Cogent Engineering

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaen20

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**To cite this article:** Bett Brian Kipchumba, Augustine Kangogo Kulei & Josphat I. Mwasiagi (2023) The study and optimization of the hygroscopic properties of selected natural products with an aim of designing a sanitary pad suitable for low- and middle-income population, Cogent Engineering, 10:1, 2196812, DOI: 10.1080/23311916.2023.2196812

**To link to this article:** https://doi.org/10.1080/23311916.2023.2196812



Published online: 12 Apr 2023.

Kipchumba et al., *Cogent Engineering* (2023), 10: 2196812
https://doi.org/10.1080/23311916.2023.2196812

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MATERIALS ENGINEERING | RESEARCH ARTICLE

# The study and optimization of the hygroscopic properties of selected natural products with an aim of designing a sanitary pad suitable for low- and middle-income population

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Received: 21 January 2023
Accepted: 22 March 2023

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Reviewing editor:
Ian Philip Jones, Metallurgy & Materials, The University of Birmingham, UK

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**Abstract:** This study came into consideration following reported cases of women and girls using unhygienic materials such as old towels to keep themselves dry during their menses. The materials can be improved in quality and usability. The polymer that replaced wood pulp is not environmentally friendly. Water hyacinth and maize stalks have proven high absorbency properties, which are from ancient and current research. The objective was to optimize the hydroscopic properties of maize stalk and water hyacinth pulp and subsequent use in the design of sanitary pad. The methodology was done according to the standard KS 507:2005. The process of extraction was done using the alkaline method, and rinsing was done to remove excess NaOH. The pulp was studied for hydroscopic properties that included the retention capacity, absorbency rate and moisture content followed by the design of the sanitary pad. The absorbency rate and the retention capacity of maize are 50% and 150 s, respectively. The absorbency properties of maize internal tissue pulp are high, and it is feasibly viable. The retention and moisture content indicate over 50% and 57%, respectively. Water hyacinth pulp has a high absorbency rate (106 s). Also, the water retention and moisture content of water hyacinth pulp is over 50% and 59%, respectively. Upon blending, the water retained and held, and

Bett Brian Kipchumba

## ABOUT THE AUTHOR

Bett Brian Kipchumba is an industrial engineer who is pursuing his Master of Science in Industrial Engineering at Moi University. He has a bachelors degree in industrial and textile engineering from the same university. He is passionate about textile engineering and his research work focuses on resolving the problems faced by girls and women while experiencing menstrual cycles despite the presence of raw materials that can be turned into absorbent pulp. Currently, he is pursuing masters of science degree in Industrial Engineering at Moi University. The study presents a viable and affordable alternative to the commercial sanitary pads.

## PUBLIC INTEREST STATEMENT

The article attempts to offer a solution to the problems faced by school-going girls in Kenya. The majority of girls come from low- and middle-income families and are forced to skip some school days during their menstrual periods. The availability of raw materials, namely water hyacinth and maize stalks, is a plus for the field of research as far as pulp production is concerned. Investigating raw materials' hygroscopic properties opens the door to the exploration of raw materials that address major concerns in developing countries. The availability of raw materials helps in the production of low-cost sanitary pads that can be distributed to girls at school. The findings in this article go a long way toward empowering the girl child and giving them a chance to be in class alongside the boy child.

absorption rate improved to 50% in 24 h, 50% (25 ml) and 2 min. The significance levels for absorbency were 15 ml to 40 ml per minute and it holds and retains up to 500 times its weight.

**Subjects: Environment & Gender; Environment & Health; Mechanical Engineering Design; Industrial Engineering & Manufacturing; Materials Science**

**Keywords: Absorption; hydroscopic properties; water retention; sanitary pad; maize stalk pulp; water hyacinth pulps**

## 1. Introduction

Traditional methods of regulating menstrual flow in Kenya include the use of old garments, paper, feathers, cotton, wool bits, and even leaves, all of which have inconsistent absorbency levels. Traditional products used during the menstruation period are unhygienic and untrustworthy and can prohibit girls from attending school. If sanitary pads could be made cheaper in terms of both cost and product quality, school attendance might be greatly increased, allowing girls to complete their basic education. Therefore, this study came into consideration following reported cases of women and girls using unhygienic methods to keep themselves dry during their menses in Kenya, especially among the rural poor households and marginalized communities. Moreover, on a high note of extreme situations, some women in selected, existing cultures dig holes and go to the extent of sitting on them during their menstrual periods (Elledge et al., 2018). As a result, the gap lies with the provision of excellent absorbent and cost-effective menstrual hygiene products that can alleviate concerns about soiling outer garments, allowing for increased school attendance among girls and women.

Surprisingly, while the boys are going on with their studies at school and other activities, the girls are forced to remain at home during their menstrual periods (Phillips-Howard et al., 2016). For example, 66% of the African females miss school when they are menstruate (Foster & Montgomery, 2021). This is a factor that makes schoolgirls perform poorly as compared to boys (Benshaul-Tolonen et al., 2020). In Kenya, statistics show that over 2.5 million adolescent schoolgirls every month lose three to five school days of active learning during their monthly periods because of a lack of sanitary towels, contributed by poverty and inaccessibility to sanitary towels (Juma et al., 2017). Girls who are in primary school between standard six and eight miss out on teaching lessons for 18 weeks out of 108 weeks, while those who are in high school lose 24 weeks out of 144 weeks (Benshaul-Tolonen et al., 2020). This shows that for girls to compete effectively with their counterparts, they require extra time to recover the missed lessons, which is not achievable for girls in rural and marginalized areas (Benshaul-Tolonen et al., 2020).

The interior tissues of the maize stalk refer to the inner part of the maize plant that is found between the nodes of the stalks. On the other hand, water hyacinth is a plant that invades lakes or water bodies and leads to suffocation of the water body. In essence, it prevents aeration of the water body. According to Rastogi et al. (2021), the two plants have tissues that can be processed in the same way as the internal tissues of the maize plant. The tissues happen to be flaccid after the turgidity is lost through drying while in the field. Therefore, this phenomenon plays a crucial role in the development of this study (Rastogi et al., 2021). The underlying principle in the development of the sanitary pad is the ability of the pulp to absorb and retain fluids. However, ethical and scarcity concerns do not allow the use of human blood during the experiments. Similarly, absorption refers to the process through which fluids, liquids, and gases are taken up by the tissues. The process of reception and taking in of the fluids becomes a locus of interest, especially while trying to improve the properties of the interior tissues of the maize plant (Jagadale & Jagadale, 2018). The study will therefore seek to exploit the locally available maize stalk tissues to extract the absorbent tissues that will be instrumental in developing sanitary pads.

The raw materials (water hyacinth and maize stalks) have good absorbency properties, which have been proven by various applications in ancient and current research (Jagadale & Jagadale, 2018). Currently, water hyacinth paper is used for the production of the pads. Moreover, high retention and absorbency capacity are justified by mulching. Most farmers in Kenya use maize stalks for mulching in nurseries and also flower beds (Ndayisaba et al., 2020). The study focuses on the absorbent materials of the sanitary pad, especially the core. In addition, the absorbent material of the sanitary towel is produced by pulping the internal tissues of the maize stalk and the water hyacinth suckers (leaves and stem). The polymer that happens to replace wood pulp is not economically and environmentally friendly (Shibly et al., 2021). Currently, wood pulp is the dominant form of absorbent material, but superabsorbent polymers (SAP) and polypropylene fibers have been introduced to aid in absorbency. Such polymers pose a disposal problem. Also, super absorbent (hydrogel) polymers have detrimental effects on the user that lead to discomfort (Park et al., 2019). Bamboo has been widely used to produce pulp. Bamboo wadding has the highest absorption index (7.86), which is higher than cotton terry cloth (0.84), hemp cloth (1.4), linen (1.57), and a commercial sanitary pad (4.38) (Foster & Montgomery, 2021). The absorbency index of maize stalks ranged from 0.05 to 0.4. Although the absorption index of maize stalk is encouraging, particularly given the abundance of bamboo in tropical low- and middle-income countries, obstacles remain in overcoming complex extraction processes from maize stalk, as described. On the other hand, wood pulp takes time to be obtained from trees, as opposed to water hyacinth and maize tissues, which grow and mature faster. In essence, the selected plants mature within a period of 3–5 months. Biodegradability is a major concern that arises when it comes to the use of sanitary pads (Shibly et al., 2021). In essence, the pulp from the two selected plants is a disposable product, which disintegrates within a short time upon disposal.

The absorbent part of the maize plant is found on the stem. The stem provides the vascular bundles that form the internal tissues of the stem. Therefore, it is evident that the vascular and ground tissues, which consist of the xylem, the phloem, and other tissues, form the main part of interest in the development of the absorbent pulp. In essence, these are the sclerenchyma and parenchyma (Jagadale & Jagadale, 2018). Singapore conducted sanitary pad research with the goal of assisting people in the developing world in obtaining affordable pads (Crofts & Fisher, 2012). The idea stems from the ability of the water hyacinth to reach maturity within a short time as compared to other natural fibers and trees (wood).

The purpose of this study was to provide a solution to girls struggling in low-income areas of Kenya by producing absorbent materials for sanitary pad making. Therefore, utilizing local materials, a pulp suitable for making sanitary pads is produced and subsequently evaluating the hygroscopic properties. In low-income environments, the inability to buy reliable sanitary supplies can contribute to school absence and is a barrier to education attainment and gender equality. In addition, a lack of sufficient disposal facilities can cause social shame as well as environmental degradation (Foster & Montgomery, 2021). With findings from this study, an alternative with suitable and optimized hygroscopic properties was developed. Since there is no abundant supply of bamboo in Kenya, the study seeks to utilize the large volume of maize stalks and water hyacinth in making pulp following the success of this study.

## 2. Materials and methods

### *2.1. The raw materials*

The materials used in absorbent hygiene products include;

- Nonwoven—It is wound around the pulp, or the core of the pad.
- The Pulp—For our case, maize stalk pulp and water hyacinth act as the absorbent material.
- Absorbent material—They are mainly present in the commercial pad and are absorbent.
- Plastic film—Mainly polyethylene is used to prevent leakages (van Eijk et al., 2019).

- Fastening device—The joints are made using adhesives and the welding process.
- Packaging—The packaging material can be either paper or a polyethylene-based polymer.

#### *2.1.1. Making a simple sanitary towel*

The design is engineered in such a manner that it allows the retention of the menstrual fluid for longer hours. The steps are pulping, grinding, formation of mat, spreading of tissue (upper, lower), sectioning of mat, wrap PE Film, hot-melt seal embossing, applying hot melt adhesive, release belt, finished products section, and lastly finished products arranged in parallel. Similarly, cut three shapes from a non-woven, release paper and the stick paper, e.g. the length must be 24 cm by 8 cm (rectangle) (Benshaul-Tolonen et al., 2020). Then, place the absorbent material between two nonwovens and a release paper below it. Lastly, join the three pieces using heat and lamination. The product has a flat shape without wings, making it easy to construct and to secure the pad within the inner cloth. Winged sanitary towels bear the advantage of having more protection against leakages (Kuhlmann et al., 2017). The absorbent portion of the pad is the most crucial layer (van Eijk et al., 2019). They are mostly made of wood pulp that has been mixed with superabsorbent polymers. The absorbent region is first created using a wood pulp (shredded) and a vacuum laid according to the required shape, design, and size. Control of weight is automated. The required thickness is formed through pressing. The pad or pulp is mixed with superabsorbent polymers to enhance its fluid-holding capacity (van Eijk et al., 2019). The superabsorbent polymer is based on an acrylic polymer that absorbs liquid, resulting in the formation of a gel-like substance. This gel is responsible for holding water up to 30 times its weight and consists of potassium acrylate, sodium acrylate, and alkyl acrylate (van Eijk et al., 2019). The absorbent pad is attached to a top sheet of spun lace nonwoven fabric that is permeable. It is then attached to a bottom sheet, a non-permeable material made of polyethylene. All the three layers are consolidated together and sealed to prevent leakage using ultrasonic vibrations and heat. The use of accessories such as glues, tapes, sealing, and others for comfort reasons and fit to the undergarments is also important. To prevent leakage, the superabsorbent polymer mixing with pulp, size and thickness, pulp weight, and seal quality must be precisely controlled. Counting and packaging can be done manually to minimize machine cost, although it may increase the recurring cost and wastage (Githinji et al., 2011).

### ***2.2. Manufacturing process***

The process of extraction was done using the alkaline method, and a thorough rinsing was done to remove excess NaOH. Afterwards, bleaching was also done on the extracted pulp with the use of an $H_2O_2$ solution. Firstly, immerse the sample (internal maize stalk tissues/water hyacinth) of 20–30 mm in length in NaOH (1%, 2%, and 3%) solution. Second, cook at 90 degrees Celsius for 20, 30, 40, and 50 min (liquor to internal maize stalk tissues/water hyacinth ratio; 4:1). Furthermore, various particles apart from the 1 cm length were achieved using a sieve. The wire diameter of the selected sieves is 1 cm, 0.5 cm, and powder (0.46 cm and 0.48 cm) after the material is ground. Finally, remove the pulp extracted and rinse in freshwater (use a mesh cloth) to neutralize the pulp.

The bleaching process involves putting the rinsed pulp sample into the beaker; adding 5% hydrogen peroxide to the container for bleaching; and adding drops of caustic soda (sodium hydroxide) (4). Finally, dry in the oven for 1–2 hours at 90°C. Therefore, the requirements (reagents) are sodium hydroxide (1%, 2%, and 3%), hydrogen peroxide, and distilled water.

The collection of data in the extraction of the pulp experiment is based on the levels and variables. The temperature is kept constant at 90 degree Celsius, and the initial mass is kept constant at 2 g. The initial mass of 2 g will undergo change during cooking/digestion using NaOH. The difference between the final mass and the initial mass will give the change in mass. On the other hand, the concentration of NaOH (%) and time (seconds) keep on changing. The levels are arrived at based on the ability to minimize the input of the variables. Similarly, the chosen input variables are NaOH (per concentration percentage) and time. For example, the levels that were run in conjunction with 20, 30, 40, and 50 min were 1%, 2%, 3%, and 4%, respectively.

#### *2.2.1. The Study of the hydroscopic nature of the pulp*

The hydroscopic properties include the retention capacity, absorbency rate, and moisture content.

#### *2.2.2. Determination of retention capacity*

The procedures for determining the retention of the pulp are as follows: First, measure 2, 4, 8 g of the absorbent filler material. Secondly, prepare a filter and a non-absorbent filter paper. Thirdly, place the absorbent filler material on the filter. Fourthly, pour 50 ml, 75 ml, and 100 ml of distilled water, respectively, to the prepared masses. Finally, record the readings filtered after 24 h.

#### *2.2.3. Determination of absorbency rate*

The apparatus used are a beaker with a depth of 100 mm or greater that is kept at room temperature, a stop watch with an accuracy of 0.2 s, and a thermometer. Cylindrical basket weighing 2.7+ or −0.3 g, of height 80 mm, diameter 50 mm with square opening of 5 mm to 20 mm, made of copper wire of 0.4 mm diameter, water tub, and lastly the weighing machine.

The steps followed in determining absorbency rates are as follows: (1) carefully isolate the absorbent filler material and weigh 5 g; (2) drop the test specimen in a horizontal position into the water beaker; (3) use the stopwatch provided to record the amount of time it will take the basket and its contents to sink below the surface of water in seconds; and finally (4) record the absorption period to the nearest 0.1 sec. Repeat the test for at least two test specimens.

The determination of the absorbency of water was determined using the evaporation of the water held by the pulp immediately after the rinsing process. In essence, the retained amount of water provides the actual behavior of the pulp when the pulp has been digested in varying concentrations of NaOH. The mass of the dry pulp will be subtracted from the mass of the wet pulp, giving the amount of water lost during the oven drying.

#### *2.2.4. Determination of moisture content*

The apparatus used in the test are (1) a weighing scale or balance having an accuracy of 0.05% of the weighted mass; (2) a waterproof when sealed container for the sample to be used to transfer, analyze, and weighing of material; and (3) an oven that is ventilated and has a temperature of 90°C.

Similarly, the procedure used performing moisture content are as follows: (1) Drying the test samples in an oven with a temperature of 90°C, (2) open the container's lid and dry the specimen inside the container, (3) leave the container open for a moment to balance the air pressure inside the container with the surrounding atmospheric pressure, weigh the container that holds the specimen again and calculate the weight of the specimen, (4) drying will take at least 30 min for first cycle. Return the beaker with the test sample pieces to the oven, for more than half the drying time of the first cycle, (5) take the beaker out and put the mass with the sample test pieces inside, and finally (6) repeat the cycles of drying and weighing the sample. Stop when there is no more change in the masses. The results will be presented in a table that has the time (seconds) and the recorded mass. The temperature is kept constant at 90°C. The records will be made at time intervals of 10 min.

#### *2.2.5. Moisture content formula*

$$MCw = \frac{WP - DP}{WP} * 100$$

MCw = Pulp moisture content on a total weight basis (%)

WP = Pulp weight including moisture

DP = Oven-dry weight of pulp

#### *2.2.6. Design of the sanitary pad*

The optimized material was used in the design of the pad and tested. Engineering technique of drawing and dimension were used to design the pad and produce the desired mold. The mold preparation was done to facilitate the compaction of the pulp into the desired shape that forms the absorbent core (see Figure 1). The absorbent core is covered on the top side with a nonwoven and on the bottom side with a leakage-proof material (see Figure 2). The sealing was done using superbond adhesive and welding with melting covers. However, there are a variety of adhesives available, including Silicone binders, vinyl acrylate, and pressure-sensitive industrial adhesives (see Figures 1 and 2). Testing was conducted to check the performance of the pad, such as absorbency, retention, leakage, and robustness (appearance) (see Figure 3).

## 3. Results

### *3.1. Extraction of the pulp*

#### *3.1.1. Extraction of maize stalk internal tissue pulp*

The process follows the Alkali Method where NaOH is used in the dissolution of the lignin. In order to quicken the dissolution, heating of the content is done at 90ºC when the pulp is immersed in aqueous NaOH.

The absorption curves provide a vivid picture of the capabilities of the optimized extraction of the maize pulp (see Figure 4). Based on the moisture content level, the pulp after being digested with NaOH led to the removal of a certain degree of lignin and cellulose. Optimization helped in making sure the content of the removed substance does not hinder the absorbency and retention capabilities of the pulp (see Figure 5). The retained content of water implies the absorbency capabilities after the water has been extracted by evaporation.

Considering the following points at 2% NaOH, giving 2.511 ml, and in the other predicted optimum values, the absorbency ranges around the optimum concentration (see Figure 5). From the experiment, minimization explains the desire to obtain the absorbent material that has its bond between the cellulose and the lignin. In essence, the dissolution of lignin opens up the pore and the surface needed for penetration of the absorbed solution (Shi, Yang, Kuga, & Matsumoto, 2015).

**Figure 1. Section design of the sanitary pad.**

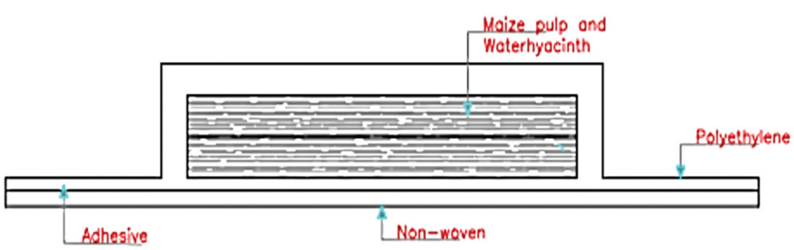
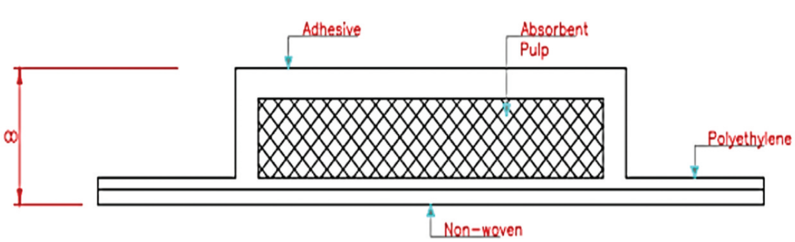



**Figure 2. Sanitary pad section.**



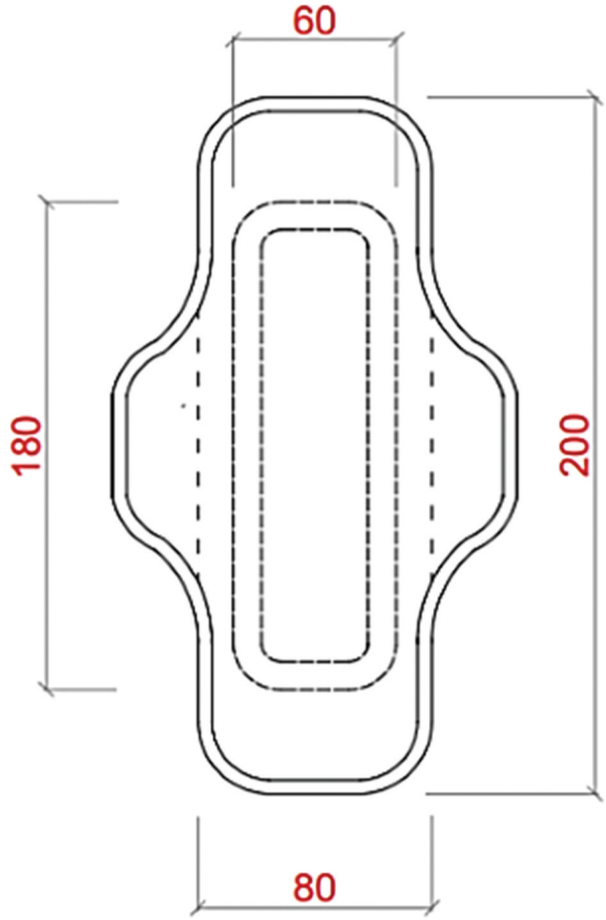



**Figure 3. The Layout of a Sanitary Pad.**

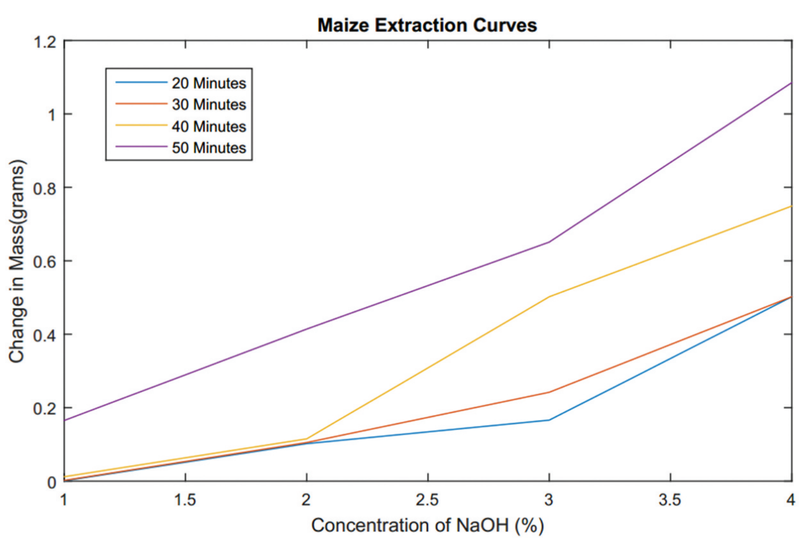


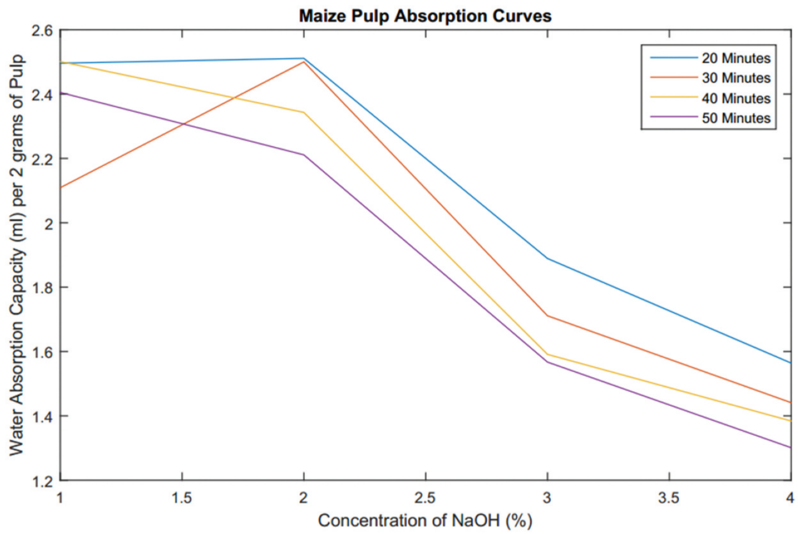

**Figure 4. Interaction of variables for maize stalk pulp.**

### *3.1.2. The model of equation for extracted maize pulp*

The model equation relied on the experimental data to give change in mass is as follows;

$$Changeinmass = 0.509 - 0.2079\,x1 - 0.03080\,x2 + 0.0539\,x1^2 + 0.000447\,x2^2 + 0.004825\,x1 * x2$$

Figure 5. Interaction curves of the maize pulp absorptions.




where : x1 = concentrationandx2 = timeinminutes

Therefore, 0.509 implies that the expected change in mass when concentration and time is zero. The product $X_1$*$X_2$ variables are present and the reaction proceeds. The slope of the concentration and time are given by 0.2079 and 0.03080, respectively. Also, the significance of the variable is determined by the magnitude of the coefficient. For example, 0.03080 of $X_2$ and 0.0539 of $X_{12}$ are the most significant coefficients in the equation influencing the change of mass. The concentration ($X_1$) is the most significant. However, the coefficients in their respective variables must be present in the proportion stipulated by the modelled equation. The R-Sq regression model value = 98.44%. In essence, 98.44% of the change in mass is deduced, and it is dependent on the concentration and the time taken during the cooking.

*3.1.3. Extraction of water hyacinth pulp*

Dissolution of lignin during heating will account for the change in mass (Shi, Yang, Kuga, & Matsumoto, 2015). Water hyacinth pulp indicates more values depicting the optimum point that can be used for the extraction process. The water hyacinth pulp retains slightly more water after absorption, implying improved absorbency and retention capabilities. At 0.5% NaOH, it gives a water absorbency of 2.31 ml, which is the best.

From the experiment, minimization explains the desired data to obtain the absorbent material that has its bond between the cellulose and the lignin. Dissolution of lignin opens up the pore and the surface needed for penetration of the absorbed solution. The optimum levels are when the concentration of NaOH is 0.5% and the time is 15 min. This will give an assurance of 95% viability of the extraction process (see Figure 6).

The mass keeps on changing due to changes in the concentration that tend to drastically dissolve lignin. However, if the concentration and time were continually increased, a point of no change in mass is reached since the active site of the reaction is finished and the process stops. Similarly, as the concentration increases, the rate of lignin dissolution also increases simultaneously (see Figure 7).

### *3.2. Absorption*

A range of optimum data is available for the production of the water hyacinth pulp and can be achieved using the following combination. Like the maize internal tissues, the process of extraction is governed by a model equation that seeks to minimize the resources used and to maximize the

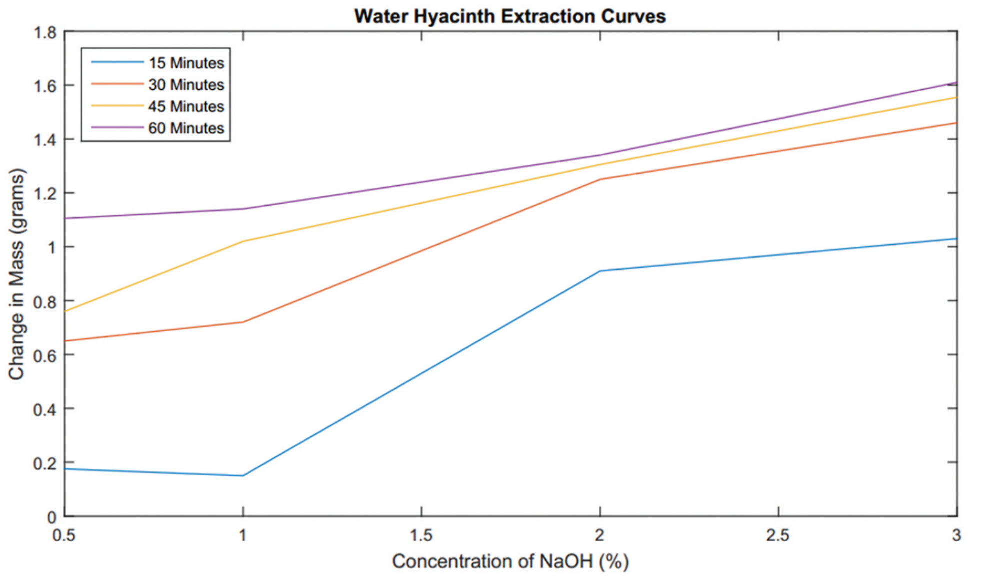



**Figure 6. Interaction plots for final mass.**

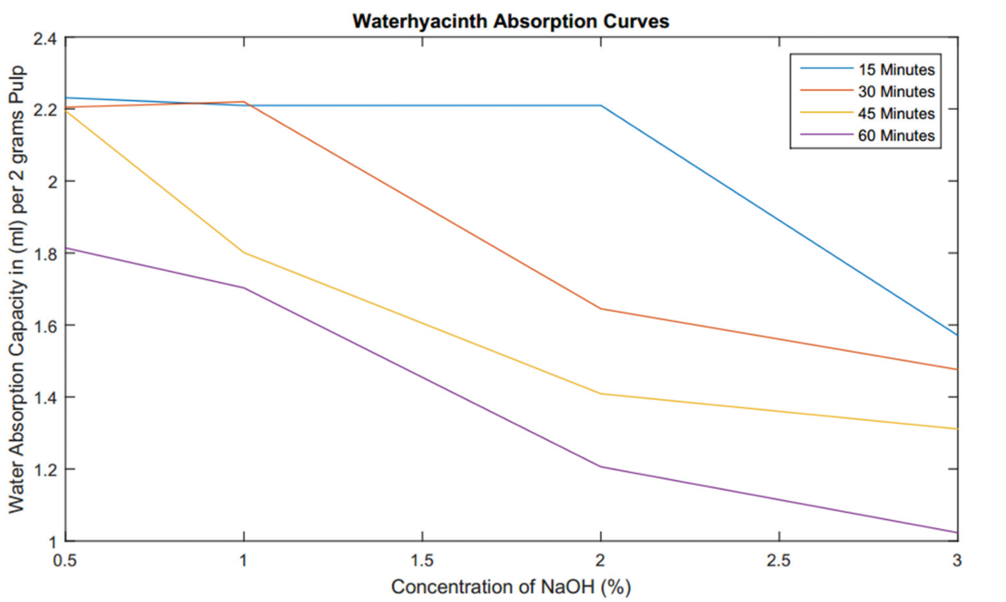



**Figure 7. Water absorption capacity at different NaOH concentration and time.**

output. Therefore, the final mass should be large enough to be used as a pulp. The model equation used in the practical to give the change in mass is as follows:

$$\text{Changeinmass} = -0.731 + 0.4703\,x1 + 0.04853\,x2 - 0.000350\,x2^2 - 0.00412\,x1 * x2 \ldots\ldots\ldots\ldots 6$$

$$\text{where: } x1 = \text{concentration and } x2 = \text{time in minutes}$$

Therefore, −0.731 implies the expected change in mass when concentration and time is zero (negligible). Furthermore, if $X_1$*$X_2$ variables are present, the reaction proceeds. The slope of the concentration and time are given by 0.4703 and 0.04853, respectively, in *Equation 6*. Also, the significance of the variable is determined by the magnitude of the coefficient. For example, 0.04853 of $X_2$ and 0.4703 of $X_{12}$ are the most significant coefficients in the equation influencing the change of mass. The concentration ($X_1$) is the most significant. However, the coefficients in their respective variables must be present in the proportion stipulated by the modeled equation. The regression model value of R-Sq is 95.48%. In essence, 95.48% of the change in mass is deduced, and it is dependent on the concentration and the time taken during the digestion that is significant and the extraction process will yield a pulp that can be used in a viable study such as absorbency. The process of bleaching water hyacinth suckers pulp with $H_2O_2$ did not yield a pure white material at a 20% concentration; however, aeration of the material occurred. Such aberration limits improve the absorbency of the material.

*3.2.1. The retention capacity of the maize internal tissue pulp*

The water retention setup of maize pulp was done to determine the amount of water in percentage that was retained by the pulp. Starting from the left, stand the commercial pad 1, maize pulp 1, maize pulp 2, and commercial pad 2, which have 5 ml, 25 ml, 25 ml, and 2 ml, respectively (see Figure 8). The arrows (orange) in the diagram indicate the level of water that was not retained. The water level demonstrates the ability at which the respective pulps retain water within 24 h.

*3.2.2. The retention capacity of the water hyacinth pulp*

The drying rate can be used to calculate the retention capacity of water hyacinth suckers pulp. Water hyacinth suckers pulp loses water at a higher rate, implying that its ability to retain water is compromised. Under the ordinary sun drying process, the pulp took 2 days to completely dry as compared to the maize stalk internal tissue pulp, which took 3 days to completely dry (see Figure 8).

*3.2.3. The absorbency rate of the maize internal tissue pulp*

The rate of absorbency ranged from 1 to 2.30 min and was improved by reducing the size of the particles by beating (see Figure 9). The value has been arrived at based on the various particle sizes and in comparison with the absorbency rate of the commercial wood pulp and polymer material (Wilson et al., 2019).

*3.2.4. The absorbency rate of the water hyacinth pulp*

The absorbency rate of water hyacinth suckers pulp has different results based on the setup of the sample. The powder form of water hyacinth suckers pulp has an absorbency rate of 25 s (see Figure 9). In essence, it implies that the pulp can quickly absorb water from the surface of the pad.

*3.2.5. Moisture content of the maize internal tissue pulp*

The maize stalk internal tissue pulp has the capability of holding or retaining water. This can be determined by the amount of water lost with time. The oven will be used to determine the water loss with time by heating. Thereafter, the calculation of the moisture content in percentage will be given. The maize stalk internal tissue pulp lost water during the heating up to 70 min, where the weight change started to remain constant. It implied that the pulp was fully dried and further

**Figure 8. Water retention setup.**

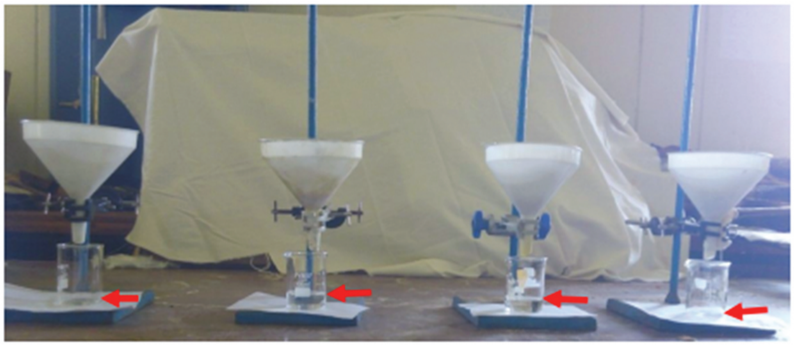
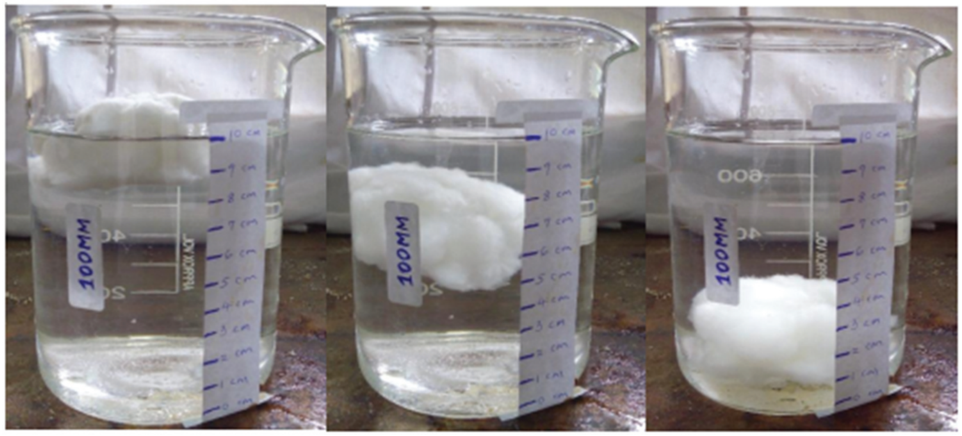


**Figure 9. Absorbency rate.**



changes could lead to charring. Based on the moisture content, the equation can be determined as a percentage. The moisture content of 10 g of maize stalk internal tissue pulp gives a significant moisture content that can help in determining the ability of the pulp to absorb and retain water. The pulp from the maize plant takes 57% of its weight in water (see Figure 10). Therefore, it implies that the pulp can absorb more than half its weight.

#### *3.2.6. The moisture content of the water hyacinth pulp*

The moisture content experiment of water hyacinth suckers pulp was performed and the experimental data recorded. In essence, it has the capability of holding or retaining water, which can be determined by the amount of water lost with time. The oven will be used to determine the water loss with time by heating. Later, the calculation of the moisture content is given in percentage. Moisture content from 4.23 g of water hyacinth suckers pulp was determined. The water hyacinth suckers Pulp takes 59.33% of weight of water content (see Figure 11). In essence, the pulp can absorb more than half its weight.

#### *3.2.7. The design of the sanitary pad*

The prototype has the dimensions as indicated in the design. However, the absorbent material was made of a single material (water hyacinth pulp or maize stalk internal tissue pulp), and the other was made of a blend. The blend is made in the early stages, immediately after bleaching, in the ratio of 1:1 water hyacinth to maize stalk pulp, respectively. Furthermore, water was added to a material of equal proportions, and a blender with beaters was used to create a homogeneous mixture (Chonsakorn et al., 2018). The ratio of 1:1 was arrived at after having studied the water retention and absorption properties of the two pulps.

**Figure 10. Change in mass vs. time- oven drying the pulp.**

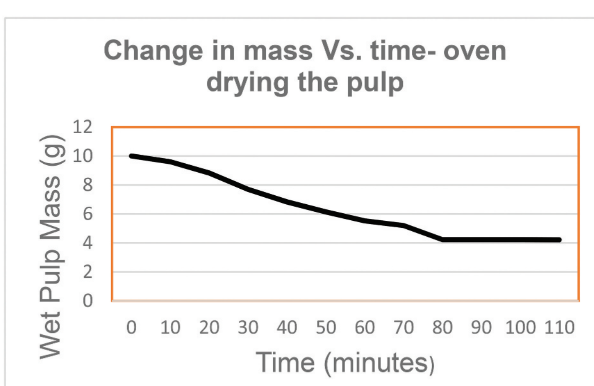
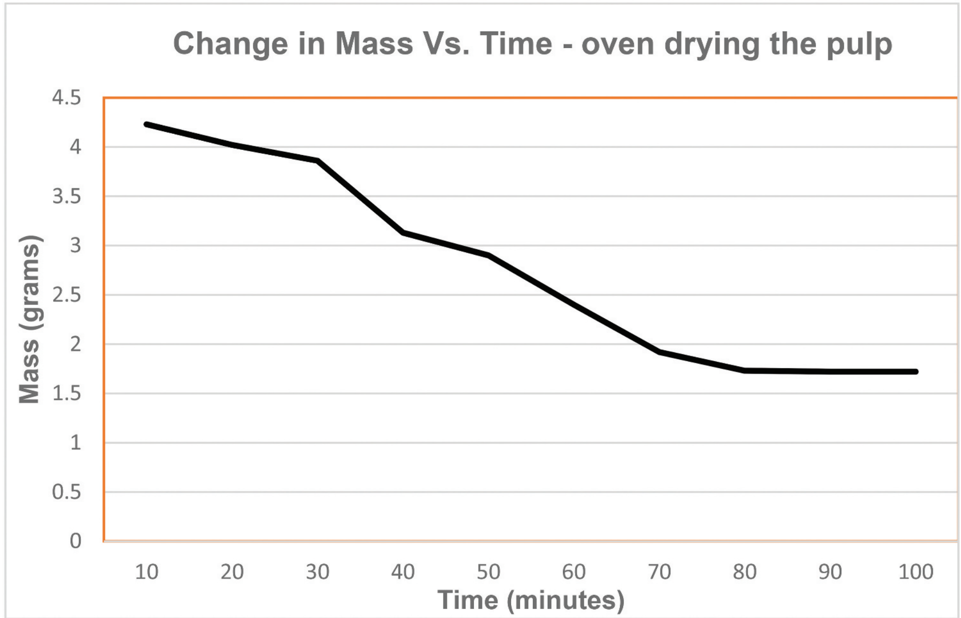


Figure 11. Change in mass vs. time - oven drying the pulp.




### *3.3. The blended pulp*

In order to optimize the two principal properties of both the pulps simultaneously, blending had to be done at a ratio of 1:1 to ensure the sanitary pad absorbs at a relatively faster rate and retains the content for a given amount of time (see Figure 12) (Ajithram et al., 2021). In addition, blending the two pulps results in a softer and fuller pulp since water hyacinth fibers are softer than maize stock pulp, this enhances the comfort of the pad (see Figures 13, 14 & 15) (See Table 1).

The prototypes developed involve both a single material core and a blended core. The blend ratio was 1:1.

The blend was developed based on the strengths of different capabilities, as indicated in the tables below. Water hyacinth had an abortion rate of 1 minute 46 seconds, while maize had a retention rate of 50% of the absorbed water. Under usability, the obtained pulp from individual and combined water hyacinth and maize stalks meets the threshold requirements of absorbency rate (3–6 min) and retention (20–30 ml) as proposed by KS 507:2005. The resulting product will be

Figure 12. The top part of the sanitary pad.


**Figure 13. The bottom part of the sanitary pad.**

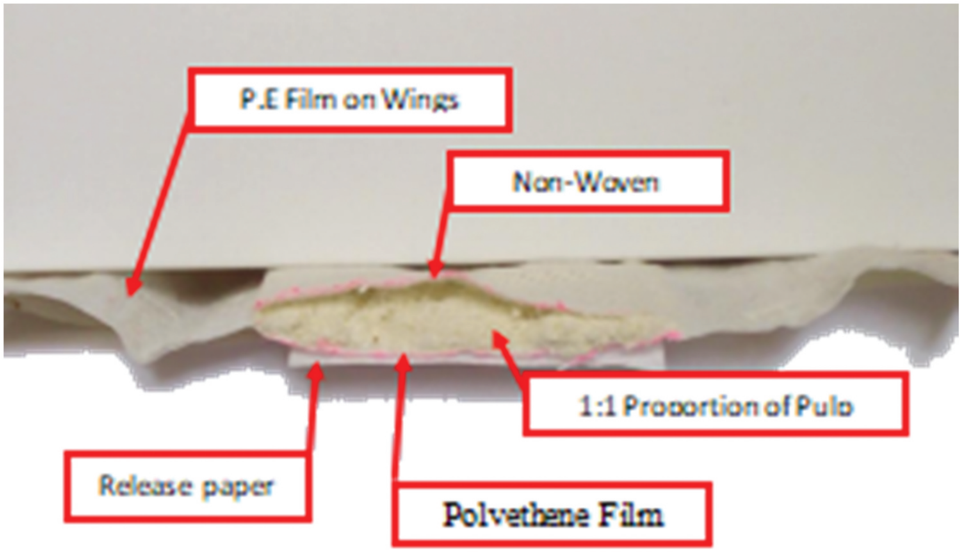



**Figure 14. The cross-sectioned of the sanitary pad.**

**Table 1. Comparison of performance of blending maize stalk pulp with water hyacinth pulp in relation to commercial pads**

| | Property | Maize Internal Tissue/Water Hyacinth Pulp | Commercial Pad |
|---|---|---|---|
| 1 | Retention | 50–55% in 24 Hours | 75% In 24 Hours |
| 2 | Retention Capacity | 50% – 25mls –under loading | 20–30 ml |
| 3 | Absorption Rate | 2 Minutes | 50 Seconds |
| 4 | Bleaching | H2O2 | HClO2 |
| 5 | Polymer Use | No | Yes |
| 6 | Disperse In Water | 2 Minutes | 5 Minutes |
| 7 | Drying Rate (Sun) | Moderate | Slow |

**Table 2. Comparison of performance of maize internal tissue pulp relation to the commercial pads**

| | Property | Maize Internal Tissue Pulp | Commercial Pad |
|---|---|---|---|
| 1 | Retention | 55% In 24 Hours | 75% In 24 Hours |
| 2 | Retention Capacity | 50% – 25- 27mls – under loading | 20–30 ml |
| 3 | Absorption Rate | 2 Minutes 30 Seconds | 50 Seconds |
| 4 | Bleaching | H2O2 | HClO2 |
| 5 | Polymer Use | No | Yes |
| 6 | Disperse In Water | 2 Minutes | 5 Minutes |
| 7 | Drying Rate | Slow | Slow |

**Table 3. Comparison of performance water hyacinth pulp in relation to the commercial pads**

| | Property | Water Hyacinth Pulp | Commercial Pad |
|---|---|---|---|
| 1 | Retention | 50 % In 24 Hours | 75% In 24 Hours |
| 2 | Retention Capacity | 50% – 25mls–under loading | 20–30 ml |
| 3 | Absorption Rate | 1 Minutes 46 Seconds | 50 Seconds |
| 4 | Bleaching | $H_2O_2$ | $HClO_2$ |
| 5 | Polymer Use | No | Yes |
| 6 | Disperse In Water | 2 Minutes 15 Seconds | 5 Minutes |
| 7 | Drying Rate | High | Slow |

affordable since the additional cost of introducing a polymer will be eliminated and the cost of peroxide bleaching agents is normally cheaper as compared to hypochlorite bleaching agents (Cazón-Martín et al., 2018; Hassan Shibly et al., 2019). The material is biodegradable since it lacks the superabsorbent polymer as opposed to those on the market (commercial pads). The maize internal tissue pulp is associated with the nature of water retention, which stands at 55% in 24 h. Similarly, the retention depends on the particle size if the pulp holds between 25 ml and 27 ml, which is 50% of the water used. The cost of maize internal tissue pulp is quite lower than polymers as evaluated on the basis of no polymer used, the products being from agricultural waste, and the use of $H_2O_2$ bleaching agent (Chonsakorn et al., 2018). The disposal of maize internal tissue pulp was environmentally friendly since there were no polymer or chlorine-based bleaching agents (See Table 2).

The water hyacinth pulp is associated with the nature of water retention, which stands at 50% in 24 h. Similarly, the retention depends on the particle size if the pulp holds 25 ml (while under loading), which is 50% of the water used. The cost of water hyacinth pulp is quite lower than polymers, as evaluated on the basis of no polymer used (Hassan Shibly et al., 2019). The products were from an invasive plant and the use of $H_2O_2$ bleaching agent. The disposal of water hyacinth pulp is environmentally friendly since there are no polymer or chlorine-based bleaching agents (See Table 3).

The blend of the selected materials acts as a competitive alternative for the section based on the comparison with polymer-based commercial pads. Similarly, the single absorbent materials (maize internal tissue pulp and water hyacinth pulp) can compete for use as absorbent materials.

## 4. Discussion

It was discovered that the maize stalk pulp had a higher retention capacity (55%) and a slower absorption rate (2 min) than water hyacinth. However, water hyacinth pulp was absorbed at a higher rate (1 minute 46 seconds) and had a lower retention capacity (50%). Therefore, according to Wilson and his team, the variation in the properties of the commercial pads is due to the presence of superabsorbent polymer in the commercial sanitary pads (Wilson et al., 2019). According to Niaounakis (2017), a hydrogel (a water-absorbing SAP) may be able to hold and retain up to 500 times its own weight in deionized and distilled water. Furthermore, the majority of commercial products are made with water-absorbing SAP (Niaounakis, 2017). It is important to reiterate that the significance levels for absorbency were 15 ml to 40 ml per minute and hold and retain up to 500 times its weight. Furthermore, the largest discrepancies in the absorbency rate and retention were due to the chosen particle size and the nature of the laboratory practical associated errors. Generally, the rate of dispersion that helps in determining the absorbency rate lies between 3 and 6 min in the commercial and KEB Standards KS 507–2005. The layers construction in the sanitary pad developed from a blend of water hyacinth and maize stalks pulp is optimized and uses nonwoven materials to encapsulate the pulp core. In this case, the superabsorbent polymer (SAP) is replaced with the pulp core (Bae et al., 2018). The limitation of the study lies with the bleaching process since the use of $H_2O_2$ does not yield a bright colour compared to $HClO_2$ (Bae et al., 2018). The strengths of the study were the availability of the raw material and the availability of standards from KEB. This simple technical study of the physical material of the blended pulp, if further examined via a social science and policy lens, might enhance school attendance, improve girls' education levels, and be a crucial step toward gender equality in low- and middle-income nations (Foster & Montgomery, 2021).

In summary, the extraction process was mainly based on an alkali method where NaOH was used to dissolve a proportion of lignin bonds to enhance absorbency. The bleaching process is performed using H2O2, which in this case is suitable (no degradation of pulp, enhanced absorption by aeration and was mild on the pulp). The optimization process of maize extraction was optimum at 2 of NaOH, 30 min, 0.105 change in mass, and 2.51 of water absorbed. On the other hand, the optimized extraction of water hyacinth was at 0.5% of NaOH, with a 15-min 0.175 change in mass and 2.231 ml of water absorbed. The development of the prototypes is in conformity with the design. The design was developed based on the medium size of the sanitary pad. The medium size is worn by the majority and acted as the alternative for the design. The width, thickness, and length are 80 mm, 8 mm, and 200 mm, respectively. The absorbent core had a width of 60 mm, a thickness of 7 mm, and a length of 180 mm. Also, the materials used are nonwoven, release paper, polythene, and the adhesives that form the enclosure of the extracted pulp. Basically, the absorbency rate and the retention capacity of maize are 50% (25–27 mL of 50 ml of water while under loading) and 2 min and 30 s, respectively. Therefore, the absorbency rate and retention capacity of maize internal tissue pulp indicate compliance with KEBS KS 507–2005 standards. Firstly, the absorbency properties of maize internal tissue pulp were high, and it is potentially viable. Secondly, the retention and moisture content indicate over 50% and 57%, respectively. On the other hand, water hyacinth pulp had a high absorbency rate (1 minute 46 seconds). Water hyacinth pulp has high absorbency rate (106 s). However, it has a high rate of water loss, which hinders water retention. Also, the water retention and moisture content of the water hyacinth pulp was over 50% and 59%, respectively. During the drying process, it is evident that the material lost water at a higher rate (less than a day under the sun). The blend of the materials provides a relatively improved absorbent material with most of the above mentioned properties being optimized.

## 5. Conclusions

Water hyacinth and maize stalks were established to produce pulps with optimized hygroscopic properties. In line with this, low- and middle-income families are in a position to get affordable sanitary pads using the locally available raw materials. Further research can be conducted on the use of $HClO_2$ and possible effects on the users. Deductively, the study addresses the gap that exists in Kenya and other developing countries that need to utilize locally available raw materials to resolve the issue of lack of enough sanitary pads for low- and middle-income populations. The findings presented form a basis for exploration of other raw materials that have advanced hygroscopic properties other than water hyacinth and maize stalk.

### 6. Recommendations

- For communities in Kenya leaving along the maize producing areas, the maize stalks can be used to develop the absorbent material
- A concentration of 2% for NaOH is recommended for pulp extraction in maize stalks, giving 2.511 ml absorbency rate.
- To accelerate the dissolution, the content is heated to 90°C, while the pulp is immersed in aqueous NaOH.
- In the case of water hyacinth, dissolution of lignin is achieved when the concentration of NaOH is 0.5% and the time is 15 min. The extraction process is 95% viable due to the combination of concentration and time parameters.
- The pulp of water hyacinth suckers loses water at a faster rate, indicating that its ability to hold water is weak. As a result, a blend with maize stalk pulp improves water retention.

| **Abbreviation** | |
|---|---|
| SAP | Super absorbent polymers |
| KEBS | Kenya Bureau of standards |
| KS | Kenyan Standards |
| NaOH | Sodium hydroxide |
| $H_2O_2$ | Hydrogen peroxide |
| C | Celsius |

**Acknowledgments**
The authors would like to acknowledge the staff of Moi University, Kenya, and Kenya Industrial Research and Development Institute, Kenya, for their technical support throughout the research process. The authors would like to thank Joab Boen and Jane Birgen for the financial support and staff at Moi University Textile Laboratory. I would like to thank Caroline Jerotich, who offered moral support as well as raw materials for the experiment.

**Funding**
The research was supported by my parents Joab Boen and Jane Birgen

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**Disclosure statement**
No potential conflict of interest was reported by the author(s).

**Data availability statement**
The article itself contains data configurations that support its conclusions.

**Citation information**
Cite this article as: The study and optimization of the hygroscopic properties of selected natural products with an aim of designing a sanitary pad suitable for low- and middle-income population, Bett Brian Kipchumba, Augustine Kangogo Kulei & Josphat I. Mwasiagi, *Cogent Engineering* (2023), 10: 2196812.

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