International Journal of Scholarly
Research and Reviews
Journal homepage: https://srrjournals.com/ijsrr/
ISSN: 2961-3299 (Online)

(Review Article)

Check for updates

Types, stages and mechanism of action of Jute retting: An overview

Zakaria Ahmed [1,*], Taslima Rahman [2], Umme Hafsa Timmi [3] and Sadia Mehrin [4]

[1] *Department of Weaving, Technology Wing, Bangladesh Jute Research Institute, Manik Mia Avenue, Dhaka 1207, Bangladesh.*
[2] *Department of Microbiology, Technology Wing, Bangladesh Jute Research Institute, Manik Mia Avenue, Dhaka 1207, Bangladesh.*
[3] *Department of Post-Harvest Processing, Bangladesh Jute Research Institute, Manik Mia Avenue, Dhaka 1207, Bangladesh.*
[4] *Department of Biochemistry, Technology Wing, Bangladesh Jute Research Institute, Manik Mia Avenue, Dhaka 1207, Bangladesh.*

International Journal of Scholarly Research and Reviews, 2023, 02(02), 009–020

Publication history: Received on 25 February 2023; revised on 06 April 2023; accepted on 09 April 2023

Article DOI: https://doi.org/10.56781/ijsrr.2023.2.2.0026

Abstract

Some factors hastening up retting process which are- retting water, retting in already used water, harvesting time, climate conditions like high temperatures, deep water (too deep water will delay retting, addition of chemicals, materials used as weights on Jak, method of retting, variety of jute, method of fiber extraction, stage of harvesting, period of retting, etc. There are few methods of retting available which are- conventional method of whole plant retting, chemical retting, microbial retting, mechano-microbial retting and *In-situ* retting with microbial consortium. There are three sequential stages in retting (based on the morphological modification, dynamics of pH and various enzymes related to them during the entire jute retting process): Stage 1 (Initial retting stage); Stage 2 (Middle retting stage) and Stage 3 (Final retting stage).

Keywords: Jute; Retting; Mechanism; Type; Enzyme; Microbial

1 Introduction

Jute is one of the most versatile bast fiber crops, commonly known as golden fiber and widely grown in the South-east Asian countries. The jute plant grows particularly well in a warm, humid climate where the land is constantly enriched by alluvial deposit (mud). Most of the world's supply of jute comes from India and Bangladesh. Jute is an important cash crop of eastern India is traditionally grown for extraction of fiber by a natural microbial process known as retting. Usually mature stems of harvested jute plants are allowed to ret in pond or ditch water. Retting is a preferential rotting process to separate the fiber from woody stem without damaging the fiber cellulose. Retting microbes consume the non-fibrous cementing materials mainly pectin and hemicellulose. Over retting causes degradation of fiber cellulose while under retting causes incomplete removal of gummy materials viz., pectin substances (Banik et al 1993). Both over retting and under retting which are very difficult to control causes production of low grade jute fiber. In conventional retting, a huge biomass undergoes decomposition in stagnant water, so retting causes environmental pollution.The harvest of jute gets ready for gathering in about 3 months, and the correct stage is recognized by the formation of the flower buds. These are not allowed to break and bloom, for that would take too much goodness from the fibers. It is a long mostly unbranched and monocotyledonous type of plant that belongs to the genus Corchorus, in the family Tiliaceae or lime family. The genus Corchorus contains about 40 species (Ahmed and Akhter 2001) and among these, the most important variety is *C. capsularis*, which is grown throughout tropical Asia not only as a fiber plant but also as a vegetable. Other varieties are e.g.-*C. capsularis*, *C. olitorius*, *C. fuscus*, *C. japonicas*, *C. monopoxensis*, *C. olitorius*, *C. fuscus*, and *C. decemangulatus*; the latter two, however, yield only a small proportion of the jute fiber. One variety found in

*Corresponding author: Zakaria Ahmed

panama, the *C. monopoxensis*, is used for brewing and infusion similar to tea. *C. japonicus* is found in Japan. Arabs and Egyptians have used *C. olitorius* for generations as a port herb (Ali et al 2015). Based on morphological characteristics of the plant, color markings of stem and flowers, maturity, and chemical properties of the fiber, 33 distinct types of *C. capsularis* were described, 30 of which were grown for fibers and three as vegetables; five types of *C. olitorius* were described (Banik et al 1993). Later studies at the Jute Agricultural Research Institute indicated more than 70 races or types of *C. capsularis* and at least 12 races or types of *C. olitorius* have been identified. An ordinary staple of jute fibers is as long as 4–7 feet, and often reach 12 feet in exceptional cases. But in spite of this, the ultimate fibers are exceedingly short, ranging only from one-eighth of an inch to one-twelfth of an inch (Ali et al 2015). Jute is a fiber of rather coarse character and dark color. It is a long, soft, shiny vegetable fiber that can be spun into coarse and strong threads. The fibers are usually off white and have flat surfaces. Jute assimilates about 5.8 ton CO_2 from the atmosphere in its lifetime. The total methane generation from jute production is estimated to be $18.8x10^{10}$g/year (Banik et al 1993).

2 Physical and Chemical Properties of Jute Fibers

Physical properties of fiber, such as breaking strength, extensibility, flexibility, moisture absorption, etc. all depend on a number of factors, of which the length of the fiber molecules, the mode of alignment among them, and the nature and intensity of inter-chain cohesive forces are most important. In pure cellulosic fiber the lateral cohesive forces, including hydrogen bonds, have maximum intensity in the crystalline regions, where the chain molecules are arranged in a more organized manner. The crystalline portions contribute to the strength and rigidity of the fibers, while amorphous portions, which allow a better freedom of movement of the chain molecule, account for extensibility, flexibility and moisture affinity. In jute fiber, crystallinity is exhibited only by a limited portion of the cellulosic fraction, amounting to about 40% of the fiber mass, while in cotton, the corresponding value is about 70%; this low crystallinity as compared to cotton arises due to the presence of non-cellulosic constituents in jute. The non-crystalline region of jute contributes to a considerable extent to its strength by the cross-linkages of incrustants which are distributed entirely in the amorphous regions. If these cross-linkages are ruptured, appreciable loss of wet strength of the fiber results (Arthanarieswaran et al 2015, Ahmed and Nizam 2008). Like tensile strength, the other properties of jute fiber s, such as extensibility and flexibility, are also influenced to a great extent by the cross-linkages in the amorphous regions. Usually, the low inter-chain cohesion in the amorphous regions permits a better freedom of movement to the chain molecules, as a result of which these regions impart the above useful qualities to the fiber. In jute, however, due to the presence of cross-linkages, the relative movement of the carbohydrate chains is much restricted, which ultimately affects both flexibility and extensibility (Nishant et al 2016, Ahmed and Nizam 2008). Jute has a fairly high affinity for moisture, and high hydroscopicity of the fiber compared to other pure cellulosic fibers is attributable to its low crystalline/non-crystalline ratio. However, jute is the second widely used vegetable fiber, exceeded only by cotton. The yield of the fiber is only about 4.5% of the green weight of stem; in fact, the yield of fiber is extremely small (Banik 2016).Jute fiber is a complex mixture of chemical compounds that are built up by a natural process (photosynthesis) during the growth of the fiber in the plant stem. The composition of jute fiber is not uniform. The condition of the soil, climate, maturity of the plants, retting, etc. creates considerable variation in the constituents of the fiber. The composition of the *C. capsularis* and *C. olitorius* fibers are more or less the same, with minor differences in constituents (Nishant et al 2016).As is evident from the composition of jute fiber, the main constituents are- α-Cellulose, hemicellulose, and lignin; the rest are very minor in proportion and give very little influence to the fiber's structure (**Table 1**).

Table 1 The composition of the jute fibers (Nishant et al 2016)

Constituents	**Amounts (percentage dry basis)**
α -Cellulose	60.00
Hemicellulose	22.00
Lignin	12.00
Nitrogenous matter (as protein)	1.00
Fatty and waxy matter	1.00
Mineral matter (ash)	1.00
Miscellaneous	3.00

In its chemical composition, jute is quite different from cotton, being composed of a modified form of cellulose known as lignocellulose which is a compound of cellulose with lignin (Bacci et al 2010, Rumpa and Mosummath 2019). Unlike pure cellulose fiber, jute fiber is highly reactive towards various chemical reagents such as acids, alkalis, and oxidizing reagents; the higher reactivity arises mainly from the non-cellulosic constituents of the fiber, namely, hemicellulose and lignin. Lignin is un-hydrolysable by acids, readily oxidizable, and soluble in hot alkali, while carbohydrates are easily hydrolyzed by strong mineral acids to water-soluble sugars and relatively resistant to oxidizing agents (Ahmed and Nizam 2008; Barai et al 2020). Jute fiber is highly susceptible to the action of light, the main features of the photochemical changes being loss of tensile strength and development of a yellow or brown color. The degradation to jute caused by light has been found to be the greatest among all natural cellulosic fibers. The reactions involved in photochemical degradation of textiles are mainly oxidative in nature, and on prolonged exposure to light the constituent chain molecules are gradually oxidized in all possible manners and ultimately broken down to smaller fragments. As a result, the tensile strength of the fiber is adversely affected. Due to the influence of light, ligneous residues (phenolic group) are transformed into colored quinoid derivatives resulting in a yellow or brown color. It is established that lignin is responsible for the yellowing of jute fiber. In the absence of moisture or atmospheric oxygen, it is claimed that this photochemical action of light on jute fiber is minimal (Arthanarieswaran et al 2015; Ahmed and Nizam 2008; Banik 2016).The nature of possible combinations of cellulose, hemicellulose and lignin that exist between these constituents are depicted in **Fig. 1**.

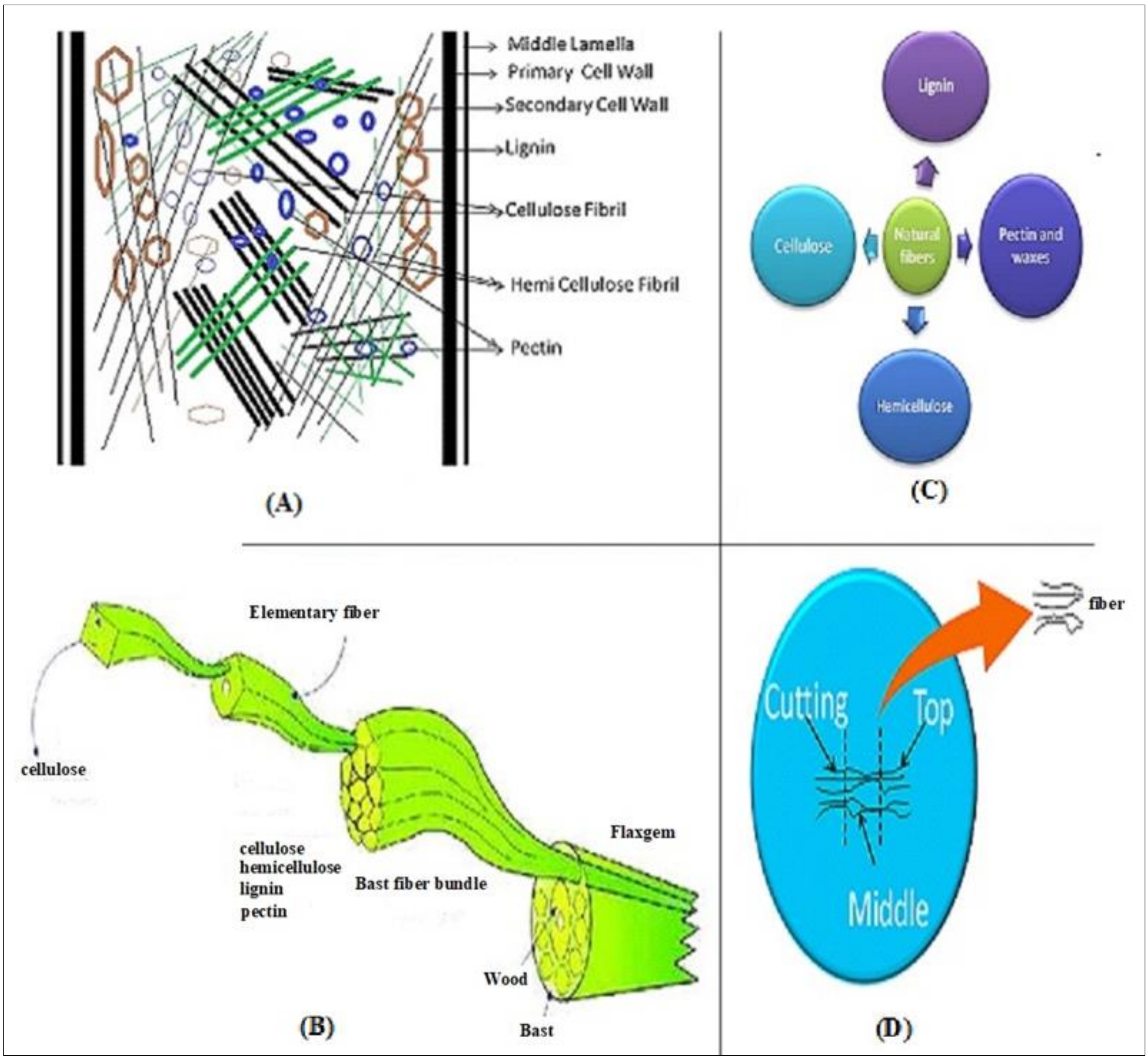

Figure 1 Structural and chemical combinations of cellulose, hemicellulose and lignin plant and fiber of jute. (A) Orientation of chemicals inside the plant cell wall; (B) Structure of jute plant; (C) Composition of natural fiber; (D) Inside of jute fiber (Arthanarieswaran et al 2015)

2.1 Retting

Retting is the process of separation and extraction of fibers from non-fibrous tissues and woody part of the stem through dissolution and decomposition of pectin's, gums and other mucilaginous substance. After the jute plants have fully grown, they are cut down and are ready for retting, which is the operation to make the jute plant ready for the separation of the bast layer from the stem of the plant. Retting is a biological process in which the bast fibers are extracted by decomposing the plants through the joint action of water and aquatic microorganisms, mostly bacteria. It is the most important and predominant of all the factors influencing the quality of jute/kenaf/Mestafiber. Retting along with other factors influences the main characteristics or parameters, which determine the quality of fiber like strength, color, luster and texture including cuttings i.e. the hard bottom parts of the fiber. In retting, the fresh jute sticks are collected and submerged in water to allow microbial degradation. The quality of jute fiber largely depends on the process of retting which is a purely biochemical process/ biological process where the best fiber is extracted by decomposing the plants through the joint action of water and aquatic microorganisms, mostly bacteria and fungi. Retting of jute is a kind of fermentation process in which the cortical and phloem tissues of the bark of the plants containing free strands are decomposed to separate fiber from non-fibrous woody stem (Abderrezaket al2014, Ahmed and Akhter 2001; Bacci et al 2010). The fermentative microorganisms consume the cementing materials (pectin, hemicelluloses and proteins) with release of galacturonic acid and sugar in retting water (Akin et al 2001). Within 20–25 days the leaves degrade appreciably to extract the fibers. This operation requires a large supply of water, since the plants must be completely submerged in water. Thus retting is a strictly anaerobic process which causes environmental pollution problems. However, most of the problems of jute retting can be minimized through ribbon retting. used for releasing fibers from jute stalk. In either of the retting processes, bundles of canes are immersed in water and weighted down by planks or stones, bacterial action then separates the outer bast layer of fibers from the canes and from each other. Improper retting lead to inferior quality fiber in spite of good crop and Fibers can be mechanically extracted, washed, dried and marketed. Some factors hastening up retting process which are- retting water, retting in already used water, harvesting time, climate conditions like high temperatures, deep water (too deep water will delay retting, addition of chemicals, materilas used as weights on Jack, method of retting, variety of jute, method of fiber extraction, stage of harvesting,period of retting, etc. The quality of fiber depends on some parameters like- color of the fiber, fitness of fiber, strength of fiber, length of fiber, proportion of faulty materials, percentage of cuttings of stem or percentage of cutting of fibers, stiffness and hardness of fiber, luster of the fiber, etc. There are few methods of retting available which are- conventional method of whole plant retting, chemical retting, microbial retting, mechano-microbial retting and In-situ retting with microbial consortium (Banik 2016). It is the most important and predominant of all the factors influencing the quality of jute/kenaf/Mesta fiber. This action may take place in 10–15 days, depending on the weather, the temperature of water, the ripeness of the cane, and the area where it is grown. During immersion, the crop is under constant surveillance to prevent over-retting, which produces weak fiber. Under-retted fibers are course, gummy, and most difficult to remove from the cane (Rumpa and Mosummath 2019). When the fibrous layer separates freely from the cane, the retting is complete. Then the fiber is washed free from stalk and vegetable debris, finally washed in clean water, dried in the sun, and ready for market (Barai et al 2020, Banik 2016).

2.2 Retting types

Retting is of two types- water retting and dew retting. In water retting, it involves lying the stems in water in tanks, ponds or in streams for around 10 days–it is more effective if the water is warm and bacteria-laden. On the other hand, in dew retting, it is a natural process that is triggered by dew that falls on the crop each morning (Sarkar and Sengupta 2015). Dew-retting, where the plant material would simply be laid out on the fields, exposed to moist/dew and further on sunlight for days to come as this process exhibits microbial and bacterial activity which helps in decomposing plant non-cellulose tissue-matter while leaving behind fiber and husk which will be made subject to further refining. When water is not available for retting immediately after harvest, plants are allowed to dry, whenever monsoon occurs, dried plants are retted. This process is called dry retting. On the other hand, when harvested plants are immediately retted directly in water without drying, this process is called wet retting. Water-retting, where the matrix is left immersed in water for literally rotting away the plant tissue and pectin. The water is at times renewed throughout the process which can go on for weeks. Moreover, retting can also have classified into two: (1) pit water retting and (2) flow water retting. Flow water retting is better, but in a place where flow water for retting purpose is lacking, pit is practiced, i.e., retting in stagnant water is ponds, ditches, etc. (Barai et al 2020, Sarkar &Sengupta 2015). After cutting, the stems were laid parallel in rows to dew ret. The stems needed turning at least once (sometimes) twice in order to allow for even retting (or rotting) being the name given to the process whereby bacteria and fungi is break down the pectin that bind the fibers to the stem allowing the fiber to be released. Retting is complete when the fiber bundles appear white, separate from the woody core and divide easily into individual finer fibers for their full length (Manimekalai and Kavitha 2017).

2.3 Conventional / Traditional retting

Conventional retting where defoliated bundles are steeped in clean or stagnant water with proper jack materials and mud or banana logs are used as jack which results in dark colored fiber and retting is completed in 18-21 days. Retting of jute done by traditional method has been learnt through experience. Collecting whole plants in bundles after shedding leaves and then submerging these bundles in the retting area are the common practice in traditional retting (Steyn 2006). While preparing the "Jack", the bundles of jute plants are arranged in such a way that there remains ample space for easy flow/ movement of water and retting microbes. Jacks are made in different layers of jute bundles. In one layer, the bundles are arranged side by side lengthwise, then in the second layer they are arranged perpendicular to the first layer and in the third layer they are again placed as the first layer and so on (Bacci et al 2010, Sarkar & Sengupta 2015). To accelerate the retting of jute urea @ 0.01% is used as per the recommendation of retting practice. The jute plant bundles are submerged by using banana stems/ water hyacinth etc. as weighting material. Through physical testing periodically when the jute plants are found to have been properly retted the fibers are manually extracted from the retted plant. Better fibers are obtained if extraction of fibers is done on the ground taking single or two plants at a time. After extraction, the fibers are washed thoroughly in clean water so that the fibers are freed /cleaned from broken jute sticks, cuticular layer of barks, clay or any other dirt. After washing the fiber is well dried by hanging in bamboo frame or by placing on clean ground (Tahir et al 2011).

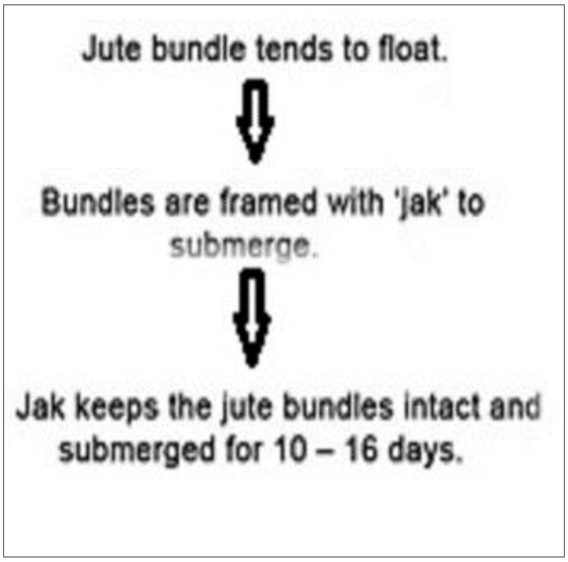

Figure 2 Traditional Process of Jute Retting

2.4 Chemical retting

In chemical retting, boiling with acid, alkali or with some salts at specific temperature for 6-8 hours are follows and applying chemicals are normally sodium hydroxide, sodium benzoate and hydrogen peroxide are used which is more efficient and can produce clean and consistent long and smooth surface bast fiber within a short time. Retting may be accelerated by urea, ammonium oxalate, calcium sulphate and magnesium phosphate. The fibers obtained in this process are little coarser, rough in the feel and stiff and this process needs higher concentration of chemicals which may reduce tensile strength and produce unfavorable color.

2.5 Microbial retting

Retting is the process of separating fibers that are held together in close association using a variety of bacteria. Fibers of jute are held together in close association and they are separated by the action of bacteria. These plants are immersed in water so that they absorb water and swell. Due to the activity of bacteria, the pectin substances of middle lamella are hydrolyzed and the fibers are separated. These separated fibers are used in making of ropes and sacks. Bacteria capable of retting jute are present in pond water, in the soil of jute fields, and on the surface of jute plants (Sun et al 1991). They probably enter stems over the whole surface through stomata, as well as through cut ends and leaf scars, after immersion for retting. A new technique for retting of jute and kenaf was developed by fermentation of piled ribbons inoculated with microbes where the fiber quality was improved and pollution of water bodies decreased by 90%, compared with retting by immersion in water (Akin et al 1998).Microbial consortium with a CFU (10^8 to 10^{10}) is preferable used in jute retting. Microbial retting consortium can be used either for ribbon or whole plant during water scarcity situation utilizing minimum amount of ground water. Two improved techniques of microbial retting are– mechano-microbial retting and *in-situ* retting of whole plant. Mechano-microbial retting involves two distinct operation- i) mechanical extraction of green ribbons through either power operated bast fiber extractor or manually operated fiber extractor, and ii) retting of green ribbons with microbial consortium (Banik et al 2007, Haque et al 2003, Sinha et al 2019).

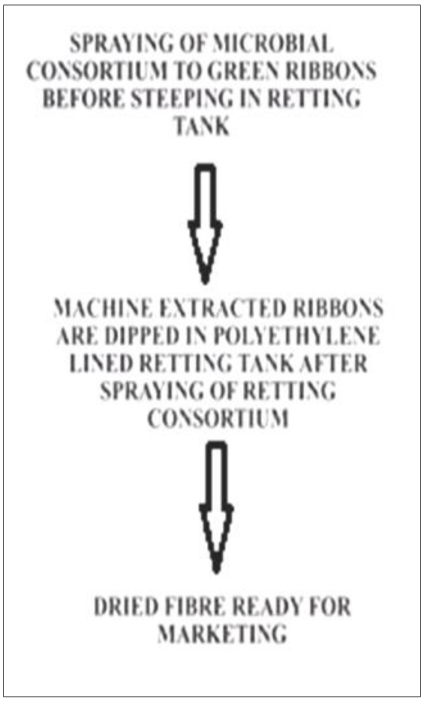

Figure 3 Microbial consortium green jute ribbon retting

2.6 Ribbon retting

In order to minimize the retting water problem, prior to retting, the green bark of the jute plants is separated by ribboner (single/double roller). Then the bark of the plants from the malted area are separated in two halves and the woody core is placed in the middle of the hook. The halves of the barks are taken around the two notches of the hook and drawn inward with a sudden forceful pull. This throws the woody core (jute stick) to a long distance ahead, leaving the barks or ribbons of the plants in the hands of worker (operator). Green ribbons /barks of three to four plants can be extracted in this way at a time. Before retting these ribbons are arranged in the form of a ring and are retted in polythene lined artificial retting tanks/ditches/shallow water pool etc. Urea @ 0.01% or retting effluent can be used as retting accelerator. In ribbon retting, ribbons are stripped out mechanically from the stem of mature jute plants, coiled and allowed to ret under water (Naik et al 2016). Ribbon retting reduces the requirement of water from 1:20 to 1:10 substrate liquor ratio, the length of retting time from 14–15 to 7–8 days and the level of environmental pollution to almost one-fourth in comparison to that of whole plant retting besides assurance of producing better quality jute fiber in terms of fiber strength, fineness, color, luster and overall absolutely bark free jute fiber (Akin et al 2001). Retting process after harvest of the crop plays a vital role in producing quality jute fiber. In traditional process of retting, a huge biomass undergoes decomposition in stagnant water. The problems associated with conventional retting are inadequate retting infrastructure, high cost of water as well as labor required for retting process which increases the cost of production up to 30 %. Ribbon retting can be a potential solution to these problems. In ribbon retting, ribbons are stripped out mechanically from the stem of mature jute plants then they are coiled and are allowed to continue the retting process under water. Ribbon retting decreases time of normal retting by 4-5 days. It saves water, space and the cost of retting process up to 50 % over the conventional method. The use of efficient pectinolytic microbial inoculum improves quality of fiber and reduces the time of retting as well as environmental pollution. The ribbon retted jute fibers are free from bark and are of higher grade as compared to fibers obtained from traditional method. So, ribbon retting is an improved technique to produce high quality jute fiber (Naik et al 2016). There is need for extension efforts to make this process popular among farmers. In ribbon retting, ribbons are stripped out mechanically from the stem of mature jute plants, coiled and allowed to ret under water. Ribbon retting reduces time of normal retting by 4–5 days. Moreover, requirement of water for ribbon retting is almost half in comparison to conventional whole plant retting under normal condition. This also reduces environmental pollution to a great extent. But use of efficient pectinolytic microbial inoculum improves quality of fiber; further reduce the time of retting and the environmental pollution (Banik et al 2003). The ribbon retted jute fibers are absolutely free from bark and were of higher grade. Moreover, the fiber filaments were stronger, improved colored and finer textured compared to conventional stem retted jute fibers. Most of the defects arising from conventional retting could be overcome by ribbon retting. So, ribbon retting is a great promise to produce high quality jute fiber in one hand and aneco-friendlier measure on the other.

2.7 Enzymatic Retting

The jute retting process is carried out by enzymes (pectinases, hemicellulases, cellulase and oxidoreductases) produced by an indigenous complex microbial community to degrade cellular tissues, pectins and gums, etc. Among all pectinases, pectin lyases are of particular interest, as they degrade pectin polymers directly by β-elimination mechanism that results in the formation of 4,5-unsaturated oligo-galacturonides while other pectinases act sequentially to degrade pectin molecule completely. It facilitates separation of cellulose fiber bundles from the matrix and plays an important role in the quality and yield of jute fibers (Kyoheiet al 2002, Majumdar et al 1991). Commercial enzyme preparations, consisting predominantly of pectinolytic enzymes were found to ret green jute ribbons within 48 h, producing fairly good quality jute fibers. The fibers produced were totally free of barky root ends. Metal complexing agents such as citrate phosphate buffer and EDTA were found to stimulate enzymatic retting thereby helping to reduce effective enzyme concentration. (Akin et al 2001 & 1998, Haque et al 2003). Jute fibers are aggregated of single cells consisting of α-cellulose, which are cemented by lignin and hemicellulose. It was assumed that cellulase acted not only on the ultimate cells but on the gummy matters on the fiber surface and the cementing gummy matters in the middle lamella (Akin et al 2007, Banik et al 2007, Kyoheiet al 2002).

2.8 Retting stages and mode of action of enzymes in retting

There are three sequential stages in retting (based on the morphological modification, dynamics of pH and various enzymes related to them during the entire jute retting process): Stage 1 (Initial retting stage, 1-2 days); Stage 2 (Middle retting stage, 3-9 days) and Stage 3(Final retting stage, 10-14 days).

2.8.1 Initial stage

The continuous change in chemical composition and pH of retting liquor because of various biochemical reactions occurring during retting process. So, this preliminary stage can be defined as the decrease of pH as well as reduction of enzyme secretion due to non-availability of their respective substrates The initial stage of retting was characterized by separation of fibrous components from other bast tissues, mainly due to pectinolytic dissolution of middle lamellas joining cells with non-lignified wall, facing intercellular spaces. Release of organic acids and sugars lowered the pH level of the medium as observed within 24 of inoculation because jute plants after absorbing water swell and burst at several places on the stem and release sugars, glucosides and nitrogenous compounds, which upon decomposition release several organic acids. The immediate response of retting microbes at low pH level was observed by lowering of the enzyme activities. At initial stage of jute retting, a sharp decrease in xylanase activity (like pectin lyase and polygalacturonse activities) of retting water was observed on second day from the initiation of retting (Akin et al 1998, Asaduzzaman and Abdullah 1998, Haque et al 2002). Also at the initial stage of retting, a sharp decrease in the pH of retting water might have resulted from release of organic acids namely butyric acid, acetic and lactic acid during microbial metabolism of sugars, pectins and other gummy materials (Majumdar et al 2021).

2.8.2 Middle stage

A steady increase in xylanase activity was observed during mid-stage of retting period on 7th day. This indicated the fact that xylan was exposed for degradation with gradual removal of pectin layer by pectinolytic enzymes as xylan was covered by pectin containing materials in jute stem. The maximum polygalacturonase activity was observed during the middle stage and the maximum activity was recorded on day 7 of retting. In middle stage of retting, after the detachment of surrounding tissues, fiber bundles were directly subjected to enzymatic attack. After the release of organic acids and other compounds, pectin, has between fiber cells becomes accessible to the retting microbes. Polygalacturonase and pectinlyase, the most significant pectin depolymerizing enzyme, plays a crucial role in jute retting process. A rapid increase in pectin lyase activity was observed with the highest value scored on day 3, followed by a decrease with a minimum value on day 6. This was due to the fact that the inducible enzyme pectin lyase acts depending on the accessibility and availability of highly methyl-esterified pectin. It reaches minimum level as soon as pectin gets depleted. Another increase in pectin lyase activity was observed on day 8. Since middle lamellas joining the fibers are modified by lignin and generally composed of less methylated pectins, they offer higher resistance and less availability to pectinolytic enzymes, thus retarding pectin lyase activity. After initial decrease at first stage, a steady increasing trend was observed in polygalacturonase activity, reaching highest value on day 7. This clearly indicates the fact that when more pectin lyase acts upon highly esterified pectins present in the plant tissues, simpler form of pectin, i.e., polygalaturonic acid is released. Polygalacturonase enzyme acts on polygalacturonic acid releasing reducing sugars into the medium, required for the growth of retting microbes. Hemicellulolytic enzymes depolymerize hemicelluloses precipitated on the surface of the fiber(Akin et al 2007). Thus, it increased the access of bleaching chemicals to the lignin layer by opening the pulp structure. Xylanases are important form of hemicellulases involved in jute retting process, for giving bio-bleaching or polishing effect to the fiber. Xylanase production dynamics showed that after initial decrease in the primary stage of retting, a steady increasing trend was observed up to day 7 and then the activity decreased to a certain level. This was possibly due to the fact that xylan present in the outer core of middle lamella can be made accessible to the retting microbes (Ali et al 2015). As soon as pectin gets degraded, xylan becomes unveiled to the microbes and are attacked for degradation. The combined actions of these three enzymes secreted by the retting consortium helps in quick biodegradation of plant pectins and hemicelluloses, which a has positive impact on the entire retting process (Barai et al 2020).

2.8.3 Final stage

At last stage of retting, pectin lyase activity is decreasing on the completion of retting. The pectin lyase degrades pectin to its simpler form polygalacturonic acid and then polygalacturonase acts on it to release reducing sugars. At end of retting period, the xylanase activity was maintained to the level of initial status. During the last stage, the polygalacturonase activity was reduced on the completion of retting. The stability in pH of retting water from day 10 to day 14 of retting was related to negligible release of organic acids due to lack of degradable substrates, which has helped in the stabilization of pH of retting liquor. At final stage of retting, the combined action of pectin and xylan degrading enzymes unveils the cellulosic network of fiber cells. Since microbial retting consortium was devoid of production of any traces of cellulolytic enzymes, structural polysaccharide remains untouched.Due to unavailability of substrates, the enzyme activity was found in significant (Ali et al 2015, Akin et al 2007).

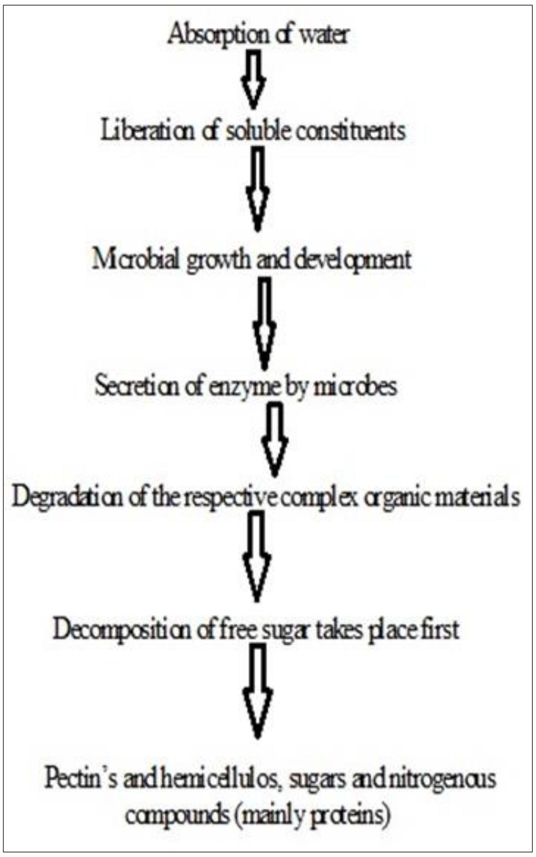

Figure 4 Mechanism of jute retting

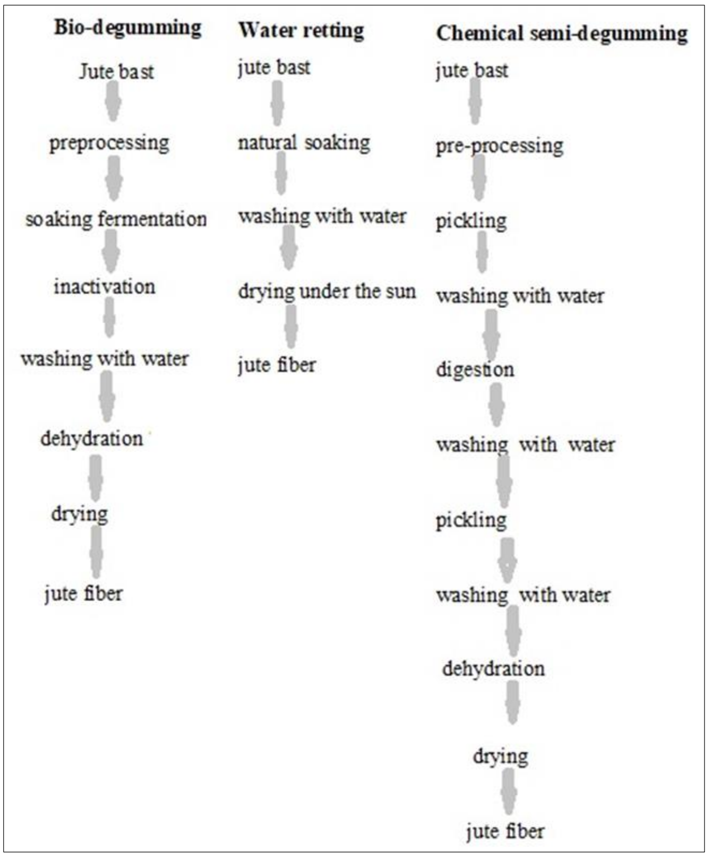

Figure 5 Different degumming technologies

2.9 Conventional / Traditional Microbial Consortium Retting

The use of microbial consortium having very high potential of enzymatic activities (polygalacturonase, pectin lyase and xylanase) helped in faster retting of jute as compared to the retting without microbial consortium characterized by lower enzymatic activity. The quick retting of jute with microbial consortium also helped in recovery of full length of fiber, thus enhancing the recovery of fiber by 10.9% as compared to the fiber recovery in retting without microbial consortium. Jute plants have less complex structure of pectin at top portion of the stem whereas middle to bottom portion of the plants have highly methyl esterified pectin, so lesser time is required for bio-degradation of top portion of the stem than their mid and basal portion (Banik et al 2003, Manimekalai and Kavitha 2017). Under conventional retting, it took longer retting duration for completion of retting, which resulted in loss of top portion of fiber hence lower fiber recovery was obtained under conventional retting. The advantage of traditional retting is that jute is retted in open natural water bodies and there is no need to require any further artificial activities as it is retted naturally. Moreover the labor is only required for cutting the jute stem in the field and carrying out it from field to the ditches, ponds and other water bodies to submerge under water. On the other hand, in ribbon retting, it requires more labor for disintergrate the fiber from the stem and forming the process (Ali et al 2015, Asaduzzaman and Abdullah 1998, Haque et al 2002). The fiber produced from microbial consortium use had higher fiber strength and fineness as compared to the fiber obtained from the control. This was due to proper and uniform retting. The jute fiber obtained using microbial consortium had very less root content compared to the fiber produced from control which indicates improper retting in conventional retting. High root content in jute fiber produced from conventional retting implies that undecomposed materials were present in larger quantity which is not desirable for quality fiber.Similar increase in fiber recovery, fiber strength along with better fineness and lower retting duration using same microbial consortium has been reported earlier. The bleaching action of component microbes of microbial consortium assisted in the recovery of lustrous fiber with golden color which was not feasible from the control trial (Asaduzzaman and Abdullah 1998). The bacterial inoculums substantially influenced the retting process resulting better fiber recovery and enhanced fiber quality.

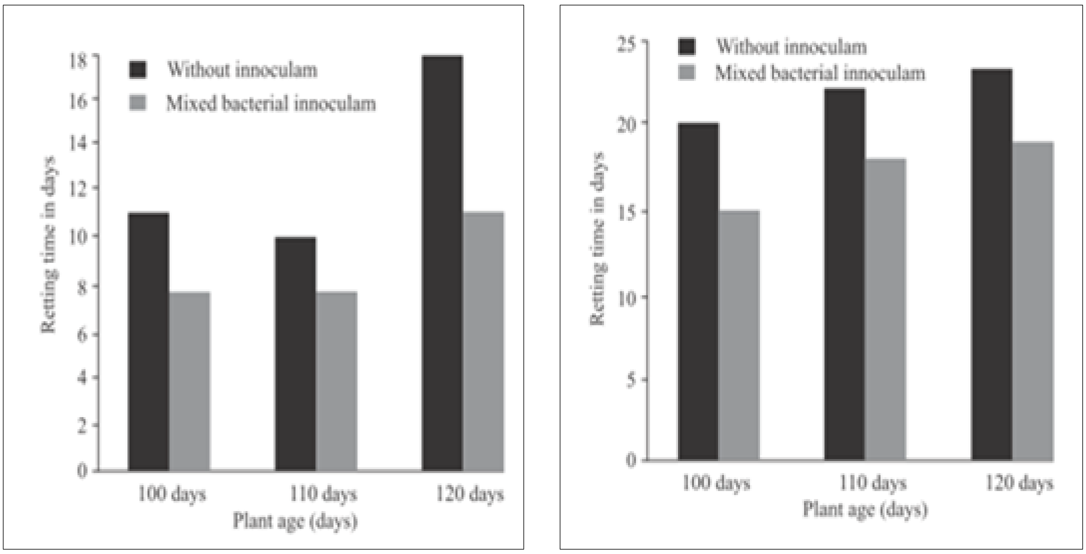

Figure 6 Effect of inoculation of bacterial culture on the retting time of ribbon retted of jute; [a] *C. capsularis* jute, [b] *C. olitorius* jute. (Sarkar and Sengupta, 2015, Banik et al., 2003).

In case of conventional retting without consortium, similar pattern of retting was noticed, except that enzymatic activities were quite low at each stage compared with retting using microbial consortium. The dynamics and combined action of enzymes liberated by a microbial consortium accelerated the biochemical process of jute retting. Hence, pre-retting treatment of jute plants with pectinolytic microbial consortium is advisable for accelerating the retting process for higher productivity and quality improvement over conventional ways of jute retting. In conventional retting of jute, increase in Electrical Conductivity (EC), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and nutrients contents including CFU of pectin, cellulose, lignin and xylan degraders but with a reduction in pH were recorded in post-retting water in comparison to pre-retting water. Conventional retting practice emits a little bit more nutrients, biogas and residues to the air and water compared to ribbon retting (Majumdar et al 2021). Mechano-microbial retting requires less volume of water (1:5) compared to 1:20 under conventional method where total fiber production is more compared to conventional whole plant retting. In Mechano-microbial retting, retting is completed within 7-9 days in comparison to 18-21 days required under conventional retting and the fiber quality is improved at least by 2 grades (Abderrezaket al2014, Asaduzzaman and Abdullah 1998). In traditional retting process, the bundles of plants are immersed in open water-lakes, rivers, ditches, canals or ponds for 15-20 days which cause microbial decomposition and dissolution of non-fibrous cementing materials viz. pectin and hemicelluloses releasing galacturonic acid and sugar in retting water (Haque et al 2003). The fibers cemented to woody core of the plants are loosened in the process. High quality fiber is not always obtained in traditional retting process due to non-uniformity of retting conditions, erratic rainfall and scarcity of clean water for retting. Ponds are not always allowed for jute retting due to pollution of environment as the water turns dark and foul smelling after retting breeds mosquitoes and becomes unfit of domestic use. Farmers are deprived of remuneration for their hard labor due to low quality of jute produced by them in the traditional process.

3 Conclusion

Due to various environmental concerns, natural fiber has been gaining special attention of technologists, engineers, industrial engineers and manufacturers for its enormous potential for application in different engineering utilities in the area of building construction, railway, automotive, packaging, defense, etc. Prior to making the natural jute fiber base composite, the fiber should be modified. In the present situation of severe competition from synthetic packaging materials, the jute industry is moving towards more diversified products. Thus with the growing demand of high quality fiber, the economic significance of fiber quality is increasing on which the future of jute will ultimately depend to great extent. But unfortunately the amount quality fiber is not increasing at the desired level which is mainly because the farmers after putting all their efforts in cultivating the crop are least bothered of negligent about the post-harvest techniques and are using the same age old retting practices without caring about its impact on the fiber quality mainly due to lack of proper knowledge and awareness about its benefit or adequate incentive/ financial benefit. Under scarce situation, mechano-microbial retting process may be suitable for farmers (Abderrezak al2014, Haque et al 2002). *In-situ* retting in micro pond with microbial consortium is another suitable option for farmers as an alternative to conventional method of retting in less time, reduced volume of water with quality improvement. The advantage of *in-situ* jute retting is that retting is completed within short period of time with low cost and the pond used in retting can be used for fish cum paddy culture after retting. Moreover, the pond embankment can be utilized for plantation of high value vegetable crops. The quality of fiber is improved at least by 2 to 3 grade. Alternative improved methods of is needed to be adopted for jute retting because the conventional whole plant retting method does not suit to farmers under water crisis situation and lack to rainfall during the retting period. Therefore, improved methods which requires very less amount of water, lesser time, improves the fiber quality, and above all which is user-friendly and eco-friendly in nature. Therefore, a simple, easily adoptable but low cost, grower friendly retting technique with assured fiber quality improvement which in turn provides adequate financial benefit to the farmers from the price differential of higher quality fiber has become inevitable.

Compliance with ethical standards

Acknowledgement

Authors thank their colleagues from Bangladesh Jute Research Institute for sharing their pearls of wisdom with us during the course of this work.

Disclosure of conflict of interest

All the authors declare to have no conflict of interest.

Author contribution statement

Zakaria Ahmed: Designed & wrote the manuscript. Taslima Rahman: assisted with manuscript drafting. Umme Hafsa Timmi and Sadia Mehrin: assisted with manuscript preparation.

References

[1] Ahmed Z and Akhter F. 2001. Jute retting: An overview. Online J. Biol. Sci., 1: 685–688.

[2] Ahmed Z and Nizam SA. 2008. Jute-Microbiological and Biochemical Research. Pl. Tissue Cult. &Biotech., 18(2):197-220.

[3] Ali MR, Kozan O, Anisur R, Islam K and Iqbal HM. 2015.Jute retting process:Present practice and problems in Bangladesh.Agricultural Engineering International: The CIGR e-journal, 17(2): 243-247.

[4] Abderrezak B, Ahmed B, Mostefa B, Fabrizio S and Katarzyna B. 2014. Novel extraction techniques, chemical and mechanical characterization of Agave americanaL. natural fibres, composites: Part B, 66:194–203.

[5] Akin DE, Foulk JA, Dodd RB and McAliser III DD. 2001. Enzyme retting of flax and characterization of processed fibres. J Biotechnol. 89, 193–203.

[6] Arthanarieswaran VP, Kumaravel A and Saravanakumar SS. 2015 Characterization of New Natural CellulosicFiberfromAcacialeucophloeaBark,InternationalJournalofPolymerAnalysisand Characterization, 20:4, 367-376.

[7] Akin DE, Rigsby LL, Henriksson G and Eriksson KE. 1998. Structural effects on flax stems of threepotential retting fungi. Text. Res. J., 68(7): 515-19.

[8] Ali MR, Kozan O, Rahman A, Islam KT, Hossain MI. 2015. Jute retting process: present practice and problems in Bangladesh. Agricultural Engineering International CIGR Journal. 17(2): 243-247.

[9] Akin DE, Condon B, Sohn M, Foulk JA, Dodd RB and Rigsby LL. 2007. Optimization for enzyme-retting of flaz with pectate lyse. Industrial Cropsand Products(25), 136-146.

[10] Asaduzzaman M and Abdullah ABM. 1998. Impact of retting and other post harvest processes on quality of jute fibre. In: Proceedings of International Seminar on Jute and Allied Fibres Changing Global Scenario. 5thand 6thFebruary 1998, Calcutta, A NIRJAFT publication, 109-113.

[11] Bacci L, Di-Lonardo S, Albanese L, Mastromei G and Perito B. 2010. Effect of different extraction methods on fibre quality of nettle (Urticadioica L.). Textile Research Journal. 81, 827–837.

[12] Banik S, Basak M, Paul D, Nayak P, Sardar D, Sil S, et al. 2003. Ribbon retting of jute- a prospective and eco-friendly method for improvement of fibre quality. Industrial Crops and Products, 17(3): 183-190.

[13] Barai S, Chattopadhyay L and Majumdar B. 2020. Studies on delignification in jute (Corchorusspp L.) fibre with promising lignin degrading bacterial isolates. J. Environ. Biol., 41, 703-710.

[14] Banik A, Sen M Sen SP. 1993. Methane emission from jute-retting tanks. Ecological Engineering.; 2(1):73-79.

[15] Banik S. 2016. Fungal dry retting of jute—an ecofriendly and water saving technology for retting of water. Indian J Fiber Text.; 41:212–6.

[16] Banik S, Basak MK, Sil SC. 2007. Effect of inoculation of pectinolytic mixed bacterial culture on improvement of ribbon retting of jute and kenaf. J Nat Fibers; 4:33–50.

[17] Banik S, Basak MK, Paul D, Nayak P, Sardar D, Sil SC, Sanpui BC and Ghosh A. 2003. Ribbon retting of jute- A prospective and ecofriendly method for improvement of fibre quality. Ind Crops Prod.; 17:183–90.

[18] Basu S, Saha MN, Chattopadhyay D and Chakrabarti K. 2009. Large-scale degumming of ramie fibre using a newly isolated Bacillus pumilus DKS1 with high pectatelyase activity. J Ind Microbiol Biotechnol.; 36:239–45.

[19] Banik S, Basak MK, Paul D, Nayak P, Sardar D, Sil SC and Sanpui BC. 2008. Ribbon retting of jute - a prospective and eco-friendly method for improvement of fibre quality. Industrial Crops and Products 17, 122-140.

[20] Candilo MD, Bonatti PM, Guidetti C, Focher B, Grippo C, Tamburini E and Mastromei G. 2010. Effects of selected pectinolytic bacterial strains on water-retting of hemp and fiber properties. J Applied Microbiology 108, 194-203.

[21] Chattopadhyay L, Majumdar B, Mazumdar SP, Saha AR, Saha R and Barai S. 2019. Use of bacterial endospore with longer shelf-life in improved retting of jute. J Environ. Biol., 40, 245-251.

[22] Chapke RR and Borkar U. 2011. Improved retting technology for quality jute fibre production. Central Research Institute for Jute and Allied Fibres (CRIJAF), 1-6.

[23] CandiloDi MPM, Bonatti C, Guidetti B, Focher C, Grippo E and MastromeiG.2010. Effects of selected pectinolytic bacterial strains on water-retting of hemp and fibre properties. J App. Microbiol., 108, 194–203.

[24] Duan S, Feng X, Cheng L, Peng Y, Zheng K and Liu Z. 2016. Bio-degumming technology of jute bast by Pectobacterium sp. DCE-01. AMB Express, 6(86): 1-7.

[25] Das B, Tripathi S, Chakraborty A and Chakrabarti K. 2011. Studies on physico-chemical and microbiological parameters of water samples before and after jute retting. J. Biol. Sci., 11, 210–215.

[26] Das S, Majumdar Band Saha AR. 2015. Biodegradation of plant pectin and hemicelluloses with three novel Bacillus pumilus strains and their combined application for quality jute fibre production. Agric. Res., 4, 354–364.

[27] Das S, Majumdar B, Saha AR, Sarkar S, Jha SK, Sarkar SK and Saha R. 2018. Comparative study of conventional and improved retting of jute with microbial formulation. Proc. Natl. Acad. Sci. India Sect. B: Biol. Sci., 88, 1351-1357.

[28] Datta S, Saha D, Chattopadhyay L and Majumdar B. 2020. Genome comparison identifies different Bacillus species in a bast fibre-retting bacterial consortium and provides insights into pectin degrading genes. Sci. Rep., 10, 8169.

[29] Das B, Chakrabarti K, Ghosh S, Majumdar B, Tripathi S and Chakraborty A. 2012. Effect of efficient pectinolytic bacterial isolates on retting and fibre quality of jute. Ind Crops Prod.; 36:415–9.

[30] Ge JP, Ling HZ, Zhao D, Song G and Ping WX. 2007. Screeningof pectinase-producing strains and preliminary study on variation of bacteria population during flax degumming. J Nat.Sci. Heilongjiang University, 24, 295–300.

[31] Haque MS, Ahmed Z, Asaduzzaman M, Quashem MA and Akhter F. 2002. Distribution and activity of microbial population for jute retting and their impact on water of jute growing areas of Bangladesh. Pak J Biol Sci.; 5(6), 704–6.

[32] Haque MS, Ahmed Z, Adhir KB and Firoza A. 2003. Identification of Micrococcus sp. responsible for the acceleration of jute retting. Pak J Biol Sci.; 67: 686–7.

[33] Kyohei J, Tokuda S, Kikumoto N and Arai M. 2002. Enzymatic Function on Jute Fiber with Various Commercial Enzymes, FIBER 58(1): 22-28.

[34] Manimekalai G and Kavitha S. 2017. A review on application of retting techniques for natural fiber extraction. International Journal of Creative Research Thoughts (IJCRT), Volume 5, Issue 4, 372-377.

[35] Majumdar S, Kundu AB, Dey S and Ghosh BL. 1991. Enzymatic retting of jute ribbons. International Biodeterioration 27(3): 223-236.

[36] Majumdar B, Saha AR, Sarkar S, Sarkar SK, Mazumdar SP, Chattopadhyay L and Barai S. 2021. An insight into the sequential changes in enzymatic activities during retting of jute (Corchorus spp. L.). J. Environ. Biol., 42, 636-643.

[37] Naik R, Majumdar B, Mazumdar S and Naik M. 2016. Ribbon Retting of Jute: A Prospective Method for Improvement of Fibre Quality. International Conference On Agriculture, Food Science, Natural Resource Management and Environmental Dynamics The Technology, People and Sustainable Development (p. 59). Nadia: KRISHI SANSKRITI.

[38] Nishant K, Shantanu B, Kartick K and Rajendra R.2016. Extraction of Natural Cellulosic Fibers from Corn husk and Its Physico-Chemical Properties, Fibers and Polymers, 17(5), 687-694.

[39] Rumpa K and Mosummath HA. 2019. Assessing the Effect of Jute Retting on pH and Dissolved Oxygen of River Water: a Case Study on Chitra River, Bangladesh." IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) 13(12), 63-66.

[40] Sarkar Sand Sengupta K. 2015. Comprehensive Technique for Jute Fibre Retting. International Journal of Bio-resource and Stress Management, 6(1), 170-175.

[41] Steyn HJH. 2006. The evaluation of conventional retting versus solar baking of agave Americana fibres in terms of textile properties. Master's Thesis, University of Free State, Bloemfontein, South Africa.

[42] Sarkar S and Sengupta K. 2015. Comprehensive Technique for Jute fibre retting. International Journal of Bio-resource and Stress Management, 6(1), 170-175.

[43] Sinha SR, Mukherjee SM, Ali N and Majumdar B. 2019. Critical review on microbial perspective of jute retting. Journal of Crop and Weed, 15(3), 126-130.

[44] Sun QX, Luo CA, Liu ZC, Yang RL and Peng YD. 1991. Study on microbial retting of jute and kenaf. III. On-land moist retting techniques. China's Fiber Crops 2, 29-32.

[45] Tahir PM, Ahmed AB, Saiful A and Ahmed Z. 2011. Retting process of some bast plant fibers and its effect on fiber quality: A Review. BioResources, 6(4), 5260-5281.