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EVALUATION OF PHYSICO-MECHANICAL PROPERTIES AND BIODEGRADABILITY OF PLANT CONTAINERS MADE FROM BIOMATERIALS FOR SUSTAINABLE AGRICULTURE

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ABSTRACT
Plastic containers used in agricultural operations accumulate in the soil, reducing soil fertility and eventually becoming hazardous to humans. The alternatives for these are biodegradable containers that are good for sustainable agriculture. Consequently, biodegradable containers were produced during 2021 at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, from three biomaterials (i.e., bamboo culm sheath, banana pseudostem, and corn husk) in the present study as alternatives for plastic containers in agricultural production. The fibre morphological properties of the biomaterials were evaluated based on International Association of Wood Anatomists standards before the formation of the containers. The tensile strength, moisture absorption, and thickness swelling, and biodegradability of the containers were also determined using the American Standards for Testing and Materials. The fibre characteristics of the biomaterials matched the acceptable standard for producing paper containers. Corn husk containers absorbed a high amount of water (203.33%) and swelled more in thickness (41.63%). Banana pseudostem and bamboo culm sheath containers had high tensile strengths (i.e., 6586.46 ± 49.38 N/m and 6437.69 ± 402.64 N/m respectively) although these were lower than that of the plastic containers (8406.72 ± 44.48 N/m). The containers from the biomaterials completely degraded on or before the 60th day in the soil. The biomaterial containers would contribute to the development of modern agriculture since they will degrade, prevent root circling and promote plant growth.

KEYWORDS: Cellulosic fibre material; horticulture; plastic nursery containers; plastic pollution; tensile strength; runkel ratio.

INTRODUCTION
Plastic is the most commonly utilized material for containers used in plant nursery and greenhouse operations (Wang *et al.,* 2015). The plant nursery industry in the United States alone uses over 4 billion petroleum-based plastic containers every year, and 98% of these containers are disposed of in landfills (Rahman *et al*., 2023). The affordability, ease of handling and transportation, and good water retention are the major advantages of plastics that drive the upsurge in their use (Muriuki *et al.,* 2013). However, their accumulation in the environment (estimated at 28 million tons per year) and rapid depletion of petroleum resources used in their production are motivating factors for research into alternative materials that can be used to make plant containers (Muhammadi *et al*., 2015). Conventional plastics are resistant to microbial degradation and can alter the chemistry of soils. Rillig *et al.* (2019) found that plastics can break down into nanoplastics and be absorbed by plant roots. They are known to release phthalic acid esters which accumulate in crops and become hazardous for humans when such crop/plant is consumed (Tomadoni *et al*., 2020). They also reduce soil porosity and air circulation, microbial populations and soil fertility. Since plastic containers need to be removed during seedling transplant, plant root damage is unavoidable (Sun *et al*., 2017). Transplanting seedlings from plastic containers is also time consuming and results in higher plant production costs.

Previous efforts to overcome the challenges associated with the use of conventional plastic containers resulted in the production of biodegradable plastics. However, the high cost, poor mechanical properties and poor water vapour permeability of biodegradable plastics limit their use (Van den Oever *et al.,* 2017). Paper-based containers made from cellulosic fibres could serve as alternatives to conventional plastic pots. These containers are relatively cheap, have good mechanical properties and will biodegrade when buried in the soil. They also allow plant roots to develop more naturally in the soil and eliminate roots spiralling and binding (Tomadoni *et al.*, 2020).

Paper-based nursery containers have largely been produced from wood fibres. Boadu *et al*. (2020) observed that the quadrupling demand for paper in the last 50 years has contributed significantly to the increasing rate of deforestation around the globe. In order to reduce deforestation and keep up with paper supply for manufacturing plant containers, there is the need for alternative fibre sources for papermaking. Previous researchers have identified several non-wood fibrous materials such as bamboo culm sheath, banana pseudostem and corn husk for pulp and paper production. Wang *et al.* (2016) reported that bamboo sheath with low lignin content which enhances its pulpability could have the potential for papermaking. This material is readily available as a residue in bamboo forests and therefore cheap to obtain. However, it is not commonly utilized by the paper industry. Furthermore, banana pseudostem is also an abundant natural resource in many subtropical and tropical countries. It is often abandoned on farms after banana bunches have been harvested. Smith *et al*. (2008) reported that fibres from banana pseudostem have high tensile strength and stiffness, which indicate their prospects as materials for producing paper containers for agricultural operations. Similarly, corn husk is a promising fibre resource for making paper containers. It contains high quantities of cellulose, which is the primary constituent of most ligno-cellulosic materials desired for the production of pulp and paper (Ekhuemelo and Tor, 2013). It also has a low lignin content which can make papers produced from it possess a very good tensile strength (Fagbemigun *et al.,* 2014). Corn husk is readily available, less expensive and environmentally-friendly (Norashikin and Ibrahim, 2009).

Based on the preceding discussion, the present work explored the possibility of making nursery paper containers from bamboo culm sheath, banana pseudostem and corn husk for use by the agricultural sector. In spite of the advantages of the paper-based containers, there are some genuine challenges. The major challenge with paper-based nursery containers is their poor water retention characteristic (Sun *et al.*, 2017). They tend to absorb high quantities of water but desorbs all within a very short time. This phenomenon makes paper-based containers vulnerable to early deterioration. Growth of fungi on the surfaces of paper-based pots during use as a result of excessive water absorption have also been reported (Alsanius and Wohanka, 2019). These fungi could inhibit the growth of plants (Alsanius & Wohanka, 2019; Meinken *et al*., 2015). Consequently, some authors (Ofosu *et al.*, 2020; Zhang *et al*., 2017) have recommended coating paper containers with beeswax to improve their water retention. They asserted that beeswax is hydrophobic due to the high quantities of lipids present, and has high plasticity. These make it insoluble in water and reduce water absorption and loss from containers whose surfaces have been coated with it (Ofosu *et al.,* 2020). Ofuso *et al.* (2020) noted an increase in absorbency time of biodegradable plates when they were coated with increasing amount of beeswax in beeswax-chitosan solution. Zhang *et al*. (2017) also found that beeswax was more water resistant than sodium alginate-gellan composite used to bio-coat paper cups for hot drinks. Therefore, the nursery containers produced from corn husk, banana pseudostem and bamboo culm sheath were coated with beeswax to improve their water absorption and retention properties. Subsequently, the water absorption, thickness swelling, tensile strength and biodegradability of the containers were evaluated. The research sought to contribute to widening the resource base for the plant container industry while reducing overexploitation of wood resources and the negative effects of plastic containers on the environment.

MATERIALS AND METHODS

Collection and processing of materials

Current study was conducted during 2021 at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. The materials used for the present study were bamboo culm sheaths, banana pseudostems, corn husks and beeswax. The bamboo (*Bambusa vulgaris*) culm sheaths were randomly gathered from the botanical gardens at the Kwame Nkrumah University of Science and Technology (KNUST) (**Coordinates:** 6.68335°N, -1.56457°W), Kumasi, Ghana during 2021. The banana pseudostems and the corn husks were also collected from a commercial banana plantation at Aduman in the Ashanti Region of Ghana and the Kronum market (**Coordinates:** 6.7527° N, 1.6435° W) in the Suame district of the Ashanti Region of Ghana respectively. The three biomaterials were first washed thoroughly to remove dirt and soil particles and thereafter cut into pieces at the Chemical Laboratory of the Faculty of Renewable Natural Resources (FRNR) in KNUST. The last material, the beeswax, was procured from Proper Management Enterprise Limited in Accra,Ghana.

Determining the fibre characteristics of the biomaterials

The fibre characteristics of the biomaterials were determined at the Anatomy Laboratory of FRNR in accordance with the International Association of Wood Anatomist (IAWA, 1989) standards. Match-stick sized samples were obtained from each of the three biomaterials. About 30 ml of Franklin solution (prepared from a mixture of 250 ml each of acetic acid and hydrogen peroxide in a ratio of 1:1) was poured into test tubes containing the samples and incubated at 65 ℃ for 3 days. The Franklin solution was carefully poured out of the test tubes and the macerates were washed with distilled water to remove any excess solution. The fibres were then transferred onto slides, teased further with a pin and covered with cover slips. The slide was then viewed under a light microscope (objective lens magnification = ×40). The length, diameter, wall thickness and lumen width of twenty-five (25) fibres from each of the materials were measured using a camera and the Amscope computer software. Derived values such as runkel and slenderness ratio and flexibility coefficient were calculated using fibre dimensions:

$$\text{Runkel ration} = \frac{\text{2 X cell wall thickness}}{\text{Lumen width}} \text{ (San } et\ al.\text{, 2016)}$$

$$\text{Flexibility coefficient} = \frac{\text{Lumen width}}{\text{Fiber diamter}} \times 100 \text{ (San } et\ al.\text{, 2016)}$$

$$\text{Slenderness ratio} = \frac{\text{Fiber length}}{\text{Fiber diameter}} \text{ (Ogunleye } et\ al.\text{, 2017)}$$

Pulping of the biomaterials

The biomaterials were pulped in accordance with the methods prescribed by Sibaly and Jeetah (2017) to obtain dry cellulosic pulp required for kraft paper making. The biomaterials were individually boiled in equal volumes of aqueous caustic soda solution at 90 ± 2.5 °C for 2 h under atmospheric pressure. The mixture was manually stirred at regular intervals to speed up the delignification process. When boiling was over, the materials were washed thoroughly to remove excess caustic soda, allowed to cool at room temperature, blended and then filtered using cheese cloth to drain the liquor.

Production of plant containers

The container moulding process followed the method used by sculptors to produce a papier-mâché. The pulp of each material was moulded into a container of 3.5 mm thickness (Ma *et al.,* 2016) and a volume of 465 cm^3 (Fig. 1) as specified by the American Standard for Nursery Stock (ANSI Z60.1-2014). Cassava starch was used as a binder in a starch to pulp ratio of 0.03:1 (Ferstl *et al.,* 2020). Eighteen containers were made from each material. The containers were air-dried for one week and coated with beeswax which had been melted in a beaker placed in a water bath at 63 °C (Buxoo & Jeetah, 2020). The melted wax was uniformly applied on the interior and exterior surfaces of the pots using the brushing method. Precautions were taken to ensure that equal amount of the wax was applied on all the pots labelled A, B and C (Fig 1). The containers were air-dried for two days and conditioned at room temperature (25°C).

Determination of the physical characteristics of the containers

Water absorption and thickness swelling

Ten test samples (dimension = 20 x 20 x 3.5 mm) were prepared from the moulded pots in accordance with the standards by the American Society for Testing and Materials (ASTM) D570. The initial weight and thickness of the samples were measured and the samples were submerged in distilled water for 7 days. The new weight and thickness were recorded (Atiqah *et al.,* 2017) and the water absorption and thickness swelling of the samples calculated:

$$\text{Water absorption (\%)} = \frac{\text{Weight of sample after immersion – weight of sample before immersion}}{\text{Weight of sample before immersion}} \times 100\%$$

$$\text{Water absorption (\%)} = \frac{\text{Thickness of sample after immersion – Thickness of sample before immersion}}{\text{Thickness of sample before immersion}} \times 100\%$$

Determination of the tensile strength of the containers

The tensile strength of the containers was determined at the Strength and Materials Laboratory of the College of Engineering, KNUST, with a tensile-testing machine. Two dumbbell-shaped specimens (parallel cut and perpendicular cut) (dimension = 19 x 3.5 x 85 mm; (Fig. 2 and 3) were taken from each of the containers in accordance with ASTM D638 as cited in Erk *et al.* (2016). The specimen was fixed into the test-piece-grip of the tensile testing machine and increasing load was applied to the sample. The maximum load that ruptured the sample was used to calculate the tensile strength

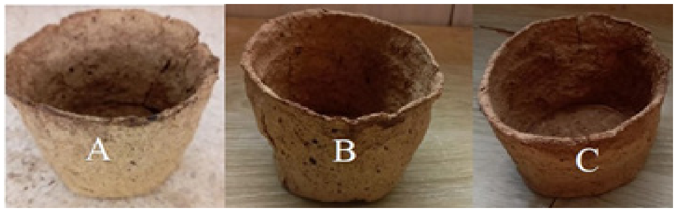

Fig. 1: Paper containers made from three biomaterials (A – Corn husk pot; B – Bamboo culm sheath pot; C – Banana pseudostem pot

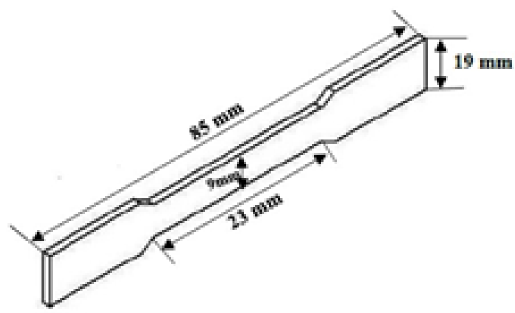

Fig. 2: Dumbbell-shaped specimen for tensile strength test

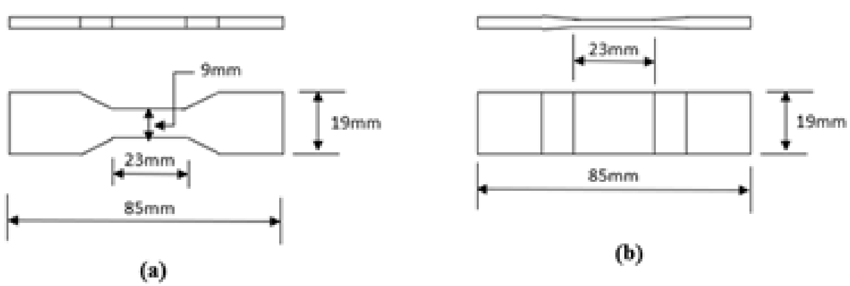

Fig. 3. Schematic drawing of (a) Parallel cut and (b) Perpendicular cut of Dumbbell-shaped specimen

of the containers:

$$\text{Tensil strength (N/m)} = \frac{\text{Maximum load at which rupture occurred}}{\text{Width of the paper}} \times 100\%$$

Determination of biodegradability of the paper containers

The containers were weighed and buried in the soil for 60 days (ASTM, 2018). Three containers from each of the three biomaterials were retrieved every 15 days. They carefully cleaned of soil debris, oven-dried (103 ± 2 °C) for 2 h and placed in a desiccator until they attained constant final weight. The biodegradability of the containers was calculated from the loss in weight of the containers:

$$\text{Weight loss(\%)} = \frac{\text{Initial weight of container} - \text{Final weight of container}}{\text{Initial weight of container}} \times 100\%$$

Data analysis and presentation

The data obtained from the tests were subjected to ANOVA at 5% significance level to determine the differences that exist in the physico-mechanical properties and biodegradability of the containers made from the three biomaterials. The data were presented in charts and line graphs.

RESULTS AND DISCUSSION

Characteristics of fibres from the biomaterials

There was a significant difference ($p = 0.00074$) in the length of the fibres from the three materials. The fibres from banana pseudostem had the greatest length (1.71 mm) while those from corn husk had the least (1.40 mm) as shown in Table 1. The properties of cellulosic fibres that influence their pulp and paper making potential are the length, diameter, lumen width

Table 1. Characteristics of fibres from the biomaterials

Fibre characteristics	Banboo culm sheath	Banana pseudostem	Corn husk
Fibre length (mm)	1.49 ± 0.052^{a}	1.71 ± 0.056^{b}	1.40 ± 0.062^{c}
Fibre diameter (μm)	19.49 ± 0.53^{a}	35.15 ± 0.90^{b}	45.39 ± 1.75^{c}
Fibre lumen width (μm)	13.31 ± 0.49^{a}	25.37 ± 0.81^{b}	34.15 ± 1.49^{c}
Cell wall thickness (μm)	6.18 ± 0.24^{a}	9.77 ± 0.54^{b}	11.23 ± 0.59^{c}
Runkel ratio	1.019 ± 0.052^{a}	0.837 ± 0.544^{b}	0.729 ± 0.045^{c}
Flexibility ratio	67.63 ± 1.09^{a}	72.20 ± 1.24^{b}	74.67 ± 1.08^{c}
Slenderness ratio	79.78 ± 3.39^{a}	49.96 ± 1.79^{b}	33.47 ± 1.59^{c}

The results are presented as mean ± standard deviation. Means in the same row with different superscripts are significantly different

and cell wall thickness. The fibre length influences the strength properties of the papers produced (Boadu *et al*., 2020). Long fibres have good inter-fibre contact and therefore produce papers with good strength (Ofosu *et al*., 2020). Fibres with the length ranging from 1-4 mm are suitable for the production of pulp with a good strength which could be moulded into paper containers (Sadiku and Abdukareem, 2018). The lengths of the fibres from the banana pseudostem (1.71 mm), bamboo culm sheath (1.49 mm) and corn husk (1.40 mm) are within this range. There was a significant difference ($p = 1.43 \times 10^{-36}$) in the fibre diameter of the three materials with the fibres from the corn husk having the greatest diameter (45.39 μm) (Table 1). The fibres with the diameter ranging from 15-20 μm are flexible and would usually pack themselves together tightly to produce smooth and dense paper containers (Dutt and Tyagi, 2011). The large diameters (30-50 μm) increase the void spaces and the volume of pulp and consequently form coarse-surfaced containers (Kaur and Dutt, 2013). While the fibres from the bamboo culm sheath (diameter = 19.49 ± 0.53 μm) will produce dense containers with smooth surfaces, the containers that will be produced from the corn husk (45.39 ± 1.75 μm) and the banana pseudostem (35.15 ± 0.90 μm) will likely have rough surfaces. There was a significant difference ($p = 8.73 \times 10^{-33}$) in the lumen width of fibres from the three materials. The fibres from the corn husk had the widest lumen (34.15 μm) while those from the bamboo culm sheath had the narrowest lumen (13.31 μm). The cell wall thickness of the fibres from the three biomaterials differed significantly ($p = 6.88 \times 10^{-12}$). The large fibre lumen width (10 – 40 μm) and the thin cell walls (2-7 μm) enhance beating and improve inter-fibre bonding which eventually promote tensile and bursting strength properties, and tearing resistance of papers (Sharma *et al*., 2014). The lumen width of fibres from the three materials are within the range proposed by Gharehkhani *et al*. (2014) and Sharma *et al*. (2014). However, the fibres from the corn husk and the banana pseudostem will produce bulky and coarse-textured containers due to their wall thickness (i.e., 11.23 μm and 9.77 μm, respectively).

Fibre derived indices

There was a significant difference in the Runkel ratio ($p = 0.00038$), slenderness ratio ($p = 1.14 \times 10^{-30}$) and flexibility coefficient ($p = 9.89 \times 10^{-5}$) of the three materials (Table 1). The fibres with a high runkel ratio (>1) are stiff and less flexible with a poor bonding ability (Kiaei *et al.*, 2014). It is usually difficult to form containers from pulp obtained from such fibres (Didone *et al.*, 2017). Such fibres also produce bulkier papers which are difficult to mould (Kiaei *et al.*, 2014). The fibres from the corn husk and the banana pseudostem had runkel ratios less than 1. They will, therefore, be flexible in producing pulp which yield themselves easily to moulding into containers. Flexibility ratio expresses the potential of fibres to easily flatten during beating (Kiaei *et al.,* 2014). Flattened fibres have more surface area for bonding and subsequently produce smooth papers. Fibres with flexibility ratio between 50 and 70 produce smooth and dense containers (Adetogun *et al.*, 2014). With the exception of the fibres from the bamboo culm sheath, the fibres from the corn husk and the banana pseudostem will produce coarse-surfaced containers. Slenderness ratio of fibres is also a significant determinant of the breaking length, burst strength and tearing resistance of pulp (Ogunjobi *et al.*, 2014). The required slenderness ratio of fibres for pulping purposes is ≥ 33. Fibres from the three biomaterials have slenderness ratio ≥ 33, which makes them suitable for pulping. However, the bamboo culm sheath and the banana pseudostem fibres will produce containers with high tearing resistance compared to those from the corn husk (Egbewole *et al.*, 2015).

Physical properties of the containers

Water absorption and thickness swelling: There was a significant difference ($p = 3.54 \times 10^{-20}$) in the water absorption of the pots from the three biomaterials and the control (plastic). Among the biomaterials, containers from the corn husk had the highest water absorption (203.33%) (Fig. 4) but the plastic containers did not absorb water. The thickness swelling of the containers differed significantly ($p = 1.44 \times 10^{-6}$). The containers made from the corn husk had the highest thickness

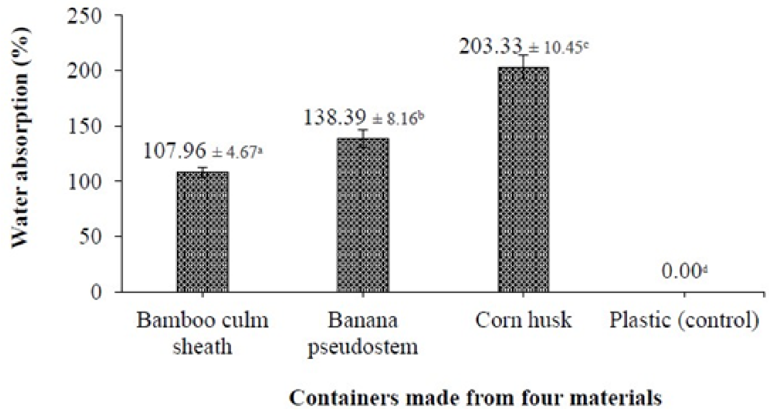

Fig. 4: Water absorption of plant containers produced from proposed biomaterials and plastic (Note: Means with the same letters are not significantly different)

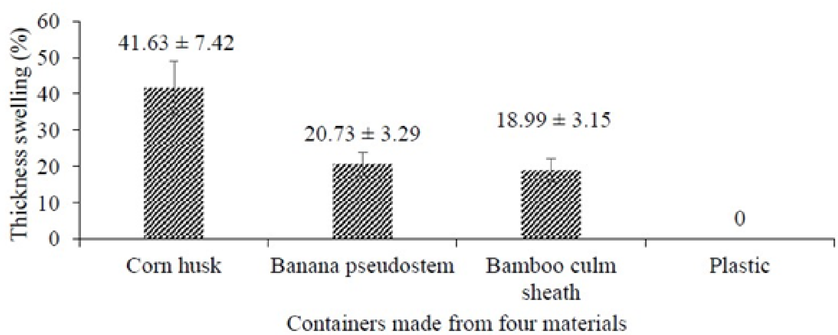

Fig. 5: Thickness swelling of plant containers produced from proposed biomaterials and plastic

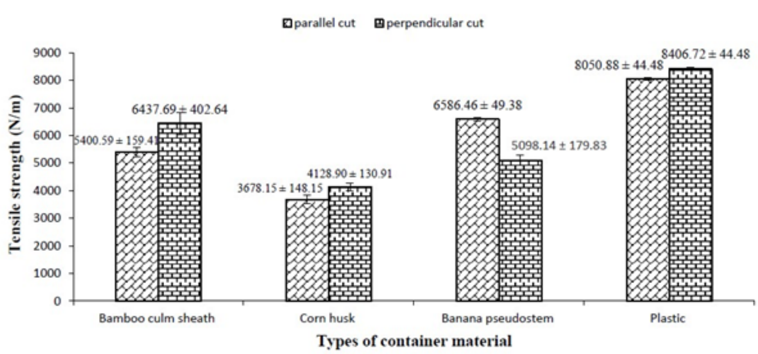

Fig. 6: Tensile strength of containers made from three biomaterials and plastic

swelling (41.63%) while the plastic containers did not record any thickness swelling (Fig. 5). Water absorption by a paper is largely responsible for swelling in the thickness of paper containers. The higher the rate of water absorption, the more liable the container will be to physical deterioration (Buxoo and Jeetah, 2020). The bamboo culm sheath containers had the least water absorption followed by the containers from the banana pseudostem. The banana pseudostem fibres contain insoluble gummy and non-fibrous cells that impede moisture absorption (Subagyo and Chafidz, 2018). Containers from banana pseudostem and bamboo culm sheath will be less vulnerable to physical deterioration when they come into contact with soil moisture. The corn husk containers absorbed much water and recorded high thickness swelling because

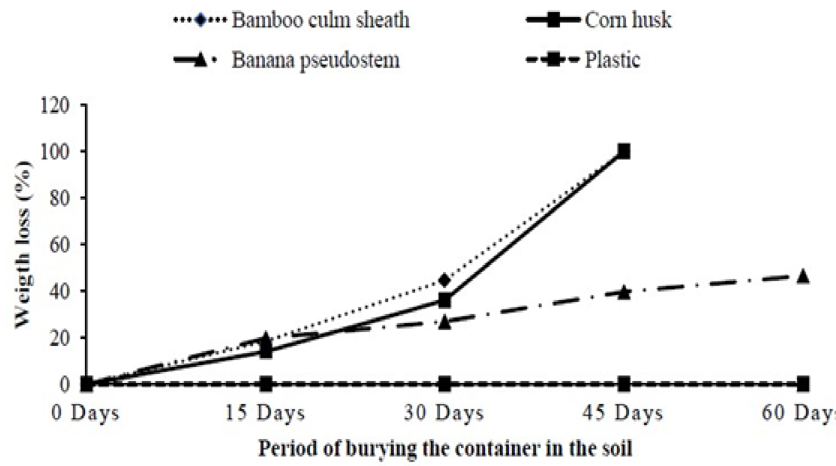

Fig. 7: Biodegradability of containers made from proposed biomaterials and plastic

corn husk fibres had comparatively thicker cell walls which reduced their ability to bond together to form strong paper sheets (Joutsimo *et al.,* 2005). The voids created in the fibre network as a result of the cell wall thickness allowed more water to be absorbed, which increased the thickness swelling of the containers.

Tensile strength of pots produced from the three biomaterials: There was a significant difference (p = 0.000) in the tensile strength of the containers. While the parallel section of the plastic container (control) had the highest tensile strength (8050.88 N/m), the containers made from the corn husk had the lowest tensile strength (3678.15 N/m) (Fig. 6). Similarly, the perpendicular section of the plastic containers had the highest tensile strength (8406.72 N/m) but that of the containers from the corn husk had the lowest tensile strength (4128.90 N/m). The tensile strength of the containers is a measure of their robustness (T 404, 1992), indicating the resistance of the pots to physical deterioration. The containers produced from the banana pseudostem had comparatively high tensile strength parallel to the grain. Those produced from the bamboo culm sheath had high tensile strength perpendicular to the grain. Long fibres contribute to strong fibre-to-fibre bonding and enhance the tensile strength of the containers. Well-bonded and firmly interlocked fibres require more force to break them apart (Fagbemigun *et al*., 2014). Thus, the length of the fibres from the banana pseudostem and the bamboo culm sheath contributed to the high tensile strength of their containers. The slenderness ratio of the fibres from these two resources may have also contributed to the tensile strength recorded for their containers (Egbewole *et al.,* 2015).

Biodegradability of the pots: There was a significant difference (p = 0.000) in the biodegradability of the containers (Fig. 7). Although containers from the banana pseudostem lost more weight by the 15th day, those from bamboo culm sheath and corn husk completely degraded before the 60th day. The plastic containers did not lose weight while in the soil for 60 days. Biodegradation of plant containers result from the dissolution of part or all of the material (Fedorak, 2005). It is facilitated by moisture in the fibres and the presence of degrading microbes. With the exception of the control, the containers from the three biomaterials are all biodegradable. Their use will eliminate the need to transplant and discard a container since they can be buried directly into the soil with the plant and ultimately decompose (Tomadoni *et al*., 2020). The insoluble gummy and the non-fibrous cells in the banana pseudostem limited the extent of moisture intake by the containers (Subagyo and Chafidz, 2018). This contributed to their slow biodeterioration. The containers from the bamboo culm sheath and corn husk will offer rapid biodegradation in soil to avoid their accumulation and root circling.

CONCLUSION

The current work investigated the physical and mechanical properties, and biodegradability of containers produced from residues of three biomaterials (banana pseudostem, bamboo culm sheath and corn husk) as replacement for plastic containers for agricultural purposes. The fibre characteristics and derived indices of the proposed biomaterials prove that they are good resources for the production of plant containers. The containers from the bamboo culm sheath and the banana pseudostem had good tensile strength properties. This coupled with their moisture absorption and thickness swelling characteristics, will promote plant growth and functionality. The bamboo culm sheath and the corn husk containers offered rapid biodegradation in soil. This will avoid their accumulation, prevent root circling and promote plant development. The current study has shown that nursery containers made from the proposed biomaterials are sustainable products that could contribute to the development of modern agriculture. They are good alternatives to replace plastics.

REFERENCES

Adetogun, A.C., K.M. Ogunjobi and S.A. Shofidiya. 2014. Investigation of pulping potential of waste from conversion of Anogeissus leiocarpus, IOSR Journal of polymer and Textile Engineering. 1(2):20-26.

Alsanius, B.W., and W. Wohanka. 2019. Root zone microbiology of soilless cropping systems. In Soilless Culture Elsevier. pp. 149-194.

ASTM. 2018. American Society for Testing and Materials (ASTM) D5988. 2018. 'Standard Test Method for Determining Aerobic Biodegradation of plastics in soil. USA.

Atiqah, A., M. Jawaid, M.R. Ishak and S.M. Sapaun. 2017. Advances in Material & Processing Technologies Conference Moisture Absorption and Thickness Swelling Behaviour of Sugar Palm Fibre Reinforced Thermoplastic Polyurethane. Available online with update at www.sciencedirect.com.

Boadu, B.K., B.M. Ansong, A.K. Afrifah and E. Nsiah-Asante. 2020. Pulp and paper making characteristics of fibers from plantation-grown Oxythenantera abyssinica and Beema bamboo (a tissue cultured clone from Bambusa balcooa). Journal of Natural Fibers. Doi: 10.1080/15440478.2020.1856270.

Buxoo, S. and P. Jeetah. 2020. Feasibility of producing biodegradable disposable paper cup from pineapple peels, orange peels and Mauritian hemp leaves with beeswax coating. SN Appl. Sci. **2**, 1359 (2020). https://doi.org/10.1007/s42452-020-3164-7

Didone, M., P. Saxena, E. Brilhuis-Meijer, G. Tosello, G. Bissacco, T.C. Mcaloone, D.C.A. Pigosso and T.J. Howard. 2017. Moulded pulp manufacturing: Overview and prospects for the process technology. Packaging Technology and Science, 30(6):231-249.

Dutt, D. and C.H. Tyagi. 2011. Comparison of various eucalyptus species for their morphological, chemical, pulp and papermaking charcteristics. Indian Journal of Chemical Technology 18:148–51.

Egbewole, Z.T., O.J. Rotowa and P.O. Omoake. 2015. 'Evaluation of fibre quality of Bambusa vulgaris (bamboo) as a raw material for pulp and paper production'. Production Agriculture and Technology Journal. 11(2):188–02.

Ekhuemelo, D.O. and K. Tor. 2013. Assessment of fibre characteristics and suitability of maize husk and stalk for pulp and paper production. Journal of research in forestry, wildlife and environmental, 5(1):41- 49.

Erk, A.K., J.J. Nash and K.H. Woods. 2016. Using mechanical testing of disposable plastic cups to illustrate processing-structure property relationships in an introductory materials laboratory course. American Society for Engineering Education, p.18-24.

Fagbemigun, K.T., O.D. Fagbemi, O. Otitoju, E. Mgbachiuzor and C.C. Igwe. 2014. Pulp and paper-making potential of corn husk. International Journal of AgriScience. 4 (4):209-213.

Fedorak, M.P. 2005. Microbial processes in the degradation of fibers. *In*: Woodhead Publishing Series in Textiles, Biodegradable and Sustainable Fibres. R.S. Blackburn (Eds). Woodhead Publishing, 2005, Pages 1-35, ISBN 9781855739161. https://doi.org/10.1533/9781845690991.1.

Ferstl, E., M. Gabriel, F. Gomernik, S.M. Muller, J. Selinger, F. Thaler, W. Bauer, F. Uhig, S. Spirk and A. Chemelli. 2020. Investigation of the adsorption behaviour of jet-cooked cationic starches on pulp fibres. Polymers. 4:1210-2249.

Gharehkhani, S., E. Sadeghinezhad, S.N. Kazi, H. Yarmad, A. Badurudin, M.R. Safaei and M.N.M. Zubir. 2014. Basic effectsof pulp refining on fibre properties. Springer, p.143-163.

IAWA.1989. List of microscopic features for hardwood identification. Rome, Italy.

Joutsimo, O., R. Wathen and T. Tamminen. 2005. Effects of fibre deformations on pulp sheet properties and fibre strength. Paperi Ja Puu. 87(6):1-16.

Kaur, H., and. Dutt. 2013. Anatomical, morphological and chemical characterization of ligno-cellulosic bye products of lemon and sofia grasses obtained after recuperation of essential oils by steam distillation. Cellulose Chemistry and Technology, 47(1-2):83–94.

Kiaei, M., M. Tajik and R. Vaysi. 2014. Chemical and biometrical properties of plum wood and its application in pulp and paper production. Maderas, Cienc. Tecnol. 16(3):313–22.

Ma, Y.C., W. Zhang, C. Wang, X. Mao, B. Zhang and H.Y. Wang. 2016. Preparation of a seedling-growing tray made of rice straw for maize seedling transplantation and its shear mechanics test. International Journal of Agric. & Biol. Eng., 9(6):44-

55.
Meinken, E., D. Lohr and C. Wöck. 2015. Colonization of growing media by saprophytic fungi-importance of carbon and nitrogen fractions. In International Symposium on Growing Media, Composting and Substrate Analysis - SusGro2015 1168 (pp. 325-332). 10.17660/ActaHortic.2017.1168.42
Muhammadi, Shabina, M. Afzal and S. Hameed. 2015. Bacterial polyhydroxyalkanoates-eco-friendly next generation plastic: Production, biocompatibility, biodegradation, physical properties and applications. Green Chemistry Letters and Reviews, 8(3-4):56-77,
Muriuki, J., A.W. Kuria, C. Muthuri and A. Mukuralinda. 2013. Testing Biodegradable Seedling Containers as an Alternative for Polythene Tubes in Tropical Small-Scale Tree Nurseries. Available at https://www.researchgate.net/publication/257761907_Testing_Biodegradable_Seedling_Containers_as_an_Alternative_for_Polythene_Tubes_in_Tropical_Small-Scale_Tree_Nurseries#pf11 accessed on 01/28/2021.
Norashikin, M.Z. and M.Z. Ibrahim. 2009 The potential of natural waste (corn husk) for production of environmental friendly biodegradable film for seedling. World Academy of Science, Engineering and Technology, 58(1):176-180.
Ofosu, S., B.K. Boadu and A.K. Afrifah. 2020. Suitability of Chrysophyllum albidum from moist semi-deciduous forest in Ghana as a raw material for manufacturing paper-based products, Journal of Sustainable Forestry, 39(2):153-166.
Ogunjobi, K.M., A.C. Adetogun and S.A. Shofidiya. 2014. Investigation of pulping potential of waste from conversion of Anogeissus leiocarpus. IOSR Journal of Polymer and Textile Engineering.1(2):26-30.
Ogunleye, M.B., J.A. Fuwape, A.O. Oluyege, B. Ajayi and J.S. Fabiyi. 2017. 'Evaluation of fibre characteristics of Ricinodedron heudelotti for pulp and papermaking'. International Journal of Science and Technology 6(1):634–641.
Rahman, Md M., D. Arup, Y. Nita, W.L. Chiwon and G. David. 2023. Soybean By-Products Bioplastic (Polylactic Acid)-Based Plant Containers: Sustainable Development and Performance Study. *Sustainability* 15(6):53-73.
Rillig, M.C., A. Lehmann, A.A.S. Machado and G. Yang. 2019. Microplastic effect on plants. New Phytologist 223 (3):1066–1070.
San, H.P., L.K. Long, C.Z. Zeng, H.C. Hul, W.Y. Seng, F.S. Lin, A.T. Hun and W.K. Fong. 2016. 'Anatomical features, fibre morphological, physical and mechanical properties of three years old new hybrid Paulownia: Green Paulownia', Research Journal of Forestry. 10:30-35.
Sadiku, N.A. and A.K. Abdukareem. 2018. 'Fibre morphological variations of some Nigerian guinea savannah timber species.' Ciencia y tecnologia, 21 (2):239-248.
Sharma, P.K., S.K. Nath and N. Murthy. 2014. Investigation on fibre characteristics of Dendrocalmus strictus and Bambusa bambos. International Journal of Engineering Innovation & Research 3 (3):254–58.
Sibaly, S. and P. Jeetah. 2017. Production of paper from pineapple leaves. J. Environ. Chem. Eng. 5:5978-5986.
Smith, N., J.G. Vergo and E.V. Buchanan. 2008. Potential of Jamaican banana, coconut coir and bagasse fibres as composite materials. Materials Characterization 59(9):1273-1278.
Subagyo, A. and A. Chafidz. 2018. Banana pseudo-stem fiber: Preparation, characteristics, and applications. Banana nutrition-function and processing kinetics, p.1-19.
Sun E., H. Huang, F. Sun, G. Wu and Z. Chang. 2017. Degradable composite containers, Bio Resources 12(1):785-798.
Tomadoni, B., D. Merino, C. Casalongué and V. Alvarez. 2020. Biodegradable Materials for Planting Pots In: Advanced Applications of Bio-degradable Green Composites. Materials Research Foundations. 68:85-103.
Van den Oever, M., K. Molenveld, M. Zee and H. Bos. 2017. Bio-based and biodegradable plastics: facts and figures: focus on food packaging in the Netherlands (No. 1722). Wageningen Food & Biobased Research.
Wang X., R.T. Fernandez, B.M. Cregg, R. Auras, A. Fulcher, D.R. Cochran, G. Niu, Y. Sun, G. Bi, S. Nambuthiri and R.L. Geneve. 2015. Multistate Evaluation of Plant Growth and Water Use in Plastic and Alternative Nursery Containers. Hortechnology. 25(1):42-49
Wang Y.J., H. Zhan, Y.L. Ding, S.G. Wang and S.Y. Lin. 2016. Variability of anatomical and chemical properties with age and height in Dendrocalamus brandisii. Bioresources. 11(1):1202–1213.
Zhang N., J. Xu, X. Gao, X. Fu and D. Zheng. 2017. Factors affecting water resistance of alginate/gellan blend films on paper cups for hot drinks. Carbohydr Polym. https://doi.org/10.1016/j.carbpol.2016.08.101.

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