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Enhancing *Dhaincha* Fibres: Unraveling the Impact of Enzyme Treatment

Monika Negi & Anita Rani

Abstract

Enzymes can selectively modify the structure of fibres, improving their properties while reducing energy consumption and environmental impact. This study investigates the enzymatic treatment of Sesbania aculeata fibres, a versatile plant material crucial for sustainable industrial applications. Various enzyme combinations were employed for scouring, enhancing fibre properties. Results indicate significant improvements in tenacity, elongation, and fineness, particularly with ES-IV (xylanase + pectinase). Despite higher tenacity in single-enzyme treatments, ES-IV displayed balanced properties, making it favorable for fibre processing. Comparison with unprocessed fibres highlights the effectiveness of enzymatic scouring. However, enzyme costs remain a concern. Overall, enzymatic treatment, especially ES-IV, shows promise for enhancing Sesbania aculeata fibre properties, crucial for sustainable industrial applications, despite cost considerations.

Keywords: *Dhaincha*; Ecofriendly; Enzyme treatment; Fibre; Properties; Scouring; Sesbania Aculeata.

Introduction

Growing public awareness of the detrimental impacts of global climate change on both humanity and the environment has led to a heightened focus on environmental protection and sustainable resource utilization. The worldwide emphasis on sustainable development and ecological preservation has shifted attention towards the exploitation of renewable and biodegradable materials to reduce waste generation. The positive concept of exploring and responsibly utilizing natural resources such as forestry products, agricultural waste, and replacing nonrenewable materials has encouraged the utilization of natural fibres.

The traditional processing of natural fibres not only requires significant energy for boiling of chemicals but also necessitates extensive rinsing and neutralization to reduce its substantial water usage. Additionally, the harsh chemical treatment often results in damage to the fibres. To overcome these challenges and enhance the sustainability profile of natural fibres, enzymatic treatment has emerged as a promising and eco-friendly strategy.

A green and sustainable approach like enzymatic treatment has emerged as a promising method to modify and enhance the properties of natural fibres. Enzymes play a significant role as process enhancers in numerous wet textile pretreatment and finishing stages, including desizing, scouring, bleaching, and finishing (such as biostoning and biofinishing). Utilizing enzyme-based technology offers increased reliability and flexibility while reducing energy usage. Enzymes are biological catalysts that can selectively modify the structure of fibres, promoting environmentally friendly and energy-efficient processes.

The enzymatic treatment of sesbania aculeata fibres involves the use of specific enzymes, such as cellulases, hemicellulases, and pectinases, to target and break down the components of the fibre matrix. This enzymatic action can result in changes to the fibre's surface morphology, crystallinity, and chemical composition. The effect of enzymatic treatment on sesbania aculeata fibres has been the subject of increasing research interest, driven by the need for sustainable and eco-friendly alternatives in various industries.

Sesbania aculeata, commonly known as sesbania or sesban, is a versatile plant that has gained attention for its various applications, including the extraction of fibres. It is commonly known as *dhaincha, danchi*, *dunchi*, *danicha* is a green manure crop grown prior to paddy cultivation. These fibres possess unique characteristics that make them suitable for diverse industrial purposes. The application of enzymes on sesbania aculeata fibres can lead to improvements in their mechanical, thermal, and chemical properties, thereby expanding their potential applications in industries such as textiles, composites, and bio-based materials. A study was designed to examine how enzymes influence the characteristics of sesbania culeata fibres, with a comparison to both unprocessed fibres and those subjected to chemical scouring.

Materials and Methods

The materials and methods used in the study are mentioned and described below:

Raw Material-Collection

Crop planting of Sesbania aculeate (*dhaincha*) took place in May on a farm in Ramnagar (Figure 1), Uttarakhand, with harvesting for stalk collection occurring in September at the same location. The fresh *dhaincha* plant underwent a process where branches, leaves, and pods were removed, and the bark was peeled from the stems (Figure 2). Subsequently, the peeled bark was dried, retted and utilized for investigating the impact of various enzyme treatments on the properties of *dhaincha* fibres.

The retting process was done by submerging the peeled barks in stagnant water for duration of 15 days. This retting procedure occurred in September, with the ambient conditions maintaining a temperature and relative humidity ranging between 30°C to 37°C and 75% to 85%, respectively. The extracted fibres underwent testing for physical properties such as strength, fineness, elongation, and moisture content.

Figure 1. Standing crop of *dhaincha* (*Sesbania aculeata*) plants and its different parts

Figure 2. Fresh and dried peeled bark of *dhaincha* (*Sesbania aculeata*)

Scouring of *Dhaincha*

(*Sesbania aculeata*) fibres

Scouring serves as the primary step in eliminating inherent impurities from textile fibres, aiming to eliminate vegetative matter. As indicated by Modibbo et al. (2007), the scouring process employs saponification to eliminate impurities such as pectin, waxes, gums, fats, and oils found in bast fibres. The conventional approach involves the application of chemicals, but in response to increasing environmental awareness, the utilization of enzymes has become more prevalent.

The scouring process of *dhaincha* (Sesbania aculeata) fibres involved the application of various formulations developed through a literature review. Seven different enzyme-based recipes, detailed in Table 1, were employed for the scouring of these fibres.

Table 1: Recipes used for the scouring of *dhaincha* (*Sesbania aculeata)* fibres

Scouring method	Code	Variables
Enzymatic Recipe I	ES-I	Pectinase
Enzymatic Recipe II	ES-II	Cellulase
Enzymatic Recipe III	ES-III	Xylanase
Enzymatic Recipe IV	ES-IV	Pectinase + Xylanase
Enzymatic Recipe V	ES-V	Cellulase +Xylanase

Enzymatic Recipe VI	ES-VI	Pectinase + Cellulase
Enzymatic Recipes VII	ES-VII	Pectinase + Xylanase + Cellulase

Scouring of Fibres with Different Enzymes and their Combination

Enzymatic scouring of *dhaincha* (Sesbania aculeata) fibres involved the use of three distinct enzymes—pectinase, cellulase, and xylanase—either individually or in various combinations. The enzymatic scouring recipes employed were sourced from existing literature, representing methodologies utilized by different researchers for diverse cellulosic fibres.

To initiate the enzymatic scouring process on *dhaincha* fibres, the extracted fibres underwent a preliminary treatment with a 50-millimole (7.35 g) EDTA solution (chelating agent) for 30 minutes at 40°C. Subsequently, they were treated with a 0.85% solution of Triton X-100 (surfactant) at 40°C for 10 minutes, maintaining a MLR (Material to Liquor Ratio) of 1:50, as per the approach outlined by Song and Obendorf (2006). These pre-treatments were instrumental in enhancing the efficacy of enzymes during the scouring process.

Scouring with Pectinase

The scouring procedure employed by Sricharussin *et al*., 2009 for pineapple leaf fibres served as the basis for treating *dhaincha* fibres. The solution was created by blending pectinase (6%) and a wetting agent (1%) at a pH of 4.5, with a Material to Liquor Ratio (MLR) of 1:50. Scouring was conducted over a 2-hour period at a temperature of 45°C.

Scouring with Cellulase

The methodology employed by Sricharussin et al., 2009 for treating pineapple leaf fibres with cellulase was applied to *dhaincha* fibres. The scouring solution was created by dissolving cellulase (6.5%) and a wetting agent (1%) at a pH of 4.5. The scouring process took place at a temperature of 55°C over a duration of 2 hours, maintaining a Material to Liquor Ratio (MLR) of 1:50.

Scouring with Xylanase

The enzymatic scouring approach employed by Patra and Madhu, 2010, utilizing xylanase for flax fibres, was adopted for scouring *dhaincha* fibres. The fibres underwent treatment with xylanase (5%) and a wetting agent

(1%) at a temperature range of 50-55°C and a pH between 5 and 5.5, lasting for 2 hours. Throughout the procedure, a consistent Material to Liquor Ratio (MLR) of 1:50 was maintained.

Scouring with Enzyme Combination

The scouring solution for enzyme combinations was prepared separately, incorporating xylanase, cellulase, and pectinase at concentrations of 5%, 6.5%, and 6%, respectively, along with a wetting agent (1%). Scouring was conducted at a pH range of 4.5-5 and a temperature between 45-50°C for duration of 1 hour, maintaining a consistent Material to Liquor Ratio (MLR) at 1:50.

Following the treatment, the fibres treated with enzymes and their combinations underwent a 10-minute boiling process in distilled water to deactivate the enzymes. Subsequently, the fibres were washed with water and dried in the shade.

The current study focused on evaluating the impact of enzymes on the properties of *dhaincha* (Sesbania aculeata) fibres. Consequently, *dhaincha* fibres subjected to various scouring treatments were re-evaluated for their physical attributes, including weight loss, tenacity, elongation, fineness, moisture regain, and whiteness index. The properties of fibres treated with enzyme formulations were also contrasted with those of fibres subjected to chemical scouring.

The scouring of fibre was also done by recipe given by Fakin *et al*., 2006, applied for scouring of flax fibre. In the procedure, the *dhaincha* fibres were scoured with the solution of sodium carbonate (10g/l), sodium hydroxide (5g/l) and wetting agent (1g/l) in distilled water at 95^0C for 45 minutes. The material to fibre ratio was kept to 1:50. After that the scoured fibres were neutralized with 2ml/l of acetic acid at 60^0C for 10 minutes and then washed with warm water and dried in shade.

Results and Discussion

Physico: Chemical Properties of Retted Fibres

The fibres obtained from 15 days stagnant water retting were examined for some physical properties such as yield of fibre, tenacity, elongation, fineness, and moisture regain.

The fibrous yield indicates the quantity of fibres obtained following the elimination of vegetative materials in the retting process. As indicated in Table 2, the *dhaincha* (*Sesbania aculeata*) fibre exhibited a yield of 58.6 percent. This outcome is likely attributed to the elimination of vegetative or noncellulosic content over the retting period. Correspondingly, Martin et al. (2013) noted a decrease in fibre yield with prolonged retting, attributing it to the cleansing of fibres and the removal of cortical parenchyma and middle lamellae from the plant stem.

Table 2. Physical properties of *dhaincha* fibres

(15 days stagnant water retting)

S. No.	properties	values
1	Yield of fibre,	58.6 percent
2	Tenacity,	5.43 g/denier
3	Elongation,	3.4%.
4	Fineness,	36.2 denier
5	Moisture regain	8.12%

As shown in Table 2, the strength of *dhaincha* fibres, obtained after a 15-day retting period, measured at 5.43 g/denier. This can be attributed to the heightened microbial activity in the retting water over an extended duration, wherein the microbes acted on the fibre surface, breaking down pectin, waxes, and other bonding materials.

The data in Table 2 also reveals that the extracted fibres exhibited an elongation of 3.4%. This phenomenon can be explained by the fibres coming into contact with microbes that enzymatically dissolve or decompose much of the cellular tissues and sticky substances surrounding the bast-fibre bundles. This action facilitates the release of fibres from the bundles when subjected to stress, as highlighted by Kholiya et al. (2011).

Table 2 illustrates that the extracted fibres exhibited a fineness of 36.2 denier and a moisture content of 8.12%. Throughout the retting process, the liberation of non-absorbing substances, such as lignin and other non-cellulosic matter, due to microbial activity in the retting water contributes to the improved fineness and moisture content of the natural fibres.

Table 3: Weight loss of fibres scoured with different enzymatic recipes

S. No.	Scouring methods	Weightloss (%) Mean ± SE
1	ES-I	5.3[b] ± 0.22
2	ES-II	4.3[a] ± 0.18
3	ES-III	6.17[c] ± 0.16
4	ES-IV	7.27[d] ± 0.14
5	ES-V	8.37[f] ± 0.13
6	ES-VI	7.3[d] ± 0.15
7	ES-VII	10.3[f] ± 0.21

- ES-I –Cellulase, ES-II –Pectinase, ES-III – Xylanase, ES-IV- Xylanase+ Pectinase, ES-V- Xylanase + Cellulase, ES-VI -Pectinase+ Cellulase, ES-VII- Xylanase + Pectinase + Cellulase

Physico: Chemical Properties of Fibres scoured with Enzymes

The scoured fibres were assessed for the physico-chemical properties. The data pertaining to the physical properties of the *dhaincha* (*Sesbania aculeata*) fibres scoured with enzyme based recipes are presented in Tables and figures.

Weight-loss

The weight loss data for *dhaincha* fibres is presented in Table 3. The overall impact indicates that fibres treated with a combination of enzymes experienced a notable weight loss compared to those treated with individual enzymes. The data reveals that the maximum weight loss (10.3%) occurred in fibres treated with ES-VII (a combination of cellulase, pectinase, and xylanase) compared to other treatments. This can be attributed to the synergistic action of enzymes on various impurities in the fibres, effectively removing non-cellulosic and vegetative matter. Saravanam et al. (2010) observed a similar effect, reporting higher weight loss in fibre samples treated with multiple enzymes compared to individual enzyme treatments, suggesting the enhanced efficacy of combined enzyme action.

Fibres treated with ES-V (xylanase + cellulase) showed a weight loss of 8.37%, while the weight loss was relatively similar for fibres treated with ES-IV (xylanase + pectinase) and ES-VI (pectinase + cellulase) at 7.27% and 7.3%, respectively. Weight loss was lower in fibres treated with individual enzymes, specifically ES-I (cellulase), ES-III (xylanase), and ES-II (pectinase), with values of 5.3%, 6.17%, and 4.3%, respectively**.** Patra and Madhu (2010) also noted that treatment with cellulase and xylanase on linen fabric resulted in weight loss (4.5% to 6.3%) due to impurity removal and surface action.

Tenacity and Elongation of Scoured Fibres

The data concerning the strength (tenacity) and stretching capacity (elongation) of *dhaincha* (Sesbania aculeata) fibres treated with enzyme-based formulations is outlined in Table 4. Examination of the data in Table 4 reveals that *dhaincha* fibres scoured with ES-II (pectinase) displayed the highest tenacity (4.78 g/denier), followed by those treated with ES-III (xylanase) with a tenacity of 4.68 g/denier. Conversely, fibres scoured with ES-VII (a combination of pectinase, cellulase, and xylanase) exhibited the lowest tenacity (3.05 g/denier). Notably, fibres treated with single enzymes demonstrated higher tenacity compared to those treated with enzyme combinations, possibly due to the specific action of individual enzymes targeting specific components. Therefore, the combination of enzymes proved more effective in eliminating a greater number of impurities through simultaneous, multiple activities, as suggested by Sricharussin et al. (2009).

Table 4: Tenacity and elongation of fibres scoured with enzymatic recipes

S. No.	**Scouring methods**	**Tenacity (g/ denier)** mean± SE	**Elongation (%)** mean± SE
1	ES-I	$4.61^{c} \pm 0.12$	$3.89^{abc} \pm 0.11$
2	ES-II	$4.78^{c} \pm 0.11$	$4.06^{bc} \pm 0.13$
3	ES-III	$4.68^{c} \pm 0.1$	$3.68^{ab} \pm 0.13$
4	ES-IV	$4.25^{b} \pm 0.12$	$4.1^{c} \pm 0.09$
5	ES-V	$4.13^{ab} \pm 0.11$	$3.96^{abc} \pm 0.12$
6	ES-VI	$4.03^{ab} \pm 0.13$	$3.72^{ab} \pm 0.1$
7	ES-VII	$3.78^{a} \pm 0.12$	$3.97^{abc} \pm 0.09$
Unprocessed		5.43	3.4

- ES-I –Cellulase, ES-II –Pectinase, ES-III – Xylanase, ES-IV- Xylanase+ Pectinase, ES-V- Xylanase + Cellulase, ES-VI -Pectinase+ Cellulase, ES-VII- Xylanase + Pectinase + Cellulase

Additionally, it is observed that the tenacity of fibres treated with cellulase (ES-I) and a combination of xylanase and pectinase (ES-IV) was 4.61 g/denier and 4.25 g/denier, respectively. Fibres scoured with a combination of xylanase and cellulase (ES-V) and pectinase and cellulase (ES-VI) exhibited tenacity values of 4.13 g/denier and 4.03 g/denier, respectively. According to Ray and Ward (2008), the effectiveness of pectinase and xylanase in removing gummy material from plant fibres influenced the tenacity of the fibres, indicating efficient opening and separation of fibres in combination recipes but resulting in reduced fibre tenacity (see Table 4).

Comparing the tenacity of unprocessed fibres to scoured fibres, it is evident that the tenacity of unprocessed fibres was higher. The percentage loss in tenacity of unprocessed fibres ranged from 11% to 27%. This reduction is attributed to the removal of waxes, vegetative matter, and other impurities such as pectin and lignin from the fibre surface through enzymatic action. Similar observations were made by Vigneswaran and Jayapriya (2010) for jute fibres and Merdan et al. (2012) for hemp fibres.

Furthermore, the treatment with different enzymes had varying effects on fibre elongation. Fibres scoured with ES-VI (xylanase + pectinase) exhibited the maximum elongation (4.1%), followed by fibres treated with ES-II (pectinase) at 4.06%. On the other hand, fibres scoured with ES-III (xylanase) displayed the minimum elongation of 3.68%. Fibres treated with ES-VII (xylanase + pectinase + cellulase) and ES-V (xylanase + cellulase) exhibited nearly identical elongation values at 3.97% and 3.96%, respectively. The elongation of fibres treated with ES-I (cellulase) and ES-VI (pectinase + cellulase) was 3.89% and 3.72%, respectively.

Comparing the elongation of unprocessed and enzyme-scoured fibres, it is evident that fibres treated with enzymes and their combinations showed better elongation than unprocessed fibres. Similar observations were made by Merdan et al. (2012) for hemp fibres and Vigneswaran and Jayapriya (2010) for jute fibres.

Fineness

Figure 3 illustrates that *dhaincha* (Sesbania aculeata) fibres scoured with ES-VII exhibited superior fineness (30.2 denier) compared to other enz yme formulations.

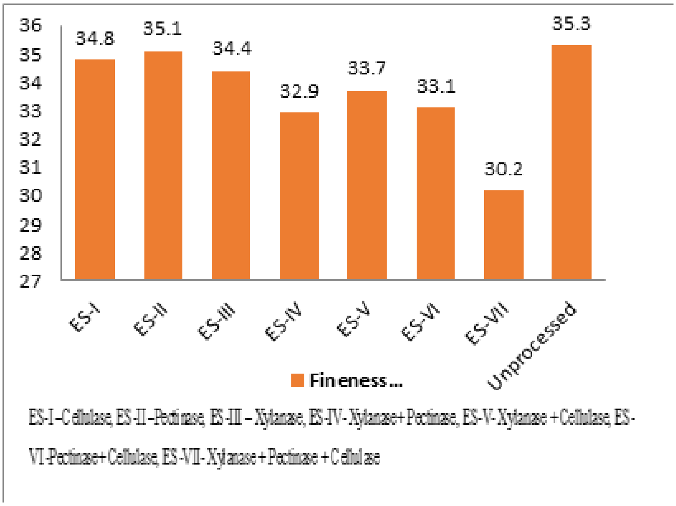

Figure 3. Fineness (denier) of scoured and unprocessed fibres

The fibres scoured with ES-I showed the highest fineness value (36.1 denier), followed by fibres scoured with ES-II and ES-III with fineness values of 35.1 denier and 34.4 denier, respectively. A higher fineness value indicates coarser fibres, suggesting less effective removal of impurities.

Therefore, the data clearly indicates that finer fibres are obtained when scoured with a combination of enzymes compared to using any single enzyme alone. The fineness values for fibres scoured with ES-IV (xylanase + pectinase) were 32.9 denier, while fibres scoured with combinations ES-V (xylanase + cellulase) and ES-VI (pectinase + cellulase) had fineness values in the range of 33.7 denier and 33.1 denier, respectively. These findings are supported by Fatima (2016), who reported that fibres of Kydia calycina scoured with a combination of enzymes (pectinase + hemicellulase + lipase + protease) resulted in finer fibres compared to other scouring agents.

Comparing with unprocessed fibres, enzymatically scoured fibres were found to be finer. The fineness of unprocessed fibres was 35.3 denier. Similar observations were made by Samantha et al. (2009), who noted that jute fibres treated with a mixture of enzymes (cellulase, xylanase, and pectinase) were finer compared to untreated fibres.

Moisture-content

It can be noticed from figure 4 that the moisture content of fibres scoured with enzyme recipe ES-VII (combination of cellulase+ pectinase+ xylanase) was maximum (8.6%), followed by ES-VI (pectinase+ cellulase) with moisture content of 7.95%. The increased moisture content might be owing to removal of non-hydroscopic impurities and non-vegetative matter. The fibres scoured with ES-III (xylanase) and ES-IV (xylanase+ pectinase) recipes showed almost similar moisture content 7.69 % and 7.65 %, respectively. The moisture content of fibres scoured with ES-I (cellulase) and ES-II (pectinase) was found to be 7.46 % and 7.31 %. Minimum amount of moisture content was observed in case of fibres scoured with ES-VI (xylanase+ cellulase). Samanta *et al.* (2009) also noticed that the jute fibres treated with mixture of enzymes resulted in increased moisture content and moisture regain of fibres.

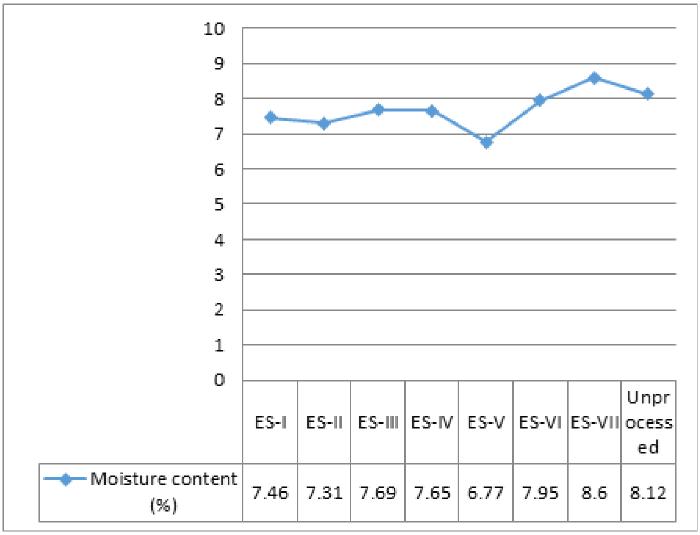

Figure 4. Moisture-regain (%) of scoured and unprocessed fibres

Selection of enzyme based scouring recipe

Analyzing the data presented in Tables 3 and 4, as well as Figures 3 and 4, regarding the characteristics of enzymatically scoured fibres, it can be inferred that fibres scoured with individual enzymes (ES-I, ES-II, and ES-III) exhibited higher tenacity. However, these fibres showed lower elongation and moisture content, and they were coarser (indicated by a higher fineness value). This coarseness can be attributed to inadequate fibre separation from bundles, resulting from the incomplete removal of binding components as enzymes primarily target individual components.

Subsequently, the scouring process was carried out using a combination of xylanase and pectinase (ES-IV) to enhance the removal of impurities from *dhaincha* fibres. Fibres treated with this combination displayed a tenacity of 4.25 g/denier, elongation of 4.1%, fineness of 32.9 denier, moisture content of 7.65%, weight loss of 7.27%, and a whiteness index of -9.18. These results suggest that the scouring recipe ES-IV, employing the combination of xylanase and pectinase, is favorable for further processing of fibres.

It can be deduced from the data regarding the properties of enzymatically scoured fibres that although fibres scoured with single enzymes (ES-I, ES-II and ES-II) exhibited higher tenacity but the elongation and moisture content was lower. Also, the fibres were coarser (higher value of fineness). This was due to the insufficient separation of fibres from the bundles due to less removal of binding components as enzymes act on a single component. Thereafter scouring was done with combination of xylanase and pectinase (ES-IV) to remove impurities from the *dhaincha* fibres. These fibres displayed 4.25 g/denier tenacity, 4.1 % elongation, 32.9 denier fineness, 7.65 % moisture content, 7.27 % weightloss and -9.18 whiteness index. Hence the chemical recipe ES IV using combination of combination of xylanase and pectinase was selected at this stage.

Comparison between Properties of Unprocessed Fibres and Selected Processed Fibres

The scoured fibres (chemicals and enzymes) those exhibited optimal properties were compared with the unprocessed fibres. The comparison of unprocessed and processed fibres was done to observe the effect of scouring on unprocessed *dhaincha* (*Sesbania aculeata*) fibres. The comparative data for unprocessed and processed fibres were given in Table 5.

It is clear from the Table 5 that the scouring of *dhaincha* fibres either by chemical or by enzymes resulted in noticeable change in all the physical properties. But the cost of enzyme is very high, and their specific action had limited their used.

Table 5: Comparison of properties of unprocessed and processed fibres

S. No	Type of fibre Properties	Unprocessed fibres	Processed fibres	
			Chemically scoured	Enzymatic scoured
1	Tenacity (g/denier)	5.43	4.7	4.25
2	Elongation (%)	3.4	4.5	4.1
3	Fineness (g/denier)	35.3	33	32.9
4	Moisture content (%)	8.12	8.24	7.65
5	Whiteness index (WI)	-11.8	-15.1	-9.18

Conclusion

The study underscores the increasing global focus on environmental protection and sustainable resource management, driven by heightened awareness of climate change's adverse effects. This emphasis has led to a shift towards renewable and biodegradable materials, such as natural fibres, to mitigate waste generation. Traditional processing methods for natural fibres are energy-intensive and environmentally harmful, necessitating a transition to more sustainable practices like enzymatic treatment.

Enzymatic treatment offers a green and sustainable alternative to modify natural fibre properties. Specifically, for sesbania aculeata fibres, enzymatic treatment involves the use of cellulases, xylanase, pectinases and the combination to modify fibre structure, leading to improvements in mechanical, thermal, and chemical properties.

The study's findings reveal that enzyme combinations result in notable improvements in fibre properties compared to individual enzyme treatments. Fibres treated with a combination of xylanase and pectinase exhibit enhanced tenacity, elongation, fineness, and moisture content, indicating the effectiveness of this enzymatic scouring recipe for sesbania aculeata fibres.

Overall, the research highlights the potential of enzymatic treatment as a sustainable and eco-friendly approach to enhance natural fibre properties, paving the way for broader applications in textiles, composites, and bio-based materials industries.

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