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Extraction and Characterization of *Dracaena fragrans* Leaf Fibre

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Article

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ABSTRACT

Textile industries have recently become prevalent environmental pollutants as a result of natural inconsistencies and resource scarcity. As a remedy, using natural fibres for textile production is strongly encouraged. *Dracaena fragrans* is an Ethiopian plant with lingo-cellulosic fibres that can be used for textile applications. This study focuses on the extraction and characterization of Ethiopian *Dracaena fragrans* leaf fibre and evaluates its application in the textile industry. For fibre extraction, water, 10% NaOH, 1% H₂O₂, EDTA di (with 1.5% and 1%, respectively), 0.2% pectinase (presoak), 0.05% alpha-amylase (for 24 hours, 18 hours, and 12 hours retting), and 5% gel retting methods were utilized. Subsequently, the properties of extracted fibre, mainly fibre length, fineness, tenacity, elongation at break, and degree of whiteness, were evaluated. Longer fibres (46 ± 0.74 cm) were obtained by pectinase retting. Comparatively, finer (11.22 ± 0.64 dtex) fibres were obtained by the water retting method. Fibre with the best tenacity (54.51 ± 0.61 , 53.54 ± 0.60 , and 52.53 ± 0.61) was obtained by EDTA di (1%), 5% gel retting and water retting methods respectively. On the other hand, higher elongation at break ($7.28 \pm 0.78\%$) was obtained by 0.05% alpha-amylase retting with a retting time of 24 hours. And finally, the best fibre whiteness ($w^* = 71$) was obtained by 1% H₂O₂ retting. Long fibres obtained by the pectinase retting method can be used for the production of packaging sacks and hessians. Fibres obtained by the water retting method can be used for the production of linen fabrics such as lace and sheeting. On the other hand, high-tenacity fibres extracted using (1%) EDTA di retting and 5% gel retting methods can be used for the production of cloths, bags, and shoes. Finally, a highly extensible fibre extracted using α -amylase (24 hours retting) can be used for the production of sports clothes.

KEYWORDS

Dracaena fragrans, leaf, fibre, extraction, characterization

INTRODUCTION

Currently, there is an increase in the utilization of natural fibres for textile applications due to their biodegradability, recyclability, and better moisture absorbance properties compared with synthetic fibres [1]. Cellulosic plant fibres obtained from a variety of plants like palm leaf, flax, and jute are used for homemade textiles and composite reinforcement materials [1-4]. Growing consumption of natural fibres, scarcity of fibre-rich resources, and an imbalance between supply and demand for natural fibres are expected reasons for using synthetic fibres in textile production [4]. Our planet is rich in diverse plants, which may have great potential for the extraction of natural fibres but have not yet been

exploited [5]. *Dracaena fragrans* is fibre rich plant popularly grown in almost all regions of Ethiopia (Amhara, Tigray, Oromia, Southern regions, Gambella, and Benshangul Gumuz regions). It is a slow-growing plant with multi-stem at the bottom and erecting long, orderly arranged leaves on the stem in 2cm intervals. *Dracaena fragrans* plant is currently used as shade for wild animals and in some cases, farmers take its leaf for decorating stage if there is a ceremony in their home. The plant propagates as its stem is cut and inserted into moist soil. Extraction of natural fibres from plants can be done using retting (water, chemical and enzymatic,) or mechanical techniques (stripping and decortication) [1-4]. Extraction of plant fibre through retting can be performed by dipping the required part of the plant in an open tanker containing distilled water or chemicals (mostly caustic soda) and waiting for a certain period until the pectin of the plant is fully separated from the fibres [3]. During plant fibre extraction, various enzymes could be utilized, and the selection relies on the constituents found in the plant [6]. By enzymatic retting, the dissolution of internal pectin results in a smoother surface of the fibres, but a reduction in the tenacity of the fibre is expected as the fibrils of the fibre bundle are less cohesive during treatment [7].

Extraction of fibre from Ethiopian Kusha stem using chemical retting (caustic soda solution), enzymatic retting (cellulose and pectinase), and water retting (pool water) was carried out, and the fibres obtained by water retting can replace jute fibres as the two fibres have congruent characteristics, and the extracted fibres were suggested for the production of composites and packaging materials [1]. Extraction, characterization, and application of natural leaf fibres from *Agave Americana* (commonly known as Aloe vera) were carried out using mechanical (decortication), chemical (acid, alkali), and water retting (using natural microbial processes) and finally, fibres that can be applied for reinforcement composites and non-woven fabrics were exploited [5,6]. Application of *Sansevieria ehrenbergii* fibres for polymer composites was investigated by analyzing fibre cross-section (using an optical microscope), fibre fineness (using a pycnometer), tenacity (using the universal tensile strength tester Instron 5500R), cellulose content (using Kurshner and Hoff's method), and the final result reveals the product is suggested for the production of light-weight composite materials [7]. An overview of existing extraction methods of pineapple fibres (scratch or manual, mechanicals mainly scorching hackling and breaking), degumming (by retting or adopting chemical or biochemical methods), and chemical modification methods for pineapple fibres was reviewed, and at the end, there was a possibility of the development of both technical and conventional textiles using pineapple fibre [8]. Experiments were carried out by taking three different lingo cellulosic (raw banana, jute, and pineapple) fibres to develop a simple process for obtaining stable nano fibril cellulose suspension. Alkali (sodium hydroxide) treatment for surface modification, steam explosion, fibre bleaching by NaClO_2 , and oxalic acid treatment methods were utilized for the isolation of nano cellulose fibrils from

raw fibres. Finally, taking product yield and quality into consideration, pineapple fibre is selective for the development of lingo-cellulosic fibrils [9].

Taking 0–40 wt% of NaOH for analysis, the effects of alkali treatment on the structure, composition, and properties of sugarcane fibres were studied. The final result reveals that there was a remarkable modification in the chemical, structural, and physical properties of sugarcane fibres as the composition of pectin decreased with increasing concentrations of NaOH [10]. The extraction and characterization of cellulose microfibrils from coconut palm leaf sheaths were investigated using chlorination and alkaline extraction methods. Finally, investigators conclude that agricultural trees like coconut palm leaf sheath are the best alternative source of cellulose, which can be applicable for different applications [11]. The extraction and characterization of lignin from non-wood cellulose biomass (wheat, straw, pine straw, alfalfa, kenaf, and flax fibre) were studied using the formic acid treatment method, and finally, lignin found in alfalfa fibre gives the greatest yield of the different sources [12]. Investigations on the possibilities of applications of wheat straws for textiles and composites were carried out, and alkaline treatment, pretreatment by using detergents, and mechanical force were applied for fibre extraction. Finally, long and coarse fibre that can be processed in a short-staple processing machine was obtained [13]. A detailed review of the effects of natural leaf fibres on the drilling of polymer composites was carried out by making 2021 drills on the product surface. The analysis was done by considering thrust force, drill geometry, feed, and speed. Finally, product ease of drilling was affected by, uncut fibres, pull-outs, and fibre breakage [14]. Effects of reinforcement of Montmorillonite (MMT) Nano clay in unsaturated polyester (up) resin matrix to investigate the impacts of MMT Nano clay wt. % on compression loading of composites were investigated. After the fabrication of the composite, the effect was analyzed and reinforcement of (MMT) Nano clay in UP-MMT improves the compressive properties of the composite product [15]. Investigation of the composite tenacity potential of natural lingo-cellulosic *Coccinia grandis* steam fibre with an unsaturated polyester matrix was analyzed. After fibre surface analysis, composite production and product morphological analysis using a Scanning electron microscope, an ideal bonding feature with a rough fibre surface was obtained [16]. However, sufficient studies have not been done on the exploitation and utilization of natural gift plant fibres like *Dracaena fragrans*. This study focuses on the extraction and characterization of fibre from Ethiopian *Dracaena fragrans* leaf to supplement biodegradable and environmentally friendly natural fibre for consumers and to investigate its application in the production of textile fabrics following extraction and characterization. This research involves a sequential process, including the collection of *Dracaena fragrans* leaves, followed by fibre extraction through water, chemical, enzymatic, and gel retting. Additionally, various fibre characterizations are conducted as part of this study.

METHODOLOGY

Aim of study

The aim of this research work is the extraction and characterization of fibre from Ethiopian *Dracaena fragrans* leaf to supplement biodegradable and environmentally friendly natural fibre for consumers and to investigate its application in the production of textile fabrics following extraction and characterization.

Samples

25 kg of *Dracaena fragrans* leaf samples were collected from the Amhara region of Ethiopia by using the zoning sampling technique. 16 kg of the leaf were taken for water retting, and the remaining 9 kg were used for NaOH, H₂O₂, EDTA di (Ethylenediaminetetraacetic disodium salt 1.5% and 1% separately), pectinase(presoak), amylase(24 hours retting), amylase (18 hours retting), amylase (12 hours retting), and gel retting each of which utilized 1 kg.

Retting Methods

In Ethiopia, bast fibre extraction is carried out using the traditional water retting method in which the fibre source plant is immersed for a certain period in the river water and the fibre is separated through intensive washing and manual combing using a traditional metal comb.

Table 1. *Dracaena fragrans* leaf retting methods with their corresponding description

Retting methods	Description	Reference
water	16 kg of <i>Dracaena fragrans</i> leaf was taken and immersed in 160 L stagnant distilled water for two weeks. During retting, a 1:10 material-to-liquor ratio (MLR) and 28 °C temperature were utilized.	[17,18]
NaOH	1 kg of <i>Dracaena fragrans</i> leaf was taken and immersed in 10% NaOH solution for 75 minutes. 1:10 Material-to-liquor ratio and 93 °C temperature was utilized during the retting process.	[17,18]
H ₂ O ₂	1 kg of <i>Dracaena fragrans</i> leaf sample was taken and immersed in 1% H ₂ O ₂ solution. 1:10 MLR was used and samples were fully immersed and stayed for an hour at 93 °C.	[17,18]
EDTA di (1.5%)	Using 1:10 MLR, 1 kg <i>Dracaena fragrans</i> leaf was taken and fully immersed in 1.5% EDTA di solution for 24 hours and washing of the sample was done following the retting.	[17]

Retting methods	Description	Reference
EDTA di (1%)	Using 1:10 MLR, 1kg <i>Dracaena fragrans</i> leaf was taken and fully immersed in 1% EDTA di solution. The sample was stayed for 24 hours in the bath and washed with distilled water following taken out from the bath.	[17]
Pectinase (pre-soak)	1 kg of <i>Dracaena fragrans</i> leaf was taken and immersed in 0.2% pectinase solution. The sample was stayed for 24 hours in the bath and it was washed with distilled water after removed from the bath. Retting was done in MLR of 1:10 and at room temperature.	[17,19]
Amylase (24hrs retting)	Using 1:10 MLR, 1 kg of <i>Dracaena fragrans</i> leaf was immersed in 0.05% alpha-amylase solution for 24 hours at room temperature. After 24 hours the sample was removed from the bath and washed with distilled water.	[17,19]
Amylase (18hrs retting)	Using 1:10 MLR, 1 kg <i>Dracaena fragrans</i> leaf was taken and immersed in 0.05% alpha-amylase solution for 18 hours at room temperature. After 18 hours of immersion, the samples were taken from the bath and washed with distilled water.	[17,19]
Amylase(12 hrs retting)	At room temperature, 0.05% of alpha-amylase solution was prepared and 1 kg of <i>Dracaena fragrans</i> leaf was immersed. The solution was prepared using 1:10 MLR. After 12 hours of immersion, the samples were removed and washed with distilled water.	[17,19]
Gel	Using 1:10 MLR, Semi cellulosic compound (hydrogel) was prepared by using a 5% gel solution. After the preparation of water-gel suspension, 1 kg of <i>Dracaena fragrans</i> leaf was taken and submerged in the suspension and stayed for an hour at 90 °C and the sample was washed with distilled water after it was taken from the bath.	[17]

Samples designation

Ten retting methods used for fibre extraction are designated by R1, R2, R3, R4, R5, R6, R7, R8, R9, and R10. Each designation with its corresponding retting method was reported in Table 2.

Table 2. Designation of the whole retting methods used during fibre extraction

Designation	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Retting	Water	NaOH	H ₂ O ₂	EDTA di	EDTA di	Pectinase	Amylase	Amylase	Amylase	Gel
Method	(160 L)	(10%)	(1%)	(1.5%)	(1%)	(0.2%)	(24 hrs)	(18 hrs)	(12 hrs)	(5%)

Schematic Representation of Dracaena fragrans leaf Fibre Extraction



Figure 1 *Dracaena fragrans* leaf fibre extraction process using selected retting methods: (a) Matured *Dracaena fragrans* plant leaf; (b) Removed matured leaf from the steam and retting plastic Container; (c) Retted *Dracaena fragrans* leaf in retting bath; (d) Extracted fibre sample after retting

Fibre conditioning and sampling

Before characterization, the samples were conditioned and the test was carried out at a temperature of 28 ± 2 °C and $65 \pm 2\%$ RH. 50 fibre samples were taken from each retting method and an investigation was carried out. Length measurement of fibres obtained in each retting method was done using measuring tape.

Fibre characterizations

Characterization of physical properties of *Dracaena fragrans* leaf fibre was carried out, and the methods and standards utilized during characterization were described as seen in Table 3.

Table 3. Methods of testing physical properties of *Dracaena fragrans* leaf fibre

Testing physical properties	Methods	Standards
Fibre length	The fibre length of extracted samples from each method was measured using measuring tape and the average result was reported.	The test was done based on ASTM D5103-07(2018).
Fibre fineness	The fineness of individual <i>Dracaena fragrans</i> leaf fibres was measured using a vibroscope having a gauge length of 20 mm.	The test of individual fibres was done based on on ASTM D1577 - 07(2012) standard.
Fibre tenacity	The tenacity of fibres obtained from each retting method was evaluated using vibrodyn having a 20 mm gauge length.	The test was carried out using ASTM D3822-07(2020) standard.
Fibre elongation at break	% Elongation at break of extracted fibre was evaluated by using a single fibre tensile strength tester machine and the average result was reported.	The test was done based on ASTM D-3822: 07(2020).
Fibre colour Measurement	The test was carried out at a temperature of 28 ± 2 °C and $65 \pm 2\%$ RH. Results of the colour measurement of samples were presented by the CIELAB (International Commission on Illumination) lab colour system. Colour coordinates (L^* , a^* and b^*) were evaluated by CIE, D65 and using a 10° observation angle. The degree of whiteness (W) of extracted fibre was evaluated using eq.1 $W = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2} \quad (1)$	The test was carried out based on CIE standard illuminant D65.

RESULTS AND DISCUSSION

The arithmetic means and variance values for the fibre length, fineness, tenacity, and percentage of elongation at break of *Dracaena fragrans* leaf fibre with its corresponding retting method were reported in Table 4.

Table 4. Analysis of physical properties of *Dracaena fragrans* leaf fibre

Physical Properties of fibres				
Retting method	Length (cm)	Fineness (dtex)	Tenacity (cN/tex)	Elongation at break (%)
R1	32 ± 9.81	11.22 ± 3.37	52.53 ± 15.76	3.41 ± 1.02
R2	33 ± 9.89	13.33 ± 4.11	46.64 ± 13.99	4.16 ± 1.25
R3	29 ± 8.71	11.33 ± 3.39	26.64 ± 7.99	2.86 ± 0.86

Retting method	Length (cm)	Fineness (dtex)	Tenacity (cN/tex)	Elongation at break (%)
R4	33 ± 9.91	22.89 ± 6.88	45.22 ± 13.56	5.81 ± 1.74
R5	28 ± 8.69	28.67 ± 8.62	54.51 ± 16.34	4.44 ± 1.33
R6	46 ± 13.78	49.33 ± 14.81	38.58 ± 11.57	3.21 ± 0.96
R7	20 ± 6.11	25.22 ± 7.51	33.01 ± 9.91	7.28 ± 2.18
R8	34 ± 9.97	31.33 ± 9.29	41.95 ± 12.58	5.24 ± 1.57
R9	33 ± 9.78	28.33 ± 8.49	43.01 ± 12.91	5.28 ± 1.58
R10	34 ± 10.11	24.01 ± 7.15	53.54 ± 16.06	2.32 ± 0.69

The length of fibres obtained in each retting method was taken from Table 4 and comparison was done using a radar chart as seen in Figure 2.

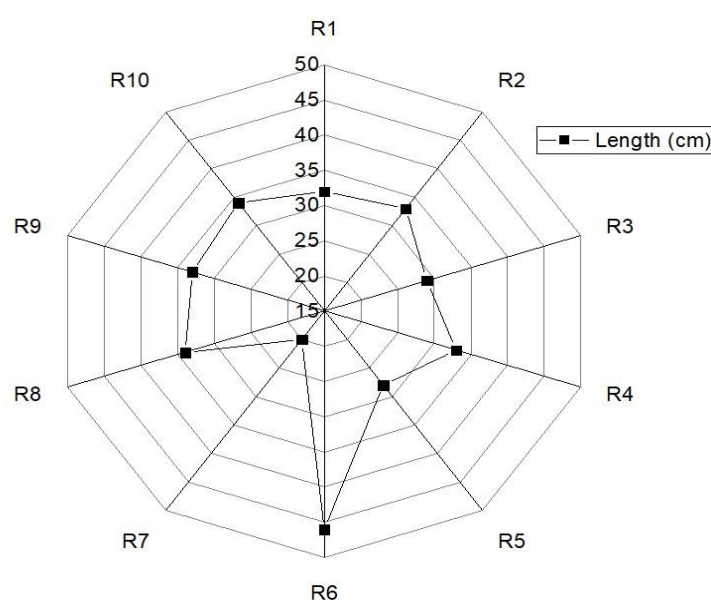


Figure 2. The fibre length of the leaf of the *Dracaena fragrans* plant using selected retting method

Comparatively long fibres (46 ± 0.74 cm) were obtained using the pectinase retting method. As shown in Table 4, in the case of amylase and EDTA di retting, the retting time and concentration of chemicals utilized during the retting process have a significant impact on fibre length. Production of packaging sacks and hessians can be achieved using *Dracaena fragrans* leaf fibre as its fibre length is congruent with packaging material producing Jute fibre. Successful blending of long *Dracaena fragrans* fibres obtained by pectinase retting with jute fibre and spinning by using a jute spinning scheme can be achieved. Beyond overcoming of drawbacks of jute including matting of jute in damp situations [20], *Dracaena*-jute blends can improve the quality of textiles.

Fibre fineness of *Dracaena fragrans* leaf fibres was analyzed by taking fibres obtained in each retting method and results were compared using a radar chart as seen in Figure 3.

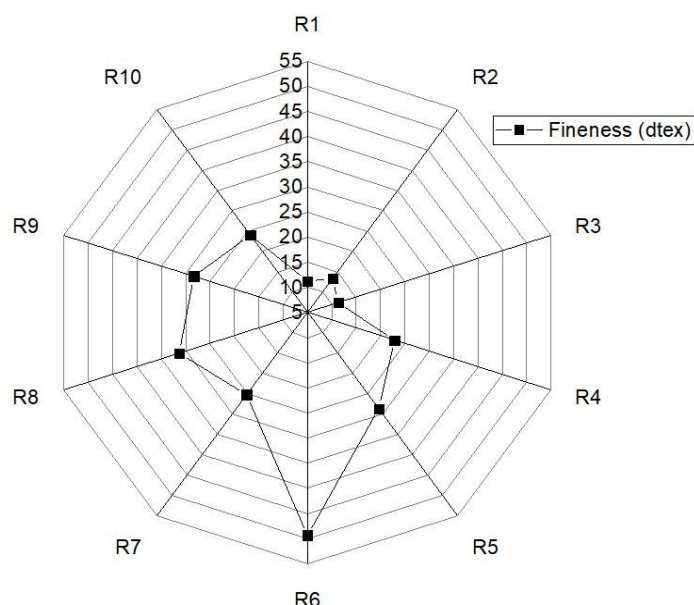


Figure 3. Fibre fineness versus selected retting treatments of *Dracaena fragrans*

Fineness of *Dracaena fragrans* leaf fibre is significantly affected by methods of fibre extraction as its fineness ranges from 11.22 ± 0.64 dtex for water retting to 49.33 ± 0.42 dtex for pectinase retting (Table 4). A radar plot of the fineness of *Dracaena fragrans* leaf fibre against treatment (Figure 3), illustrates that the highest fibre fineness was obtained by the water retting method in comparison with other selected retting methods utilized in this investigation. A large scattering of fineness values was seen in the extraction of *Dracaena fragrans* leaf fibres using selected retting methods and the cause for the spreading of results is expected to be nonconsistency of a cross-section of fibres along its length, existence of nods and compositional difference from fibre to fibre. Textile spinning ability, processability and product quality are highly influenced by the fineness of fibres [21]. Better fineness was obtained using water (11.22 ± 0.64 dtex) and H₂O₂ (11.33 ± 0.51 dtex) retting methods. Taking the cost of fibre extraction into account, the water retting method is the most preferable method for the extraction of fine *Dracaena fragrans* leaf fibre.

Linen fabrics such as lace and sheeting, can be made by using fine *Dracaena fragrans* leaf fibres extracted by water retting method and fibres are mostly suitable for ring spinning as ring spinning mostly uses fine fibres for processing [22].

The tenacity of *Dracaena fragrans* leaf fibres obtained using selected retting methods was analyzed and the visibility of difference in results was highlighted using a radar chart as seen in Figure 4.

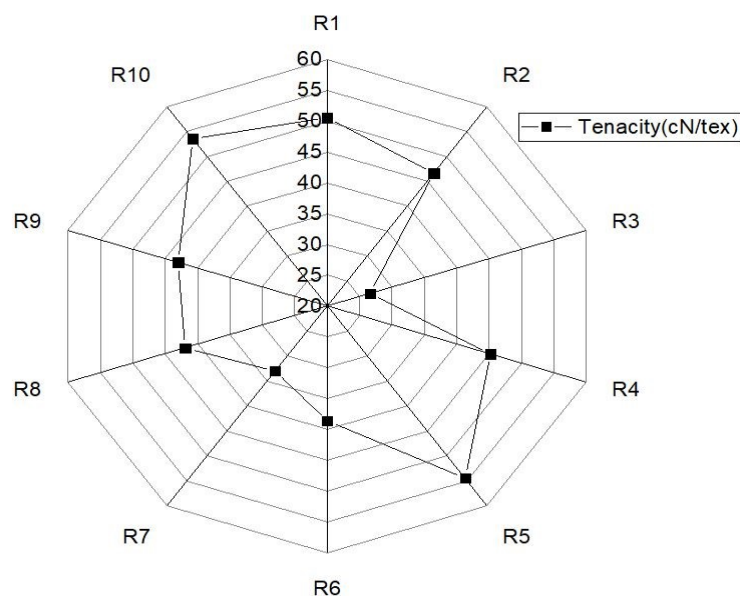


Figure 4. Fibre tenacity of *Dracaena fragrans* fibre versus different retting treatments

Comparatively, high-tenacity fibres were obtained by 1% EDTA di (54.51 ± 0.61 cN/tex), gel (53.54 ± 0.60 cN/tex) and water (52.53 ± 0.61 cN/tex). Product durability and processing of textiles are highly affected by the tenacity of fibres [23]. The tenacity result of *Dracaena fragrans* fibre is superior to South Carolina and European dew and enzyme-retted flax [24]. After the breakage of *Dracaena fragrans* fibre, unidirectional microfibrils oriented in tensile load direction have been seen. High orientation in molecular structure and crystallinity of fibre plays a great role in the tenacity of fibre [25]. Better tenacity fibres obtained by EDTA di (1%, gel and water retting methods can be used for the manufacturing of cloths, bags, and shoes. The percentage of elongation at break of *Dracaena fragrans* leaf fibres was analyzed by taking fibres obtained in each retting method and results were compared using a radar chart as seen in Figure 5.

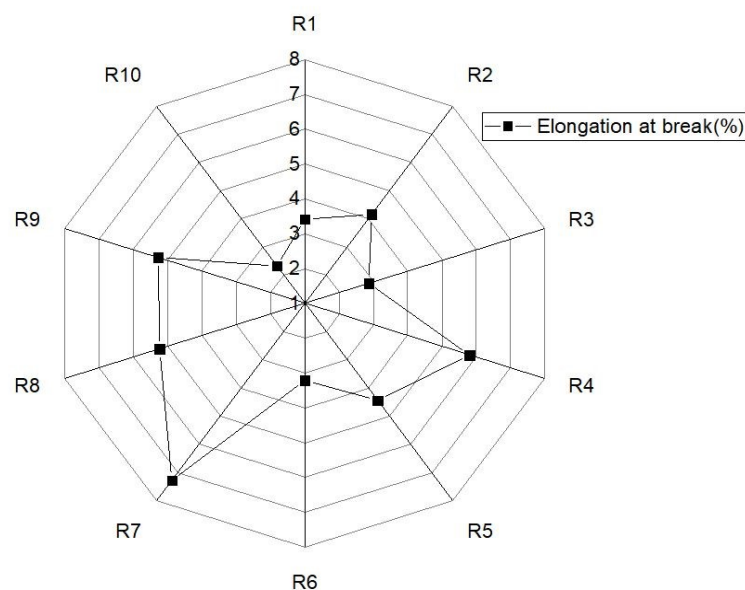


Figure 5. Elongation at break versus retting treatments of *Dracaena fragrans* fibre

Elongation at break of *Dracaena fragrans* leaf fibre ranges from $2.32 \pm 0.77\%$ to $7.28 \pm 0.78\%$. Effects of selected retting methods on the elongation of *Dracaena fragrans* fibre were checked and a significant difference was seen. The significance of enzyme α -amylase (R7) was highest ($7.28 \pm 0.78\%$) and in this case, elongation at the break of fibre is highly influenced by duration of retting time. Statistical results also reveal that fibres extracted by EDTA di retting show the highest elongation at break next to α -amylase. Natural fibre elongation can be affected by many agricultural variables including the availability of nodes and plant growth. Since percentage of elongation at break of *Dracaena fragrans* fibre agrees with reported values of natural plant fibres [26], the fibre can be used for the production of packaging materials like sacks and bags.

Fibre Colour Measurement

The degree of whiteness of fibres obtained in each retting method was analyzed and the result was reported in Table 5.

Table 5. CIELab and degree of whiteness value of *Dracaena fragrans* fibre extracted using selected retting methods

Retting	L*	a*	b*	w*
R1	63.83 ± 0.76 c	4.21	20.66	58
R2	69.39 ± 0.53 b	2.52	14.94	66
R3	59.49 ± 0.39 d	1.55	12.58	58
R4	63.42 ± 0.44 c	1.41	14.98	71
R5	67.56 ± 0.75 b	4.12	22.95	59
R6	58.82 ± 0.53 d	2.41	15.44	56

Retting	L*	a*	b*	w*
R7	57.76 ± 0.61 d	2.36	14.98	51
R8	56.87 ± 0.63 d	2.17	14.42	49
R9	68.92 ± 0.81 b	3.74	22.95	61
R10	67.97 ± 0.74 b	2.96	20.93	58

As was reported in Table 5 above, the degree of whiteness of *Dracaena fragrans* fibre obtained by H₂O₂ retting is higher (71) in comparison with other methods utilized in this investigation. The maximum whiteness value obtained in this investigation is slightly lower in comparison with previous studies [27]. However, the degree of whiteness value of fibre can be improved by pre-treatment of textile products. The expected reason for the slight decrease in the whiteness value of *Dracaena fragrans* fibre is a composition of cellulose and hemicellulose components as their composition affects the visible light absorbance of extracted fibre [28].

CONCLUSION

The selection of retting methods plays a crucial role in the extraction and characterization of *Dracaena fragrans* leaf fibre. In addition to the retting methods utilized, the length of *Dracaena fragrans* leaf fibre is highly influenced by the duration of the retting time and the concentration of chemicals used during extraction. Long fibres (46 ± 0.74 cm) are extracted by using pectinase enzyme retting. On the other hand, comparatively fine (11.22 ± 0.64 dtex) fibre was obtained by the water-retting method. Fibre with the best tenacity (54.51 ± 0.61, 53.54 ± 0.60, and 52.53 ± 0.61) was obtained by EDTA di, gel, and water retting methods, respectively. The highest elongation at break of *Dracaena fragrans* fibre was obtained using enzyme α-amylase (7.28 ± 0.78%), and the result is highly influenced by the duration of retting time. In general, taking the three important properties of lingo-cellulosic fibres, namely length, fineness, and tenacity into account, enzymatic retting (pectinase), water retting, and retting with EDTA di are recommended methods for the extraction of fibres from Ethiopian *Dracaena fragrans* leaf. Long fibres obtained by the pectinase retting method can be used for the production of packaging sacks and hessians. Fibres obtained by the water retting method can be used for the production of linen fabrics such as lace and sheeting. On the other hand, high-tenacity fibres extracted using (1%) EDTA di retting and 0.05% gel retting methods can be used for the production of cloths, bags, and shoes. Finally, a highly extensible fibre extracted using α-amylase (24 hours retting) can be used for manufacturing sports clothes.

Author Contributions

The whole work from concept and development to final submission is done by the author.

Conflicts of Interest

The authors declare there is no conflict of interest.

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REFERENCES

- [1] Amel BA, Paridah MT, Sudin R, Anwar UMK, Hussein AS. Effect of fibre extraction methods on some properties of kenaf bast fibre. *Industrial Crops and Products*. 2013; 46:117–123. <https://doi.org/10.1016/j.indcrop.2012.12.015>
- [2] Belachew T, Gebino G, Haile A. Extraction and characterization of indigenous Ethiopian castor oil bast fibre. *Cellulose*. 2021; 28:2075–2086. <https://doi.org/10.1007/s10570-020-03667-9>
- [3] Atalie D, Gideon RK. Extraction and characterization of Ethiopian palm leaf fibres. *Research Journal of Textile and Apparel*. 2018; 22(1):15–25. <https://doi.org/10.1108/RJTA-06-2017-003>
- [4] Ahmed T, Ogulata RT, and Gülnaz O. Investigations on Different Sol-gel Incorporation Methods of Green Synthesized AgNPs in Textiles for Antibacterial Activity. *Textile and Leather Review*. 2023; 6:452–474. <https://doi.org/10.31881/TLR.2023.088>
- [5] Madasamy S, Ramasubbu R, and Nambirajan N. Utilization of Reformed Coconut Fibre and Banana Stem Fibre as Green Oil Sorbent. *Journal of Natural Fibres*. 2022; 19(15):12339–12346. <https://doi.org/10.1080/15440478.2022.2057385>
- [6] Hulle A, Kadole P, and Katkar P. *Agave Americana* leaf fibres. *Fibres*. 2015; 3(1):64–75. <https://doi.org/10.3390/fib3010064>
- [7] Sathishkumar TP, Navaneethakrishnan P, Shankar S, and Rajasekar R. Characterization of new cellulose *Sansevieria ehrenbergii* fibres for polymer composites. *Composite Interfaces*. 2013; 20(8):575–593. <https://doi.org/10.1080/15685543.2013.816652>
- [8] Jose S, Salim R, and Ammayappan L. An Overview on Production, Properties, and Value Addition of Pineapple Leaf Fibres (PALF). *Journal of Natural Fibres*. 2016; 13(3):362–373. <https://doi.org/10.1080/15440478.2015.1029194>

- [9] Abraham E, Deepa B, Pothan LA, Jacob M, Thomas S, Cvelbar U, Anandjiwala R. Extraction of nanocellulose fibrils from lignocellulosic fibres: A novel approach. *Carbohydrate Polymers*. 2011; 86(4):1468–1475. <https://doi.org/10.1016/j.carbpol.2011.06.034>
- [10] Bartos A, Anggono J, Farkas AE, Kun D, Soetaredjo FE, Móczó J, Antoni, Purwaningsih H, Pukánszky B. Alkali treatment of lignocellulosic fibres extracted from sugarcane bagasse: Composition, structure, properties. *Polymer Testing*. 2020; 88. <https://doi.org/10.1016/j.polymertesting.2020.106549>
- [11] Uma Maheswari C, Obi Reddy K, Muzenda E, Guduri BR, and Varada Rajulu A. Extraction and characterization of cellulose microfibrils from agricultural residue - *Cocos nucifera* L. *Biomass and Bioenergy*. 2012; 46:555–563. <https://doi.org/10.1016/j.biombioe.2012.06.039>
- [12] Watkins D, Nuruddin M, Hosur M, Tcherbi-Narteh A, and Jeelani S. Extraction and characterization of lignin from different biomass resources. *Journal of Materials Research and Technology*. 2015; 4(1):26–32. <https://doi.org/10.1016/j.jmrt.2014.10.009>
- [13] Reddy N and Yang Y. Preparation and characterization of long natural cellulose fibres from wheat straw. *Journal of Agriculture and Food Chemistry*. 2007; 55(21):8570–8575. <https://doi.org/10.1021/jf071470g>
- [14] Jagadeesh P, Rangappa SM, Suyambulingam I, Siengchin S, Puttegowda M, Binoj JS, Gorbatyuk S, Khan A, Doddamani M, Fiore V, Moure Cuadrado MM. Drilling characteristics and properties analysis of fibre reinforced polymer composites: A comprehensive review. *Heliyon*. 2023; 9(3):e14428. <https://doi.org/10.1016/j.heliyon.2023.e14428>
- [15] Abdul Hanan U, Abu Hassan S, Uzir Wahit M, Binoj JS, Mansingh BB, and Goh KL. Experimentation, optimization, and predictive analysis of compressive behavior of montmorillonite nano-clay/unsaturated polyester composites. *Polymer Composites*. 2023; 44(1):241–251. <https://doi.org/10.1002/pc.27041>
- [16] Jebadurai SG, Raj RDE, Sreenivasan VS, and Binoj JS. *Coccinia grandis* stem fibre polymer composite: thermal and mechanical analysis. *Iranian Polymer Journal*. 2021; 30(4):369–380. <https://doi.org/10.1007/s13726-020-00896-4>
- [17] Pandey R. Fibre Extraction from Dual-Purpose Flax. *Journal of Natural Fibres*. 2016; 13(5):565–577. <https://doi.org/10.1080/15440478.2015.1083926>
- [18] Zhang Z, Jia J, Li M, and Pang Q. Lignin disintegration. *BioResources*. 2014; 9(2):3077–3087.
- [19] Dalvi P, Anthappan P, Darade N, Kanoongo N. and Adivarekar R. Amylase and pectinase from single source for simultaneous desizing and scouring. *Indian Journal of Fibre and Textile Research*. 2007; 32(4):459–465.
- [20] Akin DE, Foulk JA, Dodd RB, and McAlister DD. Enzyme-retting of flax and characterization of

- processed fibres. *Journal of Biotechnology*. 2001; 89(2–3):193–203.
[https://doi.org/10.1016/S0168-1656\(01\)00298-X](https://doi.org/10.1016/S0168-1656(01)00298-X)
- [21] Kers J, Peetsalu P, and Saarna M. Preliminary Investigation into Tensile Characteristics of Long Flax Fibre Reinforced Composite Material. *Agronomy Research*. 2010; 107-114.
- [22] Van de Weyenberg I, Ivens J, De Coster A, Kino B, Baetens E, and Verpoest I. Influence of processing and chemical treatment of flax fibres on their composites. *Composite Science and Technology*. 2003; 63(9):1241–1246. [https://doi.org/10.1016/S0266-3538\(03\)00093-9](https://doi.org/10.1016/S0266-3538(03)00093-9)
- [23] Chonsakorn S, Srivorradatpaisan S, and Mongkholarattanasit R. Effects of different extraction methods on some properties of water hyacinth fibre. *Journal of Natural Fibres*. 2019; 16(7):1015–1025. <https://doi.org/10.1080/15440478.2018.1448316>
- [24] Sharma HSS, Fauchey G, and Lyons G. Comparison of physical, chemical, and thermal characteristics of water-, dew-, and enzyme-retted flax fibres. *Journal of Applied Polymer Science*. 2019; 74(1):139–143. [https://doi.org/10.1002/\(sici\)1097-4628\(19991003\)74](https://doi.org/10.1002/(sici)1097-4628(19991003)74)
- [25] Akin DE, Foulk JA, and Dodd RB. Influence on Flax Fibres of Components in Enzyme Retting Formulations. *Textile Research Journal*. 2002; 72(6):510–514.
<https://doi.org/10.1177/004051750207200608>
- [26] Morrison WH, Archibald DD, Sharma HSS, and Akin DE. Chemical and physical characterization of water- and dew-retted flax fibres. *Industrial Crops and Products*. 2000; 12(1):39–46.
[https://doi.org/10.1016/S0926-6690\(99\)00044-8](https://doi.org/10.1016/S0926-6690(99)00044-8)
- [27] Salman SD. Effects of jute fibre content on the mechanical and dynamic mechanical properties of the composites in structural applications. *Defence Technology*. 2020; 16(6):1098–1105.
<https://doi.org/10.1016/j.dt.2019.11.013>
- [28] Akin DE, Dodd RB, and Foulk JA. Pilot plant for processing flax fibre. *Industrial Crops and Products*. 2005; 21(3):369–378. <https://doi.org/10.1016/j.indcrop.2004.06.001>