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Tensile Properties and Dye Uptake Assessment of Cotton Fabrics Sized with Corn (*Zea mays*) Starch and Sorghum (*Sorghum bicolor*) Starch

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Abstract

Sizing of textile substrate enhances the tenacity of the fibre which gives it an appreciable commercial acceptability. However, the sized textile sample is challenged with dye exhaustion and uptake. This study aimed at investigating the effects of starch molecules on dyeing of textile substrates, the recovery angle and the tenacity of the textile materials. This was carried out by treating pure cotton fabric with starch extracted from corn (*Zea mays*) and guinea corn (*Sorghum bicolor*) in the ratio 5%, 10%, 15%, 20%, 25% and the percentage starch retention was calculated in mg/g while the %dye uptake was also calculated. The mechanical properties of the sized textile samples were measured using the tensile testing machine and the crease recovery of the textile materials was evaluated. From the results, the maximum wavelength (λ_{max}) of the dye used was 530 nm. Furthermore, from the sizing of the textile samples, the highest percentage of starch retention was 3.71% and 2.733% for corn and sorghum starch respectively. The value of %dye uptake at 30 min was 29.25% and 27.1% for corn and sorghum sized while the control (i.e. the unsized textile sample) was 85.85%. The crease recovery angle of the 5% starch concentration was 12 for sorghum sized and 10 for corn sized. This value was recorded as the highest when compared to other percentage concentration of starch. The mechanical properties which measures the tensile strength shows that at 5% concentration, 14.098 mPa and 20.372 mPa tensile value was observed for sorghum and

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the corn sized samples respectively when compared to 12.097 value of the control sample. However, the highest tensile strength value was at 10% starch concentration (55.798 mPa) for sorghum sized samples and 15% starch concentration for corn sized textile samples.

1.0 Introduction

In the polymer, dye and textile industry, cotton has gained prominence among other textile materials and has become the major backbone of textile trade globally. The emphasis placed on this cellulosic material with natural origin is based on its unique features such as high strength, durability, softness, dyeability, biodegradability and lack of static electricity (neutrality towards charge build-up). (Nakamura [1], Wang *et al*. [2], Blackburn and Burkinshaw [3], Plastina [4]). Cotton consists of 90%-96% cellulose and their impurity ranges from 4%-10%. These impurities are non-cellulosic components such as waxes, pectins, and proteins. There are generally located within the cuticle layer and the primary wall, which are the outermost layers of the cotton fibers (Raza *et al*. [5], Rana *et al*. [6], Zhu *et al*. [7]). The cellulose predominantly present in the cotton is described as a polymer consisting of β-D glucopyranose units covalently linked by 1,4-glycosidic bonds (Klemm *et al*. [8], Park *et al*. [9]). While the functional group present on each glucose unit accounts for its dye fixation as well as chemical modification. Furthermore, various dyes are used for this cellulosic substrate ranging from natural to synthetic dyes. Out of these categories of dyes applied, reactive dyes have gain prominence due to its brilliancy, varieties of hue, and high wash-fastness of reactive dyes, which are anionic in nature (Kannan *et al*. [10], Chattopadhyay *et al*. [11], Lewis and Vo [12], Montazer *et al*. [13], Teng *et al*. [14]). The chemistry of dyeing cotton with reactive dyes involves the generation of slightly negative charges on the surface of the cellulosic fibres when in contact with water based on the ionization of the hydroxyl groups (Kannan *et al*. [10], Teng *et al*. [14]). However, prior to the dyeing process, certain pre-treatment operations are given to textile substrates such as singeing, sizing (application of starch paste to the textile substrate) scouring, bleaching etc. These pretreatment processes imparts certain significant properties such as tensile strength, luster and dyeability to the textile substrate (Adetuyi [15]).

In addition to these, the pre-treatment processes are essential to enhance dye-fibre interaction, forestall consequent bleeding and maximize dye exhaustion from the Dye bath while conserving the tenacity of the textile fibre (Adetuyi *et al.* [16], Raza *et al*. [5]).

The tenacity of fabrics is revealed by its tensile strength which is shown when fabrics are subjected to tensional force (Pan [17], Oyetade [18]). The tensile stress is mathematically expressed as force per unit area of unstrained specimen. While the dyeability of the textile substrate is described by direct dip dyeing, leading to absorption and transportation of the dyes molecules into the fibre matrix of the textile material. Consequent to this is a gradual decrease of dye concentration in the solution (Wang *et al*. [34]). Attention has been channel toward the use of natural dyes in dyeing base on it low level of toxicological effects. However, these categories of dyes are challenged with poor fastness properties to some vital agencies. Therefore, most natural dyes need chemical species called mordants for binding the dye to fabrics and to improve colour fastness. Mordants help in binding of dyes to fabric by forming a chemical bridge from dye to fiber thus improving the staining ability of a dye with increasing its fastness properties and forestalls subsequent bleeding (Padma [19], Adetuyi *et al*. [16]).

Many assertions have been made on the need for desizing sized textile materials prior to dyeing operation. These claims were based on the forestalling effect of the starch molecules to the transportation of dye molecules into the fibre matrix of textile materials. Hence, this research focuses on the application of natural dye on sized cellulosic textile substrate with the aim of assessing its level of dye uptake, the crease recovery angle and the tensile strength properties of the material.

2.0 Materials and Methods

2.1 Materials

The pure cotton fabric was purchased from Oja-oba market in Akure North Local Government of Ondo State, Nigeria. While the sizing materials used were Corn starch (*Zea mays*) and Guinea corn starch (*Sorghum bicolor*). Various glass wares such as – 100 ml and 500 ml measuring cylinders, 250 ml beaker, 1000 ml standard flasks, and glass stirrer were obtained from the Department of Chemistry at the Federal University of Technology Akure. Other equipments includes: oven, weighing balance, spatula, hot plate, Bunsen burner and desiccators. While the instruments used were UV-Visible spectrophotometer (1800 Unico-UV) and dyeing machine (ROACHES Model MB) from the central laboratory and Chemistry Department of the Federal University of Technology, Akure Ondo state, Nigeria.

2.2 Methods

2.2.1 Extraction of starch from corn and sorghum

The maize grains were handpicked and washed with distilled water to remove the foreign materials. Thereafter, the grains were stepped into distilled water for 72 hours to soften the kernel before grinding (Seetharaman and White [20]). The milled grains (corn meal) were sieved using porcelain cloth of mesh size 5 to remove the chaff (residue) from the filtrate. The filtrate consisting of starch solution was allowed to stand overnight. Then the following day, the water and the corn suspension were decanted off leaving behind the corn starch. The corn starch was dried in an oven at 65^{o}C and pulverized to obtain the powdery form of corn starch. The same procedure was repeated for sorghum to extract starch.

2.2.2 Preparation of starch sizes

Five (5) distinct weights of corn starch powder (0.5 g, 1.0 g, 1.5 g, 2.0 g, 2.5 g) was weighed out and transferred into five (5) 250 ml beakers respectively. Then 10 ml of distilled water was added and each beaker and swirl, then make up to 100 ml mark at 27^{o}C ± 0.2^{o}C. The starch solution in each beaker was stirred with glass rod and the procedure was repeated for starch from sorghum.

2.2.3 Sizing of the fabric using corn starch and sorghum starch

Five (5) swabs from the cotton textile sample were cut into dimension of 4 cm × 10 cm and the weight were taken as W_1 (Adetuyi *et al*. [16], Oyetade [18]). Each of the textile swabs was added into the beaker consisting of starch solution as previously discussed in 2.2.2. These were then heated using a Bunsen burner for 10 minutes. The sized textile samples were then removed and placed in a clean flat board where excess starch paste were removed by pressing out the paste. The fabrics were then placed in an oven set at 105^{o}C/l hr to dry. The fabrics were cooled inside the desiccators until a constant weight was obtained (W_2). The percentage starch regained using the formular in equation (1)

$$\text{Percentage Starch Regain} = \frac{W_2 - W_1}{W_1} \times 100. \quad (1)$$

2.2.4 Determination of crease recovery angle of the treated fabrics

Sized textile samples as discussed in 2.2.3 were folded in half across the narrow direction. Then a metal (iron) was placed on the fold for 5 minutes after which they were

hung on a horizontal wire and left to recover for three minutes. Then with the aid of a protractor the angle formed was measured.

2.2.5 Determination of the tensile property of the sized fabrics

The tensile strength of the sized textile samples was determined using the Instron Universal Testing Machine (Model 3396). The load-elongation at break of the above textile material was done at a constant rate of elongation at 500 N per tension at 25^{o}C and Relative humidity of 65% on Instron universal testing machine Tensile Tester (3396). (Oyetade [18])

2.2.6 Preparation of dye liquor

50 mg of the *Pterocarpus* dye was weighed into 1000 ml beaker and dissolved with 20 ml of 40% ethanol, swirl and finally made up to 1000 ml mark. The wave scan of the dye was carried out using UV-Visible spectrophotometer (1800 Unico-UV) from 350 nm to 750 nm to determine the maximum wavelength (λ_{max}). Thereafter, the serial dilution of dye liquor was carried out and its calibration curve plot was obtained at a predetermined wavelength (Adetuyi *et al*. [21]).

2.2.7 Dyeing of the sized textile substrate

100 ml of already known concentration (C_i) of dye liquor was measured into the dyeing tube. The 10% sized (corn starch and sorghum starch) and the unsized textile samples cut into previously discussed dimension, were added into each of the dyeing tube in the dyeing machine (ROACHES Model MB) with a liquor to goods ratio of 20:1 (Jabar *et al.* [22]). The dyeing process was carried out in the dyeing machine for 15 minutes at 60^{o}C and 100 rpm. The dyeing machine was then allowed to cool and the dyed textile samples were removed. (Mohammed and Loghman [23], Thomas *et al*. [24]). An aliquot of the used dye liquor was taken to determine its final concentration (C_f). This process was repeated for a dyeing time of 30, 40 and 60 min. the dye uptake was then calculated using the formular in equation (2):

$$\text{Percentage Dye Uptake} = \frac{C_i - C_f}{C_i} \times 100. \quad (2)$$

3.0 Result and Discussion

a. Maximum wavelength and calibration curve of the dye stuff

Figure 1 shows the wave scan of the pure *Pterocarpus* dye having a maximum

absorption (λ_{max}) at 530 nm. While Figure 2 shows the calibration curve plot of the natural dye (*Pterocarpus* dye), having an increasing absorbance as the concentration increases. This behavior obeys the Beer-Lambert law relating increase in the absorbance of colourants to increase in their concentration (Kannan *et al*. [10]). In addition to this, the value of the λ_{max} agrees with the range of values for spectra and complementary colours (Popoola [25]). Kannanmarikani *et al.* [26] in his research shows that the natural dye extract from *Lawsonia inermis* has its maximum absorption which is in tandem with the value of natural dye under study. The use of natural dyes as colourant for substrates has regained another focus based on their ease in biodegradability, versatility and their compatibility with the environment when compared with its synthetic counterparts (Osabohien [27], Otutu *et al*. [28]). However, they are challenged with poor fastness properties. Hence, the use of mordanting agents to effectively coordinate these natural dyes to substrates (especially textiles), becomes an issue of necessity (Samanta and Agarwal [29], Jothi [30]).

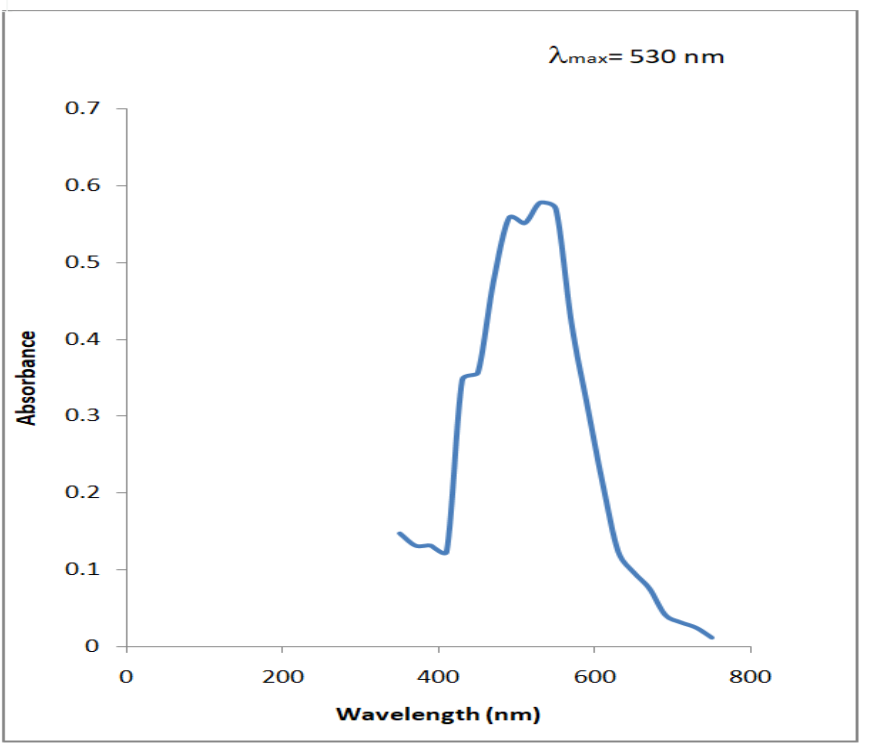

Figure 1. Wave scan of *Pterocarpus* dye.

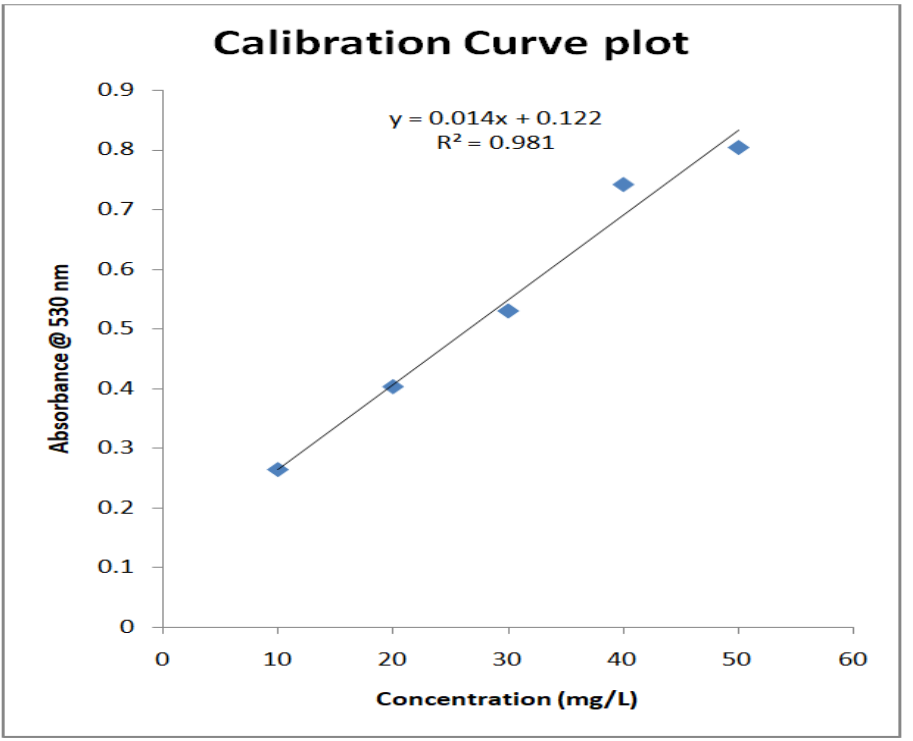

Figure 2. Calibration curve plot of *Pterocarpus* dye at 530 nm.

b. Percentage starch retained

Figure 3 shows the percentage of starch retained by the textile samples at varying concentration of starch from maize and guinea corn. From the results, the cotton textile sized with maize has the highest starch retained (3.71%) at 10% starch concentration. While for the cotton textile sized with guinea corn starch has its highest percentage of starch retained to be 2.733% at 10% starch concentration. The percentage of starch retained by textile samples is similar to the result of obtained by Selamu *et al*. [31]. However, from Figure 3 there was a sharp decrease in the percentage of starch retained with respect to increasing starch concentration. Sizing plays an important role especially by improving the physicochemical properties of the textile material and to generally enhance its tenacity to external force (Schwarz *et al*. [32]). Kovacevic *et. al.* [33]) in his research submits that deep sizing of textile or its yarn prior to woven operation plays an important role in forming outer protection of the threads.

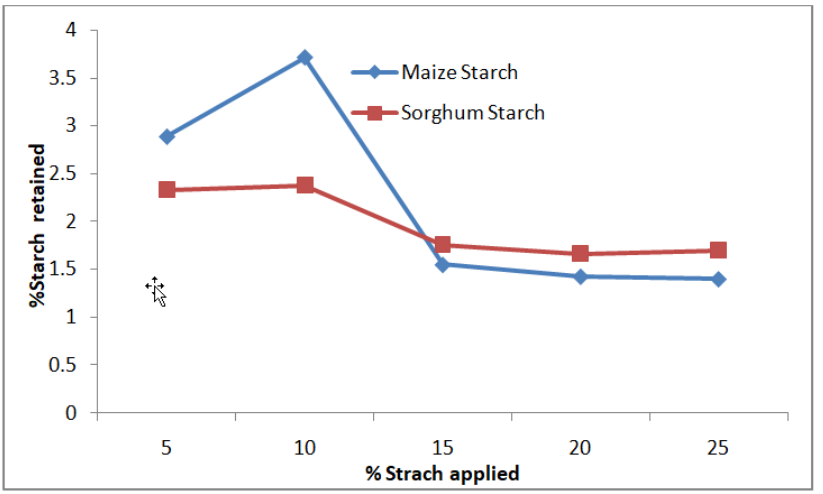

Figure 3. Percentage starch retained on the sized textile samples.

c. Percentage dye uptake of sized textile samples

Figure 4 reveals the percentage dye uptake of textile samples sized with their respective starch in comparison with unsized textile samples (control). From the results, the optimum dyeing time took place in 30 minutes for maize and sorghum sized textile samples with a percentage dye uptake of (29.25% and 27.1%). This value compared with the control (85.85%) shows that the starch content locked up in fibre matrix of the textile samples forestalls the absorption and transportation of dye molecules from the dye bath into the fibre of the textile substrate. This behavior is justified by claims on the vital importance of pretreatment operations of textile samples (especially desizing), prior to dyeing to enhance efficient dye uptake by the textile substrate and to reduce consequent bleeding (Adetuyi [15], Adetuyi *et al.* [16], Raza *et al*. [5]). In addition to this, Loum *et al*. [34] reveals the importance of desizng prior to dyeing to enhance dye-fibre interaction. While Jabar *et al*. [22] and Adetuyi [15] added that, the desizing techniques can carried out by enzymatic solubilization or chemical treatment of sized substrate before dyeing. Furthermore, it is imperative to add that from the discussion at (b), the amorphous orientation of the corn starch compared to the more ordered orientation (crystalline) of the sorghum starch on the surface and inside the fibre matrix of the textile samples may account for its higher percentage dye uptake. This is because less ordered arrangement of starch molecules and fibre matrix of the textile substrate facilitate higher percentage dye uptake when colourants are applied [29].

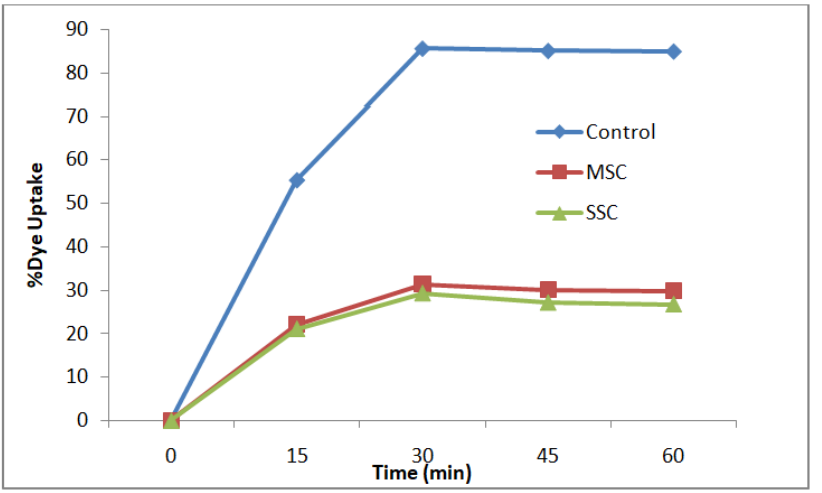

Figure 4. Percentage dye uptake of the sized textile samples.

Key: MSC: Maize sized Cotton; GSC: Guinea Corn sized cotton

d. Crease recovery angle of the sized textile samples

Table 1 shows the crease recovery angle of the maize and sorghum sized textile samples. From the Table, the textile samples sized with 5% of the starch from maize and sorghum has the highest crease recovery angle of 12 and 10 respectively. These recorded values are lower to values recorded from the study carried out by Karthik *et al.* [35] and Obiana *et al.* [36]. However, as the concentration of the starch paste applied increases, the crease recovery angle decreases. This implies that the 5% sized textile samples need less ironing than the textile samples with higher concentration of the starch paste (Obiana *et al.* [36]).

Table 1. Crease recovery angle (degree) of sized textile samples.

% Weight of starch applied	Crease recovery angle for Sorghum	Crease recovery angle for Corn
5%	12	10
10%	8	9
15%	5	7
20%	3	6
25%	2	4

e. Tensile Properties of Sized Textile Samples

Tables 2 and 3 reveal the values of the tensile strength properties of textile samples sized with starch from sorghum and maize respectively. From the tables, the tensile strength value of the textile sample sized with sorghum starch at 5% starch concentration was 14.098 mPa while 20.372 mPa was the value of textile sample sized with maize starch. Both values are higher when compared with to the control textile (i.e. textile sample not sized), having a tensile strength value of 12.097 mPa but higher elongation at break (20.05 mm/mm). In addition to this, there was a significant increase of 55.796 mPa at 10% starch concentration for sorghum sized textile. This value happens to be the highest. However, the highest tensile strength value observed for maize sized textile at 15% starch concentration was 46.36 mPa, with higher elongation at break. These exhibited properties agree with the percentage of starch retained by the sized textile samples in Figure 3. Furthermore, this progression was in agreement with the research carried out by Temesgen *et al.* [31]. In addition to these, the results suggest that the variation in the value of tensile strength may be due to the varying concentration of starch paste applied and at concentration above 10% for sorghum and 15% for corn, lower the starch retention is observed (from discussion in Figure 3) leading to the reduction in their tensile strength values.

The tensile strength properties of woven fabrics are a complex phenomenon and can be affected by different constructional parameters and various pre-treatment processes given to the fabrics of which sizing is predominant (Gürkan Ünal and Taşkın [27]). Maatoug *et al.* [38] affirms that the sizing agent (predominantly starch paste) are used to improve the stiffness, strength and smoothness of yarns which confirm the reason for the reduction of the elongation of the sized textile materials as the percentage of starch paste applied increases.

Table 2. Tensile properties of sorghum starch sized textile samples.

Starch sizes	Modulus (mPa)	Tensile stress at yield (mPa)	Tensile stress at break (mPa)	Tensile strain at yield (mm/mm)	Tensile strain at break (mm/mm)	Tensile elongation at break (mm/mm)
Control	113.40518	12.09752	-0.35449	0.13923	0.15423	20.05000
5%	695.17579	14.09842	12.61131	0.05071	0.06260	8.76406
10%	447.82991	55.79563	-4.29769	0.14643	0.15107	21.1500
15%	363.10163	50.43600	1.33574	0.17929	0.18572	26.00015
20%	372.52833	41.51832	28.93783	0.15072	0.15536	21.75031
25%	320.99684	44.55279	2.77705	0.17286	0.17750	24.85015

Table 3. Tensile properties of maize starch sized textile samples.

Starch sizes	Modulus (mPa)	Tensile stress at yield (mPa)	Tensile stress at break (mPa)	Tensile strain at yield (mm/mm)	Tensile strain at break (mm/mm)	Tensile elongation at break (mm/mm)
5%	170.89748	20.32577	1.00328	0.16822	0.17142	20.50031
10%	299.61182	32.91183	27.50591	0.15464	0.16138	22.59297
15%	362.42193	46.36028	4.46266	0.14750	0.17500	24.49984
20%	358.86626	36.30253	13.65674	0.11321	0.12554	17.57609
25%	194.13252	24.49342	1.2012	0.17786	0.18174	25.44406

4.0 Conclusion

From the investigation carried out on the cotton textile samples sized with sorghum and maize starch respectively, the textile samples sized with maize starch has higher starch retention when compared with its counterpart at 10% starch concentration. Furthermore, the dye uptake of each sized textile samples was very low when compared with the control textile. This justifies the forestalling potential of starch present in the fibre matrix of the textile samples to dye absorption and transportation. However, the tenacity of the textile was significantly enhanced when sized with the starch paste from sorghum and maize. This is displayed in their high elongation at break results, low stiffness characteristics, good fabric thickness, which indicates a good diameter increment on yarn which makes up the fabrics.

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