Sustainable Processing of Naturally Dyed Textiles Through Green Discharge Printing Techniques Using Taro Corms as a Bio-Oxidizing Agent

Menna M. Ragab
Benha University
Hanan A. Othman
Benha University
Ahmed G. Hassabo
aga.hassabo@hotmail.com

National Research Centre

Research Article

Keywords: Discharge printing, eco-friendly, sustainable textiles, polyphenol oxidase enzyme, peroxidase enzyme, natural dyes, taro corms

Posted Date: April 24th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-5960075/v1

Additional Declarations: No competing interests reported.

Sustainable Processing of Naturally Dyed Textiles Through Green Discharge Printing Techniques Using Taro Corms as a Bio-Oxidizing Agent

Menna M. Ragab [a], Hanan A. Othman [a] and Ahmed G. Hassabo [b]*

[a] Textile Printing, Dyeing and Finishing Department, Faculty of Applied Arts, Benha University, Benha, Egypt

[b] National Research Centre (Scopus affiliation ID 60014618), Textile Research and Technology Institute, Pre-treatment, and Finishing of Cellulose-based Textiles Department, 33 El-Behouth St. (former El-Tahrir str.), Dokki, P.O. 12622, Giza, Egypt

*Corresponding author: aga.hassabo@hotmail.com

Abstract

The influence of the textile industry on the environment, as well as the usage of raw materials and natural resources, is becoming a major problem. It is no longer sufficient to have a product that is simply safe for humans; the product must also be ecologically safe throughout its entire life cycle. As a result, there has been a shift toward employing enzymes in the textile sector to promote eco-friendly production. The goal of this research is to create an environmentally friendly discharge printing on cotton and wool textiles, dyed with various natural plant extracts *(Ficus benjamina, Psidium guajava leaves, Solanum melongena peel, and Brassica oleracea var. capitata rubra*) under varied circumstances by using polyphenol oxidase (PPO) and peroxidase (POD) enzymes extracted from taro corms (Colocasia antiquorum) instead of harmful reducing or oxidizing agents. The enzyme extraction temperature was 25 °C, and the solute-liquid ratio (1:4 (w/v)) at pH 5.0 after a treatment time of 5 min. The oxidative enzymes were analyzed using Gas Chromatography-Mass Spectrometer (GC-MS) Analysis, which verified the presence of a Retinol component with a molecular weight of 286.45 g/mol and a retention time of 14.7 min, which is regarded as proof of the existence of oxidative enzymes. The activity of oxidative enzymes isolated from taro corms increases over time, with PPO having the highest activity at 180 seconds at a wavelength of 420 nm. POD achieves its peak activity at 180 seconds, and the wavelength 436 was observed. These allow them to be employed as a discharge agent.

The effects of enzyme concentration, pH of the printing paste, treatment time, temperature of enzymatic treatment, and also the effect of mixing this enzyme extract with some environmentally friendly oxidizing and reducing agents were studied to determine the discharge efficiency. The results indicate that the discharge rates reached about 40-57% using the enzyme extracted from taro corms at pH 3 for wool samples and pH 5 for cotton one. Mixing with other reducing or oxidizing agents in different concentrations led to a higher discharge rate, which reached 60-66%, and different color half-tones were obtained depending on the difference in mixing ratio, concentration, pH, and other factors affecting color removal. It was also observed that the tensile strength of wool printed samples was constant in the pesidium guava-dyed sample, while the tensile strength in the remaining samples increased by 1-4%, except for the sample dyed with ficus leaves, which decreased. While the tensile strength for cotton samples increased by 4% in the ficus dyed sample and decreased by 13% in the pesidium guava-dyed sample, which is considered an acceptable range.

It has been reached that taro corms enzyme extract led to obtaining color halftones on the printed materials as a result of the partial discharge that occurred due to the biological oxidation of the enzyme extract, which is considered a vital alternative to the toxic and environmentally harmful reducing and oxidizing agents.

Keywords: Discharge printing, eco-friendly, sustainable textiles, polyphenol oxidase enzyme, peroxidase enzyme, natural dyes, taro corms.

1. Introduction

Climate change is a persistent worldwide danger to humanity, and unfortunately, the textile sector is the second-largest contributor to greenhouse gas emissions due to its extensive supply chain.[1, 2] contamination occurs in a variety of sub-sectors, including water contamination, where urea, reducing, and oxidizing agents emerge as a toxic chemical that harms both human health and aquatic life.[3-6]

The global requirement for sustainable textile technologies is increasing.[7-9] This strategy aims to promote eco-friendly and visually appealing textiles through discharge printing processes, leading to a more unique and sustainable future for the fashion and textile sectors. The achievement marks a shift towards a more sustainable and environmentally responsible textile sector, reflecting a rising worldwide commitment to natural resource preservation.[7, 10] Therefore for the textile industry has reached a crossroads: pursuing sustainability and meeting rising criteria for materials.[7, 11] As a result, the employment of environmentally friendly natural dyes, auxiliaries, and low-impact biotechnology is becoming increasingly popular.[4, 10, 12]

Natural dyes are a safe and sustainable bioresource derived from plants, animals, and microbes.[3, 10, 11] Examples include ficus leaves, pesidium guava leaves, eggplant skin, and red cabbage leaves, all of which have been commonly used in textile finishing. They are used for a variety of applications, including textile, food, medicinal, and cosmetic. Using naturally derived ingredients from renewable sources can lead to cleaner manufacture of natural dyes, resulting in higher resource uptake and reduced energy requirements for wastewater treatment.[5, 12] The use of natural dyes has increased as an eco-friendly and sustainable alternative to synthetic dyes owing to their negative impact on the environment and public health.[12] They may be used in textile dyeing, printing, finishing, and other industries. Natural dyes are becoming increasingly popular due to their antibacterial and antioxidant properties, making them ideal for textile processing.[13]

Biotechnology plays a significant role in sustainability across various fields. It has dramatically expanded the applicability of enzyme systems in all aspects of textile manufacturing. Enzymes may be programmed to perform particular reactions such as hydrolysis, oxidation, and synthesis, for a range of applications. There is growing recognition in the textile manufacturing and construction sectors that enzymes may be utilized in numerous remediation procedures to fulfill particular goals.

The present technical gaps in printing textiles using the discharge technique include balancing efficacy and environmental sustainability, as traditional methods often use synthetic chemicals such as such as reducing and oxidizing agents, acids, alkalis, and various salts, which are the most commonly and widely used and can be harmful, toxic, and polluting. [14] The limitations of conventional discharge agents are presented in some studies as follows. Denim fabric was discharge printed using potassium permanganate ($KMnO_4$), and it was observed that discharge whiteness is directly proportional to reaction time and $KMnO_4$ concentration. Although good discharge rates were obtained, tensile and tear strength were found to decrease with increasing $KMnO_4$ concentration and reaction time. This is in addition to environmental pollution and toxic fumes resulting from the use of potassium permanganate.[15] Sulphoxylate Formaldehyde ($NaHSo_2.CH_2O.2H_2O$) is an effective discharging agent used in discharge printing. However, it is very toxic and produces formaldehyde, a carcinogen linked to both sinus and nasopharyngeal cancer. Additionally, discharge printing can have a long-term impact on human health.[16] As a result, there was a need to move towards using some natural biological resources in the discharge printing process, to keep pace with the global trend towards environmental sustainability processes. Eco-friendly bio products such as laccase, enzymes, and brewer's yeast have effectively replaced hazardous chemicals and unsustainable reducing agents. Samples of many beautiful, colored halftones were obtained.[17] Enzymatic discharge printing uses a phenol-oxidizing enzyme system derived from horseradish peroxidase to selectively discharge reactive dye from cotton fabric, resulting in a discharge-printed surface.[18] Another process involves enzymatic discharge printing on the surface of cellulosic fabrics like denim, using an oxidoreductase (lacase) enzyme, which successfully produced color removal.[19]

Agricultural waste and trash are a global concern that must be addressed comprehensively. Improper handling of agricultural waste can cause major environmental issues such as soil contamination, water pollution, and air pollution.[20, 21] Recent biotechnology improvements in this approach have enabled the creation of cheaper, more suitable, environmentally friendly, and more easily available enzymes from agricultural waste such as taro corms. [22-25]

Colocasia antiquorum, which is known as "taro", [26-28] is a member of the Arum Family. [29] It is a root crop grown in many parts of the wet tropics and some parts of the Middle East. [27, 30, 31] It is a monocotyledonous crop that grows an underground stem, [31] and is a common foodstuff in many tropical and subtropical regions across the world. [32-34] The crop features a variety of characteristics, including corms, leaves, and flowers, as well as chemical fertilizers. The plant is made up of a corm that lies just below the soil's surface, with leaves growing from the bottom. [31] The nutritious section is the corm, which is created underground by a thickening of the stem's base. [35] Taro corms are shown in **Figure 1**. [26]

Figure 1: Taro corms

Taro corm is a rich source of amino acids and starch, which is finely grained. [33] Wild taro tubers and corms contain soluble oxalic acid ($C_2H_2O_4$) and insoluble oxalate salts (oxalate ions of oxalic acid). [36] Unwashed wild taro corms have been found to have skin irritation and a strong odor due to insoluble oxalate salts. [26] Furthermore, taro is a significant source of antioxidants, primarily phenolic compounds, both in terms of variety and amount, which are dispersed in the edible region of taro. [28]

Taro corms are extremely susceptible to enzymatic browning.[37] This shows that the corm has highly active polyphenol oxidase (PPO) and peroxidase (POD) enzymes. [32, 38, 39] PPO and POD are oxidoreductase enzymes that are considered major enzymes involved in enzymatic browning reactions. [40-42] They promote the hydroxylating monophenols and convert both o and p-diphenols into dark pigments like quinones and melanins in fresh-cut foods, and the oxidation of quinones to uncolored acids.[43] This attracted attention to its use as a bio-oxidizing agent in green discharge printing. [34]

Plants primarily store PPO in plastids, such as chloroplasts and leucoplasts, with higher levels in immature tissues. PPO is classified into three types based on substrate specificity and action mode: tyrosinase, catechol oxidase, and laccase.[44] All of them can be used as a biological discharge agent.[43, 45] POD is known for its high heat stability. POD produces browning to a lower level when compared with PPO, as it requires the presence of hydrogen or organic peroxide to oxidize phenols. [46]

PPO and POD have been proven to be efficient in the biodegradation of phenolic contaminants from industrial wastewater and effluent.[41] In the available literature, much information is available on the use of free and immobilized PPO in several applied areas, such as the oxidation of phenolic compounds from wastewater. [47] To date, however, an exhaustive overview on the removal of Phenolic compounds (which are responsible for the color in natural dyes from the fabric) through discharge printing instead of using harmful and toxic compounds is still lacking.

Given this information, an attempt was made to study the effect of the oxidative enzymes extracted from taro corms in biological discharge printing. These enzymes were extracted and applied to fabrics dyed with natural plant extracts, and the various factors affecting the activity of the enzymes and their ability to discharge were investigated. Different color shades were obtained as a result of partial color discharge.

2. Experimental

2.1. Materials

Bleached scoured (100%) cotton fabric with whiteness degree 51.67 (Plain 1/1, number of warps per inch (60), number of wefts per inch: (60), 100%; 158 g/m^2) supplied by Ghazel El-Mahala for Textile Industry Co., Egypt, was used during this research. (100%) wool fabric with a whiteness degree of 18.71- (Twill 2/2, number of wefts per inch (48), 100%; 210 g/m^2) supplied by Ghazel El-Mahala for Textile Industry Co., Egypt, was used during this research.

Natural coloring substances used in this work were extracted from Ficus leaves, Psidium guava leaves, eggplant skin, and red cabbage leaves, which were purchased from an agricultural farm in Egypt.

Medium viscosity sodium alginate ($C_6H_7O_6Na$) from brown algae (manufactured by SDFCL SD Fine Chem Limited company based out of Mumbai, India) was used as a thickening agent. Its chemical structure is shown in **Figure 2**. [48]

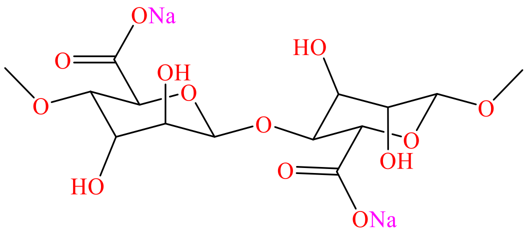


Figure 2: Sodium alginate structure

Taro corms as a bio-oxidizing agent were purchased from an agricultural farm in Egypt. Hydrogen peroxide (H_2O_2 50%) was purchased from Isochem Germany. Glucose ($C_6H_{12}O_6$) as a reducing agent was purchased from the local market. sodium hydrosulfite (sodium dithionite) ($Na_2S_2O_4$) as a reducing agent was purchased from Alpha Chemika, and its headquarters are in Andheri, Mumbai, Maharashtra, and brewer's yeast was purchased from the local market.

Sodium carbonate (Na_2CO_3) and acetic acid (CH_3COOH) are laboratory-grade chemicals to modify the pH medium. All chemicals and reagents were used exactly as supplied, with no purification.

2.2. Methods

2.2.1. Extraction of natural dyes from plants

The naturally fresh leaves and peels were properly washed and cleansed with tap water to eliminate dust and other particle debris. Then they were chopped into little pieces, and the natural dye was extracted using the water extraction method, in which 500 g of Ficus leaves pieces, 300 g of Psidium guava leaves pieces, 350 g of eggplant peels, and 700 g of red cabbage leaves pieces were soaked in one L of boiled water under constant stirring for 60 min. After which, the dye extract was filtered using gauze fabric. Then, the dye extract was kept at 4°C and utilized without additional purification. [49-55]

2.2.2. Dyeing of cotton and wool fabric with natural plant extracts

In most cases, the fabric is dyed by boiling it in a water bath containing an aqueous extract solution of a specific natural plant until all of the coloring substance has been absorbed by the cloth. The dyeing of both fabric materials was done by keeping the material-to-liquor ratio at 1:30 in a shaking water bath. And the pH of the dye bath was maintained at 10 using Na_2CO_3 in the case of cotton fabric, while it was adjusted to 5 in the case of wool fabric. The temperature was then raised to 90-100 °C in 10 minutes and the samples were left at this temperature for 60 minutes. Then the fabric samples were washed and spread out to dry gradually in the air under the sun. [56-58]

2.2.3. Preparation of taro corm extract as a bio-oxidizing agent

PPO enzyme is widespread in fruits and vegetables. This causes food quality loss, including changes in color, taste, flavor, and nutritional content. [59] PPO activity causes browning and significant losses in vegetables, such as taro corms, which are edible parts formed underground by a thickening of the base of the stem and are considered a rich source of PPO enzyme. [34]

Polyphenol oxidase was extracted using taro corms, which were purchased from the local market in Egypt. Then they were cut into small pieces. The extraction procedure was carried out at room temperature (25°C). preparation of crude extract was as follows: 75 g of cutting pieces were homogenized in 60 ml of water using a blender for 5 min, and the pH 5. The extract was filtered through gauze cloth and used as a crude enzyme. The crude taro extract was stored in a glass beaker in the freezer at 0°C until used. Extraction procedure of oxidative enzymes from taro corms is illustrated in **Figure 3**.

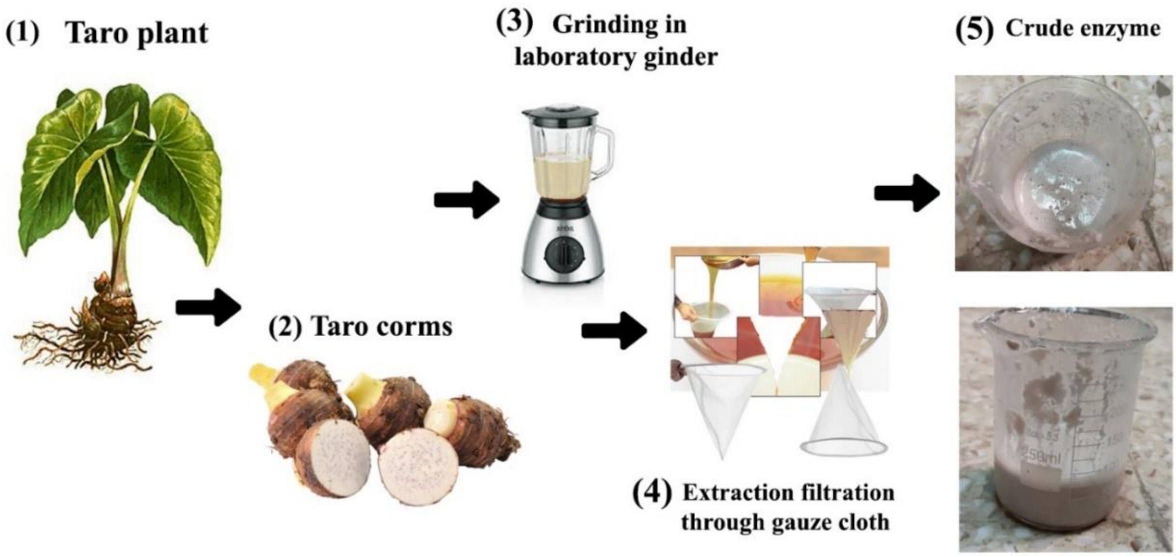


Figure 3: Extraction procedure of oxidative enzymes from taro corms

2.2.4. Bio Discharge Printing of cotton and wool fabrics dyed with various natural plant extracts using taro corm extract as a bio-oxidizing agent

Taro corms are highly sensitive to enzymatic browning, and this part indicates highly active polyphenol oxidase and peroxidase enzymes, so they have been used in bio-discharge printing. [38] The dyed cotton and wool samples were initially printed with a printing paste that just included the thickening agent (sodium alginate) and the oxidizing agent (taro corms extract) with different concentrations*,* at varying parameters using a silk screen printing technique, keeping the pH of the printing paste 5 (as it's in taro corms extract) for cotton. And in the case of wool, we added acetic acid to make the pH of the printing paste 3.

The recipe for cotton and wool printing is shown below: -

Taro corm extract:	X (50, 100, 150, 200, 250, 300) g/kg
Sodium alginate:	700 g
Acetic acid:	till pH 3 (only in the case of wool)
Water:	Y g
Total	1000 g

After printing, the cotton and wool materials were left to dry for a suitable time and temperature. Then the printed samples were washed with soap (2g/L non-ionic detergent) at 40-50˚C for 5 min, rinsed with cold water, and finally, air dried.

The printing of cotton and wool fabrics have been occurred using different concentrations of taro corms extract (50, 100, 150, 200, 250, and 300 g/kg) at different pH (3, 4, 5, 6, and 7), different times (30, 45, 60, 90, 120, 180, and 240 min), and different temperatures (0, 25, 40, 60, and 80°C).

To justify the drying conditions, various time intervals and temperatures were object as mentioned in the previous paragraph. The color depth and whiteness of fabrics printed with enzyme extract and dried at different temperatures and times were measured. The ideal drying conditions were determined through the removal rate values.

Another printing paste, including SHS as a chemical reducing agent, was created to compare its discharge effect to that achieved when the enzymatic extract was used as a bio-oxidizing agent. This paste comprised sodium alginate as a commercial thickener and the appropriate concentration of SHS (250 g/kg) at pH 10 for cotton samples and pH 5 for wool samples. After applying the paste to both samples through direct screen printing, the cotton samples were steamed at 110 °C for 15 minutes, while the wool samples were permitted to dry at room temperature (25 °C) until totally dry. SHS has been shown to have a decreasing impact at room temperature or on further heating, according to the substance and dye employed. [60]

2.3. Measurements

2.3.1. Color Measurements

The color strength (in terms of K/S value), whiteness index, yellowness index, chromatic coordinates, and CIE L a b values of the natural and synthetic colored textiles were tested using the AATCC 135-1985 procedure and (Data color International 500 reflectance spectrophotometer manufactured by DatacolorAG, a Swiss company headquartered in Risch, Switzerland) interfaced to a computer. Color strength values (K/S) of the dyed and printed samples were calculated by the Kubelka-Munk equation. [61-64]

$$\mathrm{K/S} = \frac{(1-R)2}{2R} - \frac{(1-R_{\circ})2}{2R_{\circ}}$$

where R is the reflectance of the printed sample at the wavelength of maximum absorbance, $R_{\circ}$ for uncolored (white) sample reflectance, K is the absorbance, and S is the scattering. [63, 65, 66] The Ficus leaves natural dye was measured at λ= 360 nm, whereas the Psidium guava leaves natural dye was measured at λ= 365 nm, while eggplant skin natural dye was measured at λ= 365 nm, and red cabbage leaves natural dye was measured at λ= 360 nm.

2.3.2. Mechanical properties

Tensile strength and elongation at break were measured for samples with a high whiteness index at 25°C and 65 % moisture content using the tensile strength device FMCW 500 (Veb Thuringer Industrie Werk Rauenste in 11/2612 Germany) following ASTM test method D5035. As a control sample, undyed scoured textiles were maintained.[67] The AATCC 66 - 2014 was used to calculate the crease recovery angle (CRA). [68] The fabric roughness was evaluated using the surface roughness instrument SE 1700 (manufactured by Tokyo Seimitsu Co., Ltd., a Japanese company known for its precision metrology equipment) following ASTM D 7127-13. [69]

2.3.3. Colorfastness properties

The colorfastness to washing was evaluated using the Laudner-Ometer (manufactured by SDL Atlas, a company with a significant presence in the United States, United Kingdom, Hong Kong, and China) and the AATCC Test Procedure 61-2013. [70] Colorfastness to rubbing (dry and wet) was evaluated using a Crock Meter (Shanghai JAG Textile Testing Instruments Co., Ltd) following the AATCC test method 8 - 2016. [71] Colorfastness to perspiration was measured using the AATCC test method 15 - 2013. (acidic and alkaline). [72] The AATCC test method 16.1-2014 was used to measure colorfastness to light. [73] The grayscale color change reference was used to evaluate the fastness properties of washing, rubbing, and perspiration, while the blue scale color change reference was utilized to measure the light fastness characteristics of colored materials. [66, 74]

2.3.4. *GC-MS chromatography*

The organic solvent (methanol) was used to dissolve the taro corms aqueous extract. The process typically involves liquid-liquid extraction (LLE): 1)- The aqueous extract is combined with the organic solvent in a specific ratio, 2)- The mixture is vigorously shaken or stirred to ensure thorough interaction between the two phases, 3)- After mixing, the organic phase (containing the analytes) is separated from the aqueous phase, often using a centrifuge or separating funnel, 4)-The organic phase is then collected, dried (if necessary), and prepared for injection into the GC-MS system.

The GC-MS system manufacturer is Shimadzu Corporation in Japan. The GC-MS technique employs a capillary column with a length of 30 to 60 cm and a diameter of 0.25 mm, which is filled with a helium carrier gas and used to separate the components of a mixture, while mass spectroscopy analyses each component. The substance was then identified by comparing retention times to actual standards. [66, 75-77]

2.3.5. *Determination of peroxidase and polyphenol-oxidase activity*

Polyphenol oxidase enzyme activity was measured using a spectrophotometer at 30°C by monitoring the initial rate of quinone production as evidenced by a rise in absorbance at 410 nm for 15-second intervals using catechol as substrate. PPO activity was measured using a reaction combination of 0.1 mL freshly generated crude enzyme extract, 3.9 mL of 100 mM phosphate buffer (pH 7.0), and 1 mL of 50 mM catechol. PPO activity was measured in triplicate, and the findings were represented as means. The starting rate was determined using the slope of the absorbance vs. time curve. One unit (U) of PPO activity was defined as the quantity of enzyme that raised absorbance by 0.001 per minute under the test conditions. [78]

The activity of the peroxidase can be determined by the reaction mixture containing the substrate, which was made up of 2.850 mL of phosphate buffer (50 mM, pH 7.0) and 0.015 mL of guaiacol (0.5%) ethyl alcohol solution, which was kept at 25 °C in a water bath. The reaction was started by adding 0.010 mL of the enzymatic extract and 0.450 mL of H_2O_2 (1%). After 5 minutes of reaction, the spectral absorption at 470 nm was measured with a spectrophotometer (Biospectro SP-220) and compared to a control cell in which the H_2O_2 solution was replaced by water. One unit of peroxidase activity (U) was defined as the quantity of enzyme required to generate a 0.001 increase in absorption for each minute of reaction time. [79, 80]

2.3.6. *Determination of total phenolic*

The total phenolic content of the natural plant extracts was evaluated using the Folin-Ciocalteu reagent and gallic acid as a standard phenolic component. [81, 82] The Folin-Ciocalteu technique is an electron transfer-based test that provides reducing capability as phenolic content. The total phenolic content of natural plant extracts is affected by the solvent used for extraction. The external calibration was done using different concentrations of gallic acid, i.e., 0.00, 0.25, 0.50, 0.75, and 1 mM. [83] Briefly, 200 mL of crude extract (1 mg/mL) was made up to 3 mL with distilled water, mixed thoroughly with 0.5 mL of Folin–Ciocalteu reagent for 3 min, followed by the addition of 2 mL of 20% (w/v) sodium carbonate. The mixture was incubated for 2h at room temperature, and absorbance was measured at 760 nm using a SPECTRAmax-PLUS384 UV–vis spectrophotometer. The total phenolic content was calculated from the calibration curve that explained in **Figure 4**, and the results were expressed as mg of gallic acid equivalent per g dry weight. (mg GAE/g dw). [82, 84]

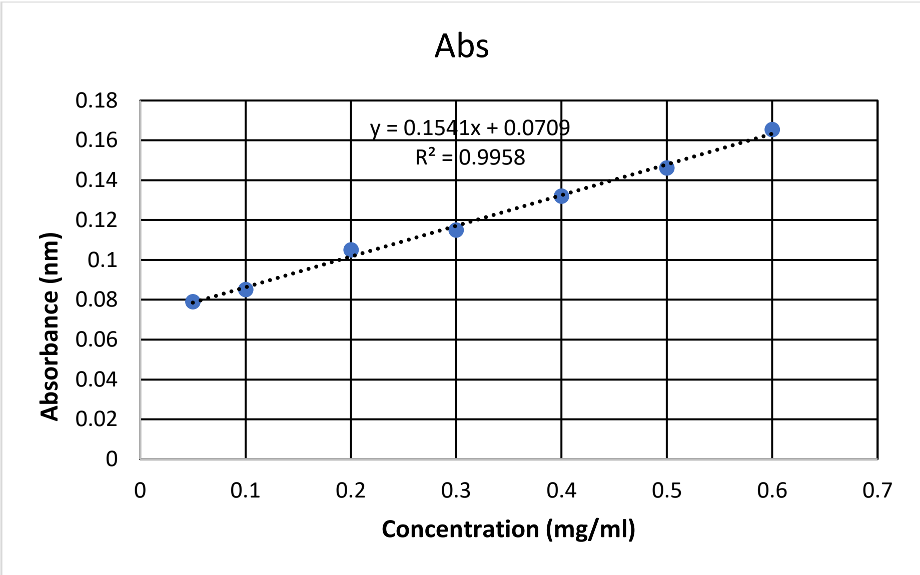


Figure 4: Gallic acid standard curve of total phenolic content

2.3.7. Particle Size Analyzer

The molecular size of the natural plant extracts was characterized by a laser particle size analyzer, MasterSizer/2000 (MALVERN Instruments, UK), according to ASTM E11:61 [85] and BS 410-1 and 2: 2000,[86] ISO 565: 1990. [87]

3. Results and Discussion

Discharge printing was based on the use of chemical reducing agents like thiourea dioxide and formaldehyde compounds to achieve a high whiteness degree on colored materials. The removal of chromogenic groups implies that these chemical reducing agents might be suitable for discharge printing of fabrics colored with specific azo-dyes.[88] Due to secondary pollution problems resulting from the use of unnecessary chemicals, researchers have explored the use of natural oxidizing enzyme extracts to decolorize textile dyes.

Complex enzymes show color-removing abilities. Concentrated taro coms extract included a synergistic combination of two key enzymes, making it appropriate for large-scale use in the textile industry. The enhanced enzymatic discharging procedure can substitute chemical discharge agents for removing color from woven, dyed fabrics. However, longer periods are needed to obtain optimal color removal, which is in addition to the difficulty of extracting enzymes and their inability to remove color 100%. Further study is needed to address this issue before commercializing biological color removal in the textile business. However, it remains superior to chemical discharge agents in terms of cost and environmental advantages.[89]

3.1. Characterization of natural plant extracts

Phenolic compounds are one of the most important chemical structures found in biological reagents. The identification of plant extracts (Ficus leaves, Psidium guava leaves, eggplant skin, and red cabbage leaves) indicated that they are a rich source of a phenolic component. Plant extracts were tested for total yield extract and total phenol, and they were (103.9 ± 0.90) in Psidium guava, (91.2 ± 0.34) in Ficus leaves, (106.3 ± 0.39) in eggplant skin, (100.4 ± 1.5) in red cabbage leaves. All of these phenolic compounds (which may be essential for the extract's coloration) are removed via enzyme oxidation. Evidence of this is the presence of discharge on textiles colored with these extracts and printed with oxidizing enzymes. **Figure 5** explains the oxidation of phenolic compounds by using oxidative enzymes to form colorless acids. [90, 91]

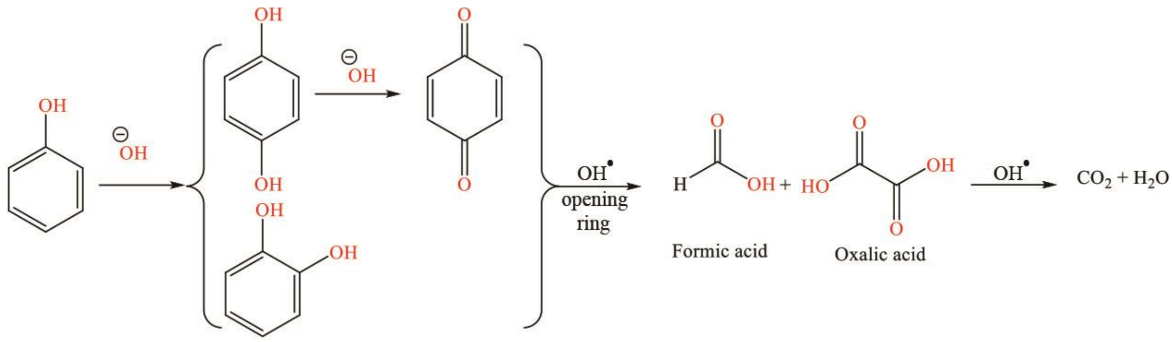


Figure 5: Possible suggested mechanism for the oxidation of a phenolic compound using oxidative enzymes.

Compounds having a catechol group were preferred for oxidation by the enzyme, but compounds containing a pyrogallol group or mono-hydroxyl substituted phenolic moieties were oxidized less often. [92]

GC-MS analysis of the aqueous extract of Psidium guava leaves, Ficus leaves, eggplant peel, and red cabbage leaves was carried out to identify compounds that are found in these extracts, and the results are similar to those illustrated by Toluwani Tella *et.al* [93], Hossam S. EL-BELTAGI *et.al* [94], Ahmed Abdelkhalek *et.al* [95] and Al-Mudhafr *et.al* [96].

It is illustrated in **Figure 6** the particle size distribution of four plant extracts in water (Ficus leaves, Psidium guava leaves, eggplant skin, and red cabbage leaves). The particle size of natural dye extracts was found to be 883, 269, 346.3, and 499.4 nm for eggplant skin, Ficus leaves, Psidium guava leaves, and red cabbage leaves, respectively. It is also important to note that the particle size of eggplant skin extract is larger than that of the other extracts, while the Ficus leaves extract has the lowest particle size, resulting in the best diffusion and the greatest K/S value.

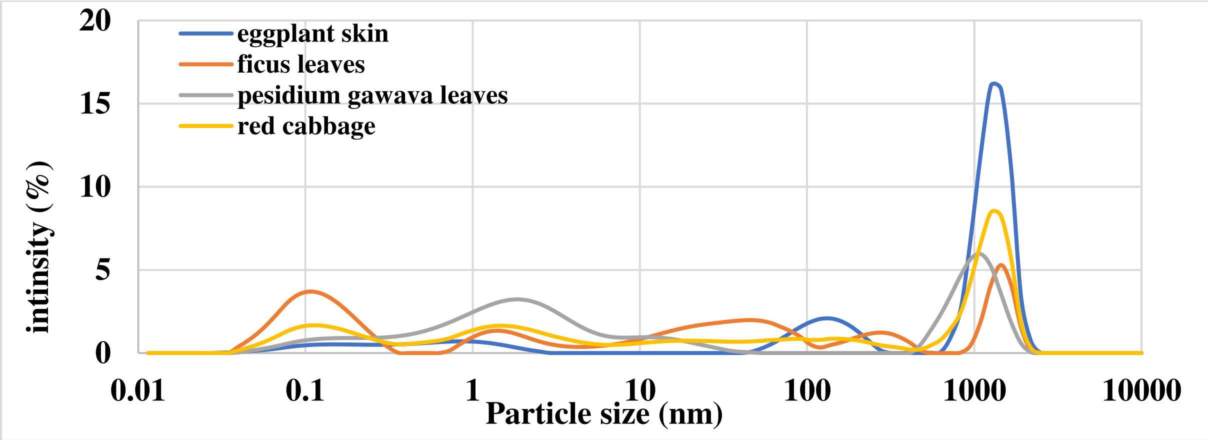


Figure 6: Particle size analyzer for different plant extracts

3.2. Characterization of the enzyme-oxidizing extract

Enzymes in textile wet processing provide significant environmental advantages and contribute to textiles' sustainability, such as Laccase, PPO, and POD enzymes, which have been utilized to enzymatically discharge colors from dyed fibers. They were also discovered to be capable of altering the hue of dyes on textiles, resulting in a unique surface color pattern.[97]

3.2.1. Gas Chromatography-Mass Spectrometer (GC-MS) Analysis

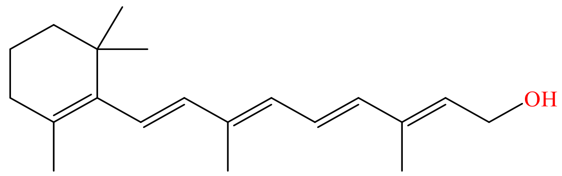
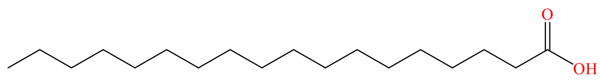
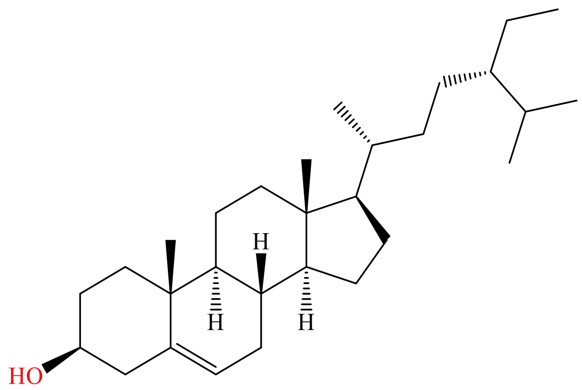
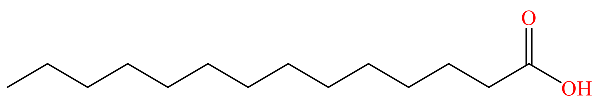
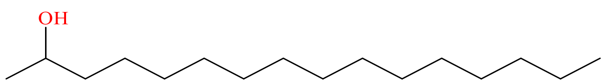
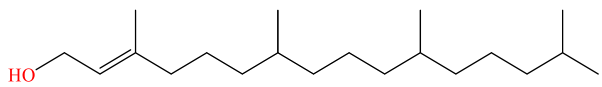
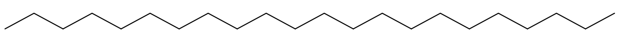
The GC–MS chromatogram of the taro corms (Colocasia antiquorum) aqueous extract was performed to discover bioactive compounds or enzymes responsible for its oxidizing ability.

The analysis revealed the presence of various compounds at different retention times, and the structures of these compounds and their molecular weights are shown in **Table 1.**

The retinol compound is the most significant among them. Dietary vitamin A is a key precursor of tissue retinol, which is converted into two types of physiologically active retinoids by consecutive oxidation processes. [98] Vitamin A is converted to retinoic acid (RA) by two successive enzymatic processes. The first requires retinol dehydrogenase (RDH) activity to oxidize Vitamin A (retinol) to retinal, while the second requires retinaldehyde activity (RALDH) to oxidize retinal to retinoic acid (RA), which is a derivative of Vitamin A (retinol). [99]

Oxidation is a natural process that occurs when molecules lose electrons in a chemical reaction. If you've ever noticed a banana or apple turning dark after being cut, you've seen oxidation. In brief, oxidation modifies the chemical structure of the components in the product, as seen with retinol compounds, which convert to dark yellow over time as the bonds are oxidized; when exposed to oxygen from the air and as a result, the color of the product, as well as the consistency and integrity of the contents, may change. [194] And this is similar to what happens with oxidizing enzymes in taro corms extract, so the retinol compound is considered evidence for the presence of these enzymes in taro corms extract.

Table 1: GC-MS analysis of taro corms (Colocasia antiquorum) water extract

Rt (min)	Identified compounds	Mol. weight	Molecular Formula	Chemical structure
14.7	Retinol	286.45	$C_{20}H_{30}O$	
14.9	Octadecanoic acid	284.48	$C_{18}H_{36}O_2$	
16.4	ß-Sitosterol	414.7	$C_{29}H_{50}O$	
17.8	Myristic acid	228.37	$C_{14}H_{28}O_2$	
18.54	2-Hexadecanol	242.44	$C_{16}H_{34}O$	
20	Trans-phytol	296.5	$C_{20}H_{40}O$	
21.55	Docosane	310.6	$C_{22}H_{46}$	

3.2.2. Enzyme activity

Taro corms Polyphenol oxidase (TPPO) activity was evaluated by measuring the initial rate of quinone production, which was shown by an increase in absorbance units (Abs) at 420 nm. The activity was measured using catechol as a substrate according to the following equation: -

$$\text{The activity of PPO} = \frac{(Abs_{3\,min} - Abs_{0\,min}) \times V_{total\ volume\ (ml)}}{V_{total\ time\ (min)} \times V_{enzyme\ volume\ (ml)}}$$

An assay of PPO activity in taro corms at a different time at a wavelength of 420 was observed at 180 sec. [100] As shown in **Figure 7**

It can be explained from **Figure 7** The activity of the polyphenol oxidase enzyme extracted from taro corms increases with increasing time, and the best activity is at 180 sec at a wavelength of 420 nm. While the activity of the peroxidase enzyme can be determined with hydrogen peroxide as a substrate according to the previous equation, an assay of the POD activity of taro corms at a different time at a wavelength of 436 was observed at 180 seconds, as shown in **Figure 7**. It can be explained from **Figure 7** The activity of the peroxidase enzyme extracted from taro corms increases with increasing time, and the best activity is at 180 sec at a wavelength of 436 nm.

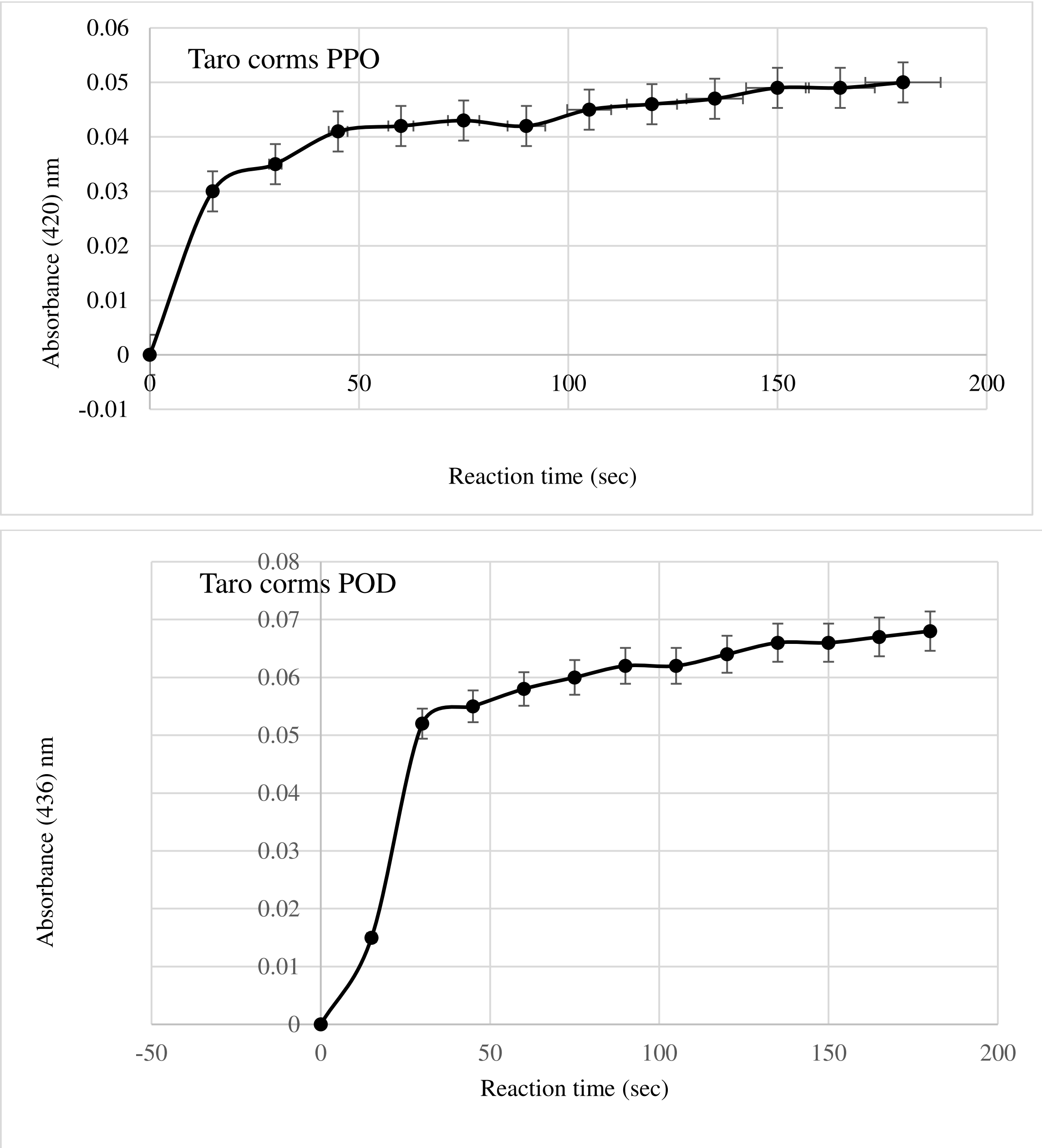


Figure 7: Effect of reaction time on PPO activity

Enzyme stability is critical in determining the economic viability of biocatalysis applications. Heat and high pH reduce the activity of catalytic proteins. According to the previous test, the enzyme was not exposed to high temperatures or a change in acidity, and therefore, the enzyme was stable throughout the storage period.

3.2.3. Mechanism of oxidizing enzymes

It is essential to understand the mechanism of oxidizing enzymes like peroxidase and polyphenol oxidase, which function as discharge agents in an oxidation reaction to decolorize the dye. [101]

3.2.3.1. Mechanism of taro corms polyphenol oxidase

The oxidation reaction is a very powerful method for destroying phenolic compounds (the main compounds in natural extracts) in aqueous solutions. Phenol removal is a quick reaction, with virtually total elimination occurring in a short amount of time. Polyphenol oxidases use molecular oxygen to catalyze the hydroxylation and dehydrogenation of phenolic substances, producing reactive o-quinones.[44, 102] 90% of phenol (whose presence in the natural extract may be responsible for its color) degradation happens during the first ten minutes of the reaction; the remainder degrades slowly and requires around half an hour to achieve complete oxidation efficiency, which is commonly greater than 98%. Thus, it is suggested that ferrous ions in enzymes react quickly with oxygen in the atmosphere, creating a high number of hydroxyl radicals when increasing the temperature from 0°C (stored temperature) to working temperature, which causes the aromatic rings to be rapidly destroyed and form colorless organic acids. [91, 103] **Figure 8** clarify the suggested mechanism for explaining the color changes observed during the reaction due to the degradation of phenol. [91, 104]

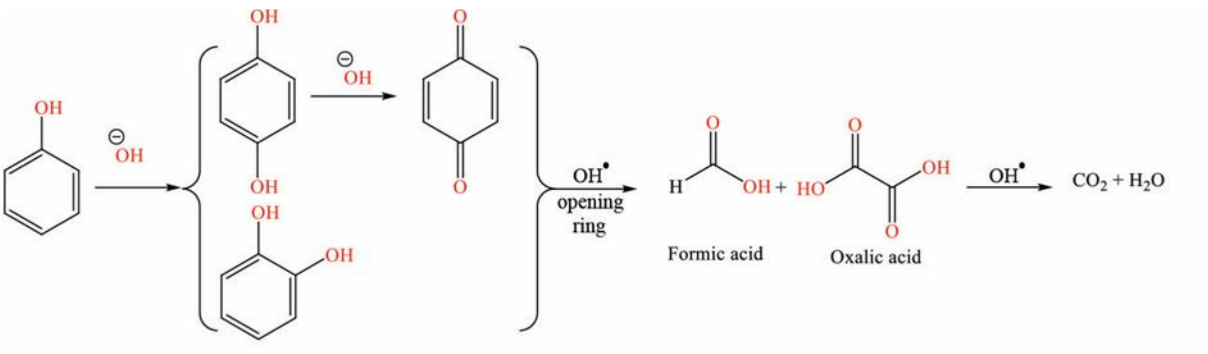


Figure 8: Suggested mechanism for explaining the color changes observed during the reaction due to the degradation of phenol

In **Figure 8**, at 60 minutes of reaction time, phenol (PHE), catechol, hydroquinone, p-benzoquinone, oxalic, and formic acids were observed; the catechol and hydroquinone come from activated HO• attacks on positions two and four, respectively; p-benzoquinone comes from hydroquinone oxidation; and oxalic and formic acids come from aromatic compound ring openings, which are colorless in water and can be oxidized again to carbon dioxide and water. [91]

Whereas in the case of PNP (p-nitrophenol). PNP, hydroquinone, p-benzoquinone, oxalic, and formic acids were isolated after 30 minutes of reaction time. After substituting NO_2 with a phenol group, aromatic ring position four is activated, and positions two and six are doubly activated; therefore, hydroquinone is formed, and further oxidation generates p-benzoquinone. The oxalic and formic acids result from the aromatic compounds' ring opening in response to HO• electrophilic attack. After 60 minutes of reaction time, both colorless acids remained, as explained in **Figure 8**.[91]

3.2.3.2. Mechanism of taro corms peroxidase

Peroxidases, a type of important antioxidant enzyme, are extensively distributed in nature and catalyze the oxidation of diverse electron donor substrates while rapidly reducing H_2O_2. They can help to minimize pollution by bioremediating wastewater, including cresols, phenols, and chlorinated phenols, as well as degrading synthetic and natural textile dyes. [105]

When peroxidase reacts with phenolic substrates (in the natural extract), a cyclic reaction occurs. This process is summarised below.

The enzyme begins in its natural state (E) and is oxidized by hydrogen peroxide or oxygen in the atmosphere to generate compound I, an active intermediate molecule (Ei), which is illustrated in **equation 1**. Compound I oxidizes one molecule of phenol (PhOH) to create a phenol-free radical ($PhO^{\bullet}$), and compound II is formed (Eii), as illustrated in **equation 2**. Compound II oxidizes a second phenol molecule, producing another phenol free radical before returning to its natural form (E), as illustrated in **equation 3**. The free radicals polymerize and precipitate insoluble chemicals. [106]

$$\mathbf{E + H_2O_2 \rightarrow Ei + H_2O} \qquad \mathbf{(1)}$$

$$\mathbf{Ei + PhOH' \rightarrow Eii + PhO^{\bullet}} \qquad \mathbf{(2)}$$

$$\mathbf{Eii + PhOH'' \rightarrow E + PhO^{\bullet} + H_2O} \qquad \mathbf{(3)}$$

3.3. Optimization of Discharge Printing Conditions

Discharge printing of textiles with grafting modification is a revolutionary method in the textile industry, allowing for customized materials with better characteristics and performance. This method attaches functional biological enzymes to textile substrates, resulting in the desired characteristics.[107]

In this research, polyphenol oxidase and peroxidase enzymes were used instead of harmful reducing or oxidizing agents, such as formaldehyde sulfoxylate, which produces formaldehyde vapors and is a human carcinogen under a variety of conditions. The effect of enzyme extract concentration, pH, drying time, and temperature, as well as the effect of adding auxiliaries, on the performance of white discharge printing, was investigated.

3.3.1. Effect of taro corm extract concentration

Cotton fabrics were first dyed with several natural plant extracts, and the dyeing procedure was previously mentioned. Different concentrations of taro corms extract (50, 100, 150, 200, 250, and 300 g/kg) were employed and combined with the printing paste, which only includes the thickening ingredient (sodium alginate) while keeping the pH at 5 and 3 in the case of cotton and wool, respectively.

The cotton and wool fabrics were then screen printed with these pastes, and another sample was printed by using a chemical reducing agent (sodium hydrosulfite $Na_2S_2O_4$) in the absence of taro corm extract for comparison. After printing, the samples were left to dry under varying conditions.

The possible explanation for the occurrence of the discharge printing effect is that the taro corms extract contains polyphenol oxidase and peroxidase enzymes that catalyze the oxidation of naturally dyed fabrics through the enzyme active site reaction with the oxygen present in the air and produces a large number of hydroxyl radicals that attack the phenolic compounds that are responsible for the color of the natural dye and cause the aromatic rings to be rapidly destroyed and form colorless organic acids. [91]

Table 2 illustrates that the increasing percent in the WI of cotton fabrics dyed with Psidium guava leaves and printed with various concentrations of taro corms extract increases progressively, and the optimum concentration of taro corms is 25%, and **Figure 9** presented the discharge printed cotton samples at the optimum concentration.

It's clear from **Table 2** that the discharge rate of cotton textiles dyed with Ficus leaves and printed with varied concentrations of taro corms increase gradually to 30%, at which they became (2.04, 31.97, and -19.59) respectively, so we may conclude that the optimum taro corms extract concentration that fulfils the best dye removal and high whiteness index is at 30% as shown in **Figure 9**.

As shown in **Table 2** The cotton samples dyed with both natural plant extracts and printed with printing paste that contains sodium hydrosulfite (SHS) as a chemical reducing agent have the highest discharge rate when compared to those printed with taro corm extract, but the difference in the discharge rate is small.

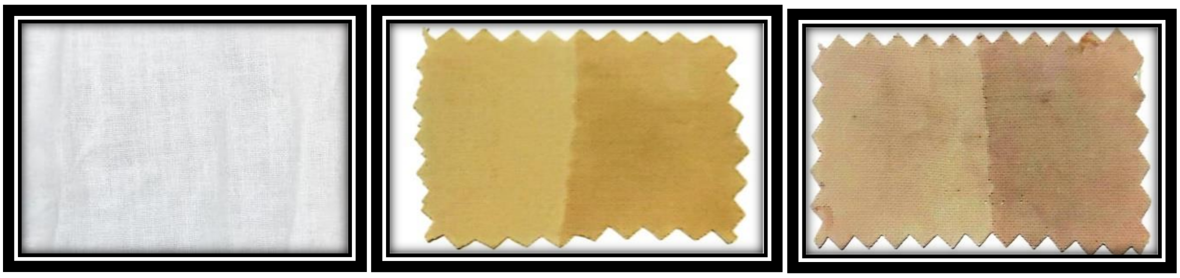
Table 2: Effect of taro corms extract concentration on discharge rate of cotton fabrics dyed with different natural dye extracts

Fabric	**Natural dye**	**Taro corms Conc. (%)**	**Color strength (K/S)**	**Decreasing in K/S (%)**	**Whiteness index (WI)**	**Increasing in WI (%)**	**Yellowness index (YI)**	**Decreasing in YI (%)**	**CIE lab system**		
Cotton	**Blank**		-	-	51.68 ± 0.86	-	4.63 ± 0.08	-	**L**	**a**	**b**
	Guava extract	**0**	2.82 ± 0.05	-	-27.21 ± 0.45	-	40.51 ± 0.67	-	**66.46**	**9.89**	**15.95**
		5	2.49 ± 0.05	11.74	-19.94 ± 0.33	26.70	29.77 ± 0.49	26.53	79.13	4.93	12.21
		10	2.41 ± 0.04	14.59	-18.34 ± 0.31	32.59	27.76 ± 0.46	31.49	80.02	4.76	11.62
		15	2.39 ± 0.04	15.30	-17.99 ± 0.3	33.88	26.85 ± 0.45	33.73	80.24	4.44	10.67
		20	2.04 ± 0.04	27.75	-17.57 ± 0.29	35.42	25.92 ± 0.43	36.03	80.29	5.32	12.97
		25	1.93 ± 0.04	31.67	-15.64 ± 0.26	42.52	25.14 ± 0.42	37.96	81.19	4.81	12.51
		30	2.02 ± 0.04	28.46	-16.27 ± 0.27	40.20	25.34 ± 0.42	37.46	80.89	4.63	10.80
		SHS *	1.76 ± 0.03	38.16	-12.07 ± 0.2	55.66	28.52 ± 0.47	46.29	69.01	8.67	14.59
	Ficus extract	**0**	3.46 ± 0.06	-	-28.48 ± 0.47	-	38.32 ± 0.64	-	**61.92**	**15.13**	**12.04**
		5	2.83 ± 0.05	18.22	-24.6 ± 0.41	13.61	35.84 ± 0.59	6.46	63.62	13.02	14.36
		10	2.82 ± 0.05	18.51	-24.2 ± 0.4	15.02	35.72 ± 0.59	6.77	67.48	11.38	13.05
		15	2.78 ± 0.05	19.67	-23.89 ± 0.4	16.11	35.59 ± 0.59	7.11	74.64	10.79	9.14

		20	2.73 ± 0.05	21.12	-22.97 ± 0.38	19.34	35.17 ± 0.58	8.21	75.01	10.23	9.33
		25	2.44 ± 0.04	29.53	-21.97 ± 0.37	22.85	34.3 ± 0.57	10.48	76.06	9.97	9.38
		30	2.05 ± 0.04	40.84	-19.6 ± 0.33	31.18	31.98 ± 0.53	16.54	76.58	9.64	8.30
		SHS *	1.98 ± 0.04	42.87	-18.76 ± 0.31	74.13	32.92 ± 0.55	22.59	75.45	6.46	11.05

* SHS: sodium hydrosulfite 25 % (250 g/kg)

Printing condition: The cotton fabric was printed with taro corms printing paste at different concentrations (5, 10, 15, 20, 25, and 30%) at pH 5 for all natural extract at 80°C for 60 min for Ficus leaves, at 25° C for 180 min for Psidium guava leaves.



(a) (b) (c) (d) (e)

Figure 9: Discharged cotton fabrics using taro corms extract at optimum concentration

(a) blank fabric (b) Discharged Guava dyed fabric (c) Guava dyed fabric
(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

From **Table 3** In both cases of wool fabrics dyed with Psidium guava leaves extract and Ficus leaves extract, the optimum concentration of taro corms extract, which achieved the highest discharge effect, was 15%, and the optimum discharge printed wool samples are shown in **Figure 10**.

It’s clear from **Table 3**, that in the case of eggplant skin extract, the whiteness degree increased from 5% up to 10%, and by increasing the taro corms extract concentration, the whiteness degree decreased regularly, so we can conclude that the optimum concentration of taro corms extract in that case is at 10% and the discharge printed sample at this optimum concentration is presented in **Figure 10**.

In the case of wool samples dyed with red cabbage leaves extract, **Table 3** clarified that the increasing percentage of whiteness increased regularly from 5% until they reached 20%. With the increase in concentration above 20%, the whiteness index decreased gradually. So it was concluded that the optimum concentration for taro corms extract on the wool samples dyed with red cabbage extract is 20%, which is presented in **Figure 10**.

It's obvious from **Table 2** and **Table 3** that cotton fabrics were only dyed with Psidium guava leaves extract and Ficus leaves extract, and then printed with taro corms extract, while wool fabrics were dyed with Psidium guava leaves, Ficus leaves, eggplant skin, and red cabbage leaves extract. This is due to the pale color that resulted in the dyeing of cotton fabric with eggplant skin and red cabbage leaves extract, and all of the colors resulted from dying at different pH mediums were light, which was attributable to the fact that natural dyeing of cotton fabrics was harder than wool or silk fabrics owing to their chemical structure. [108]

Natural cotton fabrics, as is well known, have a negative surface charge due to the hydroxyl groups produced in their chemical structure. These negative charges on the cellulose fabrics reject anionic dyestuffs such as red cabbage leaves extract and eggplant skin extract, which contain anthocyanin and anthocyanidin groups. There are two types of red-blue pigments found in plants, and the molecular structure of anthocyanins has an ionic nature, resulting in minimal dye absorption. [109, 110]

Furthermore, it was discovered that the taro corms could not produce a fully white discharge on wool samples. As a result, it can be inferred that taro corms may be effectively used to generate halftones by adjusting the printing conditions. This was evident when the samples printed with taro corm extract were compared with samples printed using SHS as a reducing agent.

Table 3: Effect of taro corms extract concentration on discharging rate of dyed wool fabrics using different natural dye extracts

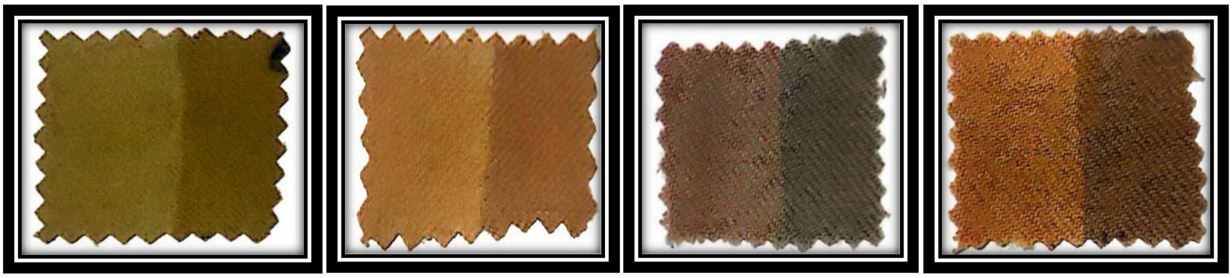
Fabric	**Natural dye**	**Taro corms Conc. (%)**	**Color strength (K/S)**	**Decreasing in K/S (%)**	**Whiteness index (WI)**	**Increasing in WI (%)**	**Yellowness index (YI)**	**Decreasing in YI (%)**	**CIE lab system**		
Wool	**Blank**		-	-	18.72 ± 0.31	-	16.46 ± 0.28	-	**L**	**a**	**b**
	Guava extract	**0**	26.45 ± 0.44	-	-171.73 ± 2.83	-	78.2 ± 1.29	-	**51.15**	**6.93**	**27.25**
		5	16.95 ± 0.28	35.94	-158.14 ± 2.61	7.90	74.25 ± 1.23	5.05	56.05	6.81	27.40
		10	14.76 ± 0.25	44.22	-155.56 ± 2.57	9.41	73.13 ± 1.21	6.49	59.13	6.84	27.78
		15	11.26 ± 0.19	57.45	-141.99 ± 2.34	17.31	68.09 ± 1.13	12.93	59.52	6.34	27.34
		20	13.65 ± 0.23	48.42	-143.23 ± 2.36	16.59	68.58 ± 1.13	12.30	59.82	6.11	26.88
		25	14.02 ± 0.24	47.02	-146.84 ± 2.42	14.49	69.89 ± 1.16	10.63	57.72	7.06	27.90
		30	14.12 ± 0.24	46.64	-150.41 ± 2.48	12.41	71.56 ± 1.18	8.49	58.77	6.19	26.13
		SHS *	9.43 ± 0.16	64.28	-136 ± 2.24	20.45	66.01 ± 1.09	15.46	57.40	7.71	26.55
	Ficus extract	**0**	12.15 ± 0.2	-	-143.21 ± 2.36	-	80.37 ± 1.33	-	**49.03**	**17.73**	**22.93**
		5	8.94 ± 0.15	26.47	-121.33 ± 2	15.28	79.76 ± 1.32	0.76	54.12	13.74	18.02
		10	8.86 ± 0.15	27.13	-108.67 ± 1.79	24.12	78.36 ± 1.29	2.50	52.02	14.50	18.89
		15	8.25 ± 0.14	32.15	-105.64 ± 1.74	26.24	74.54 ± 1.23	7.25	54.48	14.13	18.28
		20	8.33 ± 0.14	31.49	-106.04 ± 1.75	25.96	74.67 ± 1.23	7.09	48.66	15.21	18.95
		25	8.74 ± 0.15	28.11	-107.66 ± 1.78	24.82	76.34 ± 1.26	5.01	52.11	14.06	17.68

	30	8.9 ± 0.15	26.80	-110.17 ± 1.82	23.07	79.09 ± 1.31	1.59	52.69	14.41	18.92
	SHS *	3.71 ± 0.07	69.68	-99.9 ± 1.65	30.24	61.99 ± 1.03	22.87	60.96	12.05	15.88
Eggplant skin extract	**0**	13.18 ± 0.22	-	-51.49 ± 0.85	-	32.07 ± 0.53	-	**51.8**	**2.91**	**9.74**
	5	11.37 ± 0.19	13.77	-51.23 ± 0.85	0.51	31.89 ± 0.53	0.56	61.22	5.70	13.41
	10	10.03 ± 0.17	23.94	-45.45 ± 0.75	11.74	29.56 ± 0.49	7.82	63.42	5.25	13.53
	15	10.53 ± 0.18	20.15	-45.64 ± 0.76	11.37	31.01 ± 0.52	3.30	61.79	5.45	12.97
	20	10.83 ± 0.18	17.87	-49.89 ± 0.83	3.11	31.05 ± 0.52	3.18	61.49	5.50	13.38
	25	11.02 ± 0.19	16.43	-50.64 ± 0.84	1.66	31.34 ± 0.52	2.27	61.43	5.45	12.85
	30	11.33 ± 0.19	14.07	-51.18 ± 0.85	0.61	31.52 ± 0.52	1.71	61.25	5.32	13.28
	SHS *	8.63 ± 0.15	34.57	-36.81 ± 0.61	28.60	25.25 ± 0.42	21.27	34.57	28.60	21.27
Red cabbage extract	**0**	7.92 ± 0.14	-	-61.35 ± 1.01	-	47.26 ± 0.78	-	**52.14**	**7.33**	**9.88**
	5	7.05 ± 0.12	11.09	-49.82 ± 0.82	18.80	33.4 ± 0.55	29.34	55.77	10.52	12.88
	10	6.81 ± 0.12	14.12	-47.64 ± 0.79	22.36	32.65 ± 0.54	30.93	56.40	10.76	12.32
	15	6.59 ± 0.11	16.90	-46.73 ± 0.77	23.84	31.37 ± 0.52	33.64	56.77	10.15	13.39
	20	5.96 ± 0.1	24.85	-45.76 ± 0.76	25.42	30.54 ± 0.51	35.39	64.99	10.45	13.29
	25	6.36 ± 0.11	19.80	-45.85 ± 0.76	25.27	31.09 ± 0.52	34.23	57.08	10.40	13.00
	30	6.76 ± 0.12	14.75	-47.18 ± 0.78	23.11	32.56 ± 0.54	31.12	56.55	10.78	12.95
	SHS *	4.87 ± 0.08	38.62	-42.81 ± 0.71	30.23	28.99 ± 0.48	38.67	65.99	2.13	14.08

* SHS: sodium hydrosulfite 25 % (250 g/kg)

* Printing condition: The wool fabric was printed with potato peel printing paste at different concentrations (5, 10, 15, 20, 25, and 30%) at pH 3 for all natural extract at 80°C for 60 min for Ficus leaves, at 25°C for 180 min for Psidium guava, at 25°C for 120 min for eggplant skin and at 0°C for 30 min for red cabbage leaves.

(a)



(b) (c) (d) (e) (f) (g) (h) (i)

Figure 10: Discharged wool fabrics using taro corms extract at optimum concentration

(a) blank fabric
(b) Discharged Guava dyed fabric (c) Guava-dyed fabric
(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric
(f) Discharged Eggplant skin-dyed fabric (g) Eggplant skin-dyed fabric
(h) Discharged Red cabbage dyed fabric (i) Red cabbage dyed fabric

3.3.1.1. Effect of PH

Most enzymatic activity is particularly pH sensitive. Different discharge pastes containing varying concentrations of enzyme extract were generated, and the pH values were modified to 3, 4, 5, 6, and 7. The difference in lightness value between the printed image and the surrounding dyed fabric (base) reflects the efficacy of the dye discharge by peroxidase and polyphenol oxidase enzymes in taro corm extract.

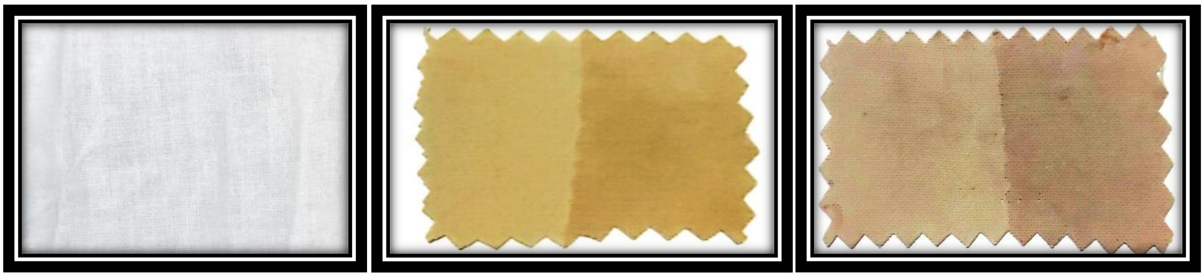
It's clear from **Table 4** In the case of samples dyed with Psidium guava and Ficus leaves extract that there is a relationship between the pH medium of the printing paste and the discharge rate. While the pH increases from 3 to 5, the discharge rate and the degree of whiteness also increase gradually; however, when the pH increases beyond 5, the discharge rate gradually decreases, and sometimes it can reach the point of increasing the color of the printed sample instead of removing it. It can be concluded that the highest degree of whiteness is obtained at pH 5 in the case of cotton samples dyed with various natural plant extracts. The optimum discarhge printed cotton samples are presented in **Figure 11**.

Table 4: Effect of pH of printing paste on discharge rate of cotton fabrics dyed with different natural dye extracts

Fabric	Natural dye	pH of the printing paste	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE lab system		
cotton	Blank		-	-	51.59 ± 3.51	-	4.62 ± 0.32	-	L	a	b
	Dyed material		2.81 ± 0.2	-	-27.16 ± 1.85	-	40.44 ± 2.75	-	**66.46**	**9.89**	**15.95**
	Guava extract	3	2.36 ± 0.17	16.01	-20 ± 1.36	26.34	35.4 ± 2.41	12.48	72.53	4.04	7.74
		4	2.23 ± 0.16	20.64	-17.11 ± 1.17	37.00	28.49 ± 1.94	29.56	72.26	7.66	19.69
		5	1.92 ± 0.14	31.67	-15.61 ± 1.07	42.52	25.09 ± 1.71	37.96	81.19	4.81	12.51
		6	2.75 ± 0.19	2.13	-23.46 ± 1.6	13.61	29.57 ± 2.01	26.90	68.28	9.07	18.60

		7	2.76 ± 0.19	1.77	-24.92 ± 1.7	8.21	32.11 ± 2.19	20.61	72.52	9.86	19.66
	Dyed material		**3.45**	3.45 ± 0.24	**-28.47**	-28.43 ± 1.94	**38.31**	38.25 ± 2.6	**61.92**	**15.13**	**12.04**
	Ficus extract	**3**	2.89 ± 0.2	16.19	-25.08 ± 1.71	11.75	37.13 ± 2.53	2.91	67.63	10.89	10.56
		4	2.33 ± 0.16	32.28	-17.58 ± 1.2	21.46	34.54 ± 2.35	9.72	72.10	10.26	9.43
		5	2.04 ± 0.14	40.84	-10.08 ± 0.69	31.18	31.94 ± 2.18	16.54	76.58	9.64	8.30
		6	2.44 ± 0.17	29.13	-19.33 ± 1.32	19.45	35.06 ± 2.39	8.35	71.05	10.77	10.27
		7	2.77 ± 0.19	19.67	-24.62 ± 1.68	13.40	36.63 ± 2.49	4.24	67.92	12.30	12.80

*Printing condition: The cotton fabric was printed with taro corms printing paste at different pH (3, 4, 5, 6, and 7) at a concentration of 300 g/kg at 80°C for 60 min for Ficus leaves, at a concentration of 250 g/kg 25°C for 180 min for Psidium guava leaves.



(a) (b) (c) (d) (e)

Figure 11: Discharged cotton fabrics using taro corms extract at optimum pH

(a) blank fabric (b) Discharged Guava dyed fabric (c) Guava dyed fabric
(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

In all wool samples, the maximum activity of polyphenol oxidase and peroxidase enzymes in taro corm extract was found to be around 3 and 4, respectively, when tested at different pH levels ranging from 3 to 7.

As illustrated in

Table 5 The highest discharge rate occurred at pH 3 in all wool samples dyed with various natural plant extracts. This pH value is considered the optimum pH at which enzymes reach their maximum activity and are capable of oxidizing the naturally dyed sample efficiently.

Table 5, shows that increasing the pH of printing paste resulted in a significant decrease in whiteness index, indicating that the activity of enzymes and their ability to oxidize are Primarily dependent on the pH of the printing paste, which is usually 3 for wool fabrics and the wool samples that were printed at this optimum pH are presented in **Figure 12**.

As shown in

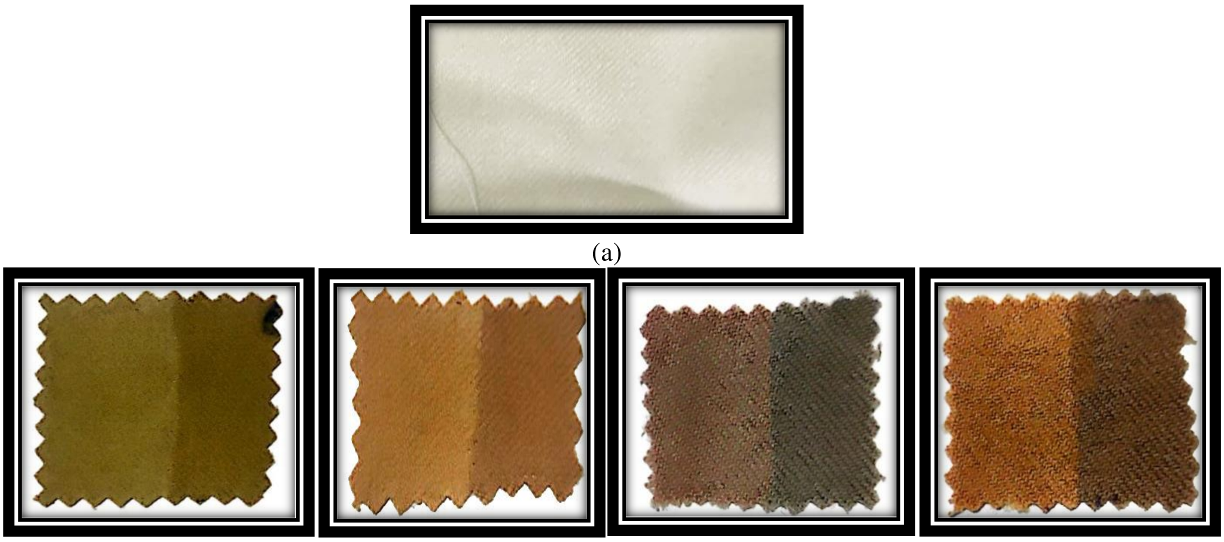
Table 5, increasing pH of the printing paste not only limited the discharging rate of the printed samples but also increased the color of the printed samples more than the original dyed material when reached pH 7, which means that the activity of the enzymes completely stopped and was not able to work because of the variation of the pH (especially when increased towards alkali medium). This variation modified the protein structure with a denaturing effect on the enzyme or a change in the ionization of the active site, which negatively impacted its activity. This phenomenon may also be due to the polymerization process that occurs when the conditions are suitable, such as an increase in pH medium towards alkali medium: the individual molecules of o-quinones (that were formed as a result of oxidizing the phenolic compound in natural dyes) join together to form bigger molecules and form a substance called melanin, rather than opening its aromatic ring and creating colorless organic acids.

Table 5: Effect of pH of printing paste on discharge rate of wool fabrics dyed with different natural dye extracts

Fabric	Natural dye	pH of the printing paste	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
Wool	Blank		-	-	18.68 ± 1.27	-	16.43 ± 1.12	-	**L**	**a**	**b**
	Dyed material		26.4 ± 1.8	-	-171.44 ± 11.66	-	78.07 ± 5.31	-	**51.15**	**6.93**	**27.25**
	Guava extract	**3**	11.24 ± 0.77	57.45	-141.76 ± 9.64	17.31	67.97 ± 4.63	12.93	59.52	6.34	27.34
		4	14.4 ± 0.98	45.47	-150.76 ± 10.25	12.06	71.32 ± 4.85	8.65	56.66	5.40	30.42
		5	17.61 ± 1.2	33.33	-166.45 ± 11.32	2.91	75.42 ± 5.13	3.39	54.99	6.14	30.34
		6	21.27 ± 1.45	19.45	-167.47 ± 11.39	2.31	76.34 ± 5.19	2.21	54.99	6.14	30.34
		7	28.24 ± 1.92	-6.93	-175.37 ± 11.93	-2.29	79.94 ± 5.44	-2.38	49.64	6.60	27.76
	Dyed material		**12.14**	12.13 ± 0.83	**-143.20**	-142.97 ± 9.72	**80.36**	80.24 ± 5.46	**49.03**	**17.73**	**22.93**
	Ficus extract	**3**	8.23 ± 0.56	32.15	-105.46 ± 7.17	26.24	74.42 ± 5.06	7.25	54.48	14.13	18.28
		4	8.35 ± 0.57	31.16	-106.52 ± 7.25	25.50	74.71 ± 5.08	6.88	54.14	14.91	22.80
		5	8.43 ± 0.58	30.50	-112.18 ± 7.63	21.54	75.84 ± 5.16	5.47	54.07	15.89	21.32
		6	8.57 ± 0.59	29.35	-142.54 ± 9.69	0.30	79.87 ± 5.43	0.46	51.00	16.01	19.53
		7	12.8 ± 0.88	-5.55	-144.21 ± 9.81	-0.86	81.5 ± 5.54	-1.57	48.17	18.63	20.26
	Dyed material		**13.17**	13.15 ± 0.9	**-51.48**	-51.4 ± 3.5	**32.06**	32.01 ± 2.18	**51.8**	**2.91**	**9.74**
	Eggplant skin extract	**3**	10.01 ± 0.69	23.94	-45.37 ± 3.09	11.74	29.51 ± 2.01	7.82	63.42	5.25	13.53
		4	10.47 ± 0.72	20.45	-45.47 ± 3.1	11.54	30.62 ± 2.09	4.36	59.94	4.96	13.79
		5	11.32 ± 0.77	14.00	-46.83 ± 3.19	8.90	30.83 ± 2.1	3.71	59.62	6.05	14.27

		6	11.4 ± 0.78	13.39	-49.24 ± 3.35	4.22	31.06 ± 2.12	2.96	59.06	4.12	14.45
		7	11.87 ± 0.81	9.82	-49.86 ± 3.39	3.00	31.86 ± 2.17	0.46	58.92	4.91	14.51
	Dyed material		**7.91**	7.9 ± 0.54	**-61.34**	-61.25 ± 4.17	**47.25**	47.18 ± 3.21	**52.14**	**7.33**	**9.88**
	Red cabbage extract	**3**	5.95 ± 0.41	24.85	-45.68 ± 3.11	25.42	30.49 ± 2.08	35.39	64.99	10.45	13.29
		4	6.29 ± 0.43	20.43	-48.22 ± 3.28	21.28	37.69 ± 2.57	20.11	56.61	9.98	13.26
		5	6.78 ± 0.47	14.24	-50.92 ± 3.47	16.86	40.6 ± 2.76	13.96	56.06	10.87	12.68
		6	7.11 ± 0.49	10.08	-52.14 ± 3.55	14.87	41.15 ± 2.8	12.79	55.73	9.14	12.92
		7	7.64 ± 0.52	3.38	-54.93 ± 3.74	10.33	44.21 ± 3.01	6.30	52.52	7.67	13.24

*Printing condition: The wool fabric was printed with taro corms printing paste at an optimum concentration of 150g/kg for Ficus and Psidium guava leaves and 100g/kg for eggplant skin and 200g/kg for red cabbage leaves at different pH (3, 4, 5, 6, and 7) at 80°C for 60 min for Ficus leaves, at 25°C for 180 min for Psidium guava leaves, at 25°C for 120 min for eggplant skin and at 0°C for 30 min for red cabbage leaves.



(a)

(b) (c) (d) (e) (f) (g) (h) (i)

Figure 12: Discharged wool fabrics using taro corms extract at optimum pH

(a) blank fabric

(b) Discharged Guava dyed fabric (c) Guava-dyed fabric

(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

(f) Discharged Eggplant skin-dyed fabric (g) Eggplant skin-dyed fabric

(h) Discharged Red cabbage dyed fabric (i) Red cabbage dyed fabric

3.3.1.2. Effect of drying time

It has been found that, at the beginning of a period, the amount of substrate change is directly proportional to the duration of treatment time. After a specific period, the reaction rate tends to slow, and the yield is no longer linearly proportional to the treatment duration. If the substrate is abundant, one explanation for this phenomenon is the progressive reduction of enzyme activity over time. [22, 104, 111]

As a result, the printed cotton and wool samples were subjected to a drying procedure at various time intervals to determine the optimal period required for maximum color removal. The drying was performed for 30, 45, 60, 90, 120, 180, and 240 min before washing and drying.

The data in **Table 6** explain a gradual increase in whiteness index until it reaches its maximum at 180 min, and the color of the printed samples deviates from yellowish brown to pale yellow.

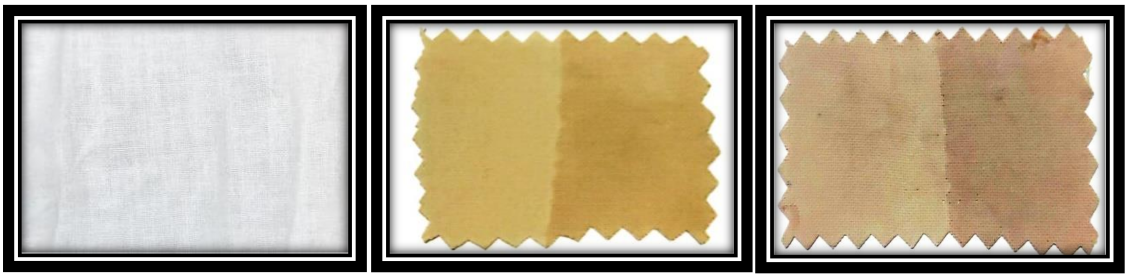
In the case of Ficus leaves extract, **Table 6** shows that color removal increased by increasing the drying time till it reached its maximum at 60 min, and the discharge printed samples at optimum time are shown in **Figure 13**. The increase of the drying time beyond 60 min caused an observed decrease in whiteness index; this might be attributed to the reduction of enzyme activity over time.

Table 6 Effect of drying time on discharge rate of printed cotton fabrics dyed with different natural dye extracts

Fabric	Natural dye	Drying time (min)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
Cotton	**Blank**		-	-	51.59 ± 3.85	-	4.62 ± 0.35	-	**L**	**a**	**b**
	Dyed material		2.81 ± 0.21	-	-27.16 ± 2.03	-	40.44 ± 3.02	-	**66.46**	**9.89**	**15.95**
	Guava extract	**30**	2.06 ± 0.16	26.69	-19.52 ± 1.46	28.10	29.74 ± 2.22	26.48	69.4	8.89	17.6
		45	1.99 ± 0.15	29.18	-18.11 ± 1.35	33.32	28.16 ± 2.1	30.38	70.66	8.29	16.39
		60	1.97 ± 0.15	29.89	-17.68 ± 1.32	34.91	27.77 ± 2.07	31.34	70.77	6.71	15.12
		90	1.96 ± 0.15	30.24	-17.05 ± 1.27	37.22	27.4 ± 2.04	32.25	71.96	7.8	15.96
		120	1.94 ± 0.15	30.96	-16.87 ± 1.26	37.88	26.43 ± 1.97	34.65	72.86	5.90	12.52
		180	1.92 ± 0.15	31.67	-15.61 ± 1.17	42.52	25.09 ± 1.87	37.96	81.19	4.81	12.51
		240	2.4 ± 0.18	14.59	-19.85 ± 1.48	26.89	33.44 ± 2.49	17.32	72.54	5.63	10.95
	Dyed material		3.45 ± 0.26		-28.43 ± 2.12	-	38.25 ± 2.85	-	**61.92**	**15.13**	**12.04**
	Ficus extract	**30**	2.89 ± 0.22	16.19	-21.26 ± 1.59	25.21	32.96 ± 2.46	13.82	68.82	11.70	11.00
		45	2.58 ± 0.2	25.18	-20.57 ± 1.54	27.63	32.81 ± 2.45	14.21	69.27	11.68	10.94
		60	1.95 ± 0.15	40.84	-19.56 ± 1.46	31.18	31.94 ± 2.38	16.48	76.58	9.64	8.30
		90	2.31 ± 0.18	33.01	-19.61 ± 1.47	31.00	32.34 ± 2.41	15.44	73.38	10.71	9.35
		120	2.32 ± 0.18	32.72	-19.64 ± 1.47	30.90	32.38 ± 2.42	15.34	72.79	10.23	8.45

		180	2.38 ± 0.18	30.98	-19.87 ± 1.48	30.09	32.51 ± 2.43	15.00	71.20	11.78	10.59
		240	2.5 ± 0.19	27.50	-19.92 ± 1.49	29.90	32.61 ± 2.43	14.74	70.05	10.72	9.57

*Printing condition: The cotton fabric was printed with taro corms printing paste at an optimum concentration of 300g/kg for Ficus leaves extract and 250 g/kg for Psidium guava leaves extract at different times (30, 45, 60, 90, 120, 180, 240 min) at pH 5 for both natural extract at 80°C for Ficus leaves, and at 25°C for Psidium guava leaves.



(a) (b) (c) (d) (e)

Figure 13: Discharged cotton fabrics using taro corms extract at the optimum time

(a) blank fabric (b) Discharged Guava dyed fabric (c) Guava dyed fabric

(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

It's clear from the data in

Table 7, that the optimum drying time that is suitable to achieve the highest WI of the printed samples was attained when the printed samples were left to dry for 180 min, and the discharge wool printed samples at optimum time are shown in **Figure 14**. When the time intervals were less than or more than 180 min, the discharge rate wasn't as high as that obtained at this point.

In the case of wool samples dyed with Ficus leaves extract

Table 7 explained that the increasing percent in WI gradually increased by increasing the drying time to 60 min, at which these values reach their maximum, as demonstrated in **Figure 14**, and by a further increase in drying time over this point, the discharge rate gradually decreased. This may be due to the loss of enzyme activity after this time, which led to a lower discharge rate above the optimum time.

Table 7

Table 7 illustrated that the discharge rate in wool samples dyed with eggplant skin extract and printed with taro corms extract regularly increased by increasing the drying time up to 120 min; however, when the drying time exceeded this value, the whiteness degree decreased again, so the optimal time suitable for drying these printed samples was 120 min, at which the discharge effect was the best and the discharge printed sample at the optimum time was shown in **Figure 14**.

In the case of wool samples dyed with red cabbage leaves extract

Table 7 explained that the highest WI was attained after conducting the drying time for 30 min; increasing the drying time beyond 30 min causes a slight decrease in whiteness degree. This may be due to the slight loss in enzyme activity, as previously stated.

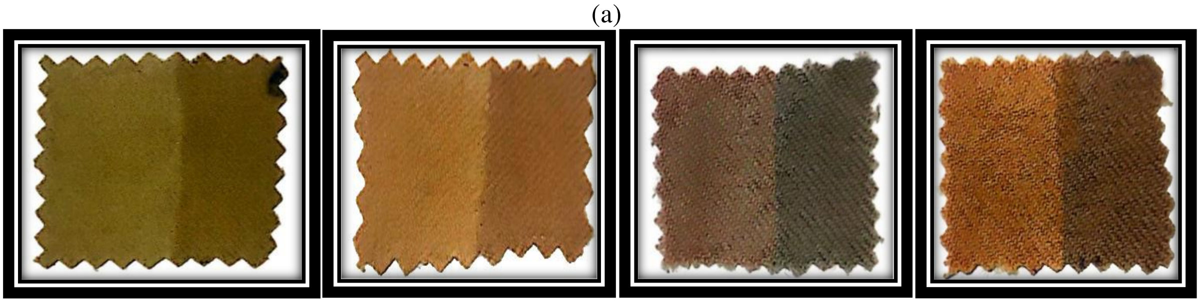
Table 7: Effect of drying time on discharge rate of printed wool fabrics dyed with different natural dye extracts

Fabric	Natural dye	Drying time (min)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
wool	Blank		-	-	18.68 ± 1.4	-	16.43 ± 1.23	-	**L**	**a**	**b**
	Dyed material		26.4 ± 1.97	-	-171.44 ± 12.77	-	78.07 ± 5.82	-	**51.15**	**6.93**	**27.25**
	Guava extract	**30**	21.96 ± 1.64	16.84	-155.8 ± 11.61	9.12	73.55 ± 5.48	5.79	53.40	6.88	26.28
		45	16.62 ± 1.24	37.07	-154.51 ± 11.51	9.87	72.67 ± 5.42	6.92	55.42	7.36	28.80
		60	15.76 ± 1.18	40.32	-148.52 ± 11.06	13.36	71.36 ± 5.32	8.60	57.26	4.79	31.41
		90	12.15 ± 0.91	54.01	-141.94 ± 10.57	17.21	70.29 ± 5.24	9.96	58.44	5.10	30.46
		120	11.32 ± 0.85	57.15	-141.88 ± 10.57	17.24	70.24 ± 5.23	10.03	59.42	6.37	24.29
		180	11.24 ± 0.84	57.45	-141.76 ± 10.56	17.31	67.97 ± 5.07	12.93	59.52	6.34	27.34
		240	24.72 ± 1.85	6.37	-162.99 ± 12.14	4.92	74.27 ± 5.54	4.86	54.99	5.12	26.06
	Dyed material		12.13 ± 0.91		-142.97 ± 10.65		80.24 ± 5.98		**49.03**	**17.73**	**22.93**
	Ficus extract	**30**	9.7 ± 0.73	20.04	-111.59 ± 8.31	21.95	78.51 ± 5.85	2.15	50.73	13.88	25.24
		45	8.55 ± 0.64	29.51	-107.49 ± 8.01	24.82	76.75 ± 5.72	4.34	50.82	15.25	27.21
		60	8.23 ± 0.62	32.15	-105.46 ± 7.86	26.24	74.54 ± 5.56	7.25	54.48	14.13	18.28
		90	8.25 ± 0.62	31.98	-105.93 ± 7.89	25.91	75.15 ± 5.6	6.33	53.09	13.23	26.58
		120	8.29 ± 0.62	31.65	-106.53 ± 7.94	25.49	75.38 ± 5.62	6.05	52.91	13.32	26.46
		180	8.44 ± 0.63	30.42	-106.54 ± 7.94	25.48	75.87 ± 5.65	5.44	52.40	13.62	26.90
		240	#VALUE!	30.01	-107.02 ± 7.97	25.15	76.73 ± 5.72	4.37	51.01	13.54	24.67
	Dyed material		13.15 ± 0.98		-51.4 ± 3.83		32.01 ± 2.39		**51.8**	**2.91**	**9.74**
	Eggplant skin extract	**30**	11 ± 0.82	16.43	-47.75 ± 3.56	7.11	30.57 ± 2.28	4.52	56.61	7.86	15.09
		45	10.9 ± 0.82	17.19	-47.08 ± 3.51	8.41	30.12 ± 2.25	5.92	57.43	7.85	14.98
		60	10.54 ± 0.79	19.92	-46.35 ± 3.46	9.83	29.73 ± 2.22	7.14	58.29	7.57	14.48
		90	10.44 ± 0.78	20.68	-46.17 ± 3.44	10.18	29.53 ± 2.2	7.80	63.27	5.3	13.52

		120	10.01 ± 0.75	23.94	-45.37 ± 3.38	11.74	29.51 ± 2.2	7.82	63.42	5.25	13.53
		180	10.94 ± 0.82	16.88	-46.66 ± 3.48	9.23	31.03 ± 2.32	7.82	61.87	5.58	13.77
		240	11.01 ± 0.82	16.35	-47.35 ± 3.53	7.89	31.28 ± 2.33	3.05	61.84	5.34	13.65
	Dyed material		7.9 ± 0.59		-61.25 ± 4.56		47.18 ± 3.52		**52.14**	**7.33**	**9.88**
	Red cabbage extract	**30**	5.95 ± 0.45	24.85	-45.68 ± 3.41	25.42	30.49 ± 2.27	35.39	64.99	10.45	13.29
		45	5.97 ± 0.45	24.60	-46.48 ± 3.47	24.12	32.33 ± 2.41	31.48	64.15	9.72	13.72
		60	6.05 ± 0.45	23.59	-46.66 ± 3.48	23.82	33.22 ± 2.48	29.59	63.83	9.68	11.73
		90	6.15 ± 0.46	22.33	-46.83 ± 3.49	23.55	33.28 ± 2.48	29.47	63.48	9.91	12.57
		120	6.22 ± 0.47	21.32	-46.96 ± 3.5	23.33	33.87 ± 2.53	28.22	63.29	9.73	13.69
		180	6.24 ± 0.47	21.06	-47.31 ± 3.53	22.76	33.89 ± 2.53	28.18	63.12	9.85	11.22
		240	6.27 ± 0.47	20.69	-48.5 ± 3.62	20.82	35.5 ± 2.65	24.77	62.62	10.00	11.91

*Printing condition: The wool fabric was printed with taro corms printing paste at an optimum concentration of 150g/kg for Ficus and Psidium guava leaves, 100g/kg for eggplant skin, and 200 g/kg for red cabbage leaves at a different time (30, 45, 60, 90, 120, 180, and 240) at pH 3 for all printed samples at 80°C for Ficus leaves, at 25°C for Psidium guava and eggplant skin and 0°C for red cabbage leaves.

(a)



(b) (c) (d) (e) (f) (g) (h) (i)

Figure 14: Discharged wool fabrics using taro corms extract at the optimum time

(a) blank fabric

(b) Discharged Guava dyed fabric (c) Guava-dyed fabric

(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

(f) Discharged Eggplant skin-dyed fabric (g) Eggplant skin-dyed fabric

(h) Discharged Red cabbage dyed fabric (i) Red cabbage dyed fabric

3.3.1.3. Effect of drying temperature

It’s necessary to optimize the optimum temperature to achieve the highest increase in whiteness in the cotton and wool samples dyed with natural plant extracts. Discharge paste containing the optimal concentration of taro corms extract thickened with alginate was prepared at pH 5, 3 for cotton and wool, respectively, and used for printing. After printing, the samples were subjected to dry at different temperatures (0, 25, 40, 60, and 80°C). Finally, the samples were washed and air-dried as described in the experimental section.

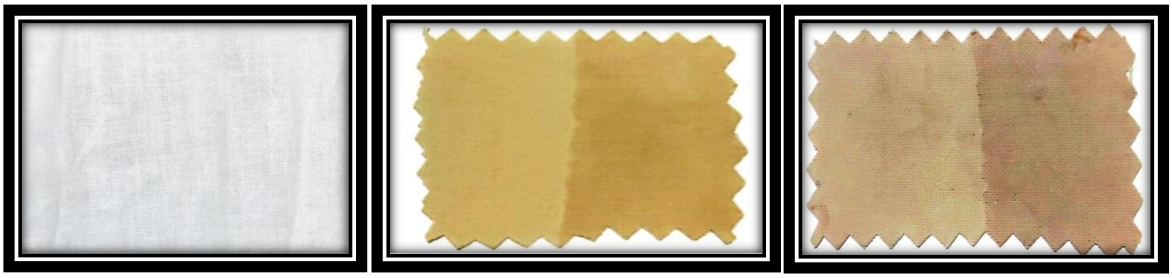
Table 8 explained that as the drying temperature increased from 0 to 25°C in the case of Psidium guava leaves, the discharge rate and whiteness degree increased, reaching their highest levels at 25°C. Further increases in drying temperature resulted in a progressive decrease in discharge rate, because of the reduction of enzyme activity at high temperatures and their inability to oxidize the natural dye chromophore.

As illustrated in **Table 8** in the case of Ficus leaves, by increasing the temperature gradually from 0 to 80°C, the discharge rate increased regularly. The ideal temperature was 80°C and the optimum discharge printed samples are observed in **Figure 15**.

Table 8: Effect of drying temperature of printed cotton fabrics dyed with different natural dye extracts

Fabric	Natural dye	Drying temp (°C)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE lab system		
cotton	Blank		-	-	51.59 ± 3.85	-	4.62 ± 0.35	-	L	a	b
	Dyed material		2.81 ± 0.21	-	-27.16 ± 2.03	-	40.44 ± 3.02	-	**66.46**	**9.89**	**15.95**
	Guava extract	0	2.64 ± 0.2	6.04	-24.38 ± 1.82	10.23	38.34 ± 2.86	5.20	61.25	12.10	23.93
		25	1.92 ± 0.15	31.67	-15.61 ± 1.17	42.52	25.09 ± 1.87	37.96	81.19	4.81	12.51
		40	2.38 ± 0.18	15.30	-16.03 ± 1.2	40.97	33.96 ± 2.53	16.03	72.18	4.38	8.08
		60	2.46 ± 0.19	12.45	-21.07 ± 1.57	22.40	38.13 ± 2.84	5.71	72.03	4.64	8.67
		80	2.48 ± 0.19	11.74	-23.61 ± 1.76	13.06	38.81 ± 2.89	4.04	72.02	4.29	8.02
	Dyed material		3.45 ± 0.26		-28.43 ± 2.12		38.25 ± 2.85		**61.92**	**15.13**	**12.04**
	Ficus extract	0	3.19 ± 0.24	17.49	-22.75 ± 1.7	19.97	33.65 ± 2.51	12.02	69.38	10.01	9.67
		25	2.6 ± 0.2	24.60	-20.87 ± 1.56	26.58	32.81 ± 2.45	13.25	71.83	11.21	8.88
		40	2.54 ± 0.19	26.34	-20.64 ± 1.54	27.38	33.18 ± 2.48	14.21	71.37	10.03	9.90
		60	2.26 ± 0.17	34.46	-20.25 ± 1.51	28.75	32.6 ± 2.43	14.76	71.84	9.39	9.06
		80	2.04 ± 0.16	40.84	-19.56 ± 1.46	31.18	31.92 ± 2.38	16.54	76.58	9.64	8.30

*Printing condition: The cotton fabric was printed with taro corms printing paste at an optimum concentration of 300g/kg for Ficus leaves extract and 250g/kg for Psidium guava leaves extract at different temperatures (0, 25, 40, 60, and 80°C) at pH 5 for both natural extract for 180 min in Psidium guava, and 60 min in Ficus leaves.



(a) (b) (c) (d) (e)

Figure 15: Discharged cotton fabrics using taro corms extract at the optimum temperature

(a) blank fabric (b) Discharged Guava dyed fabric (c) Guava dyed fabric

(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

It was found from the data in

Table 9 that as the drying temperature increased from 0 to 25°C, the whiteness index for the samples dyed with Psidium guava leaves extract increased gradually. A further increase in drying temperature of more than 25°C resulted in a clear reduction in WI, and the discharge printed wool samples that were dried at this ideal temperature is shown in **Figure 16**.

As illustrated in

Table 9, in the case of wool samples dyed with Ficus leaves extract, there is an observed increase in WI by increasing the temperature gradually from 0 to 80°C and the highest level of discharge can be obtained at 80°C, which may be due to the increase in the activity of the enzymes and their ability to break the phenolic compound (which represents the chromophore of a natural dye) at this temperature.

Table 9 demonstrated that the highest discharge impact was obtained when the samples were left to dry at 25°C (room temperature), as shown in **Figure 16**, When the drying temperature increased, the activity of the oxidative enzymes decreased, and the discharge rate likewise decreased. So the wool samples dyed with eggplant skin and printed with taro corm extract should be left to dry at 25°C, at which point the degree of enzyme activity is sufficient to complete the oxidation reaction and achieve discharge impact.

It is clear from the data in

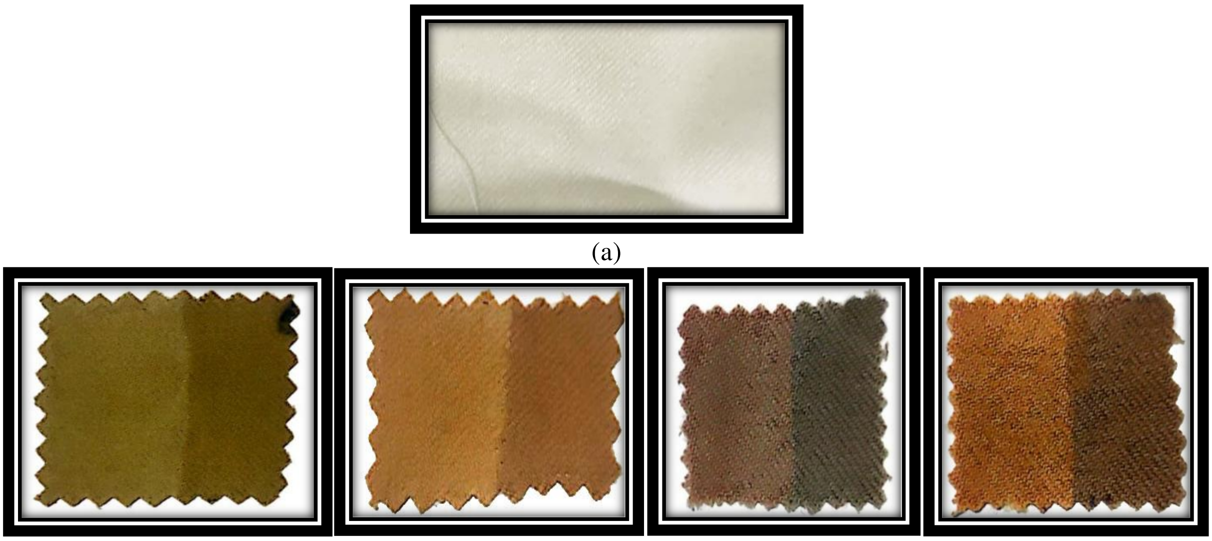
Table 9 in the case of wool samples dyed with red cabbage leaves extract that the increasing percent in WI decreases by increasing the temperature from 0 to 80°C, and the optimum temperature at which the largest amount of the color for dyed material has been removed is at a freezing temperature of 0°C, as shown in **Figure 16**.

Table 9: Effect of drying temperature on discharge rate of printed wool fabrics dyed with different natural dye extracts

Fabric	Natural dye	Drying temp (°C)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
Wool	Blank		-	-	18.68 ± 1.4	-	16.43 ± 1.23	-	L	a	b
	Dyed material		26.4 ± 1.97	-	-171.44 ± 12.77	-	78.07 ± 5.82	-	**51.15**	**6.93**	**27.25**
	Guava extract	0	15.98 ± 1.19	39.49	-156.85 ± 11.68	8.50	72.73 ± 5.42	6.84	57.06	5.22	30.99
		25	11.24 ± 0.84	57.45	-141.76 ± 10.56	17.31	67.97 ± 5.07	12.93	59.52	6.34	27.34
		40	13.29 ± 0.99	49.66	-144.65 ± 10.78	15.62	70.21 ± 5.23	10.07	59.47	4.39	31.16
		60	14.05 ± 1.05	46.79	-147.08 ± 10.96	14.21	70.73 ± 5.27	9.40	57.07	4.64	25.27
		80	14.7 ± 1.1	44.33	-149.01 ± 11.1	13.08	70.85 ± 5.28	9.25	59.11	5.97	30.26
	Dyed material		12.13 ± 0.91		-142.97 ± 10.65		80.24 ± 5.98		**49.03**	**17.73**	**22.93**
	Ficus extract	0	10.43 ± 0.78	14.03	-117.85 ± 8.78	17.57	77.14 ± 5.75	3.86	51.78	15.16	24.15
		25	10.25 ± 0.77	15.52	-115.46 ± 8.6	19.25	77.02 ± 5.74	4.01	52.69	14.91	26.8
		40	9.45 ± 0.71	22.10	-115.2 ± 8.58	19.43	76.29 ± 5.69	4.91	52.77	14.84	26.28
		60	9.23 ± 0.69	23.91	-114.61 ± 8.54	19.84	75.78 ± 5.65	5.55	53.66	15.15	26.90
		80	8.23 ± 0.62	32.15	-105.46 ± 7.86	26.24	74.54 ± 5.56	7.09	54.48	14.13	18.28
	Dyed material		13.15 ± 0.98		-51.4 ± 3.83		32.01 ± 2.39		**51.8**	**2.91**	**9.74**
	Eggplant skin extract	0	11.13 ± 0.83	15.44	-47.17 ± 3.52	8.24	31.81 ± 2.37	0.62	62.83	6.03	15.06
		25	10.01 ± 0.75	23.94	-45.37 ± 3.38	11.74	29.51 ± 2.2	7.82	63.42	5.25	13.53
		40	10.08 ± 0.76	23.41	-45.81 ± 3.42	10.88	30.53 ± 2.28	4.64	63.09	6.07	14.48
		60	10.1 ± 0.76	23.26	-46.24 ± 3.45	10.05	30.69 ± 2.29	4.14	63.16	6.11	14.65
		80	10.24 ± 0.77	22.20	-47.09 ± 3.51	8.40	31.67 ± 2.36	1.06	62.75	6.19	14.80
	Dyed material		7.9 ± 0.59		-61.25 ± 4.56		47.18 ± 3.52		**52.14**	**7.33**	**9.88**
	Red cabbage extract	0	5.95 ± 0.45	24.85	-45.68 ± 3.41	25.42	30.49 ± 2.27	35.39	64.99	10.45	13.29
		25	6 ± 0.45	24.22	-58.56 ± 4.37	4.39	43.46 ± 3.24	7.88	57.19	10.47	17.24

		40	6.46 ± 0.49	18.29	-58.59 ± 4.37	4.34	43.63 ± 3.25	7.52	56.88	11.19	17.81
		60	7.12 ± 0.54	9.95	-59.47 ± 4.43	2.91	43.9 ± 3.27	6.95	55.64	10.51	17.46
		80	7.4 ± 0.56	6.41	-60.32 ± 4.5	1.52	44.98 ± 3.35	4.67	54.81	10.44	18.00

*Printing condition: The wool fabric was printed with taro corms printing paste at an optimum concentration of 150g/kg for Ficus and Psidium guajava leaves, 100g/kg for eggplant skin, and 200 g/kg for red cabbage leaves at different temperatures (0, 25, 40, 60, and 80°C) at pH 3 for all printed samples, for 60 min for Ficus leaves, for 180 min for Psidium guava, for 120 min for eggplant skin and 30 min for red cabbage leaves.



(a)

(b) (c) (d) (e) (f) (g) (h) (i)

Figure 16: Discharged wool fabrics using taro corms extract at optimum temperature

(a) blank fabric

(b) Discharged Guava dyed fabric (c) Guava-dyed fabric

(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

(f) Discharged Eggplant skin-dyed fabric (g) Eggplant skin-dyed fabric

(h) Discharged Red cabbage dyed fabric (i) Red cabbage dyed fabric

3.3.2. Effect of adding oxidizing and reducing agents to the printing paste

To improve the effectiveness of dye removal and the whiteness degree of the discharge printed samples, as well as to obtain a high whiteness index on the printed samples, a trial was conducted to combine this bio-oxidizing agent with various reducing and oxidizing agents to investigate their effect on the dye removal.

3.3.2.1. Effect of mixing H_2O_2 with taro corms extract

Hydrogen peroxide is becoming more popular as an environmentally friendly bleaching chemical in both the domestic and commercial sectors. [112] Hydrogen peroxide, with the molecular formula H_2O_2, is an oxidizing agent that works similarly to oxygen but is much stronger. The inclusion of an additional oxygen atom in the structure of hydrogen peroxide results in its oxidizing action. This additional oxygen atom is referred to as "peroxidic oxygen" and is also referred to as "active oxygen." Hydrogen peroxide can directly oxidize some compounds. The oxygen-oxygen single bond is rather weak and can be broken down to produce •OH free radicals, as shown in **Figure 17**.

$$\textbf{H-O-O-H} \rightarrow {}^{\bullet}\textbf{OH} + {}^{\bullet}\textbf{OH} \qquad (1)$$

Figure 17: The formation of hydroxyl free radicals

The two •OH free radicals may just react with one another, producing an undesirable effect; however, the radical can attack a molecule of organic matter, producing another free radical in the process of oxidation. This is referred to as a chain-initiating step, as shown in **Figure 18.**

$$^{\bullet}\textbf{OH} + \textbf{RH} \rightarrow \textbf{H}_2\textbf{O} + \textbf{R}^{\bullet} \qquad \text{chain-initiating step} \quad (2)$$

Figure 18: The mechanism of H_2O_2 in the oxidizing organic compound

As previously explained, in the free radical oxidation of organics, this process continues until the organics are oxidized to carbon dioxide and water. [113]

The major goals of this work were to combine hydrogen peroxide as an oxidizing and bleaching agent with oxidative enzymes in taro corm extract to investigate their effect on textile color removal.

To determine the efficacy of a mixture of H_2O_2 and taro corm extract on the degree of whiteness, H_2O_2 is added to the printing paste with the optimum concentration of taro corm extract according to the type of fabric and the natural plant extract used to dye it. This oxidizing agent is also mixed at different concentrations (10, 50, and 100 g/kg) in the discharge printing paste.

It’s clear from the data in

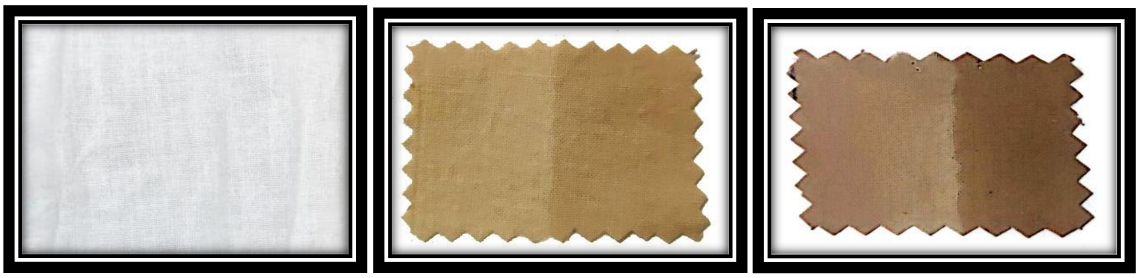
Table 10 that the mixture realized a high degree of whiteness when using H_2O_2 at a concentration of 100 g/kg and 250 g/kg of taro corms extract (the optimum concentration), and the samples that were printed using this mixture is shown in **Figure 19**. On comparing the addition of H_2O_2 alone to the printing paste and the addition of the mixture, it was found that using this oxidizing agent alone gives a slightly higher whiteness degree than the mixture; however, the original sample that was printed with only taro corms extract at optimum concentration gave the highest degree of WI, but the difference between them in terms of the degree of whiteness and discharge rate wasn't high.

Table 10 explained that the whiteness degree of cotton samples dyed with Ficus leaves extract and printed with the previous mixture increased when the concentration of H_2O_2 increased in the mixture from (1% to 10%), so it is concluded that the best discharge effect was obtained at a ratio of 100 g/kg H_2O_2: 300 g/kg taro corms extract as shown in discharge printed sample in **Figure 19**. The whiteness degree of the sample that was printed using only H_2O_2 was higher than the original sample that was printed using only taro corm extract, and also slightly higher than the mixed samples.

Table 10: Effect of mixing H_2O_2 with taro corms extract on discharge rate of cotton fabrics dyed with different natural dye extracts

Fabric	Natural dye	H_2O_2: taro corms (%)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
cotton	**Blank**		-	-	51.59 ± 3.85	-	4.62 ± 0.35	-	**L**	**a**	**b**
	Dyed material		2.81 ± 0.21	-	-27.16 ± 2.03	-	40.44 ± 3.02	-	**66.46**	**9.89**	**15.95**
	Guava extract	**0:25**	1.92 ± 0.15	31.67	-15.61 ± 1.17	42.52	25.09 ± 1.87	37.96	81.19	4.81	12.51
		15:0	1.97 ± 0.15	30.38	-15.84 ± 1.18	41.69	29.48 ± 2.2	27.14	78.62	4.07	9.16
		1:25	2.17 ± 0.17	22.77	-16.64 ± 1.24	38.73	28.23 ± 2.11	30.20	75.49	5.79	20.09
		5:25	2.11 ± 0.16	24.91	-16.03 ± 1.2	40.97	25.22 ± 1.88	37.63	76.12	4.01	7.64
		10:25	2.06 ± 0.16	26.69	-15.95 ± 1.19	41.27	25.16 ± 1.88	37.78	76.50	4	8.90
	Dyed material		3.45 ± 0.26		-28.43 ± 2.12		38.25 ± 2.85		**61.92**	**15.13**	**12.04**
	Ficus extract	**0:30**	2.04 ± 0.16	40.84	-19.56 ± 1.46	31.18	31.92 ± 2.38	16.54	76.58	9.64	8.30
		15:0	1.63 ± 0.13	52.70	-12.3 ± 0.92	56.74	26.27 ± 1.96	31.30	80.46	8.87	11.80
		1:30	2.12 ± 0.16	38.52	-19.66 ± 1.47	30.83	34.64 ± 2.58	9.44	70.23	10.17	11.21
		5:30	1.94 ± 0.15	43.74	-13.96 ± 1.04	50.88	29.1 ± 2.17	23.92	72.27	9.02	12.23
		10:30	1.69 ± 0.13	50.99	-12.74 ± 0.95	55.17	27.23 ± 2.03	28.81	77.74	9.20	15.25

*Printing condition: The cotton fabric was printed with a mixture of taro corms and H_2O_2 at different concentrations of H_2O_2 (1, 5, 10, and 15 %) at optimum concentration of taro corms (250 g/kg for Psidium guava leaves and 300 g/kg for Ficus leaves) at pH 5 for both natural extract, at 25 °C for 180 min in Psidium guava leaves, and at 80°C for 60 min in Ficus leaves.



(a) (b) (c) (d) (e)

Figure 19: Effect of mixing H_2O_2 with taro corms extract on the discharge rate of cotton fabrics

(a) blank fabric (b) Discharged Guava dyed fabric (c) Guava dyed fabric
(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

As illustrated by the data in

Table 11 As the amount of H_2O_2 in the printing paste increases, the degree of color removal also increases. This means that the mixture has the highest degree of whiteness when H_2O_2 is added at a concentration of 100 g/kg. The samples printed at the optimum mixed ratio are shown in **Figure 20**. On comparing the discharge effect of taro corms extract as a bio-oxidizing agent with H_2O_2 as a commercial oxidizing agent on wool samples dyed with Psidium guava leaves extract and printed with them, it was found that the discharge level in the case of using only taro corms extract at optimum conditions was higher than that obtained when using only H_2O_2 at the same conditions, and the mixture at the concentration mentioned above gives the greatest effect on the degree of whiteness.

It's obvious from the data in

Table 11 that the whiteness degree of wool samples dyed with Ficus leaves extract and printed with the mixture of H_2O_2 and taro corms extract increased gradually by increasing the H_2O_2 ratio from 1 to 10%, and **Figure 20** presented the wool sample that was printed at optimum mixed ratio, while the whiteness degree for the original sample that was printed with only taro corms extract was higher than the mixed sample at ratio (1%) but lower than the two other ratios, which means that the idea of mixing H_2O_2 with enzymatic extract was effective. Whereas the sample that was printed with only H_2O_2 reached the highest discharge level due to the strength and effectiveness of hydrogen peroxide as a chemical oxidant.

Table 11 presented the results for the use of H_2O_2 alone or mixed with taro corm extract in discharge paste and the effect of the mixture on the discharge rate of wool samples dyed with eggplant skin extract. From these data, we found that the increasing percent in WI increased gradually by increasing the concentration of H_2O_2 in the printing paste, which means that the best whiteness degree was achieved when the dyed sample was printed with (100:100 g/kg H_2O_2: taro corms extract), as shown in **Figure 20**, while the whiteness degree for the sample that was printed with only H_2O_2 was higher than that mixed with (10:100 g/kg H_2O_2: taro corms) but lower than the two other mixed ratios; however, the whiteness degree for the original sample, which was printed with only 100 g/kg taro corms extract was lower than the all mixed samples, which proves the effectiveness of mixing on increasing the discharge rate.

Table 11 explained the effect of mixing H_2O_2 with taro corms extract on the discharge rate of wool samples dyed with red cabbage leaves extract, and it was observed that the discharge rate increased gradually by increasing the concentration of H_2O_2 in the printing paste as mentioned in the previous samples and, as a result, the whiteness index increased, but the whiteness degree for the sample that was printed using only H_2O_2 was lower than all mixed samples, whereas the original sample that was printed with only 200 g/kg taro corms extract showed a lower discharge effect than that printed with H_2O_2 pure and also than the other mixed samples. This proves that mixing these discharge substances led to a greater enhancement of the whiteness degree than using each of them alone in the printing paste.

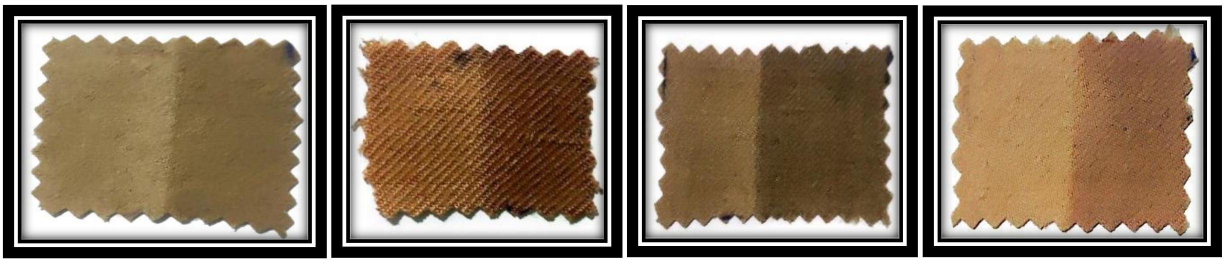
Table 11: Effect of mixing H_2O_2 with taro corms extract on discharge rate of wool fabrics dyed with different natural dye extracts

Fabric	Natural dye	H_2O_2: taro corms (%)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
wool	**Blank**		-	-	18.68 ± 1.4	-	16.43 ± 1.23	-	**L**	**a**	**b**
	Dyed material		26.4 ± 1.97	-	-171.44 ± 12.77	-	78.07 ± 5.82	-	**51.15**	**6.93**	**27.25**
	Guava extract	**0:15**	11.24 ± 0.84	57.45	-141.76 ± 10.56	17.31	67.97 ± 5.07	12.93	59.52	6.34	27.34
		15:0	22.48 ± 1.68	14.87	-151.01 ± 11.25	11.91	67.74 ± 5.05	13.24	57.45	7.60	27.03
		1:15	17.07 ± 1.28	35.37	-151.63 ± 11.29	11.55	70.87 ± 5.28	9.22	55.47	5.89	26.52
		5:15	13.03 ± 0.98	50.65	-145.37 ± 10.83	15.20	68.69 ± 5.12	12.01	55.71	5.96	25.64
		10:15	8.75 ± 0.66	66.87	-138.35 ± 10.31	19.30	62.51 ± 4.66	19.93	63.67	3.50	31.75
	Dyed material		**12.14**	12.13 ± 0.91	**-143.20**	-142.97 ± 10.65	**80.36**	80.24 ± 5.98	**49.03**	**17.73**	**22.93**
	Ficus extract	**0:15**	8.23 ± 0.62	32.15	-105.46 ± 7.86	26.24	74.54 ± 5.56	7.09	54.48	14.13	18.28
		15:0	3.32 ± 0.25	72.56	-87.19 ± 6.5	39.01	63.2 ± 4.71	21.25	58.88	4.22	6.16
		1:15	9.02 ± 0.68	25.64	-107.89 ± 8.04	24.54	74.77 ± 5.57	6.81	55.02	15.02	20.27
		5:15	7.52 ± 0.56	37.99	-98.53 ± 7.34	31.09	73.79 ± 5.5	8.04	57.35	14.43	23.61
		10:15	7.32 ± 0.55	39.64	-96.97 ± 7.22	32.18	72.47 ± 5.4	9.68	58.50	15.08	23.11
	Dyed material		**13.17**	13.15 ± 0.98	**-51.48**	-51.4 ± 3.83	**32.06**	32.01 ± 2.39	**51.8**	**2.91**	**9.74**
	Eggplant skin extract	**0:10**	10.01 ± 0.75	23.94	-45.37 ± 3.38	11.74	29.51 ± 2.2	7.82	63.42	5.25	13.53
		15:0	5.63 ± 0.42	57.26	-32.73 ± 2.44	36.33	21.92 ± 1.64	31.53	74.29	4.03	20.39
		1:10	6.48 ± 0.49	50.74	-33.75 ± 2.52	34.34	21.94 ± 1.64	31.47	59.59	8.00	17.28
		5:10	5.38 ± 0.4	59.16	-28.71 ± 2.14	44.14	18.78 ± 1.4	41.32	60.16	7.80	17.44
		10:10	4.55 ± 0.34	65.46	-27.7 ± 2.07	46.12	18.28 ± 1.37	42.91	61.70	7.49	17.48
	Dyed material		**7.91**	7.9 ± 0.59	**-61.34**	-61.25 ± 4.56	**47.25**	47.18 ± 3.52	**52.14**	**7.33**	**9.88**
		0:20	5.95 ± 0.45	24.85	-45.68 ± 3.41	25.42	30.49 ± 2.27	35.39	64.99	10.45	13.29

	Red cabbage extract	**15:0**	3.76 ± 0.28	39.8 0	-29.1 ± 2.17	36.20	29.96 ± 2.24	36.51	66.40	7.49	21.65
		1:20	4.67 ± 0.35	41.02	-38.83 ± 2.9	36.60	28.39 ± 2.12	39.84	69.66	6.66	9.41
		5:20	4.42 ± 0.33	44.18	-35.51 ± 2.65	42.03	26.15 ± 1.95	44.58	72.41	6.67	8.75
		10:20	4.31 ± 0.33	45.56	-34.33 ± 2.56	43.95	25.68 ± 1.92	45.57	73.41	5.81	8.45

*Printing condition: The wool fabric was printed with a mixture of taro corms and H_2O_2 at different concentrations of H_2O_2 (1, 5, 10, and 15%) and optimum concentration of taro corms (150 g/kg for both Psidium guava leaves and Ficus leaves, 100 g/kg for eggplant skin and 200 g/kg for red cabbage leaves) at pH 3 for both natural extract, at 25°C for 180 min in Psidium guava leaves, at 80°C for 60 min in Ficus leaves, at 25°C for 120 min for eggplant skin, and at 0°C for 30 min in red cabbage leaves.

(a)



(b) (c) (d) (e) (f) (g) (h) (i)

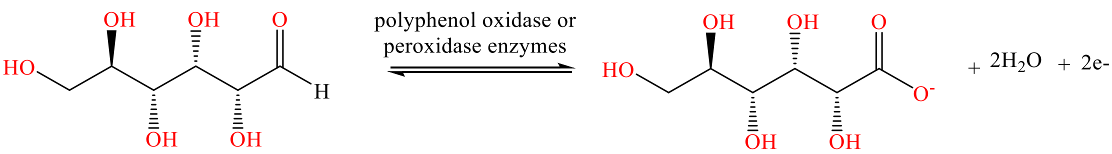
Figure 20: Effect of mixing H_2O_2 with taro corms extract on the discharge rate of wool fabric

(a) blank fabric
(b) Discharged Guava dyed fabric (c) Guava-dyed fabric
(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric
(f) Discharged Eggplant skin-dyed fabric (g) Eggplant skin-dyed fabric
(h) Discharged Red cabbage dyed fabric (i) Red cabbage dyed fabric

3.3.2.2. Effect of mixing glucose with taro corm extract

Any sugar is only characterized as a reducing sugar if it contains an open-chain form with an aldehyde group or a free hemiacetal group, like L or D glucose. [114]

In the reduction of natural colors, glucose was effectively used as a reducing sugar and **Figure 21** explains Oxidation of glucose by oxidative enzymes. A glucose aldehyde group can be converted to carboxylic acid through an enzymatic oxidation process, which is then able to reduce the phenolic and flavonoid compounds in natural dyes. [115]



Glucose Gluconate form

Figure 21 Oxidation of glucose by oxidative enzymes

The discharge printed regions using taro corms extract have a lower K/S than the ground shade, and this natural extract couldn't be able to remove all natural colors to obtain completely white discharge printing, so it is suggested that a bio-reducing agent called glucose can be mixed with the optimal concentration of taro corm extract to investigate the suitability of this mixture to discharge printing.

To achieve the aim of this process, it is supposed to prepare two different printing pastes: one that contains the optimal concentration of taro corms, and the other that contains glucose at the usual concentration. The other three mixed pastes were also prepared, containing taro corm extract and 10, 50, and 100 g/kg glucose. The cotton and wool samples were printed with these printing pastes, then dried and washed.

As illustrated in **Table 12**. It was found that the samples printed by a mixture of glucose and taro corms extract achieved a high whiteness degree by increasing the glucose concentration from 10 to 100 g/kg in the mixture, and the sample presented in **Figure 22**, showed the discharge effect obtained when using the optimum mixed ratio. It was found from **Table 12** in the case of Psidium guava leaves extract, the best whiteness degree resulted from the mixture at a concentration of 100 g/kg glucose and 250 g/kg taro corms, which was lower than that obtained when using glucose alone in printing paste. The original sample that was printed by using only taro corms extract at optimum conditions was slightly lower than that printed by using only glucose at the common concentration.

When comparing the discharge effect of taro corms extract and glucose on cotton samples dyed with Ficus leaves, as in **Table 12**. It was found that the best discharge level could be obtained when using taro corms extract at the optimum conditions mentioned previously, while the discharge effect resulting from the use of glucose alone was weak. It was also found that an increase of glucose ratio from 1 to 5 to 10% in the mixture led to a gradual increase in the whiteness index, but the original sample that was printed with taro corms was still the best one, and the difference between it and the mixed samples is slight.

Table 12: Effect of mixing glucose with taro corms extract on discharge rate of cotton fabrics dyed with different natural dye extracts.

Fabric	Natural dye	Glucose: taro corms (%)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness degree (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
									L	**a**	**b**
cotton	**Blank**		-	-	51.59 ± 3.85	-	4.62 ± 0.35	-			
	Dyed material		2.81 ± 0.21	-	-27.16 ± 2.03	-	40.44 ± 3.02	-	**66.46**	**9.89**	**15.95**
	Guava extract	**0:25**	1.92 ± 0.15	31.67	-15.61 ± 1.17	42.52	27.41 ± 2.05	30.90	81.19	4.81	12.51
		15:0	1.83 ± 0.14	34.87	-11.33 ± 0.85	58.29	25.09 ± 1.87	37.96	72.00	6.04	10.72
		1:25	2.08 ± 0.16	25.97	-20.58 ± 1.54	24.20	29.82 ± 2.22	26.28	73.61	5.15	9.29
		5:25	2 ± 0.15	28.82	-17.94 ± 1.34	33.95	27.38 ± 2.04	32.30	74.30	5.03	8.29

		10:25	1.99 ± 0.15	29.18	-17.86 ± 1.33	34.24	27.35 ± 2.04	32.38	67.64	11.21	20.47
	Dyed material		3.45 ± 0.26		-28.43 ± 2.12		38.25 ± 2.85		**61.92**	**15.13**	**12.04**
	Ficus extract	**0:30**	2.04 ± 0.16	40.84	-19.56 ± 1.46	31.18	31.92 ± 2.38	16.54	76.58	9.64	8.30
		15:0	2.35 ± 0.18	31.85	-24.55 ± 1.83	13.65	36.73 ± 2.74	3.98	64.92	12.95	13.73
		1:30	2.2 ± 0.17	36.20	-20.34 ± 1.52	28.44	35.62 ± 2.66	6.88	70.17	9.61	10.49
		5:30	2.07 ± 0.16	39.97	-19.69 ± 1.47	30.72	34.85 ± 2.6	8.89	68.67	10.94	13.46
		10:30	2.06 ± 0.16	40.26	-19.67 ± 1.47	30.79	34.84 ± 2.6	8.91	71.56	9.79	11.9

*Printing condition: The cotton fabric was printed with a mixture of taro corms and glucose at different concentrations of glucose (1, 5, 10, and 15%) and optimum concentration of taro corms (250 g/kg for Psidium guava leaves and 300 g/kg for Ficus leaves) at pH 5 for both natural extract, at 25°C for 180 min in Psidium guava leaves, and at 80°C for 60 min in Ficus leaves.

(a) (b) (c) (d) (e)

Figure 22: Effect of mixing glucose with taro corms extract on the discharge rate of cotton fabrics

(a) blank fabric (b) Discharged Guava dyed fabric (c) Guava dyed fabric (d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

As demonstrated in **Table 13** The mixture of glucose and taro corms extract realized a high degree of whiteness when using glucose at a concentration of 10% mixed with the optimum concentration of taro corms extract and used to print the wool samples dyed with both natural plant extracts (Psidium guava and Ficus leaves). When comparing the use of glucose alone in the printing paste with its addition to the mixture, it was clear that the mixture had a greater effect on the degree of whiteness compared with glucose alone. While the original sample printed with taro corms extract only represents a higher whiteness index than the glucose printed sample, both are lower than the effect of the mixture on whiteness degree in the case of Ficus leaves; however, in the samples dyed with Psidium guava leaves, it was found that the original sample printed with only taro corms extract represents the best discharge effect and a higher degree of whiteness than the sample printed with only glucose.

From **Table 13**, which presented the effect of adding glucose as a bio-reducing agent to discharge paste that is used to print wool samples dyed with eggplant skin extract and red cabbage leaves extract, we found that the discharge rate decreased gradually by increasing the concentration of glucose in the printing paste, and the maximum whiteness degree was obtained when using 10 g/kg glucose mixed with the optimum concentration of taro corms and the best discharge printed samples at optimum mixed ratio are shown in **Figure 23**. This means that increasing the glucose amount causes the opposite effect and reduces the discharge rate instead of increasing it. While the original samples that were dyed with both natural extracts and printed with taro corms extract without any addition were higher than the sample that was printed with only 150 g/kg glucose; however, the discharge rate of these original samples was lower than the samples printed with the mixture of glucose and taro corms extract, which proves that the mixture achieved the best discharge effect on these samples.

Table 13: Effect of mixing glucose with taro corms on the discharge rate of wool fabrics dyed with different natural dye extracts

Fabric	Natural dye	Glucose: taro corms	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (K/S)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
wool	Blank		-	-	16.43 ± 1.23	-	18.68 ± 1.4	-	L	a	b
	Dyed material		26.4 ± 1.97	-	-171.44 ± 12.77	-	78.07 ± 5.82	-	**51.15**	**6.93**	**27.25**
	Guava extract	0:15	11.24 ± 0.84	57.45	-141.76 ± 10.56	17.31	67.97 ± 5.07	12.93	59.52	6.34	27.34
		15:0	24.21 ± 1.81	8.32	-162.18 ± 12.08	5.39	75.33 ± 5.61	3.50	51.70	5.89	26.78
		1:15	12.76 ± 0.96	51.67	-151.98 ± 11.32	11.35	70.63 ± 5.26	9.53	53.01	6.17	25.73
		5:15	12.61 ± 0.94	52.24	-149.48 ± 11.14	12.80	70.25 ± 5.24	10.01	54.94	5.81	25.47
		10:15	12 ± 0.9	54.58	-148.35 ± 11.05	13.46	69.92 ± 5.21	10.44	58.91	4.80	29.33
	Dyed material		12.13 ± 0.91		-142.97 ± 10.65		80.24 ± 5.98		**49.03**	**17.73**	**22.93**
	Ficus extract	0:15	8.23 ± 0.62	32.15	-105.46 ± 7.86	26.24	74.41 ± 5.55	7.25	54.48	14.13	18.28
		15:0	8.54 ± 0.64	29.60	-135.88 ± 10.12	4.96	75.94 ± 5.66	5.35	52.70	14.19	21.46
		1:15	6.93 ± 0.52	42.85	-104.77 ± 7.81	26.72	72.74 ± 5.42	9.46	57.03	15.65	24.42
		5:15	4.78 ± 0.36	60.64	-101.17 ± 7.54	29.24	71.6 ± 5.34	10.76	59.30	14.54	22.28
		10:15	4.45 ± 0.34	63.35	-96.73 ± 7.21	32.35	64.41 ± 4.8	19.72	62.64	15.33	27.22
	Dyed material		13.15 ± 0.98		-51.4 ± 3.83		32.01 ± 2.39		**51.8**	**2.91**	**9.74**
	Eggplant skin extract	0:10	10.01 ± 0.75	23.94	-45.37 ± 3.38	11.74	29.51 ± 2.2	7.82	63.42	5.25	13.53
		15:0	11.73 ± 0.88	10.89	-47.65 ± 3.55	7.31	29.23 ± 2.18	7.70	57.11	8.09	18.20
		1:10	9.36 ± 0.7	28.88	-43.71 ± 3.26	14.96	24.31 ± 1.81	24.07	59.94	7.96	19.08
		5:10	9.43 ± 0.71	28.34	-44.89 ± 3.35	12.67	25.95 ± 1.94	18.93	59.84	7.84	18.88

		10:10	10.78 ± 0.81	18.10	-45.99 ± 3.43	10.53	29.54 ± 2.2	7.73	59.59	7.92	18.99
	Dyed material		7.9 ± 0.59		-61.25 ± 4.56		47.18 ± 3.52		**52.14**	**7.33**	**9.88**
	Red cabbage extract	**0:20**	5.95 ± 0.45	24.85	-45.68 ± 3.41	25.42	30.49 ± 2.27	35.39	64.99	10.45	13.29
		15:0	6.72 ± 0.51	15 .00	-52.27 ± 3.9	14.66	38.67 ± 2.88	18.04	55.82	10.22	15.82
		1:20	5.14 ± 0.39	35.08	-39.9 ± 2.98	34.86	27.2 ± 2.03	42.35	66.6	8.75	16.90
		5:20	5.42 ± 0.41	31.55	-41.77 ± 3.11	31.81	27.75 ± 2.07	41.19	65.96	9.18	16.66
		10:20	6.37 ± 0.48	19.42	-50.7 ± 3.78	17.22	32.56 ± 2.43	30.99	64.78	9.55	14.52

*Printing condition: The wool fabric was printed with a mixture of taro corms and glucose at different concentrations of glucose (1, 5, 10, and 15%) and optimum concentration of taro corms (150 g/kg for both Psidium guava leaves and Ficus leaves, 100 g/kg for eggplant skin and 200 g/kg for red cabbage leaves) at pH 3 for both natural extract, at 25°C for 180 min in Psidium guava, at 80°C for 60 min in Ficus leaves, at 25°C for 120 min for eggplant skin, and at 0°C for 30 min in red cabbage leaves.

(a)

(b) (c) (d) (e) (f) (g) (h) (i)

Figure 23: Effect of mixing glucose with taro corms extract on the discharge rate of wool fabric

(a) blank fabric

(b) Discharged Guava dyed fabric (c) Guava-dyed fabric

(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

(f) Discharged Eggplant skin-dyed fabric (g) Eggplant skin-dyed fabric

(h) Discharged Red cabbage dyed fabric (i) Red cabbage dyed fabric

3.3.2.3. Effect of mixing brewer's yeast with taro corms extract

Previous studies have shown that brewer's yeast may be successfully utilized in the discharge printing of natural materials dyed with natural dyes rather than toxic and unfriendly reducing or oxidizing agents. From this perspective, it was suggested that brewer's yeast (which is considered an excellent source of enzymes) could be combined with taro corm extract to investigate the effect of this mixture on the degree of whiteness.

The active yeast suspension was created as follows: 450 g dry weight of brewer's yeast was pasted with 150 g sugar, and then one liter of warm water (at 40°C) was added to the paste of yeast paste while stirring for some time until the yeast was brewed. [116] Then the solution was mixed with the optimum concentration of taro corm extract, and then the discharge paste was applied to the cotton and wool samples at optimum printing conditions according to the natural dye used.

When comparing the effect of brewer's yeast on discharge rate with the bio-oxidizing agent (taro corms extract) and the effect of mixing them on the whiteness degree, as presented in **Table 14**, it was found that the increasing percent in WI increased by increasing the brewer's yeast concentration in the mixture with taro corms extract from (1 to 10%), so it was concluded that the best-mixed ratio was 100g/kg brewer's yeast: optimum concentration of taro corms extract and the discharge printed samples at optimum mixed ratio are shown in **Figure 24** .

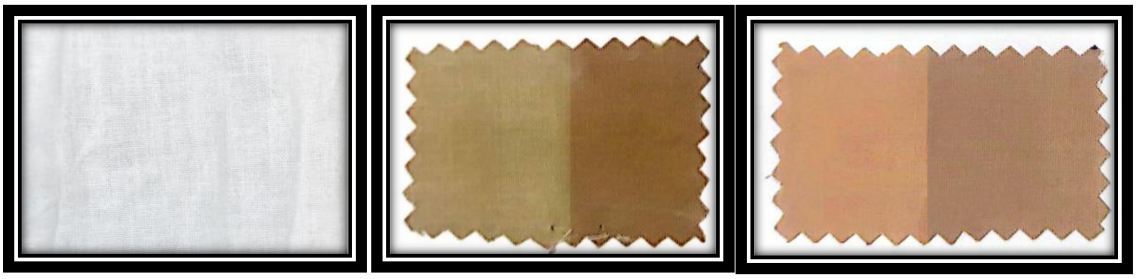
While it was found that the dyed samples that were printed with only taro corms extract reached a higher discharge level than those samples that were printed with the mixture, this original sample is also higher than the sample that was printed with only brewer's yeast in the case of Psidium guava leaves extract but lower than this one in the case of Ficus leaves extract. We can conclude that mixing brewer's yeast with taro corms extract did not achieve the desired result in the case of cotton dyed with both natural dyes.

Table 14: Effect of mixing brewer's yeast with taro corms on discharge rate of cotton fabrics dyed with different natural dye extracts

Fabric	Natural dye	Brewer's yeast: taro corms (%)	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
cotton	Blank		-	-	51.59 ± 3.85	-	4.62 ± 0.35	-	L	a	b
	Dyed material		2.81 ± 0.21	-	-27.16 ± 2.03	-	40.44 ± 3.02	-	**66.46**	**9.89**	**15.95**
	Guava extract	0:25	1.92 ± 0.15	31.67	-15.61 ± 1.17	42.52	25.09 ± 1.87	37.96	81.19	4.81	12.51
		15:0	2.3 ± 0.18	18.14	-20.64 ± 1.54	23.98	33.06 ± 2.47	18.26	71.80	8.36	14.62
		1:25	1.97 ± 0.15	29.89	-18.98 ± 1.42	30.09	32.8 ± 2.45	18.90	68.97	9.17	17.30
		5:25	1.96 ± 0.15	30.24	-17.13 ± 1.28	36.93	30.07 ± 2.24	25.66	71.78	8.06	13.72
		10:25	1.94 ± 0.15	30.96	-16.12 ± 1.2	40.64	28.16 ± 2.1	30.38	70.75	8.29	14.96
	Dyed material		3.45 ± 0.26		-28.43 ± 2.12		38.25 ± 2.85		**61.92**	**15.13**	**12.04**
	Ficus extract	0:30	2.04 ± 0.16	40.84	-19.56 ± 1.46	31.18	31.92 ± 2.38	16.54	76.58	9.64	8.30
		15:0	0.99 ± 0.08	71.29	-5.23 ± 0.39	81.62	25.9 ± 1.93	32.28	82.39	5.38	5.35

		1:30	3.22 ± 0.24	6.621	-26.29 ± 1.96	7.50	37.67 ± 2.81	1.50	66.35	10.63	12.56
		5:30	2.79 ± 0.21	18.85	-23.29 ± 1.74	18.07	36.12 ± 2.69	5.57	69.65	9.41	11.84
		10:30	2.79 ± 0.21	19.00	-22.51 ± 1.68	20.81	35.17 ± 2.62	8.05	68.49	9.69	12.79

*Printing condition: The cotton fabric was printed with a mixture of taro corms and brewer's yeast at different concentrations of brewer's yeast (1, 5, 10, and 15%) and optimum concentration of taro corms (250 g/kg for Psidium guava leaves and 300 g/kg for Ficus leaves) at pH 5 for both natural extract, at 25°C for 180 min in Psidium guava leaves, and at 80°C for 60 min in Ficus leaves.



(a) (b) (c) (d) (e)

Figure 24: Effect of mixing brewer's yeast with taro corms extract on the discharge rate of cotton fabrics

(a) blank fabric (b) Discharged Guava dyed fabric (c) Guava dyed fabric (d) Discharged Ficus dyed fabric (e) Ficus dyed fabric

Table 15 explained that the whiteness degree of wool samples dyed with Psidium guava leaves extract increased gradually by increasing the brewer's yeast concentration mixed with taro corms extract in discharge paste until it reached (10 %: 15% brewer's yeast: taro corms extract); this ratio achieved a higher discharge level than others, and **Figure 25** showed the discharge printed sample at this optimum ratio. When comparing the sample that was printed with only taro corms extract with that printed with only brewer's yeast, it was found that the original sample that was printed with taro extract achieved a whiteness degree higher than the other sample and also higher than all mixed samples, which proved that taro corms extract was effective when it was used alone without any addition.

It's clear from **Table 15** that, in the case of wool samples dyed with Ficus leaves extract, the mixture of brewer's yeast and taro corms produced a high degree of whiteness when brewer's yeast was used at a lower concentration of 1% (10:150 g/kg brewer's yeast: taro corms extract) and the printed sample is presented in **Figure 25**. As brewer's yeast concentration is increased, there is a progressive decrease in WI. When comparing the addition of brewer's yeast alone to the printing paste with the original sample that was printed using taro corms extract at optimal concentration, it was found that the whiteness degree of the brewer's yeast printed sample was lower than that of the sample printed with only taro corms extract, which indicates that the oxidizing enzymes in taro corms are more active than those in brewer's yeast.

To investigate the effect of mixing brewer's yeast with taro corms extract on the whiteness degree of wool samples dyed with eggplant skin extract. **Table 15** demonstrated that the whiteness degree increased gradually by increasing the amount of brewer's yeast in discharge paste, and the best discharge effect was obtained when the sample was printed using a mixture of (10:10% brewer's yeast: taro corms extract), as shown in **Figure 25**. While the whiteness degree for the original sample that was printed using only taro corms extract was lower than the mixed sample at a ratio (10%), but higher than the sample that was printed with only brewer's yeast.

In the case of samples dyed with red cabbage leaves extract, **Table 15** clarified that the whiteness degree of the printed samples decreased by increasing the amount of brewer's yeast in the printing paste, and the best mixing ratio was (1: 20 % brewer's yeast: taro corms extract) as shown in the samples presented in **Figure 25**, which achieved the highest discharge of the dye, and its removal was higher than that printed with only taro corm extract or only brewer's yeast.

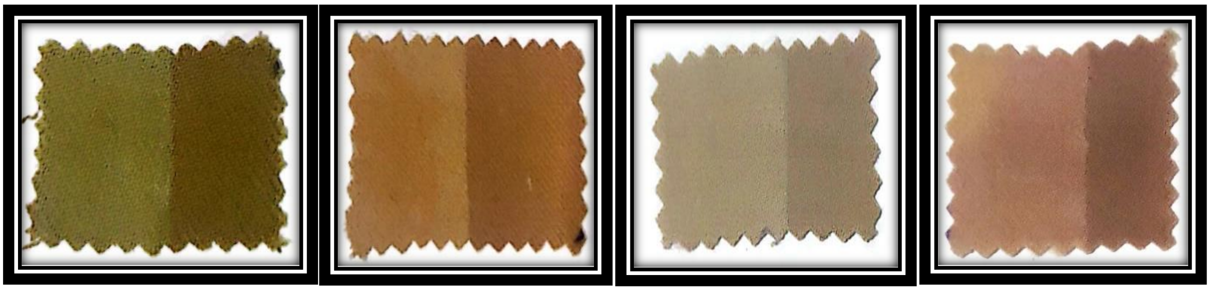
Table 15: Effect of mixing brewer's yeast with taro corms on discharge rate of wool fabrics dyed with different natural dye extracts

Fabric	Natural dye	Brewer's yeast: Taro corms	Color strength (K/S)	Decreasing in K/S (%)	Whiteness index (WI)	Increasing in WI (%)	Yellowness index (YI)	Decreasing in YI (%)	CIE Lab system		
wool	Blank		-	-	16.43 ± 1.23	-	18.68 ± 1.4	-	**L**	**a**	**b**
	Dyed material		26.4 ± 1.97	-	-171.44 ± 12.77	-	78.07 ± 5.82	-	**51.15**	**6.93**	**27.25**
	Guava extract	0:15	11.24 ± 0.84	57.45	-141.76 ± 10.56	17.31	67.06 ± 5	14.11	59.52	6.34	27.34
		15:0	15.41 ± 1.15	41.65	-143.71 ± 10.71	16.17	67.97 ± 5.07	12.93	56.94	5.99	26.07
		1:15	20.8 ± 1.55	21.23	-158.29 ± 11.79	7.67	74.02 ± 5.52	5.19	56.90	7.20	25.43
		5:15	14.99 ± 1.12	43.24	-143.64 ± 10.7	16.21	69 ± 5.14	11.61	57.29	5.89	26.37
		10:15	13.45 ± 1.01	49.06	-141.96 ± 10.57	17.19	68.67 ± 5.12	12.04	57.46	5.92	26.16
	Dyed material		12.13 ± 0.91		-142.97 ± 10.65		80.24 ± 5.98		**49.03**	**17.73**	**22.93**
	Ficus extract	0:15	8.23 ± 0.62	32.15	-105.46 ± 7.86	26.24	74.41 ± 5.55	7.25	54.48	14.13	18.28

	15:0	9.52 ± 0.71	21.53	-132.44 ± 9.87	7.37	77.74 ± 5.79	3.11	54.83	15.27	20.94
	1:15	6.45 ± 0.49	46.80	-99.42 ± 7.41	30.46	65.41 ± 4.88	18.48	63.37	12.78	25.61
	5:15	7.1 ± 0.53	41.45	-99.95 ± 7.45	30.09	65.75 ± 4.9	18.05	63.35	13.32	26.66
	10:15	7.8 ± 0.59	35.69	-104.08 ± 7.75	27.21	65.94 ± 4.91	17.82	63.31	13.03	26.60
Dyed material		13.15 ± 0.98		-51.4 ± 3.83		32.01 ± 2.39		**51.8**	**2.91**	**9.74**
Eggplant skin extract	**0:10**	10.01 ± 0.75	23.94	-45.37 ± 3.38	11.74	29.51 ± 2.2	7.82	63.42	5.25	13.53
	15:0	11.32 ± 0.85	14.00	-46.52 ± 3.47	9.50	30.71 ± 2.29	4.08	57.95	2.75	9.00
	1:10	9.84 ± 0.74	25.23	-42.48 ± 3.17	17.37	28.85 ± 2.15	9.88	64.80	5.89	14.86
	5:10	9.13 ± 0.68	30.62	-41.25 ± 3.08	19.76	27.55 ± 2.06	13.94	65.79	5.31	15.33
	10:10	9.02 ± 0.68	31.46	-41.14 ± 3.07	19.97	27.44 ± 2.05	14.28	66.43	5.99	16.67
Dyed material		7.9 ± 0.59		-61.25 ± 4.56		47.18 ± 3.52		**52.14**	**7.33**	**9.88**
Red cabbage extract	**0:20**	5.95 ± 0.45	24.85	-45.68 ± 3.41	25.42	30.49 ± 2.27	35.39	64.99	10.45	13.29
	15:0	5.07 ± 0.38	35.97	-42.98 ± 3.2	29.84	30.33 ± 2.26	35.73	56.75	10.25	15.76
	1:20	4.94 ± 0.37	37.61	-40.04 ± 2.99	34.63	26.34 ± 1.97	44.17	66.46	9.21	14.44
	5:20	5.71 ± 0.43	27.88	-43.94 ± 3.28	28.26	31.56 ± 2.35	33.11	65.56	9.26	14.10
	10:20	5.84 ± 0.44	26.24	-45.22 ± 3.37	26.17	32.47 ± 2.42	31.18	65.47	9.46	14.61

*Printing condition: The wool fabric was printed with a mixture of taro corms and brewer's yeast at different concentrations of brewer yeast (1, 5, 10, and 15%) and optimum concentration of taro corms (150 g/kg for both Psidium guava leaves and Ficus leaves, 100 g/kg for eggplant skin and 200 g/kg for red cabbage leaves) at pH 3 for both natural extract, at 25°C for 180 min in Psidium guava, at 80°C for 60 min in Ficus leaves, at 25°C for 120 min for eggplant skin, and at 0°C for 30 min in red cabbage leaves.

(a)



(b) (c) (d) (e) (f) (g) (h) (i)

Figure 25: Effect of mixing brewer's yeast with taro corms extract on the discharge rate of wool fabric

(a) blank fabric
(b) Discharged Guava dyed fabric (c) Guava-dyed fabric
(d) Discharged Ficus dyed fabric (e) Ficus dyed fabric
(f) Discharged Eggplant skin-dyed fabric (g) Eggplant skin-dyed fabric
(h) Discharged Red cabbage dyed fabric (i) Red cabbage dyed fabric

3.3.3. Characterization of naturally dyed fabrics

3.3.3.1. Fastness properties

Both natural fabrics (cotton and wool) were dyed with various natural plant extracts (Psidium guava leaves extract and Ficus leaves extract) for cotton and wool fabrics (eggplant skin extract and red cabbage extract) for only wool fabrics, then they were measured for color strength (K/S) and various fastness properties such as washing, rubbing, perspiration, and light fastness, and the data were listed in

Table 16.

The light fastness of samples dyed with various natural plant extracts ranged from good to very good (4-5), which means that the light doesn't have a huge negative effect on the color of dyed samples. The wash ability of all naturally dyed textiles, the color fastness to perspiration (acidic and alkali) in both alteration and staining and the color fastness to rubbing in both wet and dry conditions are ranged from (3-4), which means good except for the cotton sample that was dyed with Psidium guava leaves extract, whose color fastness varied from (2-3) poor to good.

Table 16: Color strength (K/S) and fastness properties of naturally dyed fabrics using various natural plant extracts

Dye type	Fabric	K/S	Fastness Properties								
			Washing		Rubbing		Perspiration				Light
							Acidic		Alkaline		
			Alt.	St.	Dry	wet	Alt.	St.	Alt.	St.	
Psidium Guava	wool	26.4 ± 1.97	4	4	3-4	4	3-4	3-4	3-4	3	6
	cotton	2.83 ± 0.22	3	2-3	3	2-3	3	2-3	2-3	3	5
Ficus	wool	12.13 ± 0.91	4	4	3-4	3-4	3-4	3-4	4	4	5-6
	cotton	3.45 ± 0.26	4	3-4	3-4	4	3-4	3-4	3-4	3	6
Eggplant skin	wool	13.15 ± 0.98	4	4	4	4	4	3-4	4	4	5-6

Red cabbage	wool	7.9 ± 0.59	4	4	4	4	4	3-4	4	4	5-6

3.3.4. Characterization of discharge printed fabrics

The mechanical and physical characteristics of discharge printed textiles, such as tensile strength, elongation at break, Young's modulus, crease recovery angle, and surface roughness, have been examined, and the findings are explained in **Table 17**.

As demonstrated in **Table 17** The tensile strength, Young's modulus, crease recovery angle, and surface roughness increased when the cotton sample was dyed with Psidium guava leaves, and these values became higher than those observed for the blank sample. However, when the dyed sample was printed with taro corm extract, it was found that tensile strength decreased up to 13.5%, and also elongation at break was reduced, which might be due to polyphenol oxidase and other oxidative enzymes that contribute to the total enzymatic hydrolysis of cellulose. We may have just begun to highlight the potential benefits and drawbacks of using several oxidative enzymes that led to simultaneous cellulose and lignin degradation. [242]

While the tensile strength for the cotton sample that was only dyed with Ficus leaves extract and all wool samples that were dyed with all-natural plant extracts were lower than those of the blank sample, this indicates that the dyeing process led to cracking in some of the bonds present in the interfacial distances of the fibers, which facilitates the penetration of the dye molecules into the material and the completion of the dyeing process, and thus results in a loss in weight and a decrease in tensile strength.

Whereas tensile strength and elongation at break were superior in cotton samples that were dyed with Ficus leaves and printed with taro corms extract, the decreasing percent in tensile strength modified from 11.5% to 7%, which means that the tensile strength of the fabric increased after printing. The reason for this may due to the enzymatic treatment that led to an improvement in the crystallization of the fibers, and this may be due to the presence of some vital compounds in the taro corms extract in addition to oxidizing enzymes, and these compounds may be interacted with those compounds in Ficus leaves extract that led to the formation of a thin layer that envelops the fibers and increases their strength and decreasing their ability to lose weight.

Tensile strength and Young's modulus for the wool sample that was dyed with Psidium guava and printed with taro extract were stable and decreased. While the tensile strength and elongation at break for the wool sample that was dyed with Ficus leaves and printed with the previous extract were slightly decreased than the dyed one, this is evidence for the removal of highly packed cementing layers that lowered the crystallinity and strength of the fiber. [117] But the tensile strength, elongation at break, Young's modulus, and surface roughness for wool samples that were dyed with eggplant skin and red cabbage leaves and printed with taro extract were higher than the dyed sample, and the reason for the increase was mentioned earlier.

The surface roughness of most cotton and wool printed samples increased; this result implies that the enzyme treatment marginally increased the roughness of the fabric. The crease recovery angle is almost constant or increasing in all cotton and wool samples compared to the blank, which means that dyeing and printing processes with taro corm extract helped to form a layer on the surface of the material, which reduced its shrinkage and crease recovery.

While comparing with the dyed samples, we found that the wool samples were almost constant or slightly decreased, but the cotton samples were highly decreased because cotton fabrics are most susceptible to crease formation since their ability to recover from the applied deformation is the least. [118] The previous results revealed that the changes in fabrics' mechanical behavior were within an acceptable range for ordinary cotton and wool textiles.

We may conclude that discharge printing with chemical agents such as reducing agents (e.g., sodium hydrosulfite) or oxidizing enzymes (e.g., peroxidase and polyphenol oxidase) impacts the wash fastness and durability of the fabric in varying degrees based on the method and chemicals used.

Traditional discharge agents typically weaken cellulosic fibers such as cotton by extreme reducing conditions that break down the fiber integrity over time.[119] In contrast, enzyme-aided discharge printing, and specifically oxidative enzyme, is less harsh on the fabric structure. The enzymes target the dye molecules specifically but do not weaken the fiber to any large extent, potentially leaving tensile strength intact compared to chemical processes.[120]Traditional discharge methods can result in color reappearing or bleeding due to incomplete breakdown of dyes or low fixation of dyes, enzyme-assisted processes have been shown to exhibit improved wash fastness due to higher dye selectivity and cleaner removal.

Table 17: Effect of discharge printing using taro corms extract on the physical and mechanical properties of cotton and wool fabrics dyed with various natural plant extracts

fabric	natural dye extract	oxidizing agent	physical and mechanical properties					
			Tensile strength (N/mm^2)	A decrease in tensile strength (%)	Elongation at break (%)	Young's modulus (kgf/mm^2)	surface roughness	CRA (warp + weft) (°)
cotton	blank		76.59 ± 5.71	-	17.03 ± 1.27	83.19 ± 6.2	16.3 ± 1.22	195.69 ± 14.58
	Psidium guava leaves	without	79.05 ± 5.89	-3.20	15.98 ± 1.19	101.34 ± 7.55	17.17 ± 1.28	227.64 ± 16.95
		taro corm extract	66.24 ± 4.94	13.51	16.65 ± 1.24	86.4 ± 6.44	17.31 ± 1.29	199.68 ± 14.87
	Ficus leaves	without	67.72 ± 5.05	11.58	30.63 ± 2.28	53.51 ± 3.99	17.31 ± 1.29	223.64 ± 16.66
		taro corm extract	71.2 ± 5.31	7.03	31.28 ± 2.33	53.1 ± 3.96	17.19 ± 1.28	209.67 ± 15.62
wool	blank		60.09 ± 4.48	-	41.05 ± 3.06	60.42 ± 4.5	17.09 ± 1.28	221.65 ± 16.51
	Psidium guava leaves	without	53.18 ± 3.96	11.49	41.27 ± 3.08	45.65 ± 3.4	17.22 ± 1.29	231.63 ± 17.25
		taro corm extract	53.18 ± 3.96	11.49	49.92 ± 3.72	40.23 ± 3	17.32 ± 1.29	229.63 ± 17.1
	Ficus leaves	without	53.15 ± 3.96	11.54	44.6 ± 3.33	32.89 ± 2.45	17.09 ± 1.28	223.64 ± 16.66
		taro corm extract	52.67 ± 3.93	12.34	42.61 ± 3.18	33.78 ± 2.52	17.09 ± 1.28	229.63 ± 17.1

	Eggplant skin	without	52.34 ± 3.9	12.89	39.27 ± 2.93	29.56 ± 2.21	17.21 ± 1.29	233.63 ± 17.4
		taro corm extract	52.96 ± 3.95	11.86	46.6 ± 3.47	39.13 ± 2.92	17.33 ± 1.29	233.63 ± 17.4
	Red cabbage leaves	without	53.5 ± 3.99	10.96	44.6 ± 3.33	34.21 ± 2.55	17.09 ± 1.28	225.64 ± 16.81
		taro corm extract	57.83 ± 4.31	3.75	44.6 ± 3.33	37.46 ± 2.79	17.4 ± 1.3	219.65 ± 16.36

R: Roughness, CRA (W+F): average Crease Recovery Angle in warp and weft directions

3.4. Conclusion

Enzyme-based biotechnology has the potential to contribute to sustainability in the textile sector through environmentally friendly procedures. Polyphenol oxidase (PPO) and peroxidase (POD) enzymes extracted from taro corms were used to achieve biological discharge printing on cotton and wool textiles, dyed with various natural plant extracts instead of harmful chemicals. The enzyme extraction temperature was 25 °C, and the solute-liquid ratio (1:4 (w/v)) at pH 5.0 after a treatment time of 5 min. The activity of oxidative enzymes extracted from taro corms rises over time, with PPO peaking at 180 seconds at 420 nm. POD reaches its highest activity at 180 seconds, with the wavelength 436 measured. This allows them to work as a discharge agent.

It was found that the discharge rates reached about 40-57% using the enzyme extracted from taro corms at pH 3 for wool samples and pH 5 for cotton one. Mixing with other reducing or oxidizing agents in different concentrations led to a higher discharge rate, which reached 60-66%, and different color half-tones were obtained depending on the difference in mixing ratio. It was also observed that the tensile strength of wool printed samples was constant in the pesidium guava-dyed sample, while the tensile strength in the remaining samples increased by 1-4%, except for the sample dyed with ficus leaves, which decreased. While the tensile strength for cotton samples increased by 4% in the ficus dyed sample and decreased by 13% in the pesidium guava-dyed sample, which is considered an acceptable range.

We may concluded that taro corms enzyme extract led to obtaining color halftones on the printed materials as a result of the partial discharge that occurred due to the biological oxidation of the enzyme extract, which is considered a vital alternative to the toxic reducing and oxidizing agents. Taro corms enzyme extract were unable to achieve 100% removal rates on naturally dyed fabrics, but they were able to achieve colorhalf tones on printed fabrics as a result of partial color removal.

Further studies should investigate immobilization techniques to improve reusability, enhance enzyme stability, and reduce operational costs, making enzyme-based discharge printing more viable for industrial applications. Exploring enzyme interactions with different fabric types (cotton, silk, blends) and dye classes will help broaden the application scope and tailor treatments to specific materials.

4. Ethical & Safety Considerations

When handling enzyme preparations, avoid inhaling aerosols and contacting skin or eyes. Enzyme inhalation may cause an immunological response in sensitive individuals.

Repeat exposures over time may cause respiratory allergies. When enzymes are breathed in the form of dust or aerosols, allergic antibodies may develop. Enzymes do not cause food allergies or skin sensitization. Proteolytic enzymes may cause irritation to the skin and eyes. Enzymes can be utilized safely with proper labor practices, engineering controls, and personal protection equipment.

Disposal is usually safe with minimal precautions, Heat the enzyme solution to 80-90°C for 15-30 minutes to denature the proteins. For further denaturation, lower the pH to 4 or raise it to 10 (with dilute HCl or NaOH). You can safely eliminate the diluted, heat-inactivated enzyme solution down the drain with sufficient flowing water.

This is a proposed strategy for commercializing sustainable discharge printing with taro corm enzymes.

Commercialization Strategy:

1. Product Advancement:
   - Enhance and optimize the enzyme extraction procedure from taro corms for industrial-scale production.
   - Formulate a standardized enzyme-based discharge printing paste
   - Develop diverse product variations (e.g. concentrated liquid, powdered form) - Perform comprehensive testing to guarantee uniform quality and performance
2. Manufacturing: - Establish an enzyme extraction and processing facility, preferably in proximity to taro cultivation areas.
   - Forge alliances with taro cultivators to ensure a consistent supply of raw materials - Institute quality assurance protocols for enzyme manufacturing - Gradually enhance production capacity in accordance with demand
3. Market Analysis and Positioning:
   - - Identify eco-conscious textile producers and printing companies as major clientele - Establish as a sustainable substitute for chemical discharge agents
   - - Highlight advantages such as diminished environmental impact and enhanced worker safety. - Execute market analysis to ascertain the most effective price plan.
4. Distribution & Sales: - Cultivate partnerships with textile chemical distributors and suppliers
   - Establish a direct sales staff to engage with major textile manufacturers
   - Develop an e-commerce platform for smaller clients to facilitate online purchases
   - Provide technical assistance and application help to clientele
5. Marketing & Promotion:
   - Establish a brand centered on sustainability and environmental consciousness
   - Participate in textile industry trade exhibitions to display products
   - Disseminate case studies and technical data to enhance credibility
   - Collaborate with organizations dedicated to sustainability for endorsements
6. Feasibility Assessment:
   - Technical Feasibility:
     i. The study establishes the technical feasibility of employing taro corm enzymes for discharge printing.
     ii. Additional optimization may be required to achieve consistent results at an industrial scale.
     iii. The stability and shelf-life of the enzyme must be evaluated.
   - Operational Feasibility:
     i. A dependable supply of taro corms must be ensured

ii. Quality control measures are essential for uniform enzyme activity
iii. Technical assistance for clients is vital for adoption

7. SWOT Assessment:

- Strengths:
  i. Environmentally sustainable alternative to chemical discharge agents
  ii. Innovative, patented technology
  iii. Conforms to industry trends favoring sustainable textile processing - Possibility for elevated pricing
- Weaknesses:
  i. Elevated initial production costs relative to known chemical alternatives
  ii. Insufficient historical performance in industrial applications
  iii. Dependence on the supply of agricultural raw materials
  iv. Potential necessity for modifications to current printing methods for implementation
- Opportunities:
  i. Expanding market for eco-friendly textile chemicals
  ii. Potential for diversification into more enzyme-driven textile applications
  iii. Collaborations with prominent textile and fashion firms emphasizing sustainability - Governmental incentives for eco-friendly technologies
- Threats:
  i. Competition from alternative eco-friendly technologies in textile printing
  ii. Variability in taro crop yields influencing raw material availability
  iii. Resistance to innovation from traditional textile manufacturers
  iv. Regulatory modifications affecting enzyme production or utilization

5. Conflicts of interest

There are no conflicts to declare

6. Funding sources

There is no fund to declare

7. Data Availability

Not applicable (this manuscript does not report data generation or analysis).

8. Ethics and Consent to Participate declarations

Ethics and Consent to Participate declarations: not applicable.

9. Consent to Publish declaration

Consent to Publish declaration: not applicable.

10. Consent to Participate declaration

Consent to Participate declaration: not applicable'.

11. Acknowledgments

The authors are gratefully-grateful to acknowledge the Faculty of Applied Arts, Benha University. Furthermore, the authors are gratefully grateful to acknowledge the Central Labs Services (CLS) and Centre of Excellence for Innovative Textiles Technology (CEITT) in Textile Research and Technology Institute (TRTI), National Research Centre (NRC) for the facilities provided.

12. Reference

1. Akhtar, M., et al., *Climate friendly MOFs synthesis for drug delivery systems by integrating AI, intelligent manufacturing, and quantum solutions in industry 6.0 sustainable approach.* Toxicology Research, 2025. **14**(1): p. tfaf011.
2. Majeed, H., T. Iftikhar, and S. Mustafa, *Statistical approach for newly isolated and identified microbial lipases production.* Polymer Bulletin, 2024. **81**(17): p. 15823-15840.
3. Khan, J., et al., *Green and efficient extraction of 10-deacetylbaccatin and cephalomanine by deep eutectic solvents from taxus chinensis.* Pak. J. Bot, 2024. **56**(2): p. 697-702.
4. Ragab, M.M., H. Othman, and A.J.E.J.o.C. Hassabo, *An overview of printing textile techniques.* 2022. **65**(8): p. 749-761.
5. Singh, M., M. Vajpayee, and L. Ledwani, *Eco-friendly surface modification of natural fibres to improve dye uptake using natural dyes and application of natural dyes in fabric finishing: A review.* Materials Today: Proceedings, 2021. **43**: p. 2868-2871.
6. Majeed, H. and T. Iftikhar, *Ecofriendly reactive printing of cellulosic fabric with sustainable novel techniques.* Cellulose, 2024. **31**(11): p. 7067-7081.
7. Ghosh, J., et al., *Union dyeing of cotton-silk blended woven fabric using Tanin bio-mordant and thyme as a Colourant.* Text Leather Rev, 2024. **7**: p. 303-326.
8. Irfan, M., et al., *A review on molecular scissoring with CRISPR/Cas9 genome editing technology.* Toxicol Res (Camb), 2024. **13**(4): p. tfae105.
9. Kumar, M., et al., *Bio-inspired nitrogen-doped carbon quantum dots: A green route for bioimaging and nano-biosensing.* Industrial Crops and Products, 2025. **227**: p. 120817.
10. Mondal, B.V., et al., *Sustainable Natural Printing of Cotton Fabric Without Metal-Based Mordant.* Journal of Natural Fibers, 2022. **19**(17): p. 15327-15342.

11. Majeed, H., T. Iftikhar, and R. Abid, *Green synthesis of insecticidal, bactericidal, UV absorbent, sustainable paint formulations using Mentha piperita (peppermint).* Reaction Chemistry & Engineering, 2024. **9**(9): p. 2358-2366.
12. Haji, A. and M. Naebe, *Cleaner dyeing of textiles using plasma treatment and natural dyes: A review.* Journal of Cleaner Production, 2020. **265**: p. 121866.
13. Ghosh, J., N.S. Rupanty, and S.C. Das, *Application of coriander to medical cotton bandage for the development of antimicrobial and wound-healing properties.* Text Leather Rev, 2023. **6**: p. 434-451.
14. Ghosh, J., et al., *Development of UV protective and antimicrobial CVC fabric using colloidal zinc oxide solution with carrot and orange peel extract.* SPE Polymers, 2024. **5**(4): p. 576-589.
15. Siddique, A., et al., *Response surface optimization in discharge printing of denim using potassium permanganate as oxidative agent.* Clothing and Textiles Research Journal, 2017. **35**(3): p. 204-214.
16. Seema, H.S., L. Deepika, and A. Babu, *A comparative study on discharge printing using conventional and ecological recipe.* Journal of Trends in Textile Engineering & Fashion Technology, 2018(3): p. 245-261.
17. Haggag, K., et al., *A review article on enzymes and their role in resist and discharge printing styles.* Life Science Journal, 2013. **10**(1): p. 1646-54.
18. Karthikeyan, K. and B. Dhurai, *New method of discharge printing on cotton fabrics using horseradish peroxidase.* AUTEX Research Journal, 2011. **11**(2): p. 61-65.
19. Abd El-Thalouth, I., et al., *Ecofriendly discharge printing on cotton fabrics using laccase enzyme.* 2008.
20. Majeed, H., T. Iftikhar, and K. Maqsood, *Synthesis of protein-based catalyst for multi-industrial applications by using agriculture and industrial waste.* Polymer Bulletin, 2024. **81**(14): p. 12633-12653.
21. Majeed, H., T. Iftikhar, and R. Abid, *Green synthesis of zinc nanoparticles with plant material and their potential application in bulk industrial production of mosquito-repellent antibacterial paint formulations.* Reaction Chemistry & Engineering, 2024. **9**(3): p. 677-683.
22. Karthikeyan, K. and B. Dhurai, *New method of discharge printing on cotton fabrics using horseradish peroxidase.* Autex Research Journal, 2011. **11**(2): p. 61--65.

23. Singh, R.L., P.K. Singh, and R.P. Singh, *Enzymatic decolorization and degradation of azo dyes – A review.* International Biodeterioration & Biodegradation, 2015. **104**: p. 21-31.

24. Hussein, S.I., *Effeciency of immobilized polyphenol oxidase on some textile dyes degradation useing batch operation system by packed bed bioreactor.* Iraqi Journal of Agricultural Sciences, 2019. **50**(3): p. 943- 950

25. Aminlari, M., *Plants-and animal-derived enzymes and their potential application in food processing and preservation*, in *Novel food grade enzymes: Applications in food processing and preservation industries*. 2022, Springer. p. 17-63.

26. Klaichoi, C., R. Mongkholrattanasit, and N. Rungruangkitkrai, *Application of Pigment Dye and Resist Printing Paste from Flour of Wild Taro (<i>Colocasia esculenta</i> (L.) Schott) for Printing of Silk Fabric.* Advanced Materials Research, 2014. **1030-1032**: p. 410-413.

27. Prajapati, R., et al., *Colocasia esculenta: A potent indigenous plant.* International journal of Nutrition, Pharmacology, Neurological Diseases, 2011. **1**(2): p. 90.

28. Ribeiro Pereira, P. and É. Bertozzi de Aquino Mattos, *Anticancer and Immunomodulatory Benefits of Taro (Colocasia esculenta) Corms, an Underexploited Tuber Crop.* International Journal of Molecular Sciences, 2020. **22**(1): p. 1-32.

29. Kaushal, P., V. Kumar, and H.K. Sharma, *Utilization of taro (Colocasia esculenta): a review.* Journal of Food Science and Technology, 2013. **52**(1): p. 27-40.

30. Sen, S., et al., *Peroxidase, Polyphenoloxidase, Total Phenol and Protein Content in Leaf Tissues of Colocasia esculenta var. antiquorum and Their Relationship to Phytophthora Leaf Blight Disease.* Journal of Vegetable Crop Production, 2014. **8**(1): p. 83-89.

31. Boampong, R., et al., *Biochemical Charcterization of Some Taro (Colocasia esculenta L. Schott) Germplasm in Ghana.* Advances in Agriculture, 2019. **2019**: p. 1-7.

32. Lee, M.Y., M.K. Lee, and I. Park, *Inhibitory effect of onion extract on polyphenol oxidase and enzymatic browning of taro (Colocasia antiquorum var. esculenta).* Food Chemistry, 2007. **105**(2): p. 528-532.

33. Guchhait, S., et al., *Quality Evaluation of Cormels of New Germplasm of Taro.* International Journal of Vegetable Science, 2008. **14**(4): p. 304-321.

34. Duangmal, K., K. Richard, and O. Apenten, *A comparative study of polyphenoloxidases from taro (Colocasia esculenta) and potato (Solanum tuberosum var. Romano).* Food Chemistry, 1999. **64**: p. 351-359.

35. Limbe, H.W., S.S. Achmadi, and D.N. Faridah, *Introducing Daluga (Cyrtosperma merkusii) starch from corms collected in Siau Island, North Sulawesi.* Earth and Environmental Science, 2019. **399**: p. 012038.
36. Tattiyakul, J., S. Asavasaksakul, and P. Pradipasena, *Chemical and Physical Properties of Flour Extracted from Taro Colocasia esculenta (L.) Schott Grown in Different Regions of Thailand.* ScienceAsia, 2006. **32**(3): p. 279.
37. Lin, D., et al., *Salicylic acid inhibition on browning of fresh-cut taro by regulating phenolic compounds and active oxygen metabolism.* LWT, 2024. **206**: p. 116591.
38. Yemenicioğlu, A., M. Özkan, and B. Cemeroğlu, *Some Characteristics of Polyphenol Oxidase and Peroxidase from Taro (Colocasia antiquorum).* journal of Agriculture and Forestry, 1999. **23**(4): p. 425-430.
39. Silva, J.R. and C.W.A.d.J.B. Nascimento, *Mineral composition, chlorophyll fluorescence, and enzyme activity of maize cultivars with different tolerance to cadmium.* 2024. **83**: p. e20230182.
40. Yuan, X., et al., *Inhibitory effects of peppermint extracts on the browning of cold-stored fresh-cut taro and the phenolic compounds in extracts.* 2023. **7**: p. 1191396.
41. Pang, X., et al., *Combined physiological, biochemical, and multi-omic analyses provide insight into the cause of differential browning in early and late harvested fresh-cut yams.* Postharvest Biology and Technology, 2025. **221**: p. 113324.
42. Singh, S., et al., *Plant-based Enzyme-mediated Biodegradation of Azo dyes: A Review.* INTERNATIONAL JOURNAL OF PLANT AND ENVIRONMENT, 2021. **7**(03): p. 187-201.
43. Liu, C., et al., *Combating browning: mechanisms and management strategies in in vitro culture of economic woody plants.* For Res (Fayettev), 2024. **4**: p. e032.
44. Zhang, S., *Recent advances of polyphenol oxidases in plants.* Molecules, 2023. **28**(5): p. 2158.
45. Chiong, T., et al., *Enzymatic treatment of methyl orange dye in synthetic wastewater by plant-based peroxidase enzymes.* Journal of Environmental Chemical Engineering, 2016. **4**(2): p. 2500-2509.
46. YEMENİCİOĞLU, A., et al., *Some characteristics of polyphenol oxidase and peroxidase from taro (Colocasia antiquorum).* 1999. **23**(4): p. 425-430.
47. Mukherjee, S., et al., *Potential use of polyphenol oxidases (PPO) in the bioremediation of phenolic contaminants containing industrial wastewater.* 2013. **12**: p. 61-73.

48. Foroughi, J., A. Mirabedini, and H. Warren, *Hydrogels Fibers*, in *Hydrogels*, S. Haider and A. Haider, Editors. 2018, intechopen: london. p. 122-129.
49. Hassabo, A.G., et al., *Naturally extracted inks for digital printing of natural fabrics.* Journal of Textiles, Coloration and Polymer Science, Accept 2023: p. -.
50. Ragab, M.M., A.G. Hassabo, and H.A. Othman, *An Overview of Natural Dyes Extraction Techniques for Valuable Utilization on Textile Fabrics.* Journal of Textiles, Coloration and Polymer Science, 2022. **19**(2): p. 137-153.
51. Diaa, M., H. Othman, and A.G. Hassabo, *Printing Wool Fabrics with Natural Dyes Curcuma and Alkanet (A Critique).* Journal of Textiles, Coloration and Polymer Science, 2022. **19**(1): p. 11-16.
52. AlAshkar, A. and A.G. Hassabo, *Recent Use of Natural Animal Dyes in Various Field.* Journal of Textiles, Coloration and Polymer Science, 2021. **18**(2): p. 191-210.
53. Hamdy, D.M., H.A. Othman, and A.G. Hassabo, *Various Natural Dyes from Different Sources.* Journal of Textiles, Coloration and Polymer Science, 2021. **18**(2): p. 171-190.
54. Hamdy, D.M., H.A. Othman, and A.G. Hassabo, *Various Natural Dyes Using Plant Palette in Coloration of Natural Fabrics.* Journal of Textiles, Coloration and Polymer Science, 2021. **18**(2): p. 121-141.
55. Ragab, M.M. and A.G. Hassabo, *Various Uses of Natural Plants Extracts for Functionalization Textile Based Materials.* Journal of Textiles, Coloration and Polymer Science, 2021. **18**(2): p. 143-158.
56. Hegazy, B.M., H. Othman, and A.G. Hassabo, *Polycation Natural Materials for Improving Textile Dyeability and Functional Performance.* Journal of Textiles, Coloration and Polymer Science, 2022. **19**(2): p. 155-178.
57. Hegazy, B.M., H.A. Othman, and A.G. Hassabo, *Polyanion Biopolymers for Enhancing the Dyeability and Functional Performance of Different Textile Materials using Basic and Natural Dyes.* Egyptian Journal of Chemistry, 2022. **65**(8): p. 177 – 196.
58. Ebrahim, S.A., et al., *A Valuable Observation of Eco-friendly Natural Dyes for Valuable Utilisation in the Textile industry.* Journal of Textiles, Coloration and Polymer Science, 2022. **19**(1): p. 25-37.
59. Selvarajan, E., R. Veena, and N. Manoj Kumar, *Polyphenol Oxidase, Beyond Enzyme Browning.* Microbial bioprospecting for sustainable development, 2018: p. 203-222.
60. Chakraborty, J.N., *Designing through dyeing and finishing*, in *Textile Design Principles, Advances and Applications*, B.G. A and K. Townsend, Editors. 2011, Woodhead: india. p. 146-171e.

61. Klaichoi, C., R. Mongkholrattanasit, and N. Rungruangkitkrai. *Printing of Silk Fabric with Reactive Dye Using Flour of Wild Taro Corm as a Resist Printing Paste*. in *Materials Science Forum*. 2016.
62. Moses, J. and Radhika, *Study of the K/S values, wash, light & rubbing fastnesses, and antimicrobial assessment on modal, cotton and modal / cotton (50: 50) blended dyed fabrics.* Applied Chemistry, 2012. **46**: p. 8185-8188.
63. Mongkholrattanasit, R., C. Klaichoi, and N. Rungruangkitkrai, *Reactive dye printing on cotton fabric using modified starch of wild taro corms as a new thickening agent.* Cellulose Chemistry and technology, 2021. **55**(9-10): p. 1119-1129.
64. Ibrahim, N.A., et al., *Combined UV-protecting and reactive printing of Cellulosic/wool blends.* Carbohydrate Polymers, 2013. **92**(2): p. 1386-94.
65. Ristić, N. and I. Ristić, *Cationic Modification of Cotton Fabrics and Reactive Dyeing Characteristics.* Journal of Engineered Fibers and Fabrics, 2012. **7**(4): p. 113-121.
66. Hegazy, B., H. Othman, and A. Hassabo, *Polycation Natural Materials for Improving Textile Dyeability and Functional Performance.* Journal of Textiles, Coloration and Polymer Science, 2022. **9**(2): p. 155-178.
67. ASTM Standard Test Method (D5035-2011 (Reapproved 2019)), *Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method)*. 2019, ASTM International.
68. AATCC Test Method (66-2014), *Wrinkle Recovery of Fabric: Recovery Angle Method*, in *Technical Manual Method* 2017, American Association of Textile Chemists and Colorists. p. 113-116.
69. ASTM Standard Test Method (D7127 - 13), *Standard Test Method for Measurement of Surface Roughness of Abrasive Blast Cleaned Metal Surfaces Using a Portable Stylus Instrument*. 2018, ASTM International: West Conshohocken, PA.
70. AATCC Test Method (61-2013), *Color Fastness to Laundering: Accelerated*, in *Technical Manual Method* 2017, American Association of Textile Chemists and Colorists. p. 108.
71. AATCC Test Method (8-2016), *Colorfastness to Crocking, Crockmeter Method*, in *Technical Manual Method* 2018, American Association of Textile Chemists and Colorists. p. 17-19.
72. AATCC Test Method (15-2013), *Colour Fastness to Perspiration*, in *Technical Manual Method* 2017, American Association of Textile Chemists and Colorists. p. 30-32.

73. AATCC Test Method (16.1-2014), *Colour Fastness to Light: Outdoor*, in *Technical Manual Method* 2015, American Association of Textile Chemists and Colorists. p. 33-48.

74. Chakraborty, J.N., *An overview of dye fastness testing*, in *Handbook of textile and industrial dyeing*, M. Clark, Editor. 2011, Woodhead: india. p. 207-224.

75. Ueberschaar, N., et al., *Soil Solution Analysis With Untargeted GC–MS—A Case Study With Different Lysimeter Types.* frontiers in Earth Science, 2021. **8**: p. 14.

76. Mahdi, A.A., et al., *GC-MS Analysis of Volatile Compounds the Peel and Pulp of Citrus Medica L. Var. Sarcodactylis Swingle (Foshou Fruit).* International Journal of Research in Agricultural Sciences, 2019. **6**(5): p. 2348 – 3997.

77. Cantwell, F.F. and M. Losier, *Chapter 11 Liquid—liquid extraction*, in *Comprehensive Analytical Chemistry*. 2002, Elsevier. p. 297-340.

78. Manohan, D. and W.C. Wai, *Characterization of Polyphenol Oxidase in Sweet Potato (Ipomoea Batatas (L.)).* international journal for the advancement of science & arts 2012. **3**(1): p. 14-31.

79. Silva, C.R.d. and M.G.B. Koblitz, *Partial characterization and inactivation of peroxidases and polyphenol-oxidases of umbu-cajá (Spondias spp.).* Food Science and Technology, 2010. **30**(3): p. 790-796.

80. Chamaraja, N., et al., *Spectrophotometric determination of peroxidase using N, N-diethyl-p-phylenediamine sulphate and 3-Aminophenol as a chromogenic reagent: Application of the method to seeds of some fruits.* Chemical Data Collections, 2017. **11-12**: p. 84-95.

81. Oviasogie, P.O., D. Okoro, and C.L. Ndiokwere, *Determination of total phenolic amount of some edible fruits and vegetables.* African Journal of Biotechnology, 2009. **8**(12): p. 2819-2820.

82. Javanmardi, J., et al., *Antioxidant activity and total phenolic content of Iranian Ocimum accessions.* Food Chemistry, 2003. **83**: p. 547–550.

83. Noreen, H., et al., *Measurement of total phenolic content and antioxidant activity of aerial parts of medicinal plant Coronopus didymus.* Asian Pacific Journal of Tropical Medicine, 2017. **10**(8): p. 792-801.

84. Can, Z., et al., *Polyphenol oxidase activity and antioxidant properties of Yomra apple (Malus communis L.) from Turkey.* Journal of Enzyme Inhibition and Medicinal Chemistry, 2014. **29**(6): p. 829-35.

85. ASTM Standard Test Method (E11 - 17), *Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves*. 2017, ASTM International.

86. ISO 3310-1:2016, *Test sieves - Technical requirements and testing. Test sieves of metal wire cloth*. 2017.

87. ISO 565:1990, *Test sieves - Metal wire cloth, perforated metal plate and electroformed sheet — Nominal sizes of openings*. 2017.

88. Othman, H., et al., *Modern Printing Techniques for Enhancing the Printability Performance of Synthetic Textile Materials Via Different Treatment Methods.* Journal of Textiles, Coloration and Polymer Science, 2023. **20**(2): p. 297-311.

89. Chatha, S.A.S., M. Asgher, and H.M.N. Iqbal, *Enzyme-based solutions for textile processing and dye contaminant biodegradation—a review.* Environmental Science and Pollution Research, 2017. **24**(16): p. 14005-14018.

90. Schmidt, B. *Let's Talk Science*. Why Do Apples Turn Brown After You Cut Them? 2010.

91. Moreno-Castilla, C., et al., *Removal of Phenolic Compounds from Water Using Copper Ferrite Nanosphere Composites as Fenton Catalysts.* Nanomaterials 2019. **9**(6): p. 1-17.

92. Kim, J., et al., *Distribution of enzymatic and alkaline oxidative activities of phenolic compounds in plants.* Phytochemistry, 2020. **179**: p. 112501.

93. Tella, T., B. Masola, and S. Mukaratirwa, *Anti-diabetic potential of Psidium guajava leaf in streptozotocin induced diabetic rats.* Phytomedicine Plus, 2022. **2**(2): p. 1-8.

94. El-Beltagi, H.S., et al., *GC-MS Analysis, Antioxidant, Antimicrobial and Anticancer Activities of Extracts from Ficus sycomorus Fruits and Leaves.* Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 2018. **47**(2): p. 493-505.

95. Ismail, I.A., et al., *The Application of Pomegranate, Sugar Apple, and Eggplant Peel Extracts Suppresses Aspergillus flavus Growth and Aflatoxin B1 Biosynthesis Pathway.* Horticulturae, 2021. **7**(12): p. 558.

96. Al-Mudhafr, A.W.H., *Detection of active compounds by GC/MS in extract of red cabbage (brassica oleracea) and their effect in the preservation of raw milk* Plant Archives, 2020. **20**(1): p. 4-8.

97. Shen, J. and E. Smith, *4 - Enzymatic treatments for sustainable textile processing*, in *Sustainable Apparel*, R. Blackburn, Editor. 2015, Woodhead Publishing. p. 119-133.

98. Ross, A.C., *Retinoid Production and Catabolism: Role of Diet in Regulating Retinol Esterification and Retinoic Acid Oxidation.* The Journal of nutrition, 2003. **133**(1): p. 291s-296s.
99. Sandell, L.L., et al., *RDH10 Oxidation of Vitamin A Is a Critical Control Step in Synthesis of Retinoic Acid during Mouse Embryogenesis.* PLoS ONE, 2012. **7**(2): p. 1-12.
100. shar, T., *How can I calculate the Peroxidase and Polyphenol oxidase enzyme activities?* 2015.
101. Muthu, S.S. and A. Khadir, *Dye Biodegradation,Mechanisms andTechniques*. Mechanism and Techniques of Dye Removal by Microflora, ed. S.S. Muthu and A. Khadir. 2022: springer. 141-163.
102. Fuerst, E.P., et al., *Polyphenol oxidase as a biochemical seed defense mechanism.* Frontiers in plant science, 2014. **5**: p. 689.
103. Mijangos, F., F. Varona, and N. Villota, *Changes in Solution Color During Phenol Oxidation by Fenton Reagent.* Environmental science & technology, 2006. **40**(17): p. 5538-5543.
104. Yıldırım, F.F., A. Yavas, and O. Avinc, *Printing with Sustainable Natural Dyes and Pigments*, in *Sustainability in the Textile and Apparel Industries : Production Process Sustainability*, S.S. Muthu and M.A. Gardetti, Editors. 2020, Springer International Publishing: Cham. p. 1-35.
105. Bilal, M., et al., *Peroxidases-assisted removal of environmentally-related hazardous pollutants with reference to the reaction mechanisms of industrial dyes.* Science of the Total Environment, 2018. **644**: p. 1-13.
106. Bansal, N. and S.S. Kanwar, *Peroxidase(s) in Environment Protection.* The Scientific World Journal, 2013. **2013**: p. 1-9.
107. Ghosh, J., et al., *Grafting modification for textile functionalization: innovations and applications.* Discover Applied Sciences, 2025. **7**(1): p. 1-29.
108. Parvinzadeh, M. and A. Kiumarsi, *Using Eggplant Skin as a Source of Fruit Waste Colorant for Dyeing Wool Fibers.* Progress Color Colorants and Coatings., 2008. **1**: p. 37-43.
109. Buket, A., E. Canitez, and A. Kirtak, *Investigation of Dyeing Properties of Red Cabbage to Cotton Fabrics in Different pH and Mordanting Conditions.* Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 2020. **24**(2): p. 244-255.

110. Khoo, H.E., et al., *Anthocyanidins and anthocyanins: colored pigments as food, pharmaceutical ingredients, and the potential health benefits.* Food & Nutrition research, 2017. **61**(1): p. 1361779.

111. Abd El-Thalouth , F., Kantouch, H. S, Nassar, and M. H, El-Hennawi, *Ecofriendly discharge printing on cotton fabrics using laccase enzyme.* Indian Journal of Fibre & Textile Research, 2008. **33**: p. 52-57.

112. Costa, F.A.P., et al., *Bleaching and photodegradation of textile dyes by H2O2 and solar or ultraviolet radiation.* Solar Energy, 2004. **77**(1): p. 29-35.

113. Woodard and Curran, *Methods for Treating Wastewaters from Industry* in *Industrial Waste Treatment Handbook*, Woodard and Curran, Editors. 2006, Elsevier. p. 149-334.

114. Raveendran, B. and D. Gokulnath. *BYJU'S*. Structure of Glucose and Fructose 2011.

115. Saikhao, L., et al., *Green reducing agents for indigo dyeing on cotton fabrics.* Journal of Cleaner Production, 2018. **197**: p. 106-113.

116. Ragheb, A.A., et al., *Bio- discharge Printing on Cotton Knitted Fabrics Using Enzyme and Brewers Yeast.* Journal of Applied Sciences Research, 2013. **9**(1): p. 205-225.

117. Zwane, P.E., et al., *Effects of enzymatic treatment of sisal fibres on tensile strength and morphology.* Scientific African, 2019. **6**: p. e00136.

118. Kanade, P.S. and M.V. Koranne, *Determining crease recovery angle at different time intervals and modeling it in terms of grams per SQ.MT(GSM).* International Journal of Textile and Fashion Technology, 2015. **5**(100): p. 1-6.

119. Pizzicato, B., et al., *Advancements in sustainable natural dyes for textile applications: a review.* Molecules, 2023. **28**(16): p. 5954.

120. Chuensangjun, C., S. Sirisansaneeyakul, and T. Kitaoka, *Structure and Surface Modification Techniques for Production of Value-Added Biocomposites*, in *Value-Added Biocomposites*. 2021, CRC Press. p. 125-156.