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Ecological and Phytochemical Assessment of *Melastoma malabathricum* L. as a Sustainable Natural Textile Dye

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ABSTRACT

Senduduk (*Melastoma malabatricum* L.) is a pioneer plant commonly found in degraded peatlands. Senduduk is considered an invasive species, but it has the potential to be developed as a natural dye. Therefore, this research focused on a comprehensive study to determine the ecological and habitat characteristics of senduduk, as well as the formulation and characterization of its potential as a natural dye. The research was conducted in the Special Purpose Forest Area (KHDTK), Sriwijaya Botanical Gardens, Ogan Ilir, South Sumatra. The experimental methods include plant species inventory and ecological studies, phytochemical test of senduduk fruit, also fabric formulation and coloring. Based on the inventory of plant species and ecological study, senduduk vegetation was found to dominate the sample plots in the sheltered area. It was particularly dominant among the shrubs and small trees group, surpassing the presence of ferns, lianas, and grasses. The density and distribution of senduduk vegetation in sheltered areas were higher than in open areas. Biomass measurements, fabric formulations, and dyeing experiments revealed that the application of mordants affected the color variations achieved on cotton fabric. The natural dye extracted from senduduk produced light brown color variations (R=187.9, G=156.0, B=129.7) with calcium carbonate mordant, reddish-gray variations (R=165.8, G=146.4, B=139.1) with alum mordant, and dark gray variations (R=102.3, G=98.3, B=100.1) with tunjung mordant. Ecologically, the utilization of senduduk as a natural dye can assist in the control of invasive species. The fruit extract of senduduk shows significant potential for development as a natural dye for textiles in the future.

1. INTRODUCTION

Senduduk (*Melastoma malabatricum* L.) is a pioneer plant in degraded peatlands, especially in tropical areas. Senduduk is a spreading, evergreen shrub that typically grows to a height of 1.8-2.0 m, while records show that it can reach up to 10m. Its spread is roughly 2 m. The stems are densely coated in tiny, stiff, appressed, ciliate scales that are upright, branched, slender, 4-sided, and scabrous. The leaves are opposite, simple, petiolate (petiole 0.5-1.9 cm), measuring 5-12 cm in length. The blades are narrowly elliptic or oblong-elliptic, sharp at both ends, and prominently 3-5 prominent nerves. Both sides are covered in short, stiff, prostrate hairs, with rows of white cells at the base of the hairs on the upper surface. The blooms are pink, violet, or mauve, measuring 7.5 cm in diameter, 3-6 in sessile terminal corymbs, 5-7 separated, and with dimorphic anthers that occur primarily in the summer. The fruit is a berry with a scaly, bristle-tipped calyx covering its red, delicious, and astringent pulp. It also has numerous tiny seeds inside. Seeds with a diameter of 1 mm are embedded in the pulp, thickly punctate, and cochleate [1, 2].

This species is categorized as an invasive species in the agricultural sector, so it must be eradicated [3], often by burning. Unfortunately, these eradication efforts produce carbon emissions and, in many cases, trigger forest and land fires [4]. Land clearing of senduduk plants by farmers is often the cause of recurring forests and land fires. Therefore, other alternatives are needed to eradicate the senduduk plants as an invasive species.

Even though it is considered an invasive plant, senduduk has various benefits for humans. Recent research highlights its potential benefits in health treatments [5, 6]. Senduduk's leaves, flowers, stems, and roots are used to treat stomachaches, low sperm count, measles, pain, jaundice, leucorrhoea, tooth decay, diarrhea, dysentery, and fever. There have been reports of senduduk pharmacological actions, which include wound healing, anticoagulant, anti-inflammatory, antioxidant, antibacterial, antidiarrheal, anticancer activity [3, 7], and platelet-activating factor inhibitor [8].

Senduduk contains 71 compounds, including flavonoids, terpenoids, tannins, sterols, amides, glycolipids, and fatty acids. Senduduk leaf extract includes active components like glycosides, alkaloids, terpenoids, flavonoids, and carotenoids. It has been found to have antidiabetic and antihyperlipidemic properties. It has been observed that senduduk leaf extract has both gastroprotective and hepatoprotective properties [9, 10]. Aside from that, senduduk has been reported as a source of bioactive compounds for cosmetic applications [11], fitoremediator [12], and natural dyes [13].

Currently, research on environmentally friendly natural dyes is continuing and being developed. Natural dyes have many advantages over synthetic dyes. Synthetic dyes are harmful to human health and the environment due to their non-biodegradability, toxicity, non-renewability, and hazardous properties [14-16]. In addition to being easy to use and reasonably priced, synthetic dye releases a significant amount of hazardous waste into waterways, which causes significant pollution of the water supply [3, 17, 18]. Consequently, natural dyes are extensively developed with various attractions.

Many plant species are considered to have potential as natural dyes. The leaves, stems, flowers, fruit, seeds, and roots of plants can be used to produce specific colors [19-21]. The community in the Sriwijaya Botanical Gardens area, South Sumatra, has begun to use the senduduk plant as a natural fabric dye as an effort to eradicate invasive plants. However, this utilization is still carried out using traditional methods. Therefore, this research involved more comprehensive observations and tests to determine the ecological and habitat characteristics of senduduk, as well as its phytochemical assessment, formulation, and characterization of the senduduk plant as a natural dye. Senduduk plants are expected to be an alternative as a natural textile dye and assist in the management of invasive species in the Sriwijaya Botanical Garden.

2. METHODS

2.1 Research location and sample plot selection

The research was carried out in the Special Purpose Forest Area (KHDTK), Sriwijaya Botanical Gardens, Ogan Ilir, South Sumatera (3°9'29,06" S; 104°32'51,03" E). Sumatra is classified as a very wet climate type region whose peak rainy season falls between October and January, sometimes until February. The island of Sumatra also has peat forests that are generally located in climate type A or B areas [22]. The Sriwijaya Botanical Gardens land with relatively flat topography, is a former oil palm plantation that was converted into a Botanical Garden in 2011. The soil type is hemic to sapric peat with a depth variation of between 1.4-5.7 m. There are small canals with 2 water gates that help maintain the water level at this location. The soil acidity level is high (pH=3-5), with high pyrite content.

Data collection was compiled from February to May 2023. A total of five sample plots with dimensions of 5 m×5 m (based on Indonesia National Standard 7724:2011 used for a woody plant that has a diameter between 2cm to 10cm) were used as the basis for calculating abundance. Samples Plots 1 to 3 are areas with shade trees, and no land cleaning has been carried out since 2015. Sample plots 4 and 5 are open areas that are cleaned regularly (Figure 1). The study [23] observed that leaves under the green 60% shade had a higher total chlorophyll content compared to the open field.

In measuring the biomass of senduduk fruit, samples of senduduk are to be dried by using an oven at a temperature of 150°C. Oven drying for 3 hours produces a relative dryness level equivalent to indoor drying for 12 days.

To make a natural dye solution by choosing seduduk fruit that is perfectly ripe, marked by a reddish purple color, cracked, and contains many seeds. This fruit is picked manually in the morning, on a day that is not rainy. In general, the fruit is picked during the rainy season.

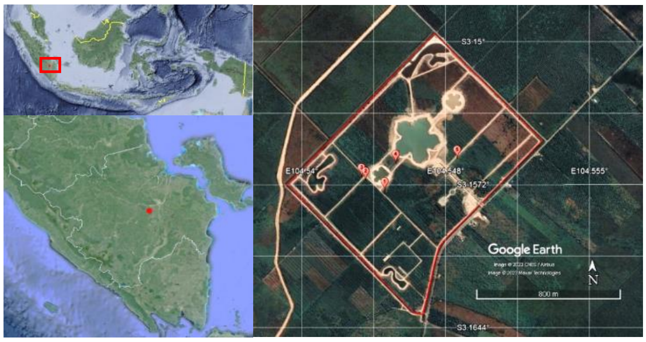

Figure 1. Relative position of sample plot points in Sriwijaya Botanical Gardens

2.2 Plant species inventory and ecological studies

Species found in sample plots were identified by comparing the morphological forms of leaves, stems, flowers, and habitus of the plants through the flora database provided by the websites worldfloraonline.org and identify.plantnet.org. The operational definitions of the variables used in the study are summarized in Table 1.

Table 1. Research variables for ecological studies

Variables	Definition (Unit of Measurement)	Calculation Method/Data Source
Relative Frequency /FR	Comparison of the probability (P) of finding species X in each sample plot compared to the total number of chances of each species being found in each sample plot (%).	$FR=\frac{P_x}{\sum_{i=1}^{i=n} P_i}$
Density/D	The number of units/U (clumps, vines, creepers, or stems based on the shape of the plant) of species X in the total area of Sample Plot (A).	$D=\frac{\sum_{i=1}^{i=n} U_i}{\sum_{i=1}^{i=n} A_i}$
Relative Density/DR	Comparison of the density of species X compared to the total density of each species.	$DR=\frac{D_x}{\sum_{i=1}^{i=n} D_i}$
Important Values/NP	A value that expresses the relative probability of species X being found and its abundance.	NP=FR+DR
Importance Value Index/INP	A value that indicates the role of species X in the community.	$INP=\frac{NP_i}{\sum_{i=1}^{i=n} NP_i}$
Diversity Index/ID	An index that indicates the diversity and abundance of species present in a community (sample plot area).	$ID=-\sum_{i=1}^{i=n}(INP_i \ln INP_i)$

Fruit production/PB	Average fruit weight (M) of *M. malabathricum* produced per *M. malabathricum* fruit density (D).	$PB=\frac{M}{D}$
Leaf Yield/RD	Average dry leaf weight (MDk) produced per kg wet leaf (MDb).	$RD=\frac{MD_k}{MD_b}$
Color gradation	Red, Green, Blue (RGB) values resulting from coloring; the average value is taken randomly from the scanned file of the colored material.	
Rainfall	height of rainwater (mm) collected in a rain gauge on a flat, non-absorbent, non-seeping and non-flowing surface on an area of $1m^2$ (mm/month).	Meteorology, Climatology and Geophysics Agency
Peat depth	The height of the peat layer from drilling is measured from the surface (cm).	Direct measurement
Ground Water Level	Groundwater level measured from the surface (cm).	Direct measurement

2.3 Biomass measurement of senduduk

Fruit samples of senduduk are dried by using an oven at a temperature of 150°C. Oven drying for 3 hours produces a relative dryness level equivalent to indoor drying for 12 days.

2.4 Phytochemical test of senduduk

2.4.1 Sample preparation and extractions

The samples used were senduduk leaves and fruits with variations in preparation, including fresh samples, 18 hours wind-dried at room temperature, and oven-dried (40°C). The prepared leaf and fruit samples were ground using a blender to form powdered simplisia. The solvents used were Aquadest and ethanol PA 99%. Sample extraction for phytochemical screening was carried out using the [24, 25] method with modifications. Samples were macerated on a shaker by each solvent (aquadest and ethanol) with a ratio of 1:5 for 24 hours. Filtrates were separated by Whatman No. 1 filter paper. The filtrate was concentrated by room temperature vaporization. Next, the extracts were stored at 4°C for further use.

2.4.2 Qualitative phytochemical screening

Identification of phytochemical compounds from leaves and fruits of senduduk used the Farnsworth (1966) method [24]. Qualitative phytochemical screening had been conducted to find the existence of alkaloids, tannins, saponins, flavonoids, and phenolic compounds. The positive results will show different colors based on the compounds.

2.4.3 Quantitative phytochemical screening

Total Phenol Content

Determination of total phenol content (TPC) in the extract using the Folin-Ciocalteu method. The content of total phenol compounds is expressed as gallic acid equivalents (mg/g extract), absorbance measurement using a UV-Visible Spectrophotometer instrument.

Total Flavonoid Content

Determination of total flavonoid content (TFC) in the extract using the colorimetric method ($AlCl_3$). Total flavonoid compound content was expressed as quercetin equivalents (mg/g extract), and absorbance measurement was performed using a UV-Visible Spectrophotometer instrument.

2.5 Fabric formulation and coloring

The senduduk fruits were picked manually from the tree, then dried indoors (without heating/sunlight) for 12 days. The coloring material was produced through a heat extraction process (boiling) of senduduk fruit with varying sample and water solvent ratios. The mordant materials: Calcium Carbonate ($CaCO_3$), alum hydrate ($KAl(SO_4)_2$), and tunjung ($FeSO_4$) were dissolved and precipitated in water as a fixing agent. The coloring formulations of the materials are summarized in Table 2. The dyeing process is carried out by dipping a white cotton cloth for five minutes into the dye solution and then drying it in the air. The dyeing process was repeated five times for each dye solution. The results of the color dyeing are then bonded using a fixing agent by dipping and drying indoors. Next step, the fabric dyeing results are compared visually and measured according to the RGB/HEX color values/codes based on the formulation of the dye and binder used.

The extraction process involves heating a mixture of water and fruit or leaves until the volume is reduced by half. Mordanting and cloth cleaning are carried out using TRO and alum, while the dyeing process is performed by dipping and drying for fine times, with this cycle repeated five times in total.

Table 2. Formulation of senduduk's dye solution and binder solution

Sample Code	Dye Extraction Process			Binder Compound
	Fruit (g)	Water (ml)	Volume After Boiling (ml)	
A1	250	1000	500	Calcium carbonate ($CaCO_3$) 50 g dissolved in 1000 ml, precipitated for 24 hours. The clear solution is then used as a fixative.
A2	500	1500	750	
A3	500	2000	1000	
B1	250	1000	500	Alum hydrate ($KAl(SO_4)_2$ 50 g dissolved in 1000 ml, precipitated for 24 hours. The clear solution is then used as a fixative.
B2	500	1500	750	
B3	500	2000	1000	
C1	250	1000	500	Tunjung ($FeSO_4$) 50 g dissolved in 1000 ml, precipitated for 24 hours. The clear solution is then used as a fixative.
C2	500	1500	750	
C3	500	2000	1000	

3. RESULTS AND DISCUSSION

3.1 Characteristics of growing land

The average monthly rainfall in February-March 2023 was in the range of 200-300 mm with normal rainfall characteristics [26], while in April 2023 it was in the range of 10-150 mm with below normal rainfall characteristics [27]. Historical data on average rainfall at the research location and its surroundings in 2021-2022 were February 221.7 mm, March 302.6 mm, April 304.6 mm, and May 204.0 mm. The average daily temperature was 27.5-28.4°C with a relative humidity of 82-83% [28-31]. Peat depth varies from 56 cm to 350 cm, with groundwater levels in the range of 5 cm to 20 cm.

3.2 Vegetation characteristics

The plant groups found in Table 3 reflect that the research location still maintains a peatland ecosystem [32]. In the sample plot in the sheltered area for the species of shrub/small tree group, senduduk vegetation was found in more dominant amounts. The dominant vegetation in the fern/liana group was found to be *Dicranopteris linearis*, while in the grass group, *Fimbristylis dichotoma* was found. All these plants still grow wild, and there has been no movement to conserve the plants in these peatlands. Local communities directly benefit from these plant conservation efforts because, if properly managed, these plants will be a viable source of income for them [33].

The vegetation in sheltered areas, senduduk plants in Sriwijaya Botanical Gardens, has higher values in the Relative Frequency and Density parameters, which means that the growth of senduduk vegetation is more widespread, and the vegetation density is higher compared to this vegetation in the open area. In the unsheltered area or open area, the Relative Density, Importance Value, Diversity Index, and Similarity Index parameters are higher. From Table 4, the importance value of senduduk vegetation growing in the open area is higher (52.006), indicating that this vegetation is a dominant plant species (powerful) in this growing area.

Table 3. Number of plants according to plant group, species, and shade characteristics

Species	Unit	Sheltered Area			Unsheltered Area	
Latin Name (Local Name)		Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Alstonia grandifolia	Tree		4			
Baccaurea motleyana	Tree		2			
Elaeis guineensis	Tree			1		
Fagraea fragrans	Tree	3		2		
Pradosia cochlearia	Tree	1				
Melastoma malabathricum	Clump	96	87	78	60	68
Vicia faba			1	2	2	
Becquerel cymosa	Creeper	77		14		
Calopogonium mucunoides	Creeper	6				
Cassytha filiformis	Creeper	2	13			
Dicranopteris linearis	Clump	8	70	40	22	2
Dischidia nummularia	Creeper		1			
Lygodium microphyllum	Creeper	4			2	10
Mimosa pudica	clump	23				
Palhinhaea cernua	Clump	4			1	
Smilax sp.	Creeper	1				
Stenochlaena palustris	Clump	8	68	23		
Ziziphus elegans	Creeper				1	
Fimbristylis dichotoma	Clump		134			120
Imperata cylindrica	Clump	25				
Pennisetum purpureum	Clump	2			1	
Lepironia articulata	Clump				2	
Scirpus sylvaticus	Clump				3	

Table 4. Vegetation parameters of senduduk in Sriwijaya Botanical Garden

Parameters (units)	Melastoma Malabathricum	
	Sheltered Area	Unsheltered Area
Relative Frequency/RF (%)	12,500	11,111
Density/D (unit/m^2)	3,480	2,560
Relative Density/RD (%)	33,164	40,895
Important Values/IV (%)	45,664	52,006
Diversity Index/DI	0,146	0,152
Similarity Index/SI	0,125	0,129

3.3 Phytochemical screening of senduduk

The large difference between the weights before and after the distillation process affects the greater yield of the dye because the more concentrated the dye obtained [34]. Based on Table 5, aqueous extract of oven-dried senduduk leaves showed the highest total phenol (394.02±0.34mg/g) and flavonoid (291.90±0.30mg/g) content. Meanwhile, aqueous extract of wind-dried senduduk leaves showed the lowest total phenol (280.54±0.32mg/g) and flavonoid (62.71±0.92mg/g) content. The significant differences in total phenol and flavonoid content between oven-dried and wind-dried senduduk leaves highlight the critical role of drying methods in preserving and enhancing bioactive compounds. Moderate heat exposure during oven drying may break down cellular structures, thereby releasing bound phenol and flavonoid compounds and making them more extractable [35]. In contrast, the aqueous extract of wind-dried leaves showed the lowest total phenol content. This result is in line with research [36] on *Chrysanthemum,* where the total phenolic acid content in oven-dried samples was higher than that in sun-drying and shade-drying.

Table 5. Quantitative phytochemical screening of the fruit and leaves of senduduk

Samples	Total Phenol Content (mg/g)	Total Flavonoid Content (mg/g)
BOE	285.95±0.30	171.32±1.78
BFA	330.18±0.25	215.82±0.98
BOA	330.98±0.46	251.63±0.10
BAA	341.61±0.34	267.75±0.94
DOE	322.09±0.28	190.66±0.49
DAA	280.54±0.32	62.71±0.92
DOA	394.02±0.34	291.90±0.30
DFA	281.30±0.34	82.10±1.95

Notes: BOE: ethanolic extract of oven-dried senduduk fruit, BFA: aquadest extract of fresh senduduk fruit, BOA: aquadest extract of oven-dried senduduk fruit, BAA: aquadest extract of wind-dried senduduk fruit, DOE: ethanolic extract of oven-dried senduduk leaf, DAA: aquadest extract of wind-dried senduduk leaf, DOA: aquadest extract of oven-dried senduduk leaf, DFA: aquadest extract of fresh senduduk leaf.

Chemical compounds present, particularly flavonoids like anthocyanins, which contribute to color and dye uptake, affect dye's performance [37, 38]. We can see the dyeing performance influenced by the chemical compounds contained in *M. malabathricum* at the stages of the fabric dyeing process (Figure 2 and Figure 3).

The slow drying process in open air likely permits enzymatic oxidation (e.g., polyphenol oxidase activity), which degrades phenolic compounds [39]. High phenol and flavonoid content in oven-dried extracts enhances the potential for vibrant, stable, and long-lasting natural dyes, as these compounds contribute to antioxidant properties and colorfastness [40]. The application of senduduk as a natural dye is well-documented, particularly for its ability to produce purple to reddish tones, attributed to the presence of anthocyanins and other flavonoids [41]. Studies have shown that senduduk contains anthocyanins, flavonoids, and tannins, which make it suitable for dyeing purposes. Anthocyanins are responsible for creating purple, red, and blue hues in plants and can produce varying fabric shades depending on pH levels. Meanwhile, flavonoids and tannins serve as stabilizing agents, enhancing the dye's color fastness and durability [5, 6].

Figure 2. Chemical compounds for dyeing performance of *Melastoma malabathricum*

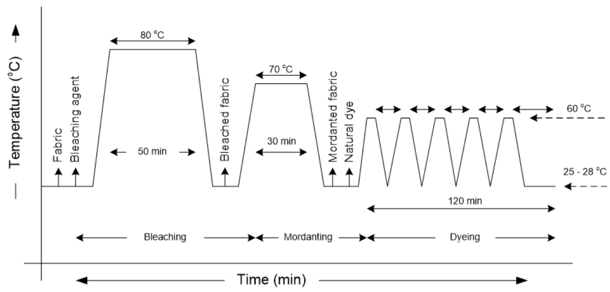

Figure 3. Dyeing process of *Melastoma malabathricum*

Table 6. Qualitative phytochemical screening of the fruit and leaves of senduduk

Qualitative Phytochemical Test	DAA	DOA	DOE	DFA	BAA	BOA	BOE	BFA
Mayer	++	++	+	+	+	+	+	+
Alkaloid Bouchardat	+	++	++	++	-	-	-	-
Dragendrof	+	++	++	++	+	+	+	++
Tannin	++	++	++	+	++	++	++	++
Saponin	-	-	+	-	-	-	-	-
Flavonoid	-	-	+	-	-	-	+	-
Phenol	++	++	++	+	++	++	++	++

Notes: DAA: aquadest extract of wind-dried senduduk leaf, DOA: aquadest extract of oven-dried senduduk leaf, DOE: ethanolic extract of oven-dried senduduk leaf, DFA: aquadest extract of fresh Senduduk leaf, BAA: aquadest extract of wind-dried senduduk fruit, BOA: aquadest extract of oven-dried senduduk fruit, BOE: ethanolic extract of oven-dried senduduk fruit, and BFA: aquadest extract of fresh senduduk fruit.

Ethanol extraction of oven-dried senduduk leaves revealed the presence of all major phytochemical compounds'tannins, saponins, flavonoids, and phenols as confirmed by qualitative tests. In contrast, distilled water extraction from fresh senduduk leaves showed a lower presence of tannins and phenols (Table 6). Qualitative phytochemical analysis further indicates that both leaf and fruit extracts contain tannins, flavonoids, saponins, and phenols when ethanol is used as the extraction solvent. These findings showed the significant influence of experimental conditions, particularly extraction solvent and drying method on the yield and detectability of phytochemicals. Ethanol, being a polar organic solvent, is more effective in solubilizing a wider range of phytochemicals compared to water, especially compounds like flavonoids and phenols that may be less soluble in aqueous media [36].

3.4 Characteristics of natural dyes from senduduk

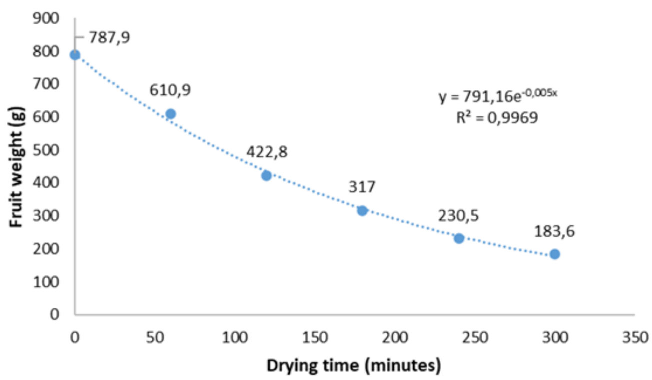

Figure 4. Weight loss of *M. malabathricum* fruit dried using an oven at a temperature of 150°C

Plants planted in an open area with a density of 2.4 clumps/m^2 produced 243.9 grams of fresh weight fruit with a water content of 73.7%. The weight loss profile through oven drying at a temperature of 150℃ is shown in Figure 4. Oven drying for 300 minutes resulted in a weight loss of senduduk fruit from 787.9 grams to 183.6 grams (>70%). Meanwhile, indoor drying (manually) for 12 days resulted in a fruit yield of 41.51%. It indicates that manual drying produces a higher dry weight than oven drying. However, manual drying is more sensitive to sample contamination.

3.5 Characterization of fabric dyeing

Variations in color and RGB values resulting from senduduk fruit dye and applying mordants are shown in Table 7 and Figure 5. In the same category of mordant, there are no differences in the color gradations produced, even though there is a slight difference visually. The use of calcium carbonate ($CaCO_3$) produces a light brown color variation (in average), R=187.9, G=156.0, B=129.7 close to 7.5R 6/4 in Munsell colors), the alum ($KAl(SO_4)_2$) produces a reddish gray color variation (in average, R=165.8, G=146.4, B=139.1 close to 2.5YR 6/2), while the tunjung ($FeSO_4$) produces a dark gray color variation (in average, R=102.3, G=98.3, B=100.1 close to 10P 4/1).

The color pigments of the senduduk fruit are produced through extraction by heating or boiling. The extraction method is chosen based on the type of compound being extracted, the form of the material, the compound properties, and efficiency. In this research, distilled water was used as a solvent in the extraction process. The choice of solvent is based on the components of senduduk fruit, which have polar compounds, including flavonoids and tannins, which can dissolve in polar solvents. Apart from water, methanol and ethanol can be used as extraction solvents. According to Wiraningtyas et al. [42], the extraction of dyes from seaweed (*Sargassum sp.*) with methanol solvent produces a more concentrated extract than ethanol. This is because methanol has more polar properties compared to ethanol, because the methanol structure has fewer C atoms.

The application of senduduk fruit dye in this study used cotton fabric. This type of cotton fabric was chosen because cotton fabric is hygroscopic and has a cellulose content of 94% which makes it easier for the fabric to be penetrated by color pigments [43]. In addition to fabric material, extraction time, dyeing time, and mordanting time can affect the fabric dyeing results. Basically, color uniformity is indicated by the uniformity of the dye molecules distributed on the fiber surface.

Based on the results, the application of mordant affects the color variations in the fabric. Calcium carbonate mordant produces a light brown color variation, alum produces a reddish gray color variation, while tunjung produces a dark gray color variation.

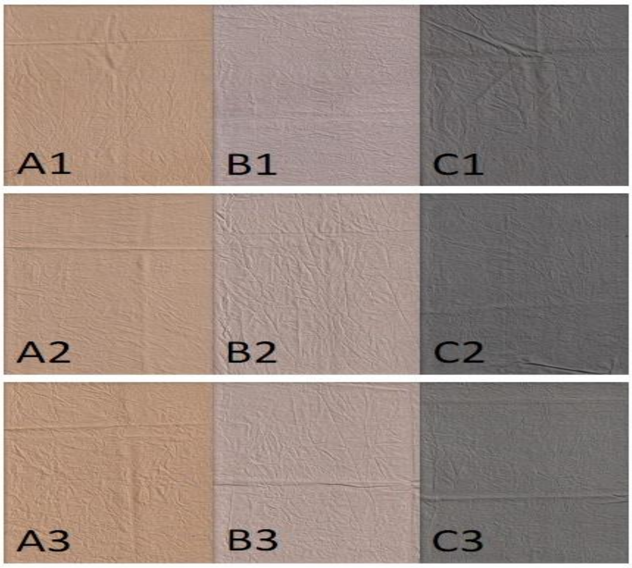

Figure 5. Color gradation of fabric resulting from dyeing and binding using senduduk fruit dye

Table 7. RGB/HEX color values/codes based on the formulation of dyes and binders

Sample	Color Value/Code															
	R	G	B	HEX	R	G	B	HEX	R	G	B	HEX	Average Value of R	Average Value of G	Average Value of B	Munsell Colors
	A1				A2				A3					Sample A ($CaCO_3$)		
1	189	163	128	#BDA380	195	164	146	#C3A492	203	174	134	#CBAE86				
2	243	216	197	#F3D8C5	214	177	159	#D6B19F	198	166	141	#C6A68D				
3	150	123	80	#967B50	212	181	161	#D4B5A1	226	183	141	#E2B78D	187.9	156.0	129.7	7.5R 6/4
4	175	153	132	#AF9984	149	120	102	#957866	151	106	85	#976A55				
5	220	192	168	#DCC0A8	104	73	52	#684934	190	149	119	#BE9577				
	B1				B2				B3					Sample B ($KAl(SO_4)_2$)		
1	182	162	135	#B6A287	177	156	155	#B19C9B	186	173	156	#BAAD9C				
2	187	165	167	#BBA5A7	125	107	107	#7D6B6B	154	119	125	#9A777D				
3	142	149	141	#8E958D	125	107	107	#7D6B6B	204	185	168	#CCB9A8	165.8	146.4	139.1	2.5Y 6/2
4	140	126	125	#8C7E7D	170	145	140	#AA918C	157	141	128	#9D8D80				
5	169	125	142	#A97D8E	173	160	151	#ADA097	196	176	139	#C4B08B				
	C1				C2				C3					Sample C ($FeSO_4$)		
1	101	102	107	#65666B	69	63	63	#453F3F	139	128	124	#8B807C				
2	87	91	92	#575B5C	82	80	83	#2053	79	75	76	#4F4B4C				
3	29	26	43	#1D1A2B	156	154	155	#9C9A9B	146	140	142	#928C8E	102.3	98.3	100.1	10P 4/1
4	118	124	114	#767C72	115	113	114	#737172	144	135	136	#908788				
5	78	56	68	#4E3844	54	52	53	#363435	137	136	132	#898884				

Notes: R=Red, G=Green, B=Blue, RGB=Red-Green-Blue, HEX=How to represent color through Hexadecimal Values.

The RGB values in Table 7 (using the formula in Table 2 with the dye source material categorized as BAA) are not statistically different, even though visually there are color variations (Table 3). It can be assumed that the dye compounds in the material can be extracted well in various experimental formulas. For practical reasons at the textile craftsman user level, the dye/water solvent ratio of 1:4 is preferred. However, considering Table 5, the dye compounds are suspected to come from the hydrolyzed tannin group and/or phenol complex. The light brown color variation is known to come from ellagic acid [44], and Alizarin is suspected to be the source of reddish gray [45].

The mordant releases metal cations that interact with the phenolic dye molecules containing hydroxyl (-OH) groups. Under these conditions, metal chelation emerges as the primary color-binding mechanism, a well-documented process in dye chemistry. Furthermore, the mordant alters the solution pH and modifies the fiber surface morphology, creating microstructural defects that are enhanced by dye penetration and adhesion processing [46].

The utilization of natural dyes in textile products requires the application of mordants. Mordanting is the process of dyeing fabric with metal or mineral substances that help the process of binding the dye. Adding mordant will strengthen the bond between the dye and the fabric fibers, ensuring the color remains vibrant and does not fade easily during heating and washing. Mordant will form a chemical bond between the color pigment and the fabric fiber [47]. The choice of type and concentration of mordant will affect the final result, so further experiments are needed to determine the right type and concentration of mordant. Aliffianti and Kusumastuti [48] reported that applying tunjung, alum, and calcium carbonate mordants in dyeing viscose rayon fabric produced different color brightness. Tunjung mordant produces darker fabric colors, followed by alum and calcium carbonate. This is in accordance with this research, where natural dyed fabrics treated with tunjung mordant have the darkest color, and calcium carbonate mordant gives the brightest color.

The color variations produced in fabrics with natural dyes that are given a mordant are caused by differences in reactions between the metal ions in the mordant with the dye and fabric fibers. Mordant functions as a bridge that will covalently bond with the hydroxyl groups of cellulose in fabric fibers with the polar groups in dyes. Tunjung mordant ($FeSO_4$) has a decrease in color brightness compared to alum mordant. This situation is in line with research by Failisnur and Sofyan [49], which shows that Al metal in alum (Kal $(SO_4)_2$) has lower complex capabilities than other metals. Apart from the type of mordant, the concentration of the mordant also affects the ability of the dye molecules to bond to the fabric.

The mordant concentration is higher, so more dye is bound. One dye molecule can form one bond with one fiber molecule. However, one mordant molecule can bind to one or more dye molecules, thereby increasing dye absorption. In addition, adding metal ions in the mordanting process can increase the complexity between fiber molecules and dye molecules so that the resulting color intensity becomes stronger [50]. Therefore, using mordant is necessary to increase the sharpness and durability of color in natural fabric dyes.

4. CONCLUSION

Senduduk vegetation was found as a dominant plant in the sheltered area of the Special Purpose Forest Area (KHDTK), Sriwijaya Botanic Gardens, Ogan Ilir, Sumatera Selatan. They grow wider and have higher density in the covered area compared to the vegetation in the open area. Applying mordants (calcium carbonate, alum, and tunjung) in senduduk natural dyes affects the color variations in the cotton fabric. Tunjung mordant has the darkest color, and calcium carbonate mordant gives the brightest color. Calcium carbonate mordant produces a light brown color variation, alum produces a reddish gray color variation, while tunjung produces a dark gray color variation. The optimal extraction time depends on the extraction method, the type of sample, and the stability of different dyes. For the future, senduduk fruit extract has the potential to be used as a promising natural dye for textiles and as being alternative for ecological protection, especially for invasive species eradication efforts.

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