest LBR and inter-nodal length of MG-1 results the maximum photosynthesis as well as fiber yield compared to O-795 and OM-1 varieties. Similar reports were described by Maity et al. (2012).

According to Mukul et al. (2020b), the fiber yield content in jute crops depends on its morphological traits like plant population, plant height, base diameter, fresh weight etc. The maximum fiber yield content is the prime objectives of jute crops (Majumder et al., 2020). The jute variety

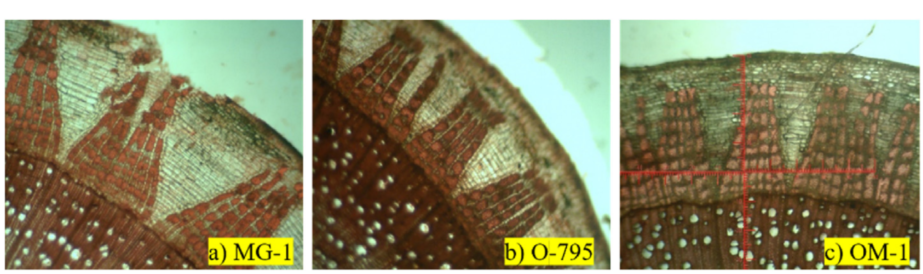


Figure 8. Transverse sectioning (TS) of a) MG-1, b) O-795 and c) OM-1 at 100 days old.

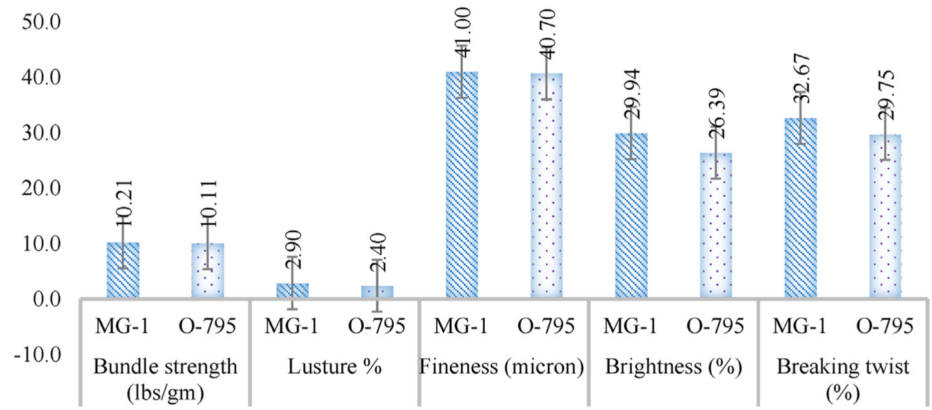


Figure 9. Comparison for fiber quality parameters between MG-1 and O-795.

Table 12. Correlation coefficient among the studied anatomical characters of jute crops.

	A	B	C	D	F	G	E	I	J	K
A	1.00									
B	0.16	1.00								
C	0.83**	0.41*	1.00							
D	0.51**	0.77**	0.90**	1.00						
F	0.08	0.97**	0.62**	0.90**	1.00					
G	0.79**	0.47*	0.99**	0.93**	0.67**	1.00				
E	0.69**	0.60*	0.98**	0.97**	0.78**	0.99**	1.00			
I	0.55**	0.74**	0.92**	0.99**	0.88**	0.94**	0.98**	1.00		
J	0.66**	0.64**	0.97**	0.98**	0.80**	0.98**	0.99**	0.99**	1.00	
K	0.14	0.96**	0.66**	0.92**	0.99**	0.71**	0.81**	0.90**	0.84**	1.00

* & ** denote significant at 0.05 and 0.01 levels of probability, respectively.

having higher good quality fiber yield potentiality is the crying need of the farmers for the present situation contributing to the national economy. Generally the jute plant phenological structure having small leaf size, narrow lanceolate type leaves, lower number of leaves having lower leaf angle and correct petiole, smooth erect and cylindrical stem with maximum height showed maximum or optimum plant population per unit area (Ngomuo et al., 2017). If the experimental plots will be over plant populated, the plants will be leaky thinner. So, optimum plant population should be kept to achieve maximum fiber yield. MG-1 gave higher and optimum plant population than O-795 indicating the possibility of higher fiber yield than O-795 variety. Plant height and base diameter of jute crops are directly involved with fiber yield. The more plant height and girth or diameter of stem gave higher fiber yield in jute (Mukul et al., 2020b). MG-1 showed higher plant height and base diameter than O-795 in both research fields and farmers' plots which were contributed to higher fiber yield. For the pooled mean over year, MG-1 showed statistically significant differences with O-795 in respect of plant height and base diameter. But non-significant differences for the means over year regarding these traits. The dry stick yield is also important for jute crops. Jute sticks are the important source of coal, fuel, carbon ink, activated carbon for removal of Pb^{2+} from aqueous solution. Its activated carbon inks are used in printer, photocopier, cosmetics elements, toothpaste. (Islam and Ali, 2017). The sticks produced by MG-1 would be used as fuel, as raw materials in industries, for fence purpose etc. The jute plant population, plant height and plant base diameter showed significant association with plant base diameter, fiber yield and stick yield at both farmers' field and research stations. The jute fiber yield is dependent on plant population, plant height, base diameter. The significant association among these traits are the pre-requisite for the breeders to select the traits to be improved or not (Khatun et al., 2009).

Flowering is normally occur in tossa jute at 140–155 days after sowing (Al-Mamun et al., 2018). According to Chowdhury and Hassan (2013), the vegetative phase exists up to 130 days after sowing, when seeds were sown after 15 March (more than 12.0–12.30 h day length; 30–35 °C temperature, 60–80% humidity). The early harvesting (90–100 days old plant) of jute increases the fiber quality but decreases the yield; on the other hand, jute fiber yield is increased but quality is gradually deteriorated if it is harvested after 120 days old. The MG-1 variety can be sown at 10 March to 15 April. Good fiber yield would be obtained if it will be sown on 10 March but after 15 March is the best time for seed sowing to achieve good plant height, fiber yield and quality. Based on the pathological nature for fungal infection, right variety and location should be selected for jute seed production in Bangladesh (Talukder et al., 2021).

MG-1 showed higher performance for bark diameter, bark thickness, area and number of fiber cell bundle, fiber bundle layer than the control O-795 and its ancestor OM-1. These anatomical traits directly or indirectly contributed to fiber yield content (Mukul, 2020). These anatomical traits showed highly significant association among them contributing to fiber yield content.

Shahid et al. (2011) reported that, the jute fiber should have good qualities like bundle strength, lusture, fineness, brightness, breaking twist etc. for its diversified uses. The MG-1 variety having good performance for these traits would be added in the textile products for supporting the national outputs. MG-1 gave comparatively higher values for brightness and breaking twist than O-795, but almost similar results for bundle strength, fiber lusture, and fiber fineness. Jute fiber quality depends on fiber bundle strength, fiber lusture, fineness, brightness and breaking twist (Chakrabarti, 1956). The tossa jute variety having maximum bark diameter, bark thickness around its stem on the cambium layer, area and number of fiber cell bundle, fiber bundle layer on its stem would be considered as good genotype or variety (Majumdar, 2002; Kumar, 2020). Jute stems having fiber bundles comprising greater number of compactly arranged long and fine ultimate cells give fibers of higher strength when retted under standard conditions (Majumdar, 2002). Fiber quality test for these parameters indicated that the proposed variety MG-1 has better quality fiber than O-795. According to the physiological nature of jute crops, MG-1 can be sown on 10–15 March; good fiber yield would be obtained; would be harvested at 110–120 days old followed by 3–4 cropping pattern which will be economic for the farmers.

5. Conclusion and way forward

BJRI Tossa Pat 7 (MG-1) performed well than BJRI Tossa Pat 5 (O-795) in respect of important morphological traits i.e. plant population, plant height, base diameter, leaf architecture, fiber yield, and anatomical features like bark diameter, bark thickness, area of fibre bundles in its transverse section (TS) of stem and finally, adaptability in different agro-ecological zones of Bangladesh. MG-1, the newly developed tossa jute variety is good for quality fiber production than the pre-released varieties. It would be recommended for commercial production of jute fiber by replacing the existing lower yielded varieties. It will be able to meet the requirement of quality fibers in jute industries.

Declarations

Author contribution statement

Md. Mia Mukul: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Nargis Akter; Mohammad Moinul Islam; Md. Solaiman Hossain Bhuiyan; Md. Golam Mostofa; Ranjit Kumar Ghosh: Conceived and designed the experiments; Performed the experiments.

Chandan Kumar Saha: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Md. Abbas Ali: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The principal author is thankful to Bangladesh Jute Research Institute, Ministry of Agriculture, Government of Bangladesh for giving the opportunity and support to conduct this study. He also thanked all the senior colleagues, staffs for their technical guidelines and inspirable assistance during laboratory & field based research works.

References

Akter, N., Islam, M.M., Begum, H.A., Alamgir, A., Mosaddeque, H.Q.M., 2009. BJRI tossa-5 (O-795): an improved variety of *Corchorus olitorius* L. Eco-friendly Agril. J. 2 (10), 864–869. https://www.academia.edu/10496398/.

Akter, S., Sadekin, M.N., Islam, N., 2020. Jute and jute products of Bangladesh: contributions and challenges. Asian Business Review 10 (3), 143–152.

Al-Mamun, M., Akter, N., Saha, C.K., 2018. Conventional Varieties of Jute, Kenaf and Mesta Crops. Breeding Division, Bangladesh Jute Research Institute, Manik Mia Avenue, Dhaka, Bangladesh. Agricultural Information Services, DAE, Khamarbari, Dhaka-1215.

Al-Mamun, M., Saha, C.K., Mostofa, M.G., Miah, A., Hossain, M.Z., 2017. Identification of suitable varieties for seed production of jute in non-traditional areas of Bangladesh. Bangladesh J. Pl. Breed. Genet. 30 (1), 33–37.

Bag, S.C., Ray, P.K., 1978. The luster of jute fibre in relation to its fine structure. Textil. Res. J. 48 (12), 710–712.

Bandyopadhyay, S.B., Sinha, N.G., 1968. An airflow method for the determination of the fibre fineness of Jute and Mesta. J. Text. Inst. 59, 148–151.

Banerjee, P., Ray, D.P., Satya, P., Debnath, S., Mondal, D., Saha, S.C., Biswas, P.K., 2015. Evaluation of ramie fibre quality: a review. Int. J. Biores. Sci. 2 (1), 65–69. https://www.indianjournals.com/ijor.aspx?target=ijor:ijbs1&volume=2&issue=1&article=011.

Basu, A., Ghosh, M., Meyer, R., Powell, W., Basak, S.L., Sen, S.K., 2004. Analysis of genetic diversity in cultivated jute determined by means of SSR markers and AFLP profiling. Crop Sci. 44 (2), 678–685.

Basu, G., Roy, A.N., 2008. Blending of jute with different natural fibers. J. Nat. Fibers 4 (4), 13–29.

Bouayed, J., Hoffmann, L., Bohn, T., 2011. Total phenolics, flavonoids, anthocyanins and antioxidant activity following simulated gastro-intestinal digestion and dialysis of apple varieties: bioaccessibility and potential uptake. Food Chem. 128 (1), 14–21.

Chakrabarti, B.K., 1956. The breaking strength of twisted bundles of jute fibre and its relation to spinning quality. Textil. Res. J. 26 (1), 17–23.

Chattopadhyay, T., Roy, S., Mitra, A., Maiti, M.K., 2010. Development of a transgenic hairy root system in jute (*Corchorus capsularis* L.) with gusA reporter gene through Agrobacterium rhizogenes mediated co-transformation. Plant Cell Rep. 30 (4), 485–493.

Chowdhury, M.A.H., Hassan, M.S., 2013. Hand Book of Agricultural Technology. Bangladesh Agricultural Research Council (BARC), Farmgate, Dhaka, p. 230. http://www.barcapps.gov.bd/documents/books/Hand%20Book%20of%20Agricultural%20Technology.pdf.

Chowdhury, M.Z.A., Uddin, M.N., Islam, M.N., Islam, M.S., 2001. Agro-economic performance of tossa jute at growers level in Bangladesh. Pakistan J. Biol. Sci. 4, 796–798.

Das, B., Chakrabarti, K., Tripathi, S., Chakraborty, A., 2014. Review of some factors influencing jute fibre quality. J. Nat. Fibers 11 (3), 268–281.

Donald, C.M., 1961. Competition for light in crops and pastures. In "*Mechanisms in Biological Competition*. Symp. Soc. Exp. Biol. 15, 282–313.

Frank, M.S., Perkins, K.D., 2017. Preparation of Plant Specimens. Retrieved from University of Florida Museum: https://www.floridamuseum.ufl.edu/herbarium/voucher.htm.

Gupta, D., Sahu, P.K., Banerjee, R., 2009. Forecasting jute production in major contributing countries in the world. J. Nat. Fibers 6 (2), 127–137.

Gupta, V.K., Parsad, R., Bhar, L.M., Mandal, B.N., 2016. Statistical Analysis of Agricultural Experiments, Part-I. ICAR-Indian Agricultural Statistics Research Institute Library Avenue, Pusa, New Delhi – 110012. www.iasri.res.

Haque, S., Begum, S., Sarker, R.H., Khan, H., 2007. Determining genetic diversity of some jute varieties and accessions using RAPD markers. Plant Tissue Cult. Biotechnol. 17 (2), 183–191, 2007 (December). https://www.banglajol.info/index.php/PTCB/article/view/3239/2726.

IJIRA-Indian Jute Industries Research Association, 2012. Jute Technology Mission: Design and Development of JDPS (Mini Vision IV). Project: Development of Jute-Bamboo Composites for Applications in Rural Areas. National Jute Board, Ministry of Textile, Govt. of India.

Islam, M., Alauddin, M., 2012. World production of jute: a comparative analysis of Bangladesh. Int. J. Manag. Bus. Stud. 2 (1), 14–22. https://www.internationalscholarsjournals.com/articles/world-production-of-jute-a-comparative-analysis-of-bangladesh.pdf.

Islam, M.M., Ali, M.S., 2017. Economic importance of jute in Bangladesh: production, research achievements and diversification. Int. J. Econom. Theor. Appl. Am. Assoc. Sci. Technol. 4 (6), 45–57. http://article.aascit.org/file/pdf/9180778.pdf.

Islam, M.M., Uddin, M.N., 2019. Research and development advances of jute seed in Bangladesh: a review. Haya Saudi J. Life Sci. 4 (2), 52–68.

JCU, 2010. Discover Nature at James Cook University (JCU), Townsville, Australia. https://www.jcu.edu.au/__data/assets/pdf_file/0004/123745/jcuprd1_065111.pdf.

Kar, C., Kundu, A., Sarkar, D., Sinha, M.K., Mahapatra, B.S., 2009. Genetic diversity in Jute (*Corchorus* spp.) and its utilization: a review. Indian J. Agric. Sci. 79 (8), 575–586. https://www.cabdirect.org/cabdirect/abstract/20093254742.

Khan, J.A., Khan, M.A., 2015. The use of jute fibres as reinforcements in composites. In: Bio-fibre Reinforcements in Composite Materials, pp. 3–34.

Khan, T., Sultan, M.T.H., Jawaid, M., Safri, S.N.A., Shah, A.U.M., Majid, M.S.A., Zulkepli, N.N., Jaya, H., 2020. The effects of stacking sequence on dynamic mechanical properties and thermal degradation of kenaf/jute hybrid composites. J. Renew. Mater. 9 (1), 73–84.

Khatun, R., Islam, M.M., Al-Hussain, M., Parvin, N., Sultana, K., 2009. Performance study of newly developed jute variety BJRI Deshi-7 (BJC-2142). Int. J. Sustain. Agril. Tech. 5 (4), 12–18. https://www.researchgate.net/publication/313314160.
Kriedeman, P.E., Neales, T.F., Ashton, D.H., 1964. Photosynthesis in relation to leaf orientation and light interception. Aust. J. Biol. Sci. 17, 591–600. https://www.publish.csiro.au/bi/pdf/BI9640591.
Kumar, V., 2020. Genetic Analysis of Fibre Anatomy Charactrs in Tossa Jute. LAP LAMBERT Academic Publishing, 17 Meldrum Street, Beau Bassin 71504, Mauritius. https://www.researchgate.net/publication/339775369.
Kumar, V., Singh, P.K., Dudhane, A.S., De, D.K., Satya, P., 2014. Anatomical and morphological characteristics of nine jute genotypes. J. Crop Weed 10 (2), 334–339. https://www.cropandweed.com/archives/?year=2014&vol=10&issue=2&article_id=633.
Kundu, A., Topdar, N., Sarkar, D., Sinha, M.K., Ghosh, A., Banerjee, S., Das, M., Balyan, H.S., Mahapatra, B.S., Gupta, P.K., 2012. Origins of white (*Corchorus capsularis* L.) and dark (*C. olitorius* L.) jute: a re-evaluation based on nuclear and chloroplast microsatellites. J. Plant Biochem. Biotechnol. 22 (4), 372–381.
Lazic, B.D., Janjic, S.D., Rijavec, T., Kostic, M.M., 2017. Effect of chemical treatments on the chemical composition and properties of flax fibres. J. Serb. Chem. Soc. 82 (1), 83–97.
Maity, S., Datta, A.K., 2010. Cyto-morphological studies in F_2, F_3 and induced amphidiploid of jute (*Corchorus trilocularis* L. X *Corchorus capsularis* L.). Nucleus 53 (3), 85–87.
Maity, S., Chowdhury, S., Datta, A.K., 2012. Jute biology, diversity, cultivation, pest control, fibre production and genetics. In: Lichtfouse, E. (Ed.), Organic Fertilisation, Soil Quality and Human Health. *Sustainable Agriculture Reviews, 9*. Springer, Dordrecht.
Majumdar, S., 2002. Prediction of fiber qualities from anatomical studies in jute stem: part-I prediction of fineness. Indian J. Fibre Text. Res. 27, 248–253. http://nopr.niscair.res.in/bitstream/123456789/22849/1/IJFTR%2027%283%29%20248-253.pdf.
Majumder, S., Saha, P., Datta, K., Datta, S.K., 2020. Fibre crop, jute improvement by using genomics and genetic engineering (Chapter 22). In: Advancement in Crop Improvement Techniques, pp. 363–383.
Mandal, A., Datta, A.K., 2011. An updated overview on cytological and cytogenetical aspects of *Corchorus* SP. (*Tiliaceae*). J. Plant Dev. Sci. 3 (1 & 2), 9–18. http://jpds.co.in/wp-content/uploads/2019/07/02.-Aninda.pdf.
Meshram, J.H., Palit, P., 2013. On the role of cell wall lignin in determining the fineness of jute fibre. Acta Physiol. Plant. 35, 1565–1578.
Moody, V., Needles, H.L., 2004. Fibre theory and formation, Chapter 1. Tufted Carpet 3–21.
Mukul, M.M., Akter, N., Ahmed, S.S.U., et al., 2020b. Genetic diversity analyses of twelve tossa jute (*Corchorus olitorius* L.) genotypes based on variability, heritability and genetic advance for yield and yield attributing morphological traits. Int. J. Plant Breed. Genet. 14, 9–16.
Mukul, M.M., Akter, N., Mostofa, M.G., Ahmed, S.S.U., Nur, I.J., Al-Mamun, M., Rashid, M.H., 2020a. Analyses of genetic variability, character association, heritability and genetic advance of tossa jute (*Corchorus olitorius* L.) genotypes for morphology & stem anatomy. Am. J. Biosci. 8 (4), 99–112.
Mukul, M.M., 2020. Elucidation of Genotypic Variability, Character Association, and Genetic Diversity for Stem Anatomy of Twelve Tossa Jute (*Corchorus olitorius* L.) Genotypes, 2020. BioMed Research International, Hindawi Publishing Group. Article ID 9424725.
Mukul, M.M., Akter, N., 2021. Morpho-anatomical variability, principal component analysis and Euclidean clustering of tossa jute (*Corchorus olitorius* L.). Heliyon 7 (5), e07042, 1-17. PMID: 34095567; PMCID: PMC8167238.
Ngomuo, M., Stoilova, T., Feyissa, T., Kassim, N., Ndakidemi, P.A., 2017. The genetic diversity of leaf vegetable jute mallow (*Corchorus* spp.): a review. Indian J. Agric. Res. 51 (5), 405–412.
Nickerson, D., 1957. A new cotton luster meter for yarns and fibres'. Textil. Res. J. 27 (2), 111–123.
NJB-National Jute Board, 2019. Ministry Textiles, Government of India. www.jute.com.
OriginPro 9.1, 2001. OriginLab Corporation, One Roundhouse Plaza, Suite 303,Northampton, MA 01060, United States, 1800-969-7720. http://www.originlab.com/.
Paridah, M.T., Basher, A.B., Saiful Azry, S., Ahmed, Z., 2011. Retting Process of Some Bast Plant Fibres and its Effect on Fibre Quality: a Review.
Pujari, S., Ramakrishna, A., Kumar, M.S., 2014. Comparison of jute and banana fiber composites: a review. Int. J. Curr. Eng. Technol. 121–126. Special Issue-2.
Rahman, K., Ahmed, N., Raihan, M.R.H., Nowroz, F., Jannat, F., Rahman, M., Hasanuzzaman, M., 2021. Jute responses and tolerance to abiotic stress: mechanisms and approaches. Plants-MDPI 10, 1595.
Roy, S., 2010. Application of Natural Fibre (Jute) Products: International Symposium on Renewable Feedstock for Bio-fuel and Bio-based Products; 11-13 August 2010, Austin, USA. IJSG-International Jute Study Group, Dhaka, Bangladesh. http://www.bestjute.com/Application-of-Natural-Jute-Products.pdf.
Roy, G., Bhattacharya, G.K., 2004. A step towards development of an automatic electronic fibre bundle strength tester. J. Textil. Assoc. 64 (5), 253–254.
Roy, S., Lutfar, L.B., 2012. Bast fibres: jute. In: Handbook of Natural Fibers, pp. 24–46.
Samira, R., Moosa, M.M., Alam, M.M., Keka, S.I., Khan, H., 2010. *In silico* analysis of jute SSR library and experimental verification of assembly. Plant Omics J. (POJ) 3 (2), 57–65. https://www.pomics.com/khan_3_2_2010_57_65.pdf.
Sarkar, S.K., Gawande, S.P., 2016. Diseases of jute and allied fibre crops and their management. J. Mycopathol. Res. 54 (3), 321–337. Indian Mycological Society, Department of Botany, University of Calcutta, Kolkata 700 019, India.
Sarlikioti, V., de Visser, P.H.B., Marcelis, L.F.M., 2011. Exploring the spatial distribution of light interception and photosynthesis of canopies by means of a functional–structural plant model. Ann. Bot. 107 (5), 875–883.
Sathishkumar, G., Rajkumar, G., Srinivasan, K., Umapathy, M., 2017. Structural analysis and mechanical properties of lignite fly-ash-added jute–epoxy polymer matrix composite. J. Reinforc. Plast. Compos. 37 (2), 90–104.
Shaha, S.K., Dyuti, S., Ahsan, Q., Hasan, M., 2011. A study on the tensile property of jute yarns using weibull distribution. Adv. Mater. Res. 264–265, 1917–1921.
Shahid, M.A., Mahabubuzzaman, A.K.M., Ahmed, F., 2011. Study on the tensile behaviour of jute-cotton blended yarn using ring and rotor spinning system. J. Innov. Dev. Strat. 5 (2), 34–40. http://ggfjournals.com/assets/uploads/MN-227_ (34-40) _FINAL_ (OK) _TP.pdf.
Shahid, M.A., Mahabubuzzaman, A.K.M., Ahmed, F., Ali, A., 2016. Investigation of the physical properties of jute blended yarn using a novel approach in spinning process. J. Textile Sci. Technol. 2, 1–6.
Sheheli, S., Roy, B., 2014. Constraints and opportunities of raw jute production: a household level analysis in Bangladesh. Progr. Agric. 25, 38–46.
Silverio, F.D., 2015. Morpho-anatomical structure and DNA extract of sun and shade leaves of jute (*Corchorus capsularis* L.). Am. J. Agric. Forest. 3 (6-1), 1–5. Special Issue: Agro-Ecosystems.
Sinha, M.K., Kar, C.S., Ramasubramanian, T., Kundu, A., Mahapatra, B.S., 2011. Wild crop relatives: genomic and breeding resources, industrial crops (*Corchorus*), (Ed.) C. Kole, XXII, 183p. Mahapatra, A.K., Saha, A., Basak, S.L., 1998. Origin, taxonomy and distribution of *Corchorus* species in India. Greenpeace J. 1, 64–82. https://www.springer.com/gp/book/9783642211010.
Statistix10- Analytical Software for Statistix, 29 August, 2017. Analytical Software, 2105. Miller Landing Rd, Tallahassee FL 32312, USA. https://statistix.informer.com/10.0.0.9/.
Talukder, F.U., Rahman, M.S., Haque, S.M.A., Mukul, M.M., 2021. Prevalence of Seedborne Fungal Invasion on Tossa Jute (*Corchorus olitorius) Seeds*. Front. Environ. Microbiol. 7 (1), 15–21. http://www.sciencepublishinggroup.com/journal/paperinfo?journalid=384&doi=10.11648/j.fem.20210701.13.
Tanmoy, A.M., Alum, M.A., Islam, M.S., Farzana, T., Khan, H., 2014. Jute (*Corchorus olitorius* var. O-72) stem lignin: variation in content with age. Bangladesh J. Bot. 43 (3), 309–314. https://www.banglajol.info/index.php/BJB/article/view/21603/14826.
Tyagi, G.K., 2010. Yarn structure and properties from different spinning techniques. Adv. Yarn Spinning Technol. 119–154.
Verhagan, A.M.W., Williams, W.A., Hall, E.H., 1963. Plant production in relationship to foliage illumination. Ann. Bot. (N.S.) 27, 627–639.
Verma, P.K., 2008. Preservation of botanical specimens retaining the natural colour pigments. J. Histotechnol. 30, 173–190. https://shodhganga.inflibnet.ac.in/bitstream/10603/53605/1/01_title. Pdf.
Virk, A.S., Hall, W., Summerscales, J., 2009. Tensile properties of jute fibres. Mater. Sci. Technol. 25 (10), 1289–1295.
Yang, W., Li, H., Chen, X., 2019. Chapter 11- Melt Electrospinning. Edited by ding, B., Wang, X., and Yu, J., 2019. Electrospinning: Nanofabrication and applications. Micro Nano Technol. 339–361.
Zakriya, G.M., Ramakrishnan, G., Rajan, T.P., Abinaya, D., 2015. Study of thermal properties of jute and hollow conjugated polyester fibre reinforced non-woven composite. J. Ind. Textil. 1–19.