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The bio-processing of fibres from *Agave sisalana* and *Agave americana*

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Abstract

Plant fibres play a major role in the lives of many rural peoples, especially women in Swaziland. It is known to produce strong and hard fibres which tend to limit the users in terms of product development. This research study, therefore, explored the use of enzymes in producing high quality fibres. It was carried out in two regions of Swaziland, where the level of fibre processing was high. It was carried out in two phases: a) preliminary phase, which was aimed at identifying plant fibre processors and hence determine current practices employed and challenges encountered; b) Laboratory Phase, aimed at employing environmentally friendly scientific techniques in improving the texture of the fibres. The study employed triangulation approach in the collection of data, wherein qualitative data was quantized and analysed qualitatively using IBM SPSS. The study found that 62% of the processors were greatly affected by the coarse nature of the fibres, as they were producing jewelry, hence a need for laboratory phase. Results from ATR-IR showed that the base performed better than the enzymes as % Transmittance (%T) of lignin, pectin and hemicellulose were reduced from about 0.015%T (Raw fibre) to about 0.005%T (NaOH) and 0.010%T (enzymes) for *A. sisalana.* Results from Tensile Strength Tester of the sisal fibres, however, showed that inasmuch as the NaOH performed better, the strength of the fibres was greatly lost in the NaOH treatment (0.060MPa) compared to the enzymes (0.072MPa) from the initial strength of the raw fibre (0.097MPa). Moreover results from Scanning Electron Microscope (SEM) showed that the enzymes were better than the base in softening the surface of the fibres. It is, therefore, recommended to use the enzymes over the base since enzymes are environmentally friendly, and they perform much better than the base.

Key words: Hemicellulose, lignin, pectin, Swaziland

Résumé

Les fibres végétales jouent un rôle majeur dans la vie de nombreuses populations rurales, en particulier les femmes au Swaziland. Ils sont connus pour la production de fibres solides et dures qui tendent à limiter les utilisateurs en termes de développement de produits. Cette étude de recherche, par conséquent, a exploré l'utilisation d'enzymes dans la production de fibres de haute qualité. Elle a été réalisée dans deux régions du Swaziland, où le niveau de traitement de la fibre est élevé. Elle a été réalisée en deux phases: a) une phase préliminaire, qui visait à identifier les transformateurs de plantes de fibres et donc de déterminer les pratiques actuelles employées et difficultés rencontrées; b) La phase du laboratoire, visait à utiliser les techniques scientifiques respectueux de l'environnement pour améliorer la texture des fibres. L'étude a utilisé l'approche de triangulation dans la collecte de données, dans laquelle des données qualitatives ont été quantifiées et analysées qualitativement l'aide d'IBM SPSS. L'étude a révélé que 62% des transformateurs ont été grandement affectée par la nature grossière des fibres, quand on produisait des bijoux, d'où la nécessité pour la phase de laboratoire. Les résultats de ATR-IR ont montré que la base produisait des meilleurs résultats que les enzymes en% de facteur de transmission (% T) de la lignine, la pectine et l'hémicellulose ont été réduit d'environ 0,015% T (fibres brutes) à environ 0,005% T (NaOH) et de 0,010% T (enzymes) pour *A. sisalana*. Les résultats à partir du teste (Tensile Strength Test) des fibres de sisal, ont montré que, dans la mesure où le NaOH obtenu de meilleurs résultats, la résistance des fibres était grandement perdu dans le traitement de NaOH (0.060MPa) par rapport aux enzymes (0.072MPa) à partir de la force initiale de la fibre brute (0.097MPa). De plus, les résultats de microscope électronique à scannage (SEM) ont montré que les enzymes ont été meilleurs que dans la base en ramollissement de la surface des fibres. Il est donc recommandé d'utiliser les enzymes sur la base puisque les enzymes sont respectueux de l'environnement, et ils font beaucoup mieux que la base.

Mots clés: hémicellulose, lignine, la pectine, Swaziland

Introduction

Fibres are long strands of molecules inter-connected to form a linear, string-like structure. They can be natural, synthetic or sometimes semi-synthetic. van Dam (2008) described natural fibres as bio-based fibres from vegetable and animal origin. Natural fibres are greatly elongated substances that can be spun into filaments, thread or rope. This definition of natural fibres includes all natural cellulosic fibres, such as cotton, jute, sisal, flax, hemp, etc. and protein based fibres such as wool and silk. Both sisal (*Agave sisalana*) and century plant (*Agave americana*) produce leaf fibres which are referred to as hard fibres (fibres obtained from leaves or fruit).

According to van Dam (2008), the United Nations declared 2009 to be the International year of natural fibres, with the central objective of promoting the use of natural fibres in current and novel applications, which contributes to increased levels of income for fibre producers, processors and traders, while at the same time contributing to the increased use of environmentally friendly materials in those applications. Sisal is known to produce long and coarse fibres which are most suitable for making ropes, twines, mats, etc. The coarse nature of the fibres restricts its uses, as observed from the Participatory Rural Appraisal (PRA) findings (Mkhonta *et al.*, 2014; Vilane *et al*., 2014), hence a need for modification. Previous studies have shown that the texture of fibres can be modified by the use of a strong alkali like sodium hydroxide (Zwane, 1997; Michalak and Krucinka, 2004; Tatus *et al*., 2010) but such experiments are not environmentally friendly since they release greenhouse gases; CO_2 in this case.

Therefore, this study was conducted to explore the use of enzymes as an alternative method of producing relatively high quality *Agave sisalana* and *Agave americana* fibres and also investigate the antibiotic activity of the waste produced during decortication, in order to obtain improved and environmentally friendly products. Specifically, the study intended to: a) to identify plant fibre processing associations in Swaziland, hence determine the current practices they use in product development; b) to employ the fibre extraction methods found to be used by the fibre processors, and then treat the extracted fibres with a strong alkali (NaOH) and enzymes; c) to compare and contrast the effect of a strong alkali (NaOH) and enzymes on the mechanical and chemical properties of the extracted *A. sisalana* and *A. americana* fibres; d) to determine bio-activity of *A. sisalana* and *A. americana* waste obtained during decortication using common bacteria and fungi; and, e) share findings with women's associations.

Methodology

Preliminary stage. A qualitative approach, to assess current practices and experienced challenges was carried out in two regions of Swaziland using the participatory rural appraisal (PRA) techniques (Corwall and Jewkes, 1995; Anyaegbunam *et al.*, 2004) and a questionnaire. The developed data collection instruments were validated and used to collect data through one-on-one interviews. The two regions of Swaziland (Hhohho and Shiselweni regions) were chosen because they are the only ones with a lot of fibre processing taking place. Snowball sampling technique was used to locate the associations of fibre processing, after which all the members in each association were used in this study.

Laboratory stage. Fibre extraction technique locally used by the fibre processors were used to extract fibres from both plants with assistance from an experienced fibre processor. As a pre-treatment step, the fibres were thoroughly washed with distilled water and dried in a vacuum oven pre-set at 80^0C for 24 hours after which raw fibres were sampled. They were then treated with diethyl ether: Hexane: Ethanol (2:2:1) followed by ethanol, a modification of Moran *et al.* (2008)'s method to ensure the removal of all polar and non-polar compounds which includes waxes and other extractives such that only macro molecules or polymers remain.

After the pre-treatment, fibres were thoroughly washed with distilled water and dried in an oven at 80^0C for 24 hours. The fibres were then treated with sodium hydroxide and enzymes. The enzymatic treatment was done in a step-wise format, because the three enzymes used differed in their pH for optimum function. The enzymes used were: Denilite II S (pH 7), Scourzyme L (pH 9) and Cellusoft Conc. L (pH 7) sourced from a lignase, pectinase and hemicelluloses, respectively. After the treatment, the fibres were then tested for both physical chemical properties for comparison purposes. There are ongoing laboratory experiments on the biological activity of the mucilage (waste produced during decortication) to add value on the waste thereby cleaning the environment.

Findings and discussions

Preliminary findings were that, all the fibre processors were relying on raw material growing in the wild, which rendered their project potentially unsustainable if there are no new managed plantations of the fibre plants. The preliminary study also showed that all the fibre processors were using mechanical and crude methods for decortication of the fibres which was further found to be a very slow and tedious exercise. Finally, the study found that the fibre processors were making variable products, ranging from household bowls, washing baskets, sleeping mats, cordage, up to jewelry; which is a similar observation to Zwane *et al.* (2011). It was, however, found that the coarse nature of the fibres was rendering it difficult for use in making jewelry (ear rings for example), hence the importance of laboratory modifications with enzymes to soften the fibres.

On the enzymatic treatment, the main focus was to remove the gluing materials found in the fibres, which are: hemicellulose, lignins and pectins. Figure 1 shows the chemical composition of the fibres after treatment with NaOH, enzymes and untreated fibres (control), as shown by Attenuated Total Reflectance Infrared Spectroscopy (ATR-IR).

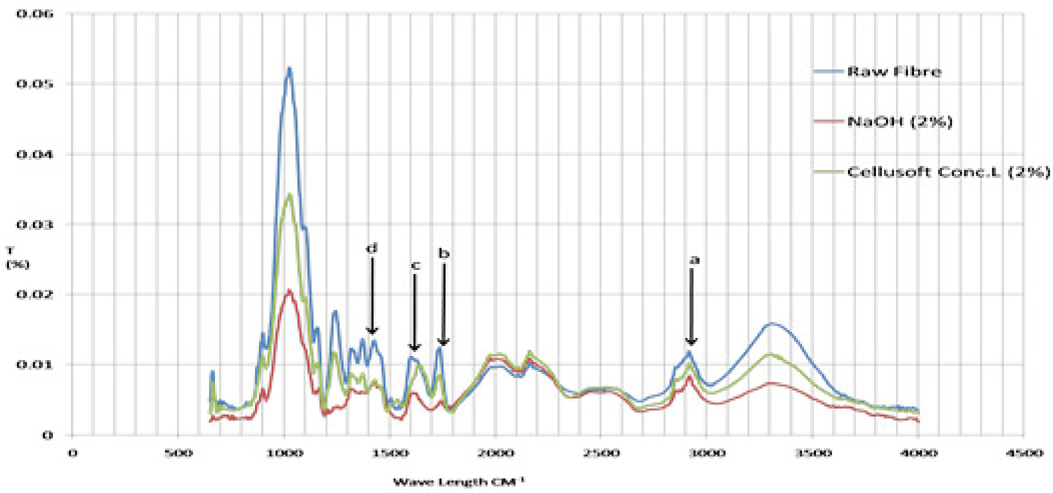


Figure 1. ATR-IR spectroscopy of Raw, NaOH (2%) treated and Cellusoft Conc. L (2%) treated fibres. Peaks (a) and (b) at 2920cm^{-1} and 1735cm^{-1} respectively, corresponding to hemicellulose; Peak (c) at 1610cm^{-1} corresponds to pectin and Peak (d) at 1440cm^{-1} corresponds to lignin.

Worth noting from these results is the fact that NaOH performs better than the enzyme at 2% concentration. However, the removal of the gluing materials had an effect on the strength of the fibres, as shown by the tensile strength test (Tables 1 and 2). This results showed that in as much as NaOH managed to perform better than the enzymes in removing the gluing materials, it also had a bigger effect on the tensile strength of the fibre as in the case of *A. sisalana* (Table 1) it was reduced to 0.060 MPa compared to the raw fibre at 0.097 MPa, while the enzyme treatment reduced the strength to 0.072 MPa. The same trend was observed for *A. americana* (Table 2).

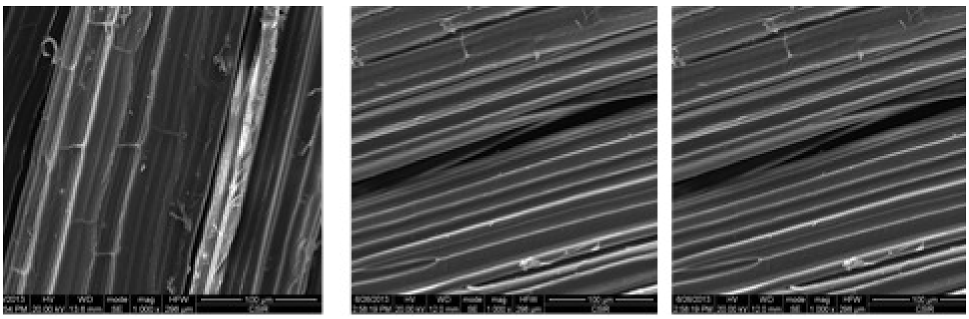
Table 1. Tensile strength test (*A. sisalana*).

Treatment	Extension at max. load (mm)	Tensile stress at break (MPa)	Maximum load (N)
Raw fibre	0.7	**0.097**	5.7
Enzyme	0.8	**0.072**	3.0
NaOH	0.9	**0.060**	3.0

Table 2. Tensile Strength test (*A. americana*).

Treatment	Extension at max. load (mm)	Tensile stress at break (MPa)	Maximum load (N)
Raw fibre	0.9	**0.168**	4.08
Enzyme	1.2	**0.111**	2.83
NaOH	2.3	**0.086**	2.2

Fibre Morphology [Scanning Electron Microscope (SEM)]



a) Raw sisal fibre b) sisal fibre treated with Enzyme c) NaOH treated fibre

Figure 2. SEM micrograms of a) raw fibre, b) fibres treated with the enzymes and NaOH treated fibre.

The treatment of fibres with enzymes and the alkali modified the surface of the fibres as demonstrated by a closer look at the morphology of the fibres using a Scanning Electron Microscope (SEM). The SEM micrograms below, Figure 2 (a), (b) and (c) show the surface of a raw fibre, enzyme and NaOH treated fibres, respectively. The pictures were viewed under a very high magnification of 100X. Both the enzyme and NaOH treated fibres looked to be smoother than the untreated fibre.

Conclusion

The results showed that both the enzymes and NaOH treatments were able to remove the gluing substances in the fibres thereby improving their surface and hence the texture, as shown by the ATR-IR and SEM. Similar results have previously been reported by Dutta *et al.* (2000) and Michalak and Krucinka (2004). The results, however, show that fibre texture modification with both the enzyme and the alkali can only be used for treating fibres wherein strength is not a necessity, like in jewelry making. In as much as NaOH can be used for fibre cleaning, it is not an environmentally friendly exercise, therefore, it is advisable to use the enzymes which are biological catalyst and are bio-degradable.

The results further showed that even though the enzymes did a relatively good job in cleaning the fibres (i.e. hydrolyzing the cementing layers: pectins, lignins and hemicelluoses), the cleaning process was not completely done, as some cementing layers still remained which made the fibres rough in texture. Therefore, there was a need to repeat experiments with higher concentrations of the enzyme for a longer treatment time. There is still need to find if the fibre waste has biological activity (anti-microbial) so as to advice fibre processors to use the waste for other products as opposed to just disposing it off.

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