ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

EVALUATION OF THE FUNCTIONAL FINISHING OF COTTON USING POKEWEED BERRY DYE MORDANTED WITH ALOE VERA

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Abstract: *Cotton has a high reputation for being one of the most used fabrics in the world but because it is hydrophilic, has an extreme susceptibility to microbial damage, causing degradation of the fabric and skin irritations. Although synthetic antimicrobial finishes for cotton have shown effectiveness over time, they carry issues of environmental toxicity and the development of microbial resistance, therefore, the need for sustainable and plant-based alternatives must be fulfilled. This paper presents the use of a plant-derived functional finish using pokeweed (Phytolacca americana) berry dye and aloe vera (Aloe barbadensis) extract, together to cotton fabric. A two-step pre-treatment method was employed on the used cotton to increase the fabric's absorption potential. The procedure consisted of applying fresh aloe vera extract (varying concentrations 10% - 100% v/v) as the pre-mordant, then applying an aqueous pokeweed dye. To evaluate for antimicrobial activity of the finished samples before and after laundry (following AATCC LP2 procedure), Staphylococcus aureus and Escherichia coli were used as test organisms with AATCC 147 qualitative test procedure. Results indicated that aloe vera is a viable bio-mordant, the antimicrobial activity of the fabrics increased with increasing concentration of aloe vera pre-mordant with the maximum zone of inhibition occurring at the 100% concentration of the aloe vera extract. However, the after-laundry test showed a dramatic loss of activity, emphasising the need for non-toxic cross-linking agents for practical applications. This paper provides a foundational framework for the use of indigenous bio-resources in green fashion for hygiene-sensitive textile industries.*

Key words: *Antimicrobial textiles, sustainable cotton, bio-based finish, zone of inhibition, synergistic interactions*

1. INTRODUCTION

Cotton is one of the mainstays of the international textile market and is currently estimated to generate over $600 billion each year as an unprocessed good [1], with a unique cellulosic structure and desirable qualities contributing to its superior moisture management, allowing application for everyday garments, specialised textiles and home beddings [2], [3]. Additionally, due to cotton's natural ability to retain moisture, microorganisms can proliferate on the fiber leading to fabric deterioration, offensive odors, and skin irritation [4],[5], While there are synthetic antimicrobial compounds that can control the growth of bacteria and other microorganisms, their

environmental toxicity and tendency to cause microorganisms to develop resistance to them have created urgency for a need to develop safe, environmentally sound, naturally-derived alternatives [6], [7], [8].

This study examined an alternative natural-based finishing process through the use of pokeweed berries and aloe vera extract. Pokeweed provides a high concentration of anthocyanins, which provide color and some antimicrobial efficacy [9]. Aloe vera provides more than 75 components that can act against bacteria, including aloin and saponins, which are bactericidal by interrupting the bacterial cell membrane [10]. Although previous studies have documented the benefits of these individual plants, there is a limited amount of research that documents the synergistic effect of these two natural products. The presence of natural finishes on fabrics has been shown to decrease their effectiveness as a result of mechanical action caused during laundering and exposure to common detergents [11]. Therefore, the objective of this study is to identify how concentration of aloe vera added to pokeweed-dyed cotton will affect the antimicrobial characteristics and durability of the dye system as a means to create sustainable innovations in textiles.

2. EXPERIMENTAL MATERIALS AND METHODS

This study was conducted using a laboratory-based experimental design at Uganda Industrial Research Institute (UIRI). The cotton substrate obtained from UIRI was prepared through a two-stage treatment procedure to increase absorbance of the substrate, scouring with 2g/L of Na_2CO_3 at 90°-95°C and bleaching with 30% H_2O_2 (pH 10.5) at 70°-80°C. pH-neutralising of the scoured and bleached cotton with acetic acid was done, then performed mass per unit area (ASTM D3776), thickness (ASTM D1777) and pH characterisation to establish a baseline of the cotton's structural and chemical characteristics for use with bioactive agents.

The bioactive agents used in this study were extracted from onsite fences and farms in Kampala Uganda, and were used to ensure sustainability; specifically, aloe vera inner gel was extracted by hand and later centrifuged to generate concentrations of 10, 30, 50, and 100% v/v of the fresh extract; pokeweed dye was made by aqueous extraction method using 2:1 pokeweed berries: water ratio, and left to stand for atleast 12hours. Pre-mordanting of cotton in aloe vera solutions of varying concentrations for one hour, at 60°C, then dyeing with the pokeweed berry dye with a liquor ratio of 1:20 at the same conditions, at a pH of 4.5, to combine the cellulose and the anthocyanin pigments of the dye was done. Flat drying was done in the shade for at least 24 hours.

To evaluate the level of antimicrobial activity before and after laundry following the AATCC LP2 lab procedure against Escherichia coli and Staphylococcus aureus, the antimicrobial activity via the Zone of Inhibition (ZOI) was tested using the AATCC 147 qualitative test, where bacterial strains were revived and incubated overnight in a nutrient broth at 37 °C on Mueller-Hinton agar plates. The tests were done in triplicate per finish, and an average of the ZOI obtained from a 50x25mm cotton sample was recorded in the tables. An inoculum was prepared by transferring 1.0+_0.1mL of the 24hr broth culture into a 9.0+_0.1mL of sterile distilled water contained in a small flask followed by mixing well using agitation. The process was repeated 8 times for proper dilution, and the colony-forming units (CFU)were counted using a colony counter machine, and the CFU/mL was calculated.

3. RESULTS AND DISCUSSIONS

3.1 Pretreatment of cotton

Table 1: *Effect of pretreatment on cotton*

Cotton sample	GSM in (g/m2)	Thickness (mm)	pH
Before pre-treatment	133	0.42	7.92
After pre-treatment	145	0.47	7.65

GSM increased by 12 g/m² and thickness by 0.05 mm due to fabric shrinkage and increased thread density, as all individual fibres returned to their original curled form following the scouring process, there were additional threads per square foot [12]. The 0.42 pH change was minimal and was created by the neutralisation action that helps protect cellulose from alkaline hydrolysis and also improves the fabric's ability to receive naturally bioactive materials, resulting in alkaline soaps being converted into protonated acids, which are more easily rinsed from cellulose [13].

3.2 Dyeing performance and Biomordant synergy

Visual results indicated a strong correlation between aloe vera concentration and colour depth. Shades transitioned from bright fuchsia pink (100% aloe) to pale pink (0% aloe). This probably could have been due to aloe vera acting as an effective bio-mordant and fixative because its gummy polysaccharides and metallic ions (magnesium, calcium, sodium) create a "bridge" between the cellulose hydroxyl groups and the dye molecules [14]. Higher concentrations produced deeper shades due to the lightness value being a function of dilution of the aloe compounds [15].

In addition, the enzymatic properties of the aloe vera gel increase the wettability and absorbency of the fibers, allowing for exhaustion of the dye without the need for synthetic salts [16]. Conversely, the alum mordants resulted in a pale pink dyeing, confirming its ineffectiveness as a mordant for cellulose fibers because of the low number of reaction sites for the coordination of metal salts [17].

3.3 Antimicrobial efficacy and Optimal concentration

Table 2: *ZOI for the tested bacteria on the pretreated and finished control cotton samples*

Finished Control Cotton Sample	ZOI for the tested bacteria in (mm)	
	Staphylococcus aureus of Colony forming units (CFU/ml) $2.6x10^8$	Escherichia coli of forming units (CFU/ml) $8.8x10^8$
Known Antibiotic (GMYCIN)	9.5	5.5
Aloe Vera alone	2.5	1
Poke weed alone	0.5	0
Cotton only	0	0

Table 3: *ZOI for the tested bacteria on different cotton samples pre-wash*

Finished Cotton Sample	ZOI for the tested bacteria (mm)	
	Staphylococcus aureus of Colony forming units (CFU/ml) $2.6x10^8$	Escherichia coli of forming units (CFU/ml) $8.8x10^8$
100% Aloe vera and pokeweed dye	3	1.5
50% Aloe vera and pokeweed dye	1.5	0.5
30% Aloe vera and pokeweed dye	1	0
10% Aloe vera and pokeweed dye	0.5	0
Pokeweed Alum pre-mordant	0.5	0

Fabrics research confirmed a synergistic antimicrobial effect. Fabrics treated with both pokeweed and aloe vera indicated a larger inhibition zone than untreated and singly treated samples. This synergy could probably be due to a result of the combination of pokeweed's anthocyanins, which interfere with protein function, and aloe vera's anthraquinones and saponins, which disrupt bacterial cell walls and metabolic functions [18], [19].

Findings showed that the antibacterial effect was highly correlated positively with concentration. No evidence of saturation was found; the maximum ZOI occurred at 100% aloe vera concentration across *S. aureus* as well as in *E. coli* strains. These findings support the hypothesis that increasing the concentration of resulting active components like aloin and acemannan leads to greater disruption of bacterial cell functions [20].

3.4 Durability and Diffusion Challenges

Table 4: *ZOI for the tested bacteria on different cotton samples post-wash.*

Finished Cotton Sample	ZOI for tested bacteria in (mm)	
	Staphylococcus aureus of Colony forming units (CFU/ml) $2.6x10^8$	Escherichia coli of forming units (CFU/ml) $8.8x10^8$
100% Aloe vera and pokeweed dye	1.5	0.5
50% Aloe vera and pokeweed dye	0.5	0
30% Aloe vera and pokeweed dye	0	0
10% Aloe vera and pokeweed dye	0	0
Poke weed berry dye alone	0	0
Pokeweed Alum pre-mordant	0	0

Antimicrobial activity declined drastically after washing, as bioactive compounds are not wash-fast [21]. Measurable activity was only observed in samples treated with 100% aloe vera pre-mordant, and even then, at minimal levels. While aloe vera demonstrates partial durability due to

stronger binding at high concentrations, achieving industrial-grade durability will require crosslinking or binding agents to prevent removal during laundering and mechanical agitation [22].

A notable observation during testing was the diffusion of pink colour from the cotton fabric into the media, forming a dark, bloody, and seemingly roasted appearance inside the petri dishes. This could have resulted due to pokeweed dye being water-soluble and loosely adhering to the cotton fabric, moving from high concentrations on the cotton fabric to the lower concentrations through passive diffusion, altering the clarity of the media.

4. CONCLUSIONS

This research highlights an urgent requirement for the development of non-toxic biodegradable finishing chemicals for textiles in order to support innovation in the fabric industry. Higher concentrations of aloe vera demonstrated deeper pokeweed berry dye shades and higher antimicrobial effects on cotton fabrics. Washing significantly reduces antimicrobial activity; thus, the use of cross-linking agents and optimisation of application methods will be required to facilitate industrial transitioning.

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