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Evaluation of Antioxidant, Antibacterial and Fastness Properties of Erythrina abyssinica Extracts on Cotton Fabric Using Biomordants

Vrednotenje antioksidativnih in protibakterijskih lastnosti ter barvnih obstojnosti izvlečkov Erythrina Abyssinica na bombažni tkanini z uporabo biočimž

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Abstract

Due to the toxicity of synthetic dyes, natural dyes have been touted as possible alternatives owing to their eco-friendliness and ability to impart bio-functional properties, such as antibacterial, antifungal and antioxidant properties, especially when natural dyes are mordanted using with biomordants. The aim of the study was to evaluate the effects of using biomordants on the natural dyeing properties of Erythrina abyssinica dye extract, and to evaluate their antioxidant and antimicrobial biofunctionalization properties on cotton fabric. The biomordants used in this study were from mango bark and rosemary extracts. The antioxidant activity of the dyed cotton fabric was established using the 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) method, while the antimicrobial activity of cotton fabric was measured against the Escherichia coli and Staphylococcus aureus strains of bacteria using the direct absorbance method. The use of biomordants in dyeing led to an increase in colour strengths from 0.601 to 0.762 and 0.692 for rosemary and mango biomordants, respectively. Cotton dyed using E. abyssinica demonstrated an antioxidant activity of up to 78.6 1%. The dye imparted a microbial reduction ability of up to 69.11% and 70.06% against E. coli and S. aureus, respectively, to the fabric. Dyeing properties, such as wash fastness, light fastness, colour fastness and perspiration, improved after biomordanting. It can thus be concluded that E. abyssinica dye extracts are suitable for textile dyeing and biofunctionalization

Keywords: natural dyes, antioxidant activity, antimicrobial activity, biomordants, dye fastness

Izvleček

Zaradi toksičnosti sintetičnih barvil naravna barvila vse bolj pridobivajo na pomenu kot okolju prijazna zamenjava, ki lahko poleg obarvanja vlaken zagotavlja tudi biofunkcionalne protibakterijske, protiglivične in antioksidativne lastnosti, še zlasti takrat, ko se uporabljajo skupaj z biočimžami. Cilj raziskave je bil ovrednotiti učinke uporabe biočimž na obarvljivost bombažnih tkanin z izvlečkom barvila Erythrina abyssinica ter proučiti antioksidativne in protimikrobne biofunkcionalne lastnosti tako obarvane bombažne tkanine. Biočimži, uporabljeni v tej raziskavi, sta bili pridobljeni iz lubja manga in izvlečkov rožmarina. Antioksidativno delovanje obarvane bombažne tkanine je bilo ocenjeno z metodo lovljenja prostih radikalov 2,2-difenil-1-pikrilhidrazila (DPPH), protimikrobna aktivnost pa ocenjena proti bakterijama Escherichia coli in Staphylococcus aureus z metodo neposredne absorpcije. Uporaba biočimž pri barvanju je privedla do povečanja intenzitete obarvanja (K/S) od vrednosti 0,601 na vrednost 0,762 in 0,692 za biočimži iz rožmarina oziroma manga. Bombaž, obarvan z E. abyssinica, je dosegel do 78,61-odstotno antioksidativno aktivnost in dobro protimikrobno aktivnost z 69,11-% in 70,06-% redukcijo rasti bakterij E. coli in S. aureus.. Z uporabo biočimž so se izboljšale obstojnosti barve pri pranju, svetlobi in znoju. Rezultati potrjujejo, da je izvleček barvila E. abyssinica v kombinaciji z biočimžami primeren za barvanje in doseganje biofunkcionalnih lastnosti bombaža.

Ključne besede: naravna barvila, protioksidativno delovanje, protimikrobno delovanje, biočimže, obstojnost barvila

1 Introduction

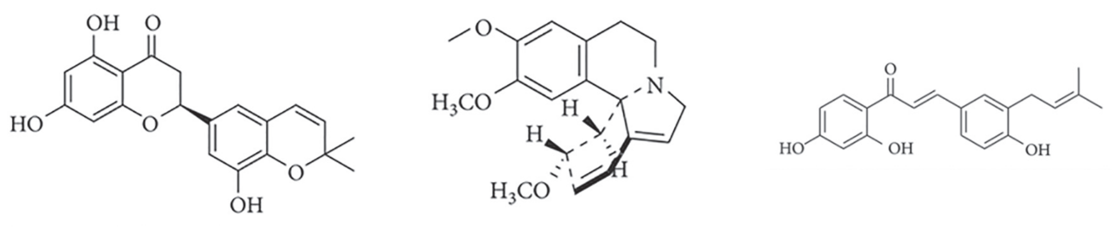
Due to increased environmental concerns, the use of natural dyes in textile, food and leather has been discouraged because of their potential environmental toxicity [1]. Currently, between 15–40% of dyes are released as textile effluents into the environment, leading to adverse effects such as water coloration, toxicity, carcinogenicity and allergic effects [2]. Because of their high solubility, the process of removing most synthetic dyes is both expensive and difficult. For this reasons, natural dyes have often been touted as possible alternatives to their poisonous counterparts [3, 4]. Natural dyes comprise colorants derived from plants and mineral origins, with their main advantages being that they result in unique, soft and attractive shades with additional properties such as antimicrobial, antifungal, UV protective, skin friendly, etc. [5, 6].

Despite the fact that natural dyes have a many advantages, most of them have low colour fastness, meaning that they easily lose their shade, as they lack a good affinity to most fibres. For this reason, natural dyes are often combined with synthetic mordants to help bind the dyes to fabric. Most synthetic mordants are polyvalent metallic salts that work by chelating to dye molecules, resulting in a complex link formation between the dye structure and the fibre. Currently, the most common mordants are copper sulfate, the potassium dichromate salts of iron, such as iron sulphate, and the salts of tin, such as tin chloride. [7]. Research shows that during the dyeing process, a fraction of the applied metallic mordant is absorbed by the fabric while a vast amount finds its way into the environment [8].

Conversely, there is equal concern that, despite most natural dyes being environmentally friendly, the amount of synthetic mordants dispelled into the environment still make it environmentally unfriendly. For this reason, natural or biomordants have been suggested. Studies have shown that biomordants generally improve both the colour strengths and fastness characteristics of natural dye in a similar way that has been observed with metallic mordants [9, 10]. This can be attributed to the diversity of phytochemical compounds present specifically in plants that are rich in compounds, such as tannins, which have specifically been identified as excellent biomordants in the dyeing of linen and woollen fabric, using kapok flower extract in tandem with tannin-based natural mordant [11].

Apart from additional shades, natural dyeing and biomordanting, when combined, often lead to the biofunctionalization of textiles. This includes UV-protective properties, antioxidant, antibacterial, antifungal and deodorizing effects. Apart from these properties, natural textile materials, such as cotton and silk, are susceptible to different microbial attacks because they naturally provide suitable conditions, such as temperature and moisture, that enhance growth and the multiplication of microbes. Thus, textiles that have been finished with antibacterial properties are currently preferred by most contemporary consumers [12–14].

The aim of this research was to the determine effects of biomordants from rosemary plant and mango bark on the dyeing properties of *E. abyssinica* natural dye extracts, and to evaluate the antioxidant, fastness and antimicrobial potentials of the natural dye on cotton fabric. The *E. abyssinica* plant, has been found to be rich in several phytochemicals such as flavonoids, isoflavonoids, alkaloids and chalcones. Some of the chemical structures of the compounds that have been isolated from this plant are as shown in Figure 1 [15–17].



Signoid C- A flavone (+)-Erysotrine-An alkaloid Licoagrochalcone A- a chalcone

Figure 1: Compounds that have previously been isolated from Erythrina Abysinnica

2 Materials and methods

2.1 Materials

The stem bark of the *E. abyssinica* plant was harvested from the Nandi hills (0°07'36.8"N and 35°10'29.7"E) in Nandi County in Kenya. Plain woven and commercially bleached cotton fabrics (20 ends/cm, 13picks/cm, 17.34 tex and 97.1 g/m^2) were obtained from Rivatex East Africa, the textile facility of Moi University, and subsequently used for dyeing.

2.2 Extraction of the natural dye

The plant samples were first cleaned with tap water for the removal of impurities and dust particles. The cleaned samples were subsequently in the shade until there was no change in masses. They were then ground to fine powder to increase the extraction of surface area to volume ratio. The aqueous extraction method was used to extract the dye, which was then filtered using filter paper.

2.3 Cotton pre-treatment

The wetting of 1g of cotton was carried out using 5 g/L of a non-ionic soap detergent for thirty minutes (Rivatex EA). The pretreatment of the fabric to increase its absorption ability was performed according to the method prescribed by [1]. The fabric was dipped in a 4% tannic acid (Loba Chemie, India) solution and pretreated for two hours, and subsequently washed and dried.

2.4 Dyeing experiments and biomordanting

The extraction of mango bark biomordant was performed as described by [18]. Extraction was done for one hour at a temperature of 90 °C using 75 g/L of the sample dissolved in distilled water. *Rosmarinus* *officinalis,* commonly referred to as rosemary plant, was purchased from the Eldoret local market, dried under in the shade and subsequently ground to powder. A total of 20 g/L of the powder was dissolved in distilled water at 100 °C for 60 minutes. The biomordanting process was carried out using pre-mordanting, simultaneous/meta-mordanting and the post-mordanting methods.

The fabric was reduced into equal sizes of 1g each. The fabric was wetted with 5 g/L of non-ionic soap detergent for half an hour before dyeing with *E. abyssinica* aqueous dye extract. After the dyeing process, the dye bath (material to liquor ratio of 1:40) was left to cool and the subsequently dyed samples rinsed with cold water for the removal of any unfixed dyes. They were then subjected to soaping using 2 g/L of soap solution, followed by washing with distilled water and then air dried.

2.5 Colorimetric measurements

The colour characteristics of the dyed fabric samples were then measured using a Spectro -Flash X-rite SP62 spectrophotometer device with a D65 light source coupled with a 10° observer. The CIELAB coordinates that were measured in this study were a reddish-greenish colour that ranged between the points (+$a*$ = red, -$a*$ = green), a yellowish-bluish colour in the range (+$b*$ = yellow, -$b*$ = blue), with the light or brightness denoted as ($L*$), and the colour saturation (C) and hues ($H*$) with a plain undyed cotton fabric acting as the fabric blank.

The colour strengths denoted by the (K/S) values were determined using the Kubelka–Munk equation [19] as shown in equation 1.

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \quad (1)$$

where K represents the coefficient of absorption, S represents the coefficient of scattering and R represents the minimum reflectance of the dye sample.

2.6 Fastness tests

Colour fastness was determined as follows: the dyed fabric were paired with another piece of the same material (cotton), and the two stitched together following the specifications of the ISO 105-C06:1994 standard. This combined fabric was then immersed in a solution containing 5 g/L of non-ionic detergent, maintaining a material-to-liquor ratio of 1:50, and processed at 50 °C for 45 minutes using an SDL Atlas Launder-o-meter. The samples were evaluated for colour loss, with differences assessed using the grey scale method according to the ISO 105-A02:1993 standard for colour change [20, 21].

For fastness to light, thin fabric strips, approximately 1 cm by 8 cm, were placed in test tubes and suspended on an exposure rack. The samples were then exposed to illumination for 4 hours using a 500 W SDL ATLAS light fastness tester. The loss of shade depth was subsequently evaluated using the grey scale method according to the ISO 105-A02:1993 [22–24] standard.

Rub fastness was tested using a Crock-meter (AATCC Model M238AA SDATLAS) according to the ISO 105-X12:2001 standard. The dyed fabric was mounted on the Crock-meter panel and rubbed ten times in both wet and dry conditions. The extent of staining was then evaluated on the specialised white fabric [22–24].

2.7 Antioxidant activity

The antioxidant activity of the undyed and dyed fabrics was calculated using the DPPH radical scavenging assay according to [13] . Pure and dyed cotton fabric measuring 2.54 cm^2 was separately immersed in a test tube containing a 50mL solution of DPPH that was diluted in methanol (0.15 mM). Afterwards, the samples were incubated at room temperature inside a dark room for half an hour. The solution's absorbance was then measured using a Beckman Coulter 720 (USA) UV-Vis device at a wavelength of 517 nm, and the percentage antioxidant activity calculated using the equation 2:

$$A = \frac{A_{control} - A_{sample}}{A_{control}} \times 100\ (\%) \qquad (2)$$

where A represents the calculated percentage antioxidant activity, $A_{control}$ represents the initial absorbance and A_{sample} represents the absorbance of DPPH remaining after incubation with the sample.

2.8 Antibacterial activity

The antibacterial properties of both dyed and biomordanted fabric were assessed using the absorbance technique as described by [13]. A piece of fabric, measuring 1.27 cm^2, was dipped into a 25 mL solution of nutrient broth that had been inoculated with *E. coli* and *S. aureus*. The broth was again incubated in an automated incubator (Unitronic – J.P. Selector) at 37 °C for exactly 24 hours and the absorbance of the bacteria culture media evaluated at 595 nm using a UV-Visible Beckman Coulter 720 (USA) spectrometer. The reduction percentages of the bacterial growths were the calculated using equation 3:

$$R = \frac{B - A}{B} \times 100\ (\%) \qquad (3)$$

where R represents the percentage reduction in antimicrobial activity and B represents the absorbance of media that has been inoculated with the microbe and subsequently introduced in the undyed cotton fabric. A represents the absorbance of media inoculated with microbes and introduced in the dyed cotton fabric.

2.9 Percentage durability of antibacterial finishing to washing cycles

The antibacterial and antioxidant durability on the cotton fabric was evaluated after the fabric was subjected to several wash cycles, namely after the 1^{st}, 5^{th} and 10^{th} wash cycles according to [25, 26]. This was done by washing the samples in a washing solution of 2 g/L commercial detergent with a material to liquor ration of 1.50.

2.10 UV-VIS analysis of dye

Extracts of *E. Abyssinica* were analysed using a UV-Visible Beckman Coulter 720 (USA) device in the ranges of 200–800 nm.

3 Results and discussion

3.1 Colorimetric analysis of biomordanted cotton fabric

The colorimetric analysis of the fabric dyed with *E. abyssinica* was evaluated and the results are presented in Table 1.

Table 1: Colorimetric values of E. abyssinica dyed fabric

Mordanting method	Mordant	L^*	a^*	b^*	C^*	$H°$	K/S	Fabric
-	None	87.9	-0.8	+20.1	18.7	92.7	0.601	
Pre-mordanting	Mango bark	86.1	+1.4	+15.1	15.2	84.5	0.692	
	Rosemary	86.0	+0.6	+26.2	23.1	88.3	0.762	
Meta-mordanting	Mango bark	87.5	+2.0	+14.7	23.9	88.4	0.618	
	Rosemary	86.7	+0.4	+25.2	23.0	88.4	0.663	
Post-mordanting	Mango bark	87.9	+2.2	+14.5	23.5	88.3	0.611	
	Rosemary	85.9	+0.9	+27.2	22.9	88.1	0.630	

All the dyed fabric resulted in different shades of brown with the introduction of mordants, leading to the brightening of the shades of brown. This can be concluded from the *L* values, where the cotton fabric dyed without the mordant and the one post-mordanted with Mango had the highest *L* value of 87.9, while the others had lower values [27]. Equally, the results suggest that the use of biomordants successfully improved the colour strengths (*K*/*S*) of the dye from 0.601 to a high of 0.7620 for rosemary and 0.692 for mango biomordants [28, 29]. Moreover, the highest colour strengths were achieved when fabric dyeing was performed using pre-mordanting in both cases.

3.2 Fastness properties of dyed fabric

The colour, wash, rub, light and perspiration fastness were evaluated and the reports presented in Table 2.

Table 2: Colour fastness properties of dyed cotton fabric using different mordanting techniques

Method	Mordant	Washing fastness		Rubbing fastness		Perspiration fastness		Light fastness
		Colour change	Colour staining	Dry	Wet	Colour change	Colour staining	
-	Without	2.5	2.5	3.0	3.0	4	4	3.0
Pre	Mango bark	4.5	4.5	5	5	4.5	4.5	4.5
	Rosemary	4.5	4.5	4.5	4.5	5	5	4
Meta	Mango bark	4	4.5	4	4	4.5	4	4
	Rosemary	4	4.5	4	4	4.5	4.5	4
Post	Mango bark	4	4.5	4	4	4.5	4.5	4
	Rosemary	4	4.5	4	4	4.5	4.5	4

The wash fastness of the fabric dyed without any mordant was average before the introduction of mordants. After mordants were used, there was a significant improvement in the wash properties from an average of (2.5) to excellent (4.5). This shows that the mordants successfully improved the fixation of the dye to the fabric [30]. Similar results have also been reported with other natural dyes, where the introduction of mordants and biomordants, significantly improved dye wash fastness properties [31–33].

It is can also be concluded from the table that biomordanting improved the rubbing, perspiration and light fastness of the fabric [28]. In general, the pre-mordanting technique of dyeing achieved the best overall results, as it significantly improved the wash, rub, perspiration and light fastness compared with other methods.

3.3 Antibacterial activity of the dyed cotton fabric

The antibacterial activity of the biomordanted fabric was evaluated using the absorbance method and the results are presented in Figure 2. Previous literature indicates that most natural dyes extracts of *E. abyssinica* demonstrate antimicrobial activity [16].

It is evident from Figure 2 that the dyeing of cotton with biomordants increased bacterial reduction abilities from 61.3%, when unmordanted, to 68.6% and 69.1%, respectively, when mordanted with mango and rosemary in *E. coli*. Moreover, for *S. Aureus,* the bacterial reduction percentage also increased from 64.3%, when unmordanted, to 68.9% and 70.1%, respectively. This results, are similar to other results reported in literature, where biomordants not only improved fabrics fastness but also introduced bacterial reduction properties [12].

Fabric biomordanted with rosemary extracts demonstrated a higher bacterial reduction efficacy than fabric biomordanted with mango bark extracts. This could be attributed to the presence of additional phenolic hydroxyls groups from the rosemary biomordant extracts, which enhance the bacterial inhibition ability of the dye [28].

3.4 Antibacterial activity after wash cycles

The laundering durability of the dyed samples was assessed and the results presented in Figure 2.

Percentage bacteria reduction refers to the percentage decrease in the bacteria population [6] It is evident from the results above that antibacterial activity decreased continuously as the number of washes increased. Similar results have also been observed in literature, where antimicrobial inhibition activities decrease with an increase in the number of washes [4, 11, 12].

In this case, it was observed that the decrease in antimicrobial efficacy was negligible for mordanted fabric compared with unmordanted fabric. The ability to retain the antimicrobial activity of the dyed fabric in some cases above 50% even after the 10th successive wash proved that the *E. divinorum* dye extract was good for the development of antimicrobial functionalized textile fabric [4].

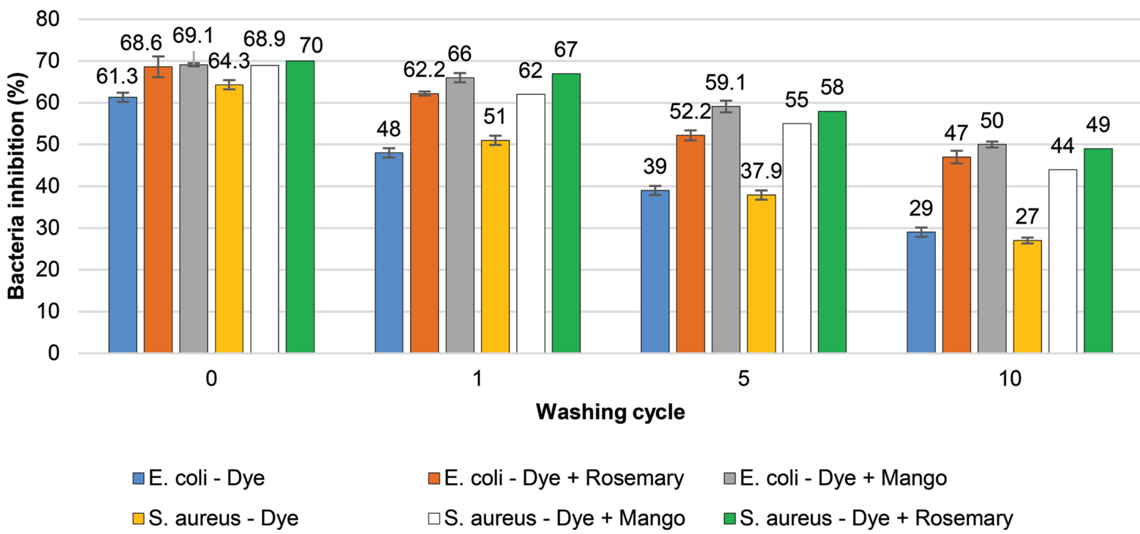


Figure 2: Bacteria reduction of fabric against E. coli and S. aureus after washing cycles

3.5 Percentage antioxidant activity of the dyed fabric before and after wash cycles

The antioxidant activity of the dyed cotton fabric is shown in Figure 3. It can be concluded from Figure 3 that the mordanting of fabric with biomordants increased the antioxidant activity of the fabric from a low of 26.9, without mordant, to a high of 78.6 when dyed with rosemary mordant [34]. This result is similar to others which suggest that both mango and rosemary extract biomordants increase the antioxidant properties of fabric due the high number of polyphenols present in them [34–36].

In addition, the antioxidant activity was examined after the 1st, 5th and 10th wash cycles as seen in Figure 3. A reduction in the antioxidant activity was observed as the number of washes increased, as has

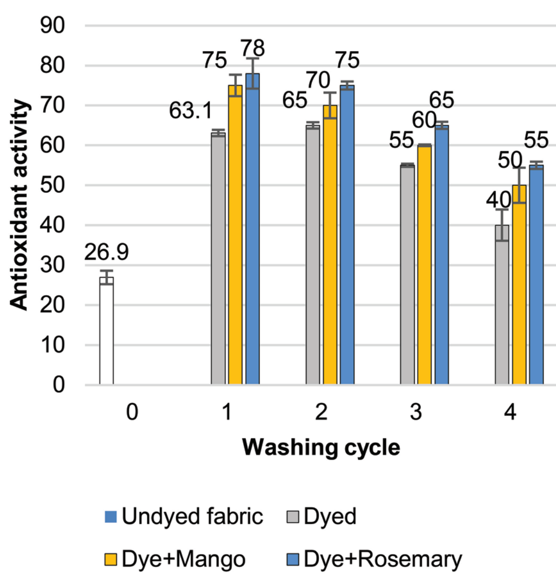


Figure 3: Antioxidant activity after wash cycles

been recorded in similar studies [37]. Overall, the rosemary mordanted fabric had higher antioxidant activities even after 10 wash cycles.

3.6 UV VIS spectroscopy analysis

A UV-Visible analysis of the *E. abyssinica* dye extracts (Figure 4) showed that the dye contained a mixture. This is not unique to these extracts, as other natural dyes have also been discovered to be a mixture of compounds as previously discussed by [38, 39].

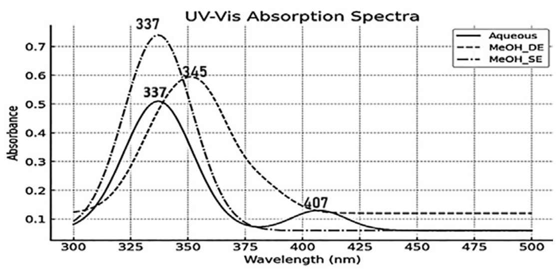


Figure 4: UV-Visible spectra of E. abyssinica extracts

The extracts showed several peaks at 407 nm, 345 nm and 337 nm. These peaks have previously been proven to belong to flavonoids that are usually yellowish in colour. It can thus be suggested that *E. Abyssinica* dyes are flavonoid rich [40].

4 Conclusion

Dyeing cotton fabric with extracts of *E. abyssinica* in the presence of biomordants enhanced the colour strength of the dyes from 0.601 to 0.762 and 0.692 for rosemary and mango biomordants, respectively. The *E. abyssinica* dye extract imparted an antimicrobial activity to a maximum of 69.11% and 70.06% against *E. coli* and *S. aureus*, respectively. The antimicrobial and antioxidant activities were increased when biomordants were used. Dyeing properties, such as wash fastness, light fastness, colour fastness and perspiration, were examined before and after biomordanting, with the results indicating that the biomordants improved the dyeing properties of *E. Abysinnica dye*. As a result, it can be concluded that *E. Abyssinica* dye extracts are suitable for use and the development of biofunctionalized textile fabric.

Author contributions: conceptualization – Scolastica Manyim and Ambrose Kiprop; methodology – Scolastica Manyim, Ambrose Kiprop, Josephat Mwasiagi, Cleophas Achisa and Mark Odero; formal analysis – Scolastica Manyim and Mark Odero; investigation – Scolastica Manyim and Josephat Mwasiagi; writing (original draft preparation) – Scolastica Manyim and Mark Odero; writing (review and editing) – Ambrose Kiprop, Josephat Mwasiagi and Cleophas Achisa; visualization – Scolastica Manyim; supervision – Ambrose Kiprop, Josephat Mwasiagi and Cleophas Achisa. All authors have read the manuscript and have approved it for publication.

Conflicts of interest: The authors declare that there is no conflict of interest.

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