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STUDIES ON PHYSICAL, CHEMICAL AND MICROBIOLOGICAL PROPERTIES AFFECTING JUTE FIBER QUALITY

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Abstract - *Different factors that influence the production of quality jute fibers are presented. These include the soil, retting, and jute genotype. Several soil quality parameters influence fiber quality. Different aspects of retting, right from quality and quantity of retting water, microorganisms with balanced pectinolytic and xylanase activi-ties with minimal or low cellulase activities, largely determine fiber quality. Efficient pectinolytic bacteria as well as fungi could be used in retting process. Future research needed in this respect has been expressed.*

Key Words: jute, fiber quality, soil quality, retting water, pectinolytic bacteria, enzyme activity.

1.INTRODUCTION

Jute, also known as Golden Fiber, is an internationally traded major com-modity originating primarily from two developing countries— Bangladesh and India. It occupies a unique position in the national economy in terms of its contributions to employment in industry and agriculture, as also in foreign exchange earnings. It is basically composed of lingo-cellulosic mate-rial, totally biodegradable, hence eco-friendly and cheaper. It is the second most important vegetable fiber after cotton, in terms of usage, global con-sumption, production, and availability. Bangladesh (1,523,320 tonnes), India (1,237,270 tonnes), China (43500 tonnes), Myanmar (30000 tonnes), Nepal (14,418 tonnes), and Thailand (2,184 tonnes) are the major producers of jute(http://en.wikipedia.org/wiki/Jute). The total area under jute cultivation in India varies between 0.638 and 1 million hectares, which is the high-est in the world. Several districts of West Bengal account for 71% of area of jute cultivation and 73.09% of total raw jute production in India (Roul 2009). The important jute growing districts of West Bengal include Nadia, Murshidabad, Cooch Bihar, West Dinajpur, Jalpaiguri, Malda, Hoogly, and North 24-Parganas. Jute fiber is widely used now-a-days both in the industry as well as in the manufacture of various value-added materials for domestic use. The major issue today in jute industry is to produce quality fiber. A jute fiber sample is categorized as good when its strength varies from 26.5 to 29.4 g tex−1, fine when the fineness lies between 3.2 and 2.8 tex and very fine when it is < 2.8 tex (Govt. of India 2008). It is widely believed that the quality of the fiber largely depends on retting process, which is essentially microbiological and biochemical in nature. Several literatures are available in this respect but in a scattered form. Apart from retting, the influence of soil parameters on jute quality is poorly studied. The effect of jute cultivars on fiber quality is also poorly studied. Present review is a compilation of such scattered informations under one umbrella with a view to helping the future researchers.

2.JUTE GROWING SOIL AND FERTILIZATION

Coarser and light-body fiber is obtained from sandy soils, whereas clay-loam soils with silt give fiber of superior quality (Ahmed and Nizam 2008). The plate count of soil from a field used for growing jute varied from 1.0 to 2.5 h 105 bacteria g−1, being highest in July (Jalaluddin 1970). Saha et al. (2000) investigated the changes in soil properties and crop productivity as affected by long-term fertilization for 25 years in the New Gangetic alluvial soil (Eutrochrept) with jute–rice–wheat cropping sequence. Highest response in fiber and grain yields was obtained with 150% of recommended dose (N:P2O5:K2O::80:40:40). Effect of FYM (farm-yard manure) was perceptible in jute as well as in the succeeding crops of rice and wheat. A general decline in organic carbon and available zinc and an increase in available iron were observed during jute cultivation (Tarafdar et al. 1981). The distribution of urease and acid and alkaline phosphatase in some jute-growing soils was also investigated (Tarafdar et al. 1981). Compost manuring gives a high fiber yield in Corchorus capsularis, but not in C. olitorius. Application of 20 to 40 lbs of nitrogen per acre gives a 30% to 200% increase in fiber yield (Banerjee 1955). All those studies mainly reflect agronomic aspects of jute and the soil chemistry, but not jute fiber quality. In-depth studies concerning soil quality and jute fiber quality are prac-tically absent. Although it is widely accepted that retting water largely determines fiber quality, in a recent study, Das et al. (2010) reported that many soil quality parameters have high bearings on jute fiber quality. The related soil parameters consisted of pH, organic carbon, phosphorous, Mn content, bacterial colony forming unit, basal soil respiration, aryl sul-phatase activity, Fe content, fungal colony forming unit, and β -glucosidase activity.

3.RETTING PROCESS

It is the separation and extraction of fibers from nonfibrous tissues and woody part of the stem through dissolution and decomposition of pectins, gums, and other mucilaginous substances (Haque et al. 2002). The quality of the fiber produced and the ease with which it is spun into yarns depend on the proper control of the retting process (Shorllon 1975). Ahmed and Akhter (2001) opined that plants should be harvested at small-pod stage and retting is to be carried out at an optimum temperature of 34◦ to 35◦ C. The retting can be carried out either chemically or microbiologically.

3.1.Chemical Retting

Chemical retting includes treatment with acids and bases (Dujardin 1948), surfactants, and chelators (Henriksson et al. 1998). It produces low-quality fibers (Van Sumere 1992). In chemical retting, the cementing material can be removed by dissolution with certain chemicals. The fiber obtained by chemical method of retting seems to be a little coarser, rough in the feel and stiff. Chemical retting is considered expensive, and it is not environment friendly due to high consumption of chemicals and energy.

4.MICROBIAL RETTING

Different types of microbiological retting are in vogue viz., dew and water retting. In dew retting, the harvested plants are left in the fields and retting is carried out by filamentous fungi present both in soil and on plants. The process is accelerated by changes in environmental conditions like high humidity and low temperatures during the night and higher temperatures and drier conditions during the day. Important properties of colonizing fungi are the high level of pectinase activity, ability to attack noncellulosic cell types without attacking cellulosic fibers, capacity to penetrate the cuticular surface of the stem and efficient fiber release from the core (Henriksson et al. 1997). During water retting, plants absorb water when steeped in it and swell. Ultimately bursting occurs at several places and the soluble constituents which include sugars, glucosides, and nitrogenous compounds are liberated creating the surrounding environment a good start medium for the growth of microorganisms present in water as well as in the plants (Ali and Islam 1963; Ali et al. 1976). These organisms gradually develop and multiply by utiliz-ing free sugars, pectins, hemicelluloses, proteins etc. derived from the plants as nutrients (Majumdar and Day 1977; Mohiuddin et al. 1978; Sarkar 1964). Specific enzymes secreted by the organisms cause degradation of the com-plex organic materials to simpler compounds which are then metabolized for their life processes. A modification of water retting involves enzymatic treatment, where pectin degrading enzymes are directly added to tank water (Sharma and Van Sumere 1992). However, at present, enzymatic retting is not yet feasible due to high cost of the process. Dew retting is usually less uniform than the water retting. It is affected by the fungal colonization along the plant stems (Akin et al. 1998). Moreover, there is risk of over-retting due to the proliferation of cellulolytic fungi (Henriksson et al. 1997). Microbiological retting in water bodies is the cheapest and it is widely practiced method for the commercial extraction of jute fibers in Asian countries (Ahmed and Akhter 2001; Munshi and Chattoo 2008).

5.FACTORS AFFECTING DURATION OF RETTING AND QUALITY OF FIBER

5.1.Fertilization of Crop

Experiments have shown that use of ammonium sulphate increases the yield of the fiber (Banerjee 1955). Higher dose of nitrogenous fertilizer applied to the crop was found to reduce the retting period. The reverse happens when phosphatic fertilizers are used (Ahmed and Akhter 2001).

5.2.Plant Age

Jute plants require 100 to 130 days from seed germination to maturity and the crop is harvested from June through October, C. capsularis usually harvested earlier than C. olitorius (Banerjee 1955). Harvesting may be performed at three stages of crop development: (a) when the flowers begin to appear; (b) when the plants are in full flower or fruit; (c) when all the plants are fully mature. Harvesting is usually carried out at the second stage when about half of the plants have fully developed fruit. The yield then is good and the quality of fiber is excellent (Banerjee 1955). At the earlier stage, most plants are immature and the fiber is weak and low in yield. At the later stage, the fiber becomes coarse and reddish. As the jute plant grows older, the tissues become more mature; the structure of the decomposable matters like pectins and hemicelluloses may change to more resistant forms and their quantity may increase. As a result, microorganisms take longer time to ret a plant (Ahmed and Akhter 2001). Usually, fiber loss is 17.3% and 9.5% if 75-day-old plant and 120 days are ribboned, respectively.

5.3.Retting Water

Water plays a dominant role in determining the quality of jute fiber. Several physico-chemical properties of water, viz. pH, hardness, metal contents, and microbial parameters play important role for obtaining good quality fiber (Ahmed and Akhter 2001; Jarman 1985). Retting is a biochemical process in which a series of reactions occur in water (Chaudhuri 1951). Analysis of retting water revealed the pres-ence of decomposed products such as organic acids (acetic, lactic, butyric, ketoglutarics, etc.), acetone, ethyl alcohol, butyl alcohol, and various gases (Debsharma 1976). Accumulation of organic acids and other products released during retting causes hindrance to the growth and activity of the microorganisms in stagnant water. Retting does not produce any toxic substances, and the materials released during the process are fully biodegradable. However, the quality of water after jute retting becomes degraded transitorily. The microbial load increases excessively and the water becomes discoloured (Haque et al. 2002). Very fast moving water removes the materials released during retting quickly, but it carries away the microbial population along with it (Ahmed and Akhter 2001). During retting, a bacterial succession occurs: the first to grow is aerobic bacteria, which by consuming all the oxygen present creates an anaerobic environment for the anaerobic bacteria to grow (Tamburini et al. 2004). In areas where water is scarce, retting is carried out in same water bodies repeatedly. In those cases, good-quality fiber is obtained in first few charges, but with a progress of retting, fiber quality deteriorates (Adhikary et al. 2005). Retting is best carried out in slow moving clear water (canal, river, etc.) with low contents of iron and calcium. The presence of iron, particularly ferrous iron, is not desirable as it imparts a dark colour to the fiber. During retting, tannin is liberated from jute stems. Iron reacts with the liberated tannin to produce Fe– tannate, which makes black patches on fiber (Jarman 1985). Retting in stagnant waters makes the water darker; there is bad odor and transitory loss in retting water quality. Due to organic mass released, there is increased microbial load and depleted O2 levels is prolonged. After some time, these negative effects disappear. Therefore, the situation could be described as transitory polluting. Environmental aspect, therefore, should form important component of retting studies (Haque et al. 2002). Mondal and Kaviraj (2008) observed severe deterioration of water quality during jute retting in ponds, canals, floodplain lakes, and other inland water bodies in the rural areas of West Bengal, India. They evaluated the changes in the physico-chemical parameters of water caused by jute retting, and their impact on the survival of two species of freshwater fish and fresh-water invertebrate. Results showed that jute retting in a pond for 30 days resulted in a sharp increase in the BOD (>1,000 times) and COD (>25 times) of the water, along with a sharp decrease in dissolved oxygen (DO). Free CO2, total ammonia, and nitrate nitrogen also increased (3—5 times) in water as a result of jute retting. In an attempt to explore the key determinants of retting water parame-ters those have influence on jute fiber quality, Das et al. (2010) collected water samples at different stages of retting (pre-retting, after first and second charge of retting) and jute fiber samples (after first and second charge of retting) from Sonatikari and Baduria, West Bengal, India. The physicochemical, microbiological, and biochemical parameters of the retting water varied significantly between different stages of retting. The jute fiber strength and fineness at first charge were superior to the second charge. Subjecting the various variables to multiple regression analysis, it revealed that major influential water quality parameters were pH, electrical conductivity (EC), chemical oxygen demand (COD), hardness, bicarbonate, Ca, Cl– , Fe content, bacterial count, fungal count, and spore-forming bacterial count. Das et al. (2011) studied the effect of jute retting on various physico-chemical and microbiological parameters of retting water, before and after retting, from three well-known jute growing areas of N-24 Parganas viz., Sonatikari (22◦ 41 27 N, 88◦ 35 44 E), Baduria (22◦ 44 24 N, 88◦ 47 24 E), and Swarupnagar (22◦ 49 59.88 N, 88 ◦ 52 0.12 E), West Bengal, India. Irrespective of the locations, the pH of the post-retting water samples was more acidic than the pre-retting water samples. Other physico-chemical parameters like EC, COD, hardness, and metal contents increased in the post-retting water samples. The post-retting water samples also registered higher bacterial, fungal, pectinolytic, and spore-forming bacterial colony forming units.

5.4.Activators

Retting is accelerated in the presence of several activators both natural and synthetic chemicals. Natural activators include dhaincha (Sesbania aculeata) and sunnhemp (Crotalaria juncea) plants which are generally introduced into the jute stem bundles put for retting. Tribasic calcium phosphate, diba-sic potassium phosphate, ammonium sulphate, ammonium oxalate, dibasic ammonium phosphate, calcium carbonate, monobasic potassium phosphate, sodium oxalate, calcium nitrate, potassium nitrate, bone dust, and gelatin has been recommended as activators by Indian Central Jute Committee. These activators create highly nutritious environment for the growth and activity of the retting microbial community (Ahmed and Akhter 2001).

5.5.Microbes involved in retting

Research efforts have been made to identify bacteria involved in jute retting. Members of the genera Aerobacter, Bacillus, Flavobacterium, and Pseudomonas were isolated from jute retting tanks by Betrabet and Bhat (1957). Several workers have isolated jute retting bacteria from decompos-ing stems, but it is not clear how widely they are distributed (Jalaluddin 1970). The bacteria involved in both aerobic and anaerobic retting processes include spore formers and thus have a great potentiality for survival; in fact 70% of the isolates studied by Ahmed (1963) belonged to Bacillus macerans, B. polymyxa, B. subtilis, and B. cereus. The fungi Aspergillus niger, Macrophomina phaseolina, Mucor sp., Chaetomium sp., Phoma sp., and several Penicillium spp. were reported as good retting agents (Ahmed 1963). Several aerobic species of the genus Bacillus viz., B. subtilis, B. polymyxa, B. mesentericus, and B. macerans (Bhattacharyya 1971–1974) and anaerobic species of the genus Clostridium viz., C. tertium, C. aurantibutyricum, C. felsineum etc. were isolated from retting water (Alam 1970). Bacterium felsenium considerably shortened the retting period and improved the fiber quality (Ali et al. 1972). Haque et al. (2002) studied the microbial population dynamics of pre and postretting water samples in different jute growing areas of Bangladesh. The microbial populations (aerobic and anaerobic bacteria and fungi) were higher at the postretting stage. The numbers varied from 1.5 h 105 to 2.9 h 106 at preretting stage and 1.6 h 106 to 6.0 h 106 at postretting stage for aerobic bacteria; 0 to 5.5 h 105 at preretting stage and 2.5 h 105 to 5.9 h 106 at postretting stage for anaerobic bacteria; 0 to 4.1 h 106 at preretting stage and 1.5 h 105 to 6.6 h 106 at postretting stage for fungi. Haque et al. (2003) isolated Micrococcus sp. from jute-retting water samples and found it as promising bacteria that retted jute within 6 days. Munshi and Chattoo (2008) studied the bacterial population struc-ture of jute retting ponds located in Krishnanagar and Barrackpore, West Bengal, India, using molecular techniques. The bulk of clones came from Proteobacteria (~37, 41%) and a comparatively smaller proportion of clones from the divisions— Firmicutes (~11, 12%), Cytophaga–Flexibacter– Bacteroidetes group (CFB; ~9, 7%), Verrucomicrobia (~6, 5%), Acidobacteria (~4, 5%), Chlorobiales (~5, 5%), and Actinobacteria (~4, 2%) was identified. In addition, 32 bacterial species were isolated on culture media from the two retting environments and identified those by 16S rDNA analysis, confirm-ing the presence of phyla, Proteobacteria (~47%), Firmicutes (~22%), CFB group (~19%), and Actinobacteria (~13%) in the retting niche. Several reports exist on the involvement of different genera of bacteria and fungi in jute retting. However, biochemical aspects of retting have been poorly reported. Biochemical reactions are enzymatic in nature. In jute retting several types of enzymes are involved. The pectinolytic enzymes polygalac-turonase (Tamburini et al. 2003) and pectin lyase (Soriano et al. 2005) are the primary retting agents. They selectively breakdown pectin, the cement-ing agent that hold the fibers with the stalk. The enzyme xylanase brings smoothness of the fibers, while cellulase activity degrades the fiber strength. Thus it is mandatory to study not only the microorganisms involved in jute retting but also their above enzyme make-up for efficient retting. Enzyme activities of the retting microorganisms involved in hemp, flax, ramie, and kenaf retting have been reported (Basu et al. 2009; Candilo et al. 2010; Juárez et al. 2009; Tamburini et al. 2003; Yu and Yu 2007; Zheng et al. 2001). Such informations for jute are scarce. Das et al. (2012) isolated 38 pure pectinolytic bacterial strains from jute-retting water bodies occurring at Sonatikari and Baduria, West Bengal, India. The range of enzyme activities varied from: polygalacturonase—8.74 to 41 IU g−1, pectin lyase— 2.23 to 75.7 U mL−1, xylanase—0 to 1.052 μmol mL−1min−1, and cellulase—0 to 0.316 μmol mL−1min−1. Based on their bal-anced proportion of pectinolytic activity and low or no cellulolytic activity, eight organisms were selected for detailed characterization. Majority of the isolates were found to be rod shaped, gram positive, spore former, could utilize starch, sucrose, mannitol, lactose, and were catalase positive. The 16S rDNA sequences of the isolates were similar to the species: Agrobacterium sp. BN-2A, Bacillus pumilus strain Geo-03-422, Microbacterium sp. PVC8, Bacillus pumilus strain IK-MB12-518F, Bacillus sp. L6, Bacillus pumilus strain EK-17, Bacillus sp. YACS30, Bacillus pumilus strain IK-MB13-518F. Among those bacteria, Agrobacterium and Microbacterium were not earlier reported as jute-retting bacteria. Das et al. (2013) also studied the community level physiological profiles (CLPP) as well as genomic diversity of bacterial communities in water sam-ples collected during pre-retting, after first and second charge of jute retting at Sonatikari and Baduria, West Bengal, India. The CLPP, expressed as net area under substrate utilization curve, was studied by carbon source uti-lization patterns in BIOLOG Ecoplates. Molecular diversity was studied by polymerase chain reaction (PCR) followed by denaturing gradient gel elec-trophoresis (DGGE) of total DNA from water samples. Both between loca-tions and stages of retting, substrate utilizations pattern were carbohydrates> carboxylic acids>polymers>amino acids> amines/amides>phenolic com-pounds. Differential substrate utilization pattern as well as variation in banding pattern in DGGE profiles was observed between the two locations and at different stages of retting. The variations in CLPP in different stages of retting were due to the change in bacterial communities.

6.USE OF MICROBIAL INOCULANTS IN JUTE RETTING AND THEIR IMPACT ON FIBER QUALITY

Banik et al. (2003) studied the effect of pectinolytic mixed bacterial culture on ribbon retting of jute. Green ribbon samples of 100- to 130-day-old jute plants (JRO-524) were used for retting. Retting was conducted artificially in cement retting tank using tap water with substrate liquor ratio of 1:10 and pectinolytic mixed bacterial culture was used as inoculum. Inoculation of mixed bacterial culture was effective in reducing time of retting in compari-son to uninoculated control. The pH of the retted water gradually decreased from 7.26 at first day before start of retting to 5.54 at day 15, and Eh 150 mV at first day before start of retting to −267 mV at day 15. Fiber grade became infe-rior with progress of retting of plants. The temperature of retting water was 27◦ C.The 100-day-aged plants took 16 days in inoculated treatment (fiber strength 21.6 g tex−1 and fiber fineness 2.3 tex) and 19 days in control to complete retting. The retting period was increased to 18 days with inoculums (fiber strength 22.1 g tex−1 and fiber fineness 2.3 tex) and 21 days in control (fiber strength 24.3 g tex−1 and fiber fineness 2.4 tex) for 112-day-old plants. For 120-day-old plants, the retting period was 19 days with inoculum (fiber strength 22.1 g tex−1 and fiber fineness 2.3 tex) and 22 days in control (fiber strength 23.9 g tex−1 and fiber fineness 2.5 tex). In another experiment, Banik et al. (2007) observed that the com-bined effect of urea and pectinolytic mixed bacterial culture reduced the ribbon retting time compared to uninoculated control. The combined effect of inoculation of mixed bacterial culture produced stronger, finer, brighter-colored and less defective fiber in comparison to uninoculated control. One hundred and twenty-day-old jute plant was found to be optimum and most suitable for ribbon retting. Inoculation of efficient pectinolytic bacteria can improve ribbon retting of jute. Das et al. (2012a) studied the effect of efficient pectinolytic bacterial isolates on retting and fiber quality of jute. Four bacterial strains with high balanced polygalacturonase and pectin lyase, and xylanase with minimal cellulase activity were used in jute retting. The organisms were: Bacillus sp. L6, Bacillus pumilus strain EK-17, Bacillus pumilus strain Geo-03-422, and Bacillus pumilus strain IK-MB12-518F. The organisms in different combinations of consortia reduced the retting period to 11 to 13 days as compared to 19 days in the control. Microbial inoculation produced remarkable improve-ment in jute fiber strength (26.62–28.91 g/tex-1) and fineness (2.76–2.92 tex) over control.

7.EFFECT OF CHEMICAL COMPOSITION OF JUTE CULTIVARS ON FIBER QUALITY

Haque et al. (2001) studied the retting properties of six different cultivars of jute. The cultivars released from Bangladesh Jute Research Institute were two from C. olitorius (OM-1 & OF-390) and four from C. capsuiaris (C-718, C-2035, C-2005 & C-2143). The cultivars were compared for their retting properties, morphological differences as well as their physical properties of the fiber extracted from them. Among them, white fiber with fewer cuttings and "A" and "B" grade fibers were obtained by retting from C-718 and OF-390 varieties, respectively, yielding higher quantity of fibers. Other cultivars were found inferior in quality in all aspects. Ahmed et al. (2003) reported that jute cultivars vary in their chemical composition, which seems to affect the retting process and ultimately fiber quality. They studied the chemical composition of different cultivars (C-718, C-2005, C-2193, C-2035, and OM-1) of jute fibers and their effect on jute fiber quality. The moisture content (%) and the chemical parameters like cellulose content (%), hemicellulose content (%), lignin content (%), ash content (%), and fat content (%) in three parts of jute plant—top, middle, and bottom to ascertain the better cultivar in order to produce good-quality fiber. The authors proposed a guideline for establishing chemical method for fiber grading. From the chemical point of view, they concluded that moisture, hemicellulose, and lignin contents in all the cultivars were more or less similar but they differed in cellulose, ash, and fat content. Among the cultivars tested, C-2035 and C-2193 were found better one.

8.CONCLUSION

Important factors controlling the production of quality fiber are: (1) proper cultivation practices in good quality soil, (2) controlled retting process, and (3) genetic make-up of jute cultivars. Soil quality is intimately con-nected to the quality and quantity of crop produced. But reports are scanty about the influence of soil quality on jute fiber quality. Investigations are also required to study the effect of different jute cultivars on fiber qual-ity. Among the different retting processes, water retting is largely in vogue. Successful water retting demands slow moving abundant water with proper physico-chemical as well as microbial characteristics. Efforts have been directed to find out the involvement of various microorganisms, mostly aerobic, in retting process through conventional microbial technique. This reflects a small fraction of total microorganisms involved in retting process. This limitation could be tackled by wide application of currently available molecular techniques. Efforts should also be directed to explore the role of nonculturable microorganisms in retting process. Ribbon retting is superior to that of whole plant retting. Pectinase, xylanase, and cellulase activities influence the production of quality fibers. Jute retting with efficient area-specific microorganisms having high pectinase and xylanase activities with low or nil cellulase activity accrues benefit.

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