

**EFFECT OF ALKALINE TREATMENT ON MORPHOLOGY AND BIODEGRADATION
OF BAGASSE AND MAIZE CELLULOSE**

TSHWAFO ELIAS MOTAUNG
SEFAKO MAKGATHO HEALTH SCIENCES UNIVERSITY
SOUTH AFRICA

ELLA CEBISA LINGANISO-DZIIKE
UNIVERSITY OF THE WITWATERSRAND
SOUTH AFRICA

ZIKHONA TETANA
UNIVERSITY OF SOUTH AFRICA
SOUTH AFRICA

LEHLOHONOLO FORTUNE KOAO
UNIVERSITY OF THE FREE STATE
SOUTH AFRICA

SETUMO VICTOR MOTLOUNG
CENTRAL UNIVERSITY OF TECHNOLOGY
SOUTH AFRICA

RECEIVED FEBRUARY 2025

ABSTRACT

This study investigates the biodegradation behaviour of cellulose extracted from sugarcane bagasse (SCB) and maize using chemical treatments involving sodium hydroxide (NaOH), sodium chlorite, and buffer solutions (NaOH and glacial acetic acid). The extraction process yielded cellulose at 38.00% from SCB and 45.14% from maize, based on the weight of the raw material. The resulting celluloses were characterized using Fourier transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD), confirming their structural and chemical integrity. Biodegradability was evaluated through composting tests, revealing weight losses of

9.08% for SCB cellulose and 29.47% for maize cellulose. The higher degradation rate of maize-derived cellulose suggests enhanced biodegradability.

KEYWORDS: Maize stalks, sugar cane bagasse, alkalization, biodegradation.

INTRODUCTION

Alkaline treatment is a widely used method to modify the structure and enhance the biodegradability of lignocellulosic biomass such as bagasse and maize residues. Among forms of plant biomass, lignocellulosic biomass is particularly well-suited for energy applications because of its large-scale availability, low cost and environmentally benign production (Shabangu et al. 2019, Shibata et al. 2002, Ridzuan et al. 2015, Lu et al. 2012). In particular, many energies production and utilization cycles based on cellulosic biomass have near-zero greenhouse gas emissions on a life-cycle basis (Kasyapi et al. 2013, Morelli et al. 2012, Huda et al. 2008, Fan et al. 2013, Cao et al. 2007, Mostafa et al. 2018, Liganiso et al. 2019, Li et al. 2009, Li et al. 2011, Nishino et al. 2011, Siqueira et al. 2009, Montane et al. 1998, Sun et al. 2002). The primary obstacle impeding the more widespread production of energy from biomass feedstocks is the general absence of low-cost technology for overcoming the recalcitrance of these materials (Lu et al. 2012).

Sugarcane bagasse and maize are examples of lignocellulosic biomass, primarily composed of three major components: cellulose, hemicellulose, and lignin, along with minor amounts of extractives and ash. These components are unevenly distributed within the cell wall, where cellulose serves as the structural skeleton, hemicellulose acts as a linking material, and lignin provides rigidity. Their distinct roles contribute to the mechanical properties of the biomass (Morelli et al. 2012, Huda et al. 2008, Fan et al. 2013, Cao et al. 2007, Mostafa et al. 2018, Liganiso et al. 2019).

Several studies have explored chemical modifications of bagasse and maize to enhance their properties, sometimes leading to unexpected surface interactions. For instance, Khumalo et al. 2002 investigated the effect of mixed acids on the morphology, crystallinity, and thermal properties of cellulose nanocrystals (CNC). Their findings revealed that acid hydrolysis significantly increased crystallinity and thermal stability. Similarly, Mohomane et al. (2017) examined the influence of extraction time on cellulose derived from sugarcane bagasse (SCB) and softwood (SW). Their method involved alkali treatment followed by bleaching with sodium chlorite at varying durations. Results indicated that prolonged extraction enhanced cellulose crystallinity, particularly when combined with mixed acid hydrolysis, further improving thermal stability. In another study, Mohomane et al. (2021) investigated the impact of nanosilica modification on SCB and SW cellulose. The extraction process involved three key steps: thermal pre-treatment, alkaline treatment, and bleaching. The results showed that nanosilica treatment led

to increased crystallinity, while surface morphology analysis revealed that the modified cellulose fibers became swollen, with small silica particles agglomerating on their surfaces

While the effects of alkaline treatment on surface interactions with other chemical substrates including its impact on the properties of different polymers have been fairly well studied (Nyerere et al. 2024, Aguiar et al. 2001) the characterization of biodegradation for alkali-treated materials remains insufficiently explored. Biodegradation of bagasse (sugarcane residue) and maize residues (stalks, husks, and cobs) is a microbial process that breaks down these lignocellulosic materials into simpler organic compounds. These residues primarily consist of cellulose, hemicellulose, and lignin, which require enzymatic action from microorganisms for decomposition. Various bacteria (e.g., *Bacillus*, *Pseudomonas*, *Clostridium*) and fungi (e.g., *Trichoderma*, *Aspergillus*, *Phanerochaete chrysosporium*) produce cellulases, hemicellulases, and ligninases to facilitate degradation. The biodegradation process is influenced by factors such as moisture content, temperature, pH, and oxygen availability, making it essential to optimize conditions for efficient breakdown. Characterization of this process involves monitoring weight loss, enzymatic activity, and chemical composition changes. Weight reduction over time serves as an indicator of microbial degradation, while enzymatic assays (e.g., cellulase, xylanase, and laccase) quantify the breakdown of structural polysaccharides and lignin.

The current study aims to investigate the effects of alkali treatment on the biodegradation of sugarcane bagasse cellulose and maize cellulose by assessing microbial weight loss reduction over time.

MATERIAL AND METHODS

Materials

Sugarcane bagasse (SCB) was sourced from a sugar company in Empangeni, KwaZulu-Natal, South Africa, while maize was collected from rural areas of Vryheid, KwaZulu-Natal, South Africa. Sodium hydroxide (NaOH) and sulphuric acid (H₂SO₄) of both 98%, glacial acetic acid (CH₃COOH 85%), acetic anhydride, sodium chlorite, polyethylene glycol 1000, acetyl acetone, dioxane, HCl (37%), methanol, were obtained from laboratory consumables.

Alkali treatment

Both sugarcane bagasse and maize were first washed to remove dust at 100°C for 4 h and then left at room temperature overnight. Alkali treatment was performed to remove lignin and hemicellulose in both materials. The dried SCB as well as maize were treated with 2wt. % sodium hydroxide (NaOH) solution at 100°C for 4 h. This step was then followed by bleaching using sodium chlorite (2wt%) in water and an acetate buffer (54g NaOH) and 150 ml glacial acetic acid, diluted to 2 l volumetric flask using deionised water. The treatment was performed under mechanical stirring and repeated four times with filtering and rinsing with

deionised water in every hour. The fibre was then dried for 24 h at 30°C in an oven. Then the dried cellulose fibres were crushed or ground again into finer powder(>1mm).

Acetylation of cellulose

A powdered sample of 35 g of each cellulose was used. Acetic anhydride (100 mL), glacial acetic acid (100 mL) and sulfuric acid (10 mL) were mixed and the mixture was cooled to 7°C. Cellulose were added slowly to the mixture with agitation to bring about the acetylation process; this step produced the primary cellulose. Hydration of the primary cellulose (viscous fluid) was achieved by diluting with 30 mL of equal parts of concentrated acetic acid (99.8%) and sulfuric acid (98%) and, then, the primary cellulose was allowed to age for 15 h. The resulting viscous fluid was centrifuged in order to separate the final product. Plasticizer (polyethylene glycol 1000) was added at 25% by volume of the viscous cellulose with agitation; this formed the final product which was dried in an oven at 60°C until a constant weight in order to get the product in the form of film ready for analysis.

Elemental analysis

The untreated SCB and maize in this study were analysed to determine their chemical composition. The contents of lignin, cellulose, and hemicellulose were quantified according to the TAPPI standards (Shabangu et al. 2019, Khumalo et al. 2002, Linganisio et al. 2019, Mohomane et al. 2017, Mohomane et al. 2021).

Fourier transform infrared spectroscopy (FT-IR)

FT-IR was used to determine structural functional groups of untreated, chemically treated and the structure of cellulose acetate. The spectra of raw materials, cellulose and CA were investigated by FTIR spectroscopy and analysis was carried out on a Bruker Tensor 27 FT-IR spectrometer using a standard ATR cell. The gauge was adjusted to 100 for sufficient contact. All samples were scanned over the wavenumber (450cm^{-1} - 4000cm^{-1}).

X-ray diffraction (XRD)

X-ray diffraction measurements were performed to determine the sample crystallinity of untreated, chemically treated SCB and maize, and cellulose. The XRD profiles were obtained using powder X-ray diffraction spectroscopy (Bruker AXS Advance D8 diffractometer) in 2θ range of 5°- 90° at a rate of 1s per step. The XRD usually confirms the amorphous and crystalline peaks.

Biodegradation tests

Samples in the form of film(5 g) of the were vacuum dried for 24 h at 45°C, weighed precisely and, next, buried into the municipal solid waste mixture. Then, they were examined for possible biodegradation. The mixture consisted of leaves, paper waste, cow manure, food waste, wood waste and water. The mixture was kept in an oven at 55°C, at which the maximum

growth of thermophilic microorganisms occurred (Ridzuan et al. 2015). The samples were weighed every two days in order to determine the percentage of weight loss.

RESULTS AND DISCUSSION

Chemical composition

The chemical composition of the SCB and maize is summarised in Tab. 1. The contents of cellulose, lignin and hemicelluloses from maize sample indicated the common trend in literature where cellulose dominate lagged by hemicellulose (Shabangu et al. 2019, Shibata et al. 2002, Ridzuan et al. 2015). Nonetheless the sample of sugar cane bagasse, in this study, showed almost the same content of lignin and hemicellulose that could be related to a degree of biodegradation mechanism (Lu et al. 2012, Kasyapi et al. 2013, Morelli et al. 2012, Huda et al. 2008, Fan et al. 2013, Cao et al. 2007, Mostafa et al. 2018).

Tab. 1: Displays percentages of used lignocelluloses.

Raw material	Cellulose (%)	Lignin (%)	Hemicellulose (%)
SCB	38.90	30.75	30.35
Maize stalk	31.28	23.50	45.22

Fourier transform infrared spectroscopy (FTIR)

Fig.1(A) represents the FTIR spectra of untreated SCB and untreated maize, whereas Fig. 1(B) and Fig. 1 (C) represent treated SCB and treated maize and their respective celluloses. The spectra of both SCB and maize have similar pattern within experimental uncertainty. The broader absorption band at wavenumber of 3346 cm^{-1} and 3343 cm^{-1} was assigned to the -OH stretching of cellulose and hemicellulose.

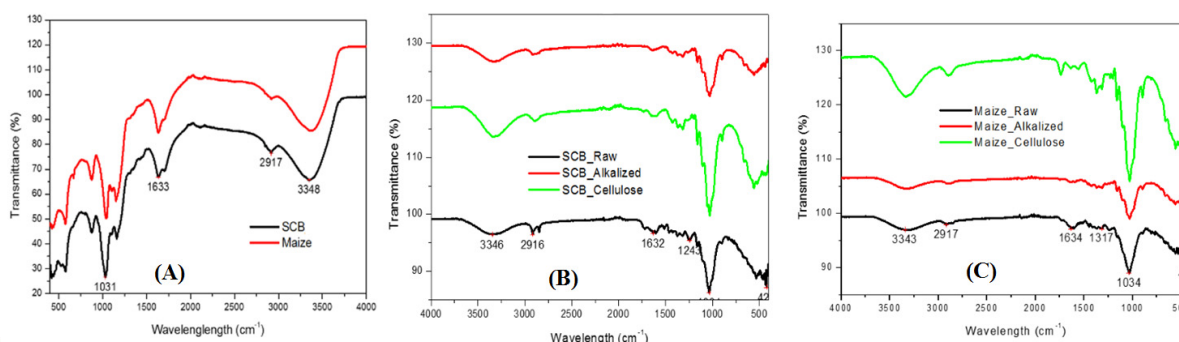


Fig. 1: FTIR spectra of sugarcane bagasse and maize stalk (A), untreated biomass, NaOH treated biomass and cellulose for (B) SCB and (C) maize stalk.

The intensity peak absorption band at wavenumber 2916 cm^{-1} and 2917 cm^{-1} was attributed to the asymmetric and symmetric of C-H stretching of cellulose and hemicellulose. The

absorption band around at wavenumber 1632 cm^{-1} and 1634 cm^{-1} was characterised for O-H deformation which could be assigned to water absorption. The peak at wavenumber 1034 cm^{-1} corresponded to C-O stretching of cellulose and hemicellulose. As expected, the removal of non-cellulosic components led to increased intensities of most peaks (Huda et al. 2008, Fan et al. 2013, Cao et al. 2007), some peaks which are normally related to the presence of lignin (the peak at 1632 cm^{-1}) were less pronounced during alkali treatment and cellulose (Morelli et al. 2012, Huda et al. 2008, Fan et al. 2013, Cao et al. 2007).

X-Ray diffraction (XRD) analysis

Fig.2 (A) represents the XRD profiles of untreated SCB and untreated maize, whereas Fig. 2(B) and Fig. 2 (C) represent treated SBC, treated maize and their respective celluloses. It can be seen that the diffraction patterns displayed similar peaks at values of about 16.261° , 21.71° and 35.09° for SCB and 15.92° , 22.32° and 34.87° for maize, even though the maize exhibited higher intensity than SCB. Those peaks were actually relative to the crystalline structure of cellulose I known in literature (Linganiso et al. 2019, Li et al. 2009). Actually, the similarity implied that alkali treatment did not necessarily change the structure of fibres but altered slightly the crystallinity of fibres. It is observed that comparable XRD patterns around 21.27° , 26.96° and 36° - 40° appear in the two samples. The peak around 26.96° in the curves is ascribed to the typical crystal lattice of cellulose I (Li et al. 2011, Nishino et al. 2011, Siqueira et al. 2009), indicating that all samples exhibit the diffuse characteristics pattern of an amorphous phase. In this study, the diffraction peak at 26.96° of (0 0 2) reflection is sharper and narrower in celluloses, especially for the maize to our surprise. Chemical compositions and image analysis suggested a smoother SCB, which normally get digested easily, however in this study the opposite happened. The change in sharpness of the peaks indicates the removal of lignin and hemicellulose, as predicted by FTIR, chemical composition analysis and the images. In line with literature that also results in an increase in the degree of crystallinity and a higher tensile strength (Montane et al. 1998, Sun et al. 2002).

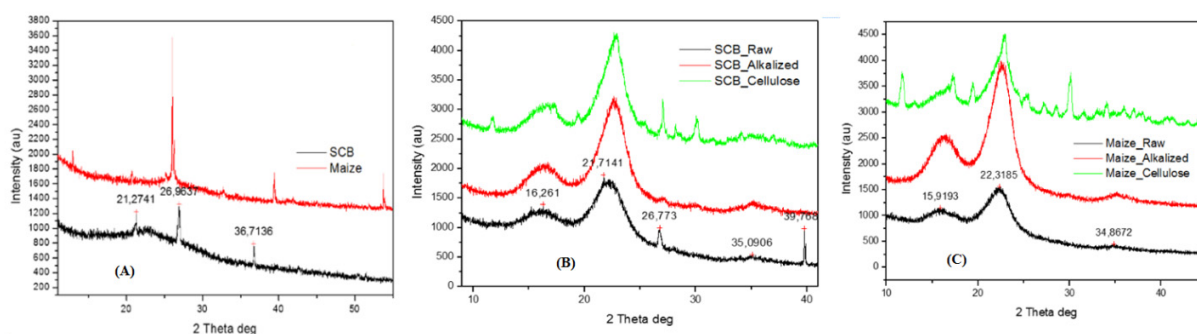


Fig. 2: Typical XRD patterns for SCB and maize (A), untreated biomass, NaOH treated biomass and cellulose for (B) SCB and (C) maize stalk.

Biodegradation

Fig.6. below presents the results of biodegradation from composting and bench-scale simulated composting tests for both SCB cellulose (Fig. 6a) and maize cellulose (Fig. 6b). The figure indicates that, during the biodegradation tests from composting, maize cellulose and SCB cellulose lost 57.69% and 51.31% of their weight, respectively, within the first two days. Interestingly, SCB appears to have lost 10% more than maize cellulose within this period. The weight loss continued to increase over time, reaching 84.16% for maize stalk cellulose and 60.39% for SCB cellulose after 14 days. Aguiar et al. 2021 attributed a similar pattern to the increased rates of hydrolysis in bagasse pre-treated with sodium hydroxide, phosphoric acid, and steam. They reported achieving 35% hydrolysis of pre-treated sugarcane bagasse using 4% sodium hydroxide, followed by heating at 121°C for 15 min. In this study, it is possible that the hydrolysis effect of pre-treatment was more aggressive on sugarcane bagasse cellulose than on maize cellulose, leading to differences in biodegradation rates. In addition, taking the study of Shabangu et al (2019). into consideration, it is possible that higher cellulose content of maize could explain its delayed biodegradation.

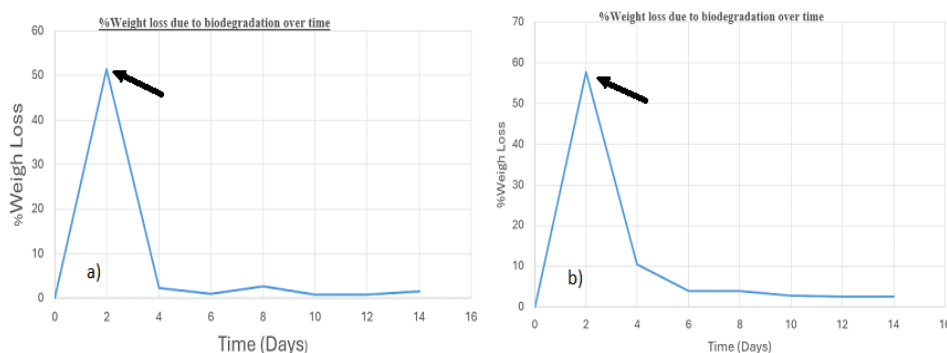


Fig. 3: Compost's percentage weight loss due to biodegradation (by composting and bench-scale) of CA produced from SCB (a) and maize (b).

CONCLUSIONS

The cellulose from sugar cane bagasse and maize were successfully extracted through alkali and acetylation process. The alkali pre-treatment effectively removed lignin and hemicellulose, while acetylation process produced more concentration of cellulose I as confirmed by the XRD pattern. FTIR analysis further validated this by showing -OH stretching of cellulose at 3346 cm^{-1} for sugarcane bagasse (SCB) and 3343 cm^{-1} for maize. Biodegradation tests using compost revealed different degradation rates, with SCB degrading at a higher rate. After 14 days, the weight loss reached 84.16% for maize-derived cellulose and 60.39% for SCB.

ACKNOWLEDGEMENTS

The University of Zululand is acknowledged for OM and XRD. Opinions expressed and conclusions arrived at, are those of the authors and are not necessarily to be attributed to the institutions.

REFERENCES

1. Shabangu, T., Liganiso, L.Z., Motaung, T.E., Campus, K., Setumo, M.V. and Koa, L.F., 2019: Comparison of fibre from maize stalk domains and sugar cane bagasse. *Wood Research* 64(4): 601-612.
2. Shibata, M., Takachiyo, K.I., Ozawa, K., Yosomiya, R. and Takeishi, H., 2002: Biodegradable polyester composites reinforced with short abaca fiber. *Journal of Applied Polymer Science* 85(1): 129-138.
3. Ridzuan, M.J.M., Majid, M.S.A., Afendi, M., Kanafia, S.N.A., Nurima, M.B.M., 2015: Effects of alkaline concentrations on the tensile properties of Napier grass fibre. *Applied Mechanics and Materials* 786: 23–27.
4. Lu, P., Hsieh, Y.L., 2012: Preparation and characterization of cellulose nanocrystals from rice straw. *Carbohydrate Polymers* 87(1): 564–573.
5. Kasyapi, N., Chaudhary, V., Bhowmick, A.K., 2013: Bionanowhiskers from jute: Preparation and characterization. *Carbohydrate Polymers* 92(2): 1116–1123.
6. Morelli, C.L., Marconcini, J.M., Pereira, F.V., Bretas, R.E.S., Branciforti, M.C., 2012: Extraction and characterization of cellulose nanowhiskers from balsa wood. *Macromolecular Symposia* 319: 191–195.
7. Huda, M.S., Drzal, L.T., Mohanty, A.K., Misra, M., 2008: Effect of chemical modifications of the pineapple leaf fiber surfaces on the interfacial and mechanical properties of laminated biocomposites. *Composite Interfaces* 15(2–3): 169–191.
8. Fan, G., Wang, M., Liao, C., Fang, T., Li, J., Zhou, R., 2013: Isolation of cellulose from rice straw and its conversion into cellulose acetate catalyzed by phosphotungstic acid. *Carbohydrate Polymers* 94(1): 71-76.
9. Cao, Y., Wu, J., Meng, T., Zhang, J., He, J., Li, H. and Zhang, Y., 2007: Acetone-soluble cellulose acetates prepared by one-step homogeneous acetylation of cornhusk cellulose in an ionic liquid 1-allyl-3-methylimidazolium chloride (AmimCl). *Carbohydrate Polymers* 69(4): 665-672.
10. Mostafa, N.A., Farag, A.A., Abo-dief, H.M. and Tayeb, A.M., 2018: Production of biodegradable plastic from agricultural wastes. *Arabian Journal of Chemistry* 11(4): 546-553.
11. Liganiso, L.Z., Buthelezi, T., Motaung, T.E., 2019: A comparative study of sugarcane bagasse and soft wood. *Wood Research* 64: 273-28.
12. Li, R., Fei, J., Cai, Y., Li, Y., Feng, J., Yao, J., 2009: Cellulose whiskers extracted from mulberry: A novel biomass production. *Carbohydrate Polymers*: 76(1), 94–99.

13. Li, Q., Rennecker, S., 2011: Supramolecular structure characterization of molecularly thin cellulose I nanoparticles. *Biomacromolecules*, 12(3):650-659.
14. Nishino, T., Kotera, M., Suetsugu, M., Murakami, H., Urushihara, Y., 2011: Acetylation of plant cellulose fiber in supercritical carbon dioxide. *Polymer* 52(3):830-836.
15. Siqueira, G., Bras, J., Dufresne, A., 2009: New process of chemical grafting of cellulose nanoparticles with a long chain isocyanate. *Langmuir*, 26(1):402-411.
16. Montane, D., Farriol, X., Salvado, J., Jollez, P., Chornet, E., 1998: Application of steam explosion to the fractionation and rapid vapor-phase alkaline pulping of wheat straw. *Biomass and Bioenergy*, 14(3):261-276.
17. Sun, R., Sun, X.F., 2002: Structural and thermal characterization of acetylated rice, wheat, rye, and barley straws and poplar wood fibre. *Industrial Crops and Products* 16(3):225-235.
18. Khumalo N., Mohomane S.M., Motlounge S.V., Koao L.F., Malevu T.D., Motaung T.E., 2022: Effect of H₂SO₄/HClO₄ mixture on properties of sugarcane bagasse cellulose crystals. *Wood Research* 67(6): 929-940.
19. Mohomane, S.M., Linganiso, L.Z., Buthelezi, T., Motaung, T.E., 2017: Effect of extraction period on properties of sugarcane bagasse and softwood chips cellulose. *Wood Research* 62: 931-938.
20. Mohomane, S.M., Motlounge, S.V., Koao, L.F., & Motaung, T.E. (2021). Effect of silica on alkaline bagasse cellulose and softwood cellulose. *Wood Research* 66(1): 85–94.
21. Nyerere G., Kyokusiima S, Nabaterega R., Tumusiime G., Kavuma C., 2024: The synergy of maize straw cellulose and sugarcane bagasse fibre on the characteristics of bioplastic packaging film. *Bioresource Technology Reports* 28, 102-107.
22. Aguiar C.L., 2001: Biodegradation of the cellulose from sugarcane bagasse by fungal cellulase. *Ciencia y Tecnologia Alimentaria* 3(2) 117-121.

MOTAUNG TSHWAFO ELIAS*
SEFAKO MAKGATHO HEALTH SCIENCES UNIVERSITY
DEPARTMENT OF CHEMISTRY
P.O. BOX 94, MEDUNSA 0204, SOUTH AFRICA

ELLA CEBISA LINGANISO-DZIIKE
¹UNIVERSITY OF THE WITWATERSRAND
MOLECULAR SCIENCES INSTITUTE, SCHOOL OF CHEMISTRY
PRIVATE BAG 3, JOHANNESBURG 2050, SOUTH AFRICA
DSI/NRF CENTRE OF EXCELLENCE IN STRONG MATERIALS
BRAAMFONTEIN 2050, SOUTH AFRICA
²SEFAKO MAKGATHO HEALTH SCIENCE UNIVERSITY
DEPARTMENT OF CHEMISTRY
P.O. BOX 94, MEDUNSA, GA-RANKUWA, PRETORIA 0204, SOUTH AFRICA

ZIKHONA TETANA
UNIVERSITY OF SOUTH AFRICA
INSTITUTE FOR NANOTECHNOLOGY AND WATER SUSTAINABILITY
COLLEGE OF SCIENCEENGINEERING AND TECHNOLOGY
FLORIDA CAMPUS, JOHANNESBURG 1709, SOUTH AFRICA

LEHLOHONOLO KOAO
UNIVERSITY OF THE FREE STATE (QWAQWA CAMPUS)
DEPARTMENT OF PHYSICS
PRIVATE BAG X13,PHUTHADITJHABA 9866, SOUTH AFRICA

SETUMO V. MOTLOUNG
CENTRAL UNIVERSITY OF TECHNOLOGY
PRIVATE BAG X 20539, BLOEMFONTEIN 9300, SOUTH AFRICA
*Corresponding author: motaungte@live.com or Tshwafo.motaung@smu.ac.za