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Fastness and Antibacterial Properties of Washable Woven Cotton Surgical Face Masks Dyed with Plant-Based Colorants

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Nazan AVCIOĞLU KALEBEK*

Gaziantep University, Fine Art Faculty, Textile and Fashion Design, Gaziantep, Turkey

Abstract

Harmful effects of synthetic dyes have become obligation of choosing natural dyes extracted from plant-based colorants in textile sectors due to eco-friendly nature. The current study has been conducted to investigate possible food products (cinnamomum and curcuma longa) as a source of dye for washable woven cotton surgical face mask. Brown and yellow color was obtained at the end of the dyeing process. Dyeing process was performed with salt (NaCl) and apple cider vinegar (CH_3COOH) in order to improve color strength, colorfastness and antibacterial. Dyed surgical facemask was accessed for color coordinates L*, a*, b*, K/S, ΔE* and color fastness to washing, perspiration and, antibacterial activity.

Keywords: Plant-based colorant; Cotton; Face mask; Color fastness; Sustainable resources

***Corresponding author:** Nazan AVCIOĞLU KALEBEK, Gaziantep University, Fine Art Faculty, Textile and Fashion Design, Gaziantep, Turkey

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Introduction

In textile industry, synthetic dyeing is mostly because of availability [1], economic, superior color fastness, and different excellent color shades in spite of environmental and human beings' hazardous effects [2]. The use of natural dyes extracted from roots [3], barks [4], leaves [5], flowers [3], fruits [6,7], skins and shell of plants has become a necessity for future generations. In recent years, national and international legal regulations and standards [4] have been made thanks to the conscious behavior of consumers [2]. Plant-based colorants have been used for dyeing and printing [4] not only leather but also textile fibers wool [7-9], silk [10], cotton [11], flax since ancient times. At the same time, some natural dyes are used for antibacterial [12,13], deodorizing [14] and healing functions.

Poor fastness properties [15] of dyed fabrics with plant-based natural colorants were well known facts. Mordant [11,16] has been used to improve this problem and even to develop various shades with the same dye. However, most of the mordant contain metal ions [15] that have harmful effects on the environment. Many potential mordant [16,17] obtained from natural sources such as salt, vinegar and lemon juice, but have attracted very limited research attention.

Cinnamomum is aromatic trees belonging to the laurel family. Leaves and bark of cinnamomum has aromatic oils, therefore it is mostly used for spice. Therefore, it is economically important plants. Branches are light brown color. Curcuma longa L. plant is a member of the Zingiberaceae family and is known as Turmeric in our country [18]. It is a perennial plant that grows naturally in China, India, Indonesia, Malaysia and Cambodia, and is widely cultivated in many tropical regions. It is traditionally used as food additives for colorants, taste, aroma [3], perfumes, medicines, and coloring of textile materials. It is most expensive spice belong yellow pigments. At the end of the dyeing process with cinnamomum

and curcuma longa different brown and yellow color shades are obtained. At the same time with cinnamomum, it can be obtained excellent smell. The purpose of selection of these plants is brown and yellow, which are the trend colors of Autumn/Winter 2022 Fashion Season.

In this research, surgical masks, which we have to use frequently these days due to the pandemic, were dyed with cinnamomum and curcuma longa. The aim of dyeing with them is to improve fastness values and antibacterial characteristics. Covid-19 outbreak is affecting not only Turkey, but also all over the World nowadays. The epidemic spread all over the World after a short period of time, turned the global health crisis. This epidemic has changed the individual's behaviors of human beings. It has been affected every part of our day to day lives such as wearing facemask. Our research aims to investigate changes of color for each dyeing process (CIELAB), the color fastness to perspiration & washing, and antibacterial activity of woven cotton surgical face masks dyed with cinnamomum and curcuma longa. Most people prefer fashionable face masks, with different color according to their clothes. And also, they wear surgical mask only one time and then throw the surrounding. This behavior of the consumers causes an important environmental problem and the direct contact with masks dyed with synthetic dyes with the respiratory system causes health problems. Therefore, it is thought that this problem can be overcome thanks to natural dyeing technique by plant-based dyestuff with different two natural mordant.

Material and Method

Material

The detailed properties of %100 cotton plain woven sample used in the present study were illustrated in Table 1. The cotton fabric used in this study was obtained from the Sayin Company/ Turkey.

Table 1: Properties of cotton woven used in the study.

Areal Weight (g/m2)	Thickness (mm)	Density	
		ends/cm	picks/cm
80	0,157	76	76

Methods

Cotton fabrics used in this study were cut 10*10cm^2 for mordanting and dyeing. After, the cotton fabrics were washed in non-ionic soap at 50 °C for approximately 20 minutes, rinsed and dried at room temperature without air circulation in open air. Salt (NaCl) and apple cider vinegar (CH_3COOH) were selected for mordanting. The mordanted and non-mordanted cotton fabrics were dyed with cinnamomum and curcuma longa with ratio of 1:50 at 90 °C for 90 minutes. Dye baths were prepared according to [19,20] after dyeing mordanting process was performed. Dye concentration used was 1% and 3% based on the fabric weight. The amount of colorant used in the dye bath was calculated using above Equation (1);

$$M=(C*M_f)/100*(100/TS) \quad (1)$$

M=mass of the colorant from cinnamomum and curcuma longa (g)

C=concentration of colorant (%)

M_f=mass of fabric (g)

TS=total colorant (%)

A post-mordanting process was performed at 40 °C for approximately 30 min. with 3wt.% of cotton fabrics with each mordant (NaCl and CH_3COOH). The dyed fabrics were rinsed in distilled water at 30 °C for 5 min. and dried to air thoroughly 24 hours. Two repetitions were performed for fabrics in each dye concentration in order to obtain higher color values and greater color strength.

After the dyeing process, colors of the dyed samples were investigated for each dyeing process using a spectrophotometer (CM-2500d, Konica Minolta, İstanbul) to measure L*, a*, b*, ΔE and K/S values [19]. The CIELab values provide L* ("0" black, "100" white), the higher L values, the lighter the color. Also, the a* value indicates red (+a*) and green (-a*), while the b* value indicates yellow (+b*) and blue (-b*). The greater the magnitude of the a^* and b^* values, the deeper the colors. The color change (ΔE) value was calculated from the L*, a* and b* values by using illuminant D65 and 10 °C standard observer angle. In addition, color strength, K/S, was calculated from the reflectance values; the higher the value, the greater the color strength.

The fabrics are performed color fastness to perspiration (acidic and alkaline) referring to the fabric's tendency not to fade or stain in the event of perspiration. In daily life, textiles touch the skin for long periods of time and they come into contact with the sweat, potentially leading to the transfer of dyes onto the skin. Thus, it is particularly important to test clothing products for color fastness to perspiration. This is performed according to TS EN ISO 105-E04 (2013): Textiles: Test for Color Fastness: Part E04: Color Fastness to Perspiration [21] using SDL Atlas Perpiration Tester (M231/PR1).

The color fastness to washing of dyed fabrics was determined according to ISO 105-C06:2010 standards [22]. The differences between control samples and multifibers, before and after washing cycles was compared visually with gray scale according to color change and staining according to ISO 105-A04:2019; Textiles-Tests for Color Fastness-Part A04: Method for the Instrumental Assessment of the Degree of Staining of Adjacent Fabrics and color change of fabrics with gray scale at the end of the test [23]. The transfer of color from the test specimen to an adjacent specimen is observed with gray scale for staining. Five standard pairs are used. One half of each standard is white, and the second half ranges from white (no staining) to a gray comprising the chroma value of the test specimen (heavy staining). A value of 5 corresponds to virtually no staining, while 1 indicates poor color-fastness. The conditions were observed under the D65 day light.

The level of antibacterial activity of diffusible antimicrobial agents' gram-positive bacterium on masks dyed with cinnamomum and curcuma longa. This is performed according to AATCC

147-Antibacterial Activity Assessment of Textile Materials [24]. Specimens of the test material, including corresponding untreated controls of the same material, were placed in close contact with growth agar which had previously been streaked with test organism. After incubation, a clear area of interrupted growth underneath and along the sides of the test material indicates antibacterial activity of the specimen. Two types of bacterium were selected. The Gram-negative Bacterium; *Klebsiella Pneumoniae* (*K. pneumonia*) is a popular test organism nowadays. The pathogenic Gram-positive Bacterium; *Staphyloccus aureus* (*S. aureus*) has been a major cause of cross-infection in hospitals [25,26].

Result and Discussion

CIE Lab Values

As shown in Table 2, test results indicated that face masks dyed with plant-based colorant, with addition of two types of mordant, yield different brown and yellow shades according to mordant types and the face mask dyed without mordant was used as a control samples.

Table 2: CIELAB values.

Plant-Based Colorant	Mordant Type	Cont. (%)	L*	a*	b*	K/S	ΔE	Color	
Cinnamomum	Non-Mordant	1	96.13	2.01	5.82	3.04	4.84	Light Brown	
		3	92.35	2.6	5.48	3.14	5.74	Light Brown	
	Salt	1	92.92	2.74	6.74	3.29	2.17	Brown	
		3	87.59	3.94	11.74	4.1	2.1	Caramel	
	Vinegar	1	89.7	3.5	9.65	4.35	1.6	Dark Brown	
		3	65.14	4.65	13.25	6.75	1.98	Chocolate Brown	
Curcuma Longa	Non-Mordant	1	62.46	2.19	5.78	1.37	4.19	Yellow	
		3	57.46	2.16	12.47	4.16	6.57	Daisy	
	Salt	1	51.39	3.29	7.16	1.25	2	Bumble Bee	
		3	45.36	3.97	15.76	3.45	3.16	Gold	
	Vinegar	1	50.78	3.37	8.02	4.68	1.77	Mustard	
		3	44.82	4.89	9.48	5.74	2.23	Mustard	

(L*= lighter the color, a*=red values, b*=yellow values, K/S=color strength, ΔE= total color change).

The highest lightness (L*) values are belong to dyed without mordant in both plant-based colorants (Cinnamomum and Curcuma Longa) for 1 and 3wt. % o.w.f. The lowest lightness (L*) are belong facemask dyed with two different mordant for both plant-based colorants. Increasing of mordants % lightness (L*) values are decreased from 96.13 to 92.35 for Cinnamomum and from 62.46 to 57.46 for Curcuma Longa. It means that when the face masks were dyed with using cinnamomum and curcuma longa with salt and vinegar mordant for both 1 and 3wt. % o.w.f., which produced deeper shades of brown and yellow color was observed, the L* values were found to be lower. The L* values were found to be higher for non-mordant dyed samples which correspond to lighter shades. By contrast, facemask dyed non-mordant yielded lower a* and b* values than the facemask dyed with the salt and vinegar. Also, when the face masks were dyed using salt and vinegar mordant for both 1 and 3wt. % o.w.f., which commonly yield bright shades of brown color (cinnamomum) and yellow color (curcuma longa), the red values (a*) and yellow values (b*) values were found to be higher, resulting in darker shades of brown and yellow color than those non-mordant. It was evident that there are many similar studies supporting these results [27,28]. Furthermore, the total color change (ΔE) can help to explain how the mordant change color. The samples of dyeing without mordant were taken as a reference for comparison. Color change (ΔE) value of natural brown and yellow color on facemasks on washable woven cotton surgical face mask dyed with cinnamomum and curcuma longa using mordant were lower than the same face masks dyed without mordant. The findings of this study showed that use of vinegar mordant leads to less of a total color change (ΔE) for %1 dye concentration is 1.60 for cinnamomum and 1.77 for curcuma longa. Interestingly, the ΔE values of given in Table 2 washable woven cotton surgical face mask dyed with 3% concentration without

mordant is 5.74 for cinnamomum and 6.57 curcuma longa. Such findings can be explained by the fact that cotton fabrics dyed with plant-based colorant was less affected by any mordant in terms of color change. Cotton fabric dyeing was difficult process without mordant. The reason of difficult dyeing can be explained that there was not any affiliation between plant-based colorant and cotton fabric. Therefore, analyzing CIELAB values (L*, a*, b*, ΔE, K/S) in conjuction with different types of mordant (non-mordant, salt, vinegar) processes can help researchers and the textile industry about natural dyeing. K/S values were increased with an increase of dye concentration [8]. K/S values of dyed increased in the order of from Apple Cider Vinegar to without mordant for both cinnamomum and curcuma longa. It is remarkable that washable woven cotton surgical face mask dyeing with cinnamomum and curcuma longa extract using vinegar mordant have higher K/S values. In all cases, the vinegar mordant yielded the best dyeing results with 4.35 (1%), 6.75 (3%) for cinnamomum and 4.68 (1%), 5.74(3%) for curcuma longa. According to dyeing process, this situation is thought to be related that vinegar mordant tend to form strong bonds with the plant-based colorants and fiber. Salt mordant blocks dye and reduce the dye interaction with the fiber. The obtained values shown in Table 2, washable woven cotton surgical facemask dyed without mordant had light brown color (cinnamomum) and light-yellow color (curcuma longa), while those mordanted with salt had darker and duller brown (cinnamomum) and yellow color shades (curcuma longa). With vinegar mordant, color shades are darker and duller because of reacting to acidic acid with oxygen in the air [4,28,29].

Color fastness to perspiration

Color fastness to acidic perspiration test results of washable woven cotton surgical face masks dyed with plant-based colorants and without mordant results is presented in Table 3. The acidic fastness grades of control fabric dyed with cinnamomum and curcuma longa showed poor (2), poor to fair (2-3) or fair (3) resistance to color change and color staining. The reason for drastic color change and stain of washable woven cotton surgical face masks is bad interaction between the dye and the fiber. While salt mordanted washable woven cotton surgical facemask showed good (4) & very good (4-5) for dyed % 1 and very good (4-5) and excellent (5) for dyed %3 resistance to color change and staining to cinnamomum and curcuma longa for acidic perspiration fastness. These results show that color does not fade significantly with the use of mordant. Apple cider vinegar mordanted washable woven cotton surgical face mask had better acidic perspiration fastness with % 3 dyed cinnamomum and curcuma longa than salt mordant. According to International Organization of Standardization (ISO) for textile materials, it is considered acceptable in the condition to a grade of 4 or higher for color change and 3 or higher for staining. Therefore, evaluation of color change and staining for both % 1 w.t. and % 3 w.t. dyed with cinnamomum and curcuma longa using non-mordant did not meet ISO standards. Dyeing with cinnamomum and curcuma longa with mordant was acceptable according to standard. Same results obtained previous researchers by dyeing plant based with and without mordant [26,29].

Table 3: Gray scale (Acidic).

			1 wt. %			3 wt. %		
			Non-Mordant	Salt	Vinegar	Non-Mordant	Salt	Vinegar
Color Change		Cinnamomum	3	4	4-5	3	5	5
Color Stain	Acetate		3	4	4-5	2	5	5
	Cotton		2	4	5	2	4-5	5
	Polyamide		2-3	4	4	2	5	5
	Polyester		2	4	5	2-3	5	5
	Polyacrylic		3	4-5	4-5	3	5	4-5
	Wool		2	4	4	3	5	5
Color Change		Curcuma Longa	2	4	4-5	3	4-5	5
Color Stain	Acetate		3	4	4	2	5	5
	Cotton		2	4	5	2	4-5	4-5
	Polyamide		2-3	4-5	4	2	5	5
	Polyester		2	4	4	2-3	4-5	5
	Polyacrylic		2	4-5	4-5	3	5	4-5
	Wool		2	4	4	2	5	5

Color fastness to alkaline perspiration test results of washable woven cotton surgical facemask dyed with plant-based colorants and without mordant was presented in Table 4. The alkaline fastness grades of control fabric dyed with cinnamomum and curcuma longa showed poor (2), poor to fair (2-3) and fair (3) resistance to color change and color staining. Cotton exhibited good resistance to color change and stain due to alkaline perspiration irrespective of the any kind of mordant used. The ratings obtained perspiration fastness to alkaline in terms of the degree of color change and stain of washable woven cotton surgical facemask dyed with cinnamomum and curcuma longa with mordant was good (4), very good (4-5) and excellent (5) as shown in Table 4. Alkaline perspiration fastness

dyed with vinegar mordant were sight improvements in case of salt mordant for both color change and stain of cinnamomum and curcuma longa. And also slight increase in color change and stain was noted in case of salt and vinegar mordanted cottons over control samples. In other words, increase in color was observed in all mordanted samples. The reason of slight increase of fastness values for both acidic and alkaline, mordants helps good affinity between washable woven cotton surgical facemask and plant-based colorant. The probable reason attributed that mordant may help the bonding with the cotton fiber easily, thereby assisting in proper fixation to fibrous structure of washable woven cotton surgical facemask. Hence, dyeing with mordant improves the fastness properties of surgical facemask. Same results obtained previous researchers by dyeing plant-based colorants with and without mordant [4,30].

Table 4: Gray Scale (Alkaline).

			1 wt. %			3 wt. %		
			Non-Mordant	Salt	Vinegar	Non-Mordant	Salt	Vinegar
Color Change		Cinnamomum	3	4	4-5	3	4	4-5
Color Stain	Acetate		3	4-5	4	3	4-5	5
	Cotton		2-3	4	5	2-3	4-5	5
	Polyamide		2-3	5	4	2	4	5
	Polyester		2	4-5	5	2-3	4	5
	Polyacrylic		3	4-5	5	3	4-5	4-5
	Wool		2	4	4-5	3	5	5
Color Change		Curcuma Longa	3	4	4	3	4-5	4-5
Color Stain	Acetate		3	4-5	5	3	4-5	4-5
	Cotton		2	4	5	2	4-5	5
	Polyamide		2-3	4	4	2	5	4-5
	Polyester		2	4	4	2-3	4-5	5
	Polyacrylic		3	4	4-5	4	4	4-5
	Wool		3	4	4	3	5	5

Color fastness to washing

The washing fastness ratings of washable cotton surgical face mask using plant-based colorants at different dye concentration with and without metallic mordant are given in Table 5. Table shows that the wash fastness ratings of non-mordanted dyed samples were very poor (1), very poor to poor (1-2) and poor (2). This may be due to weak plant-based colorants-cotton fibre bonding. Similar test processes have been obtained as a result of dyeing with natural dyestuff with plant based by many researchers before [8,30]. All mordanted washable woven cotton surgical face mask is found to have better fastness values than non-mordanted. When comparing washing fastness of cinnamomum and curcuma longa, similar values were observed for 1w.t. % and 3w.t. % dyeing concentration. In addition, it can be said that the use of mordant changes slightly the washing fastness. Fastness values of samples dyed with vinegar mordant were very good (4-5) and excellent (5) as shown in Table 5. In fact, the acidic acid was easily formed with the cotton fibers, and this could affinity between plant-based dyestuff and cotton fibre. In other words, mordant was assisted in proper fixation on the cotton fibre easily. Hence, mordanting alters the washing fastness ratings into positive as well as makes them insoluble with water and ultimately improves washing fastness properties [7,9,30]. Low washing fastness values might to be due to migration of plant-based dyestuff from not firmly attached to the fabric surface. Because water molecules were removed easily some water-soluble dyes by the action of washing conditions. The results indicated that fastness ratings with mordant dyeing obtained from plant-based dyestuff were suitable for all fibers (acetate, cotton, polyamide, polyester, polyacrylic, wool).

Table 5: Color fastness to washing.

			1 wt. %			3 wt. %		
			Non-Mordant	Salt	Vinegar	Non-Mordant	Salt	Vinegar
Color Change		Cinnamomum	1	4	4-5	1	4-5	5
Color Stain	Acetate		1	4	4-5	1	4-5	5
	Cotton		2	4	4-5	1	4-5	5
	Polyamide		1-2	4	5	1	4-5	5
	Polyester		2	4	5	2	4-5	5
	Polyacrylic		2	4	5	1	4-5	4-5
	Wool		2	4	4-5	1	4-5	5

Color Change		Curcuma Longa	2	4	4-5	1	4-5	5
Color Stain	Acetate		2	4	5	1-2	4-5	5
	Cotton		2	4	5	2	4-5	4-5
	Polyamide		1-2	4	4-5	1-2	4-5	5
	Polyester		1-2	4	4-5	1-2	4-5	5
	Polyacrylic		2	4	4-5	2	4-5	4-5
	Wool		2	4	4-5	2	4-5	5

Antibacterial Activity

Figure 1 shows the antibacterial activity of washable cotton woveurgicaln face masks dyed using plant-based colorants with and without mordant.

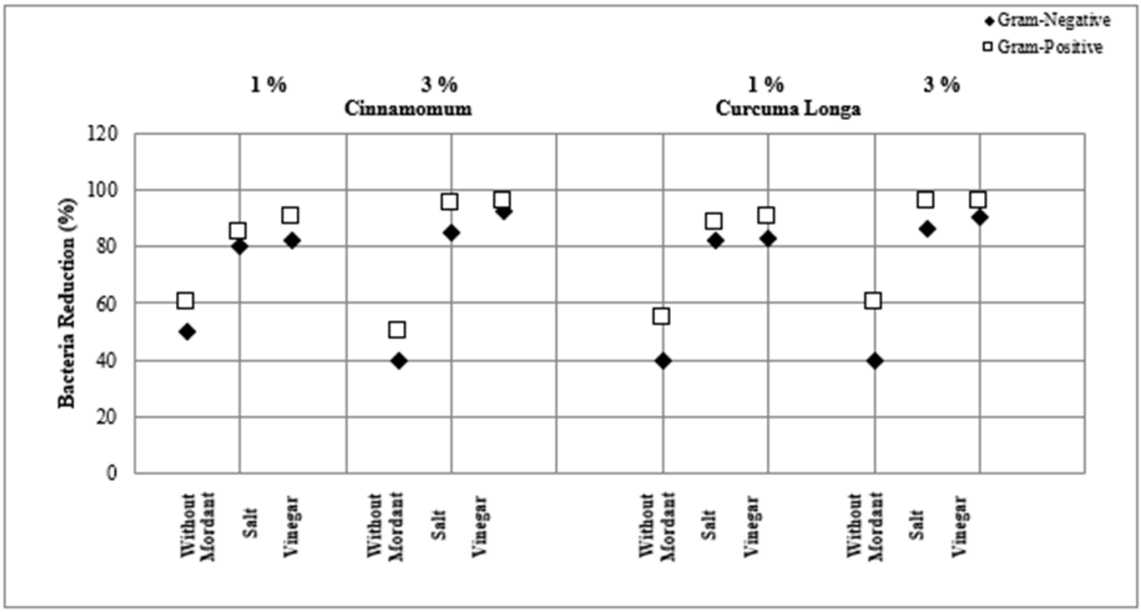

Figure 1: Reduction of bacteria.

While washable woven cotton surgical face masks dyed with cinnamomum without mordant showed 50% & 60% (1% wt.) and 40% & 50% (3% wt.) bacteria reduction against Gram-negative bacteria *K. pneumonia* & Gram-positive bacteria *S. aureus*, washable woven cotton surgical facemask dyed using curcuma longa without mordant showed a 40% & 55% (1% wt.) and a 40% & 60% (3% wt.) bacteria reduction against Gram-negative bacteria *K. pneumonia* & Gram- positive bacteria *S. aureus*. Washable woven cotton surgical face masks dyed using cinnamomum mordanting with salt and vinegar with showed 80%, 82% (1% wt.) and 85%, 92% (3% wt.) of bacteria reduction for gram-negative and 85%, 90% (1% wt.) and 95%, 96% (3% wt.) for gram-positive with respectively. Washable woven cotton surgical face masks dyed using curcuma longa mordanting with salt and vinegar with showed an 82%, 83% (1% wt) and an 86%, 90% (3% wt.) of bacteria reduction for Gram-negative bacteria and an 88%, 90% (1%wt.) and an 96%,96% (3% wt.) for Gram-positive with respectively. Differences between Gram-negative and Gram-positive bacteria seem very important. The antibacterial ability towards Gram-negative bacteria was lower than towards Gram- positive bacteria. Many researchers found the same results [26,28]. The main reason of these results is that plant-based colorants are more effective against Gram-positive bacteria. Cinnamomum and curcuma longa work more effectively against Gram-positive bacteria than Gram-negative bacteria.

Conclusion

Natural dyes have become increasingly popular nowadays, because of not only decreasing fossil resources and increasing ecological and human health sensitivity all over the world. Therefore, since ancient times natural dyes have been extracted from different natural resources such as plant, animal and fungal species in order to use food, cosmetic, medical and textile industry. In this study, the reason for choosing plant-based colorants as a sustainable source for washable woven cotton surgical face masks for natural dyes was investigated. The effects of two natural mordants (NaCl and CH_3COOH) and a non-mordant (control sample) on the dye uptake, improved color fastness and antibacterial activity of washable woven cotton surgical face masks dyed using cinnamomum and curcuma longa was examined with salt (NaCl) and apple cider vinegar (CH_3COOH).

The experimental results of this study are summarized below;

- Color of dyed samples was highly affected by the type of mordant types.
- Apple cider vinegar (CH_3COOH) give the best dyeing results and exhibited darker color than salt (NaCl) mordant.
- Dyeing with mordant improves color strength (K/S), fastness and antibacterial activity compared to the non-mordant control samples.
- Washable woven cotton surgical face masks dyed without mordant showed little antibacterial activity against Gram-positive and Gram-negative bacteria.
- Antibacterial activity against Gram-positive and Gram-negative bacteria was not observed in the washable woven cotton surgical face masks dyed using natural cinnamomum and curcuma longa with mordant.
- Improvement of K/S values dyed with mordant means higher dye adsorption.
- K/S values increased in the order of CH_3COOH > NaCl >non-mordant
- A variety of brown (cinnamomum) and yellow (circuma longa) color hues were obtained respect to the mordant type and without mordant.
- It was investigated that mordant helps good affinity between washable woven cotton surgical face mask and plant based colorant.
- The fastness properties ranged from good to excellent with mordant used, while it is poor to poor with non-mordant (control sample)
- The control samples which dyed without mordant exhibit poor fastness to washing, and perspiration due to weak dye-fiber bonding.
- Dyeing of cotton with cinnamomum and curcuma longa extract as natural materials can be a feasible commercial alternative to synthetic dyes for textile dyeing industry.
- Plant based natural dyestuff is environmentally friendly colorants for sustainable textile industry to satisfy local regulatory requirements.
- Plant based natural dyestuff is cleaner potential source besides synthetic dyestuff with requires less water and energy during production and using by the textile industry.

Experimental results may contribute to develop new natural dyestuff for textile industry and researchers to motivate sustainable textile.

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