Enzymatic methods for producing innovative biofibers from banana pseudostem waste

A. Galindo[1*], A. Rovira[1], M. Brouta-Agnesa[1], Z. Ortega[2], M. Morón[1], M. Guillén[1], M.Vidal[1].

[1] Acondicionamiento Tarrasense Asociación - LEITAT, Terrassa C/Innovaciò, 2,08225, Spain
[2] Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria 35017; Spain
* E-mail: amgalindo@leitat.org

1. Introduction

Enzyme selection

Selection of study parameters and design Box-Henken composite experimental

Experimental procedure in Ugolini

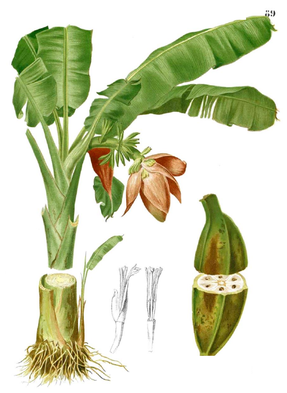
Scaling up bioprocess in ICYMA machine

Fiber characterization

Non-edible components of banana plants represent about 88% of plant weight which is otherwise discarded and processed as waste[1]. The exploitation of wastes, such as banana pseudostem waste, as alternative materials, provides new industrial materials from renewable sources with multiple advantages over synthetic materials.

Suitability of banana tree pseudostem to be used as biosource of weaving yarn, was improved by an enzymatic process. An enzymatic pretreatment was applied to decrease fiber cohesion, remove non-cellulosic constituents and obtain longer fibers, thus avoiding fiber breakage of conventional-chemical methods [2]. After digesting during 6h under optimized conditions (enzyme dilution 1:40, 100% over fiber weight of BiopectinaseK, 45°C, pH 4.5 and bath renewal after 3h), the obtained fiber presented desirable properties. The optimum enzymatic bioprocess was scaled up to retrieving 1kg of fiber in an ICYMSA garment dyeing machine.

The textile trials showed that **enzymatic pre-treated fibers are suitable to be used for yarn production** and derived technical fabrics.



2. Materials and methods

1. Lab scale reactions:

All experiments were carried out in Ugolini lab exhaustion machine (Figure 1) with constant temperature (45°C), constant orbital agitation, pH 4,5 and banana fiber to water ratio of 1:40. The fibers from banana pseudostem were cut in 5cm length and pre-treated with two different enzymatic cocktails: Biopectinase K and Biopectinase M01. The fibers were also treated in extreme chemical conditions. The refining grade of the fibers was determined by SEM microscopy and visual determinations.

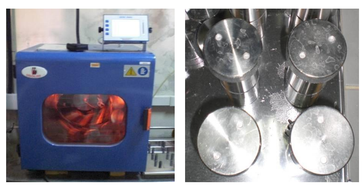


Figure 1. Ugolini exhaustion machine

Enzyme concentration and time of reaction were investigated using central composite experimental design with a rotation of 1.41 to optimise the reaction conditions. Figure 2 shows the final design for *BiopectinaseK* enzymatic cocktail. Enzymatic bath renewal and enzymatic stability were also parameters investigated.

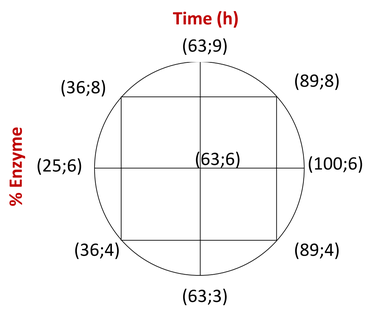


Figure 2. Final entral composite design for BiopectinaseK.

2. Scaling up to 1kg of fiber:

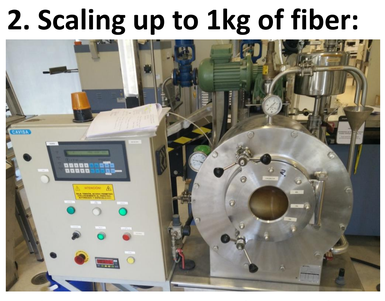


Figure 3. ICYMSA garment dyeing machine

The reaction conditions set at lab scale were scaled up to retrieving 1kg of fiber in an ICYMSA garment dyeing machine (Figure 3). Final reaction fibers were examined by microscopy (observed at different magnifications, under normal and polarized light.), SEM (transversal and longitudinal cuts), tenacity (cN/tex) and thermal stability, performed at 220 °C (temperature chosen as it is a usual temperature in thermoplastic parts processing). Samples were tested up to 10 individual fibers.

3.1. Results: Lab scale reactions

The **optimal conditions chosen** for scaling up were**: temperature 45°C**, **initial pH 4,5 ratio of 1:40**, stirring **200rpm**, **enzyme load at 100 o.f.w.%** (with respect of fibers) and **bath renewal after three hours**. pH was not controlled in order to ease the bioprocess thinking of its industrialisation.

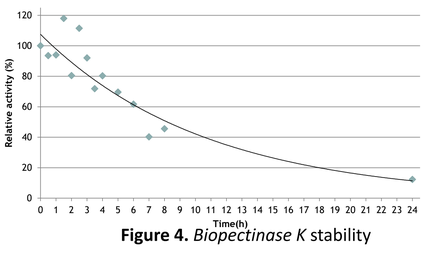


Figure 4. *Biopectinase K* stability

The initial DoE was performed with low enzymatic concentration (1-5%) to select the most adequate cocktail: ***BiopectinaseK.*** Fiber depletion does not occur, indicating parameters limits should be increased.

The final DoE was performed with a higher enzyme concentration (25-100% o.f.w.) for 6h, with a bath renewal every 3h considering enzymatic stability of *BiopectinaseK* (Figure 4). Results of mechanical testing and microscopic observations led to the reduction of two enzymatic treatments as to visualize significant differences. The fibers from treatment 100% o.f.w (Figure 5, C). are the thinner ones, showing microfibrillation due to the removal of hemicellulose and pectin, bonding agents between microfribills.

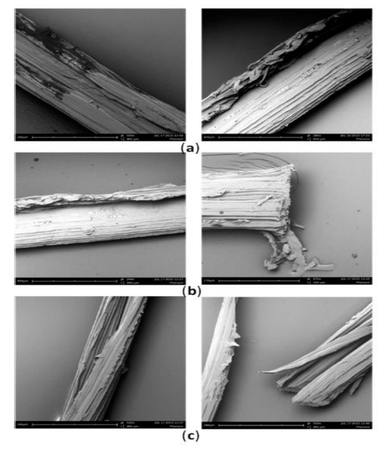


Figure 5. *SEM Microscopy of a) untreated fibers, b) fibers after pretreatment with 25% enzyme and c) with 100% o.f.w.*

The **chemical treatment** provoked fiber burn and irreparable damage at 95°C with a concentration of NaOH from 0,5 to 5% (Figure 6).

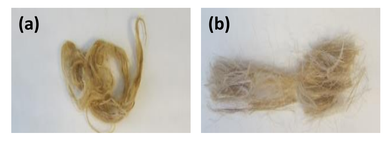


Figure 6. *Visual comparison of a) fiber treated with NaOH 5% and b)untreated fibers.*

3.2. Results: Scaling up 1kg fiber

The data obtained from central composite experimental design was not enough to be fitted to a model polynomial equation. The results from lab scale 25 and 100% o.f.w. were carried to pilot scale for further measures and to provide yarn for spinning tests.

-Optical microscopy

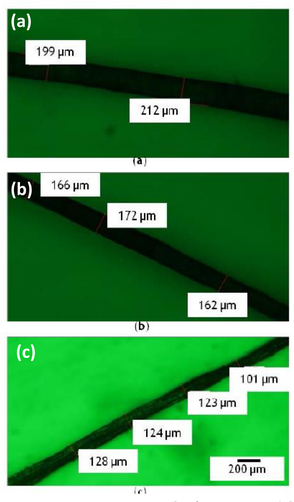


Figure 7. *Microscopy of a) untreated fiber b)treated fibers with 25% o.f.w. and c) 100% o.f.w.*

Figure 7 shows virgin banana fiber had an average diameter of about 200 m, while treated fibers show smaller average diameters: 160 m for fiber after treatment a) and 114 m for b). Diameters of micro-fibrils measure approx. 23 µm for virgin fibers and 16µm for treated ones.

-Transversal SEM microscopy

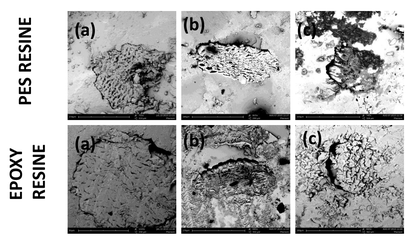


Figure 8. *SEM microscopy of a) untreated fiber b)treated fibers with 25% o.f.w. and c) 100% o.f.w.*

The channels of the fibers are practically elliptical in untreated fiber (Figure 8, a) meanwhile treated fibers (Figure 8, b and c) appear with a more irregular shape. Thus indicating a morphological change.

-Mechanical Properties of banana fibers

Results show a tensile strength of 42.8 6.5 cN/tex for virgin banana fibers. As can be observed in Figure 9, the tensile strength of fibers with Treatment 25% o.f.w. is virtually unchanged, while a reduction of 14% is observed for fiber with Treatment 100% o.f.w..

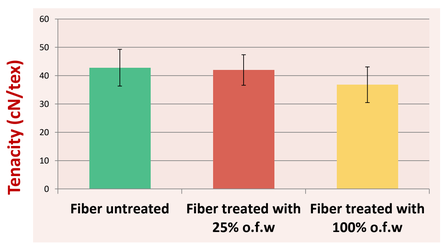


Figure 9. Tenacity of the different fibers from the scaling up

-Thermal stability

Isothermal tests in Figure 10 show higher weight loss for untreated fiber (39.7%); an important decrease in this parameter was observed for treated fibers: 25.2% and 15.2% for fibers after treatments at 25% and 100% o.f.w., respectively. **Higher thermal stability achieved from the enzymatic treatments** due to removal of less thermally stable substances (hemicelluloses and pectin).

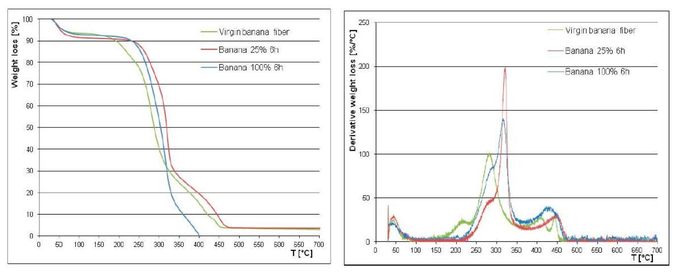


Figure 10. TG and DGT curves

4. Conclusions

- An **enzymatic treatment of banana fibers** has been developed for refining them to obtain yarn and further textile products.
- Optimal conditions for banana fiber enzymatic treatment are: 100% Biopectinase K, 6 h; 45 C, pH = 4.5, with bath renewal after 3 h. Stability studies have demonstrated that over 80% of its activity takes place in the first 3 h.
- **Simple upscaling setup was established** in order to ease the bioprocess development in an industrial scale and resulting in **products of higher quality** and bioprocess of **lower energy consumption**.
- Promising results were obtained with final reaction medium produced in terms of **yarn production to be woven**. Further optimization is needed to reduce enzymatic dose.

5. References

[1] N. Reddy and Y. Yiqi, "Fibers from Banana Pseudo-Stems." *Innovative Biofibers from Renewable Resources*. Springer Berlin Heidelberg, (2015) 25-27.

[2] A. Kumar, BP .Singh, RK. Jain , AK. Sharma. Banana Fibre (*Musa sapientum*): "A Suitable Raw Material for Handmade Paper Industry via Enzymatic Refining". *International Journal of Engineering Research & Technology*. (2013); 2(10); 1338-1350.

Acknowledgments:

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