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Exploring the ethnobotany of natural dye plants in Kalibawang Sub-district, Wonosobo District, Indonesia through traditional knowledge, conservation, and community empowerment

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Abstract. *Sulton MN, Guzherra RMR, Fahimah RA, Putri RA, Permatasari RI, Saensouk S, Iskandar J, Supriyatna J, Setyawan AD. 2025. Exploring the ethnobotany of natural dye plants in Kalibawang Sub-district, Wonosobo District, Indonesia through traditional knowledge, conservation, and community empowerment. Nusantara Bioscience 17: 155-168.* The use of synthetic dyes can cause environmental and health problems. Natural dyes can be a novelty to replace synthetic dyes because they contain materials that are more environmentally friendly, non-toxic, and sustainable. This ethnobotanical research was carried out to reveal the traditional knowledge of the people in Kalibawang Sub-district, Wonosobo District, Indonesia, regarding the use of various species of plants as a source of natural dyes. The purpose of this study is to analyze the species of plants that can produce natural colors used by the people of Kalibawang Sub-district, as well as to assess their conservation and sustainability and empower the community. The method used is an ethnographic study through in-depth interviews with informants, field observations, and documentation of plant species. The quantitative method used is recording how many people use the coloring plants and calculating the RFC. This study identifies various species of plants used as natural dyes and their utilization. A total of 53 plant species from 37 families have been identified and utilized as color producers in Kalibawang Sub-district. The most widely used plant parts are fruit (36%) and leaves (28%), the plant forms are herbs (49%) and trees (26%), the colors are red (28%) and green (15%), used to color food (49%), and drinks (42%). Most of these plants are intentionally planted (53%), but most of them are rarely used (43%), only a few are frequently used (26%), among the most important are turmeric (*Curcuma longa* L.) (RFC 0.891) for yellow color, and pandan (*Pandanus amaryllifolius* Roxb. ex Lindl.) (RFC 0.633), and green grass jelly (*Cyclea barbata* Miers) (RFC 0.613) for green color. The sustainability of several species needs attention because of their conservation status, namely *Tectona grandis* L.f. (EN), *Coffea arabica* L. (EN), and *Cinnamomum verum* J.Presl (VU). The dye extraction method usually uses water or other natural ingredients. This study shows that natural dyes have the potential to be further innovated. However, this traditional knowledge is in danger of being lost due to lifestyle changes and the lack of interest of the younger generation. Hence, it needs to increase public awareness of the potential of natural dyes as an alternative to synthetic dyes and to engage the community in this important issue.

Keywords: Conservation, *Curcuma longa*, ethnobotany, natural dyes, sustainability, traditional knowledge

INTRODUCTION

Dyes are defined as chromophoric substances that are capable of interacting chemically or physically with a substrate, thereby selectively absorbing certain wavelengths of light and producing a visible color (Alegbe and Uthman 2024). As a country with abundant biodiversity, Indonesia is a country with great potential to provide natural materials that can be used as a source of natural dyes (Maskun et al. 2021). These natural materials are usually called coloring plants. Coloring plants themselves refer to various types of plants that have the ability to produce natural coloring compounds, which can be used in various applications, especially in the food, textile, and cosmetic industries (Mohamad et al. 2019). Generally, natural colorants that are easy to find are derived from plant pigments (Lakshmi 2014). The use of natural dyes provides significant environmental benefits, such as reducing pollution and chemical waste and supporting plant conservation as natural colorants. There are four main groups of pigments from plants, namely chlorophyll (green), carotenoids (yellow, red, orange), flavonoids (anthocyanins, red, blue, purple), and betalains (red, yellow, purple) (Malabadi et al. 2022).

The use of coloring plants has been known for thousands of years and is an important part of the culture and traditions of various societies around the world. More than 2,000 color variations have been produced from various plant components, but only 150 colors are used economically. Colors can be taken from various parts of the plant, such as seeds, fruits, roots, stems, and bark, and

produced through several processes, namely boiling, burning, grinding, and direct use (Berlin et al. 2017). Different plant components can produce one or more colors, depending on which part is taken from the plant (Ebrahim et al. 2022). These coloring plants are environmentally friendly and safer compared to synthetic dyes, which often contain harmful chemicals. The use of natural dyes can also support sustainability as the raw materials come from renewable sources (Raturi et al. 2023).

Knowledge of dye plants is often passed down through generations in communities, especially in rural areas that still utilize natural resources traditionally. In Kalibawang, an area known for its rich biodiversity and traditional agricultural practices, dye plants have long been utilized by the community. They use local plants, such as teak leaves, turmeric, and mahogany bark, to produce natural colors that are used for various needs. These natural dye colors are influenced by various factors such as light, the presence of oxygen, and water activity which are a testament to the local knowledge that must be preserved (Novais et al. 2022). Natural dyes are usually categorized by color, solubility, chemical constitution, application, and origin (Sk et al. 2021). The Kalibawang community frequently uses coloring plants to promote appetite, as an element of tradition, and as a means of play for children. The Kalibawang community's primary source of income is farming and animal breeding (Herdananta et al. 2024), which determines how plants are utilized to make dyes, particularly natural food dyes.

In the food sector, natural colorants are used to enhance the visual appeal of food, provide vibrant colors, and sometimes add flavor. From a technological point of view, the addition of colorants is considered natural because some foods undergo discoloration during processing and storage, so colorants are added to restore or adjust the lost color (Ribeiro and Veloso 2021). Coloring plants can also add value to products, increasing marketability in a market that is increasingly concerned with health and sustainability. While natural colorants have many benefits, there are some drawbacks and challenges in their use. Natural dyes do not always provide the desired color variation, and their availability is limited (Pranta and Rahaman 2024). Natural dyes also tend to fade quickly, and their quality may not be as consistent as synthetic dyes (Affat 2021). Because of the consequent color inconsistencies, natural dyes are being phased out. As a result, this local knowledge may be lost if not preserved.

Therefore, the aims of this study were to (i) analyze the species of plants that can produce natural colors used by the people of Kalibawang Sub-district, (ii) assess their conservation and sustainability, and empower the community. The findings of this research aim to preserve dye plants as part of the culture and promote environmentally friendly natural dyes compared to the numerous synthetic dyes available.

MATERIALS AND METHODS

Study area

This research was conducted in the Kalibawang Sub-district, Wonosobo District, Central Java Province, Indonesia (Figure 1). This sub-district has an area of 5,217.6 ha and an altitude of 25-350 meters above sea level (m asl.). This research was conducted in four villages of Kalibawang Sub-district, namely Dempel, Kalialang, Karangsambung, and Mergolangu. The four villages are close together. Dempel Village has an area of 773.2 ha, Kalialang Village has an area of 656.9 ha, Karangsambung Village has an area of 643.4 ha, and Mergolangu Village has an area of 502.8 ha. The selection of these four villages is due to the similarity of the landscape area, which is still natural with hilly areas, dominated by agroforestry and production forests. Kalibawang Sub-district is one of the farthest sub-districts from the nearest city center, and it has a strong influence on Javanese culture.

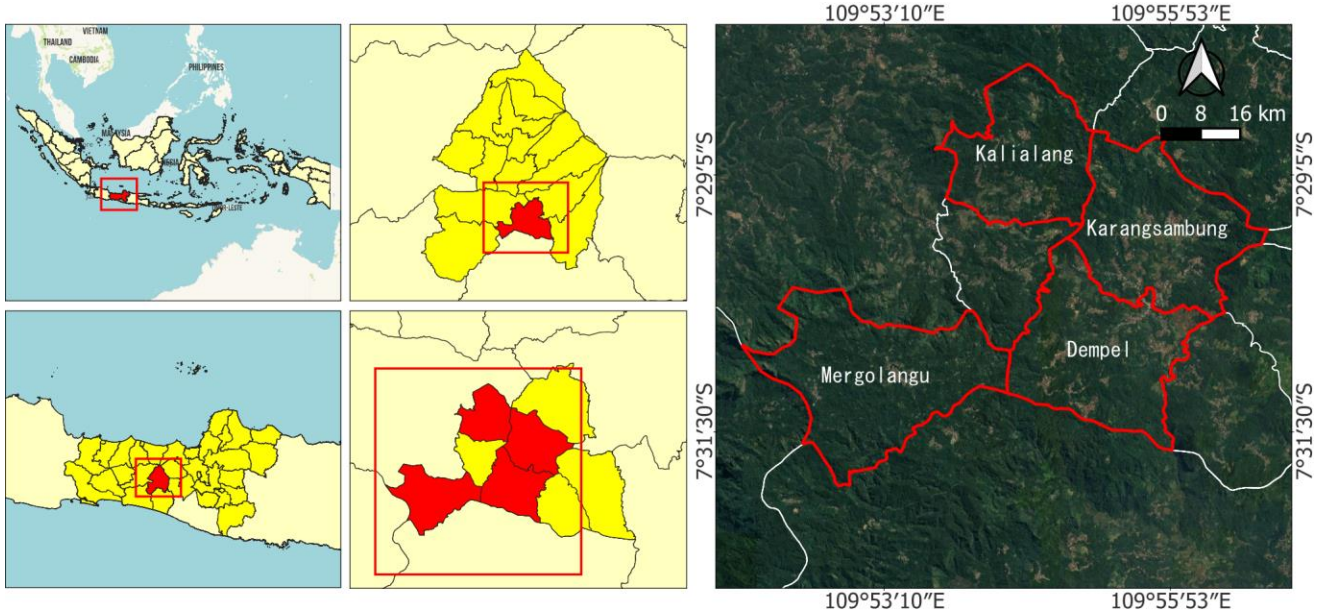

Figure 1. Administrative map of Dempel, Kalialang, Karangsambung, Mergolangu Villages in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

Data collection

The method used is an ethnographic study through in-depth interviews with informants, field observations, and documentation of plant species. We picked respondents from local communities through purposive sampling who use and are familiar with plants as natural dyes and are at least 18 years of age. We used Slovin's formula to calculate the total number of respondents (Yamane 1967). There are 9829 households in Kalibawang Sub-district. We obtained 101 respondents and 5 key informants in this study. In addition, we used village heads and stakeholders as key informants to investigate dye plant management using Forum Group Discussion (FGD). Interviews were conducted by asking several questions, such as what plants are used as dyes, which parts are used, what colors are produced, what is the plant habitus, where it comes from, how to extract it, how often it is used, and what it is used for (food, drinks, medicine, etc.). The frequency of use is determined by the degree of community utilization in one year. If it is used only 1-2 times per year, it is rarely used; if it is used 3-6 times per year, it is used sometimes; and if it is used more than 6 times per year, the community frequently uses it (Luong et al. 2023). We target our respondents with a group of 5 levels of education, namely not in school, elementary school, junior high school, high school, and university.

In addition to interviews, field observations and plant recording were conducted to directly identify the types of plants that grow and are used by the local community for their use of natural dye plants. We utilized the observational data and plant species documentation to supplement and reinforce the information provided by the respondents. The names of local plants obtained were then identified by their scientific names using Plants of the World Online (POWO) (https://powo.science.kew.org/) and Global Biodiversity Information Facility (https://www.gbif.org/).

To determine the conservation status of the species found, we used data from the IUCN Red List 2024 (https://www.iucnredlist.org/) and Indonesian protected animals and plants regulations (P.106/2018). We also conducted semi-structured interviews with key informants to examine indigenous knowledge on natural dye plants and their implications for community empowerment.

Data analysis

The quantitative method used is recording how many people use the coloring plants and calculating the RFC (Relative Frequency of Citation). The RFC (Relative Frequency of Citation) is a calculation used to measure how important a plant species is in the research area (Ahmad et al. 2014). This calculation is done by dividing the number of respondents who know or use plant species by the total number of respondents interviewed (Jan et al. 2022).

The calculation formula is as follows:

$$RFC = \frac{FC}{N}$$

Where: FC: Number of respondents who know or use the plant species; N: Total of all respondents

The results of the RFC calculation become a measure of the frequency of community use of a species. The closer the value of RFC is to 1, the more frequently the species is used by the community, while the closer the value is to 0, the less frequent to never.

RESULTS AND DISCUSSION

Sociodemographic characters

Based on the data collected, the distribution of respondents in this study shows that the majority of respondents are women, which is 71 people (71%) of the total respondents. In comparison, male respondents only amounted to 30 people (30%) (Table 1). This shows that women's participation in this study is still dominant, which is influenced by the characteristics or needs of the study that are more relevant to women, or social and cultural conditions that cause more women to be involved.

Furthermore, the data on the respondents' village of origin also showed considerable variation. Most respondents came from Dempel village, at 33%, followed by Mergolangu Village, which accounted for 31% of the total respondents. Kalialang and Karangsambung Villages contributed 20% and 17%, respectively, to the overall sample. Dempel and Mergolangu appear to be the two villages that participated the most, which could be due to geographical factors, higher levels of awareness or socialization in these villages, or the characteristics of a larger population compared to other villages. The respondents' level of education shows an alarming pattern. A significant 47% of the respondents have only an elementary school education, and 13% did not attend school at all. This data underscores the urgent need to address the issue of low formal education in the community.

The prevalence of low educational attainment in Kalibawang Sub-district is strongly associated with the predominance of traditional agriculture as the primary livelihood among its population (59%). Statistical data from the Central Bureau of Statistics (BPS 2023) indicate that over 54% of Kalibawang's residents rely on the agricultural sector for subsistence. Further supporting this observation, Nuraini et al. (2024) argue that limited formal education constrains the local community's capacity to sustainably harness natural resources, including the utilization of flora for daily necessities.

As many as 30% of respondents are junior high school graduates, which is the first level of secondary education. Only 6% have completed high school, and even fewer, at 5%, have attended university. In addition, 13% of respondents have not had the opportunity to attend school at all. This data underscores the significant challenges in accessing education in the study area and the socio-economic factors that restrict opportunities for individuals to pursue higher education. This data provides a clear picture that the majority of respondents have relatively low levels of education, which may have an impact on their perceptions, knowledge, and ability to engage with the issues we're exploring in this study.

Table 1. Respondent information was obtained from four villages in Kalibawang, Wonosobo, Central Java, Indonesia (n = 101)

Variable	Freq	Percentage
Gender		
Male	30	30%
Female	71	71%
Village		
Kalialang	20	20%
Karangsambung	17	17 %
Dempel	33	33%
Mergolangu	31	31%
Last education		
No school	13	13%
Elementary School	47	47%
Junior High School	30	30%
High School	6	6%
University	5	5%
Occupation		
Farmers	59	58.4%
Housewives	15	14.9%
Laborers	12	11.9%
Traders	8	7.9%
PNS/Polri/TNI	6	6.0%
Others	1	1.0%

Plant diversity

Table 2 shows that the food coloring plants found in Kalibawang Sub-district, Wonosobo District, especially in Kalialang, Mergolangu, Karangsambung, and Dempel Villages, are 53 species from 37 families. More than 30 different plant families reflect the diversity of the flora in this region. Species-rich families include Fabaceae, Arecaceae, and Solanaceae (3 species, 5.66%). Amaranthaceae, Brassicaceae, Cucurbitaceae, Lauraceae, Myrtaceae, Piperaceae, Poaceae, Rosaceae, Rubiaceae, and Rutaceae represent 2 species (3.77%), and the other 24 families were represented by one species each.

Our study of plant families uncovers a wealth of practical uses from well-known families such as Zingiberaceae, Fabaceae, Solanaceae and Myrtaceae. Each family is home to a variety of plant species, each with its own unique applications. For instance, the Zingiberaceae family is represented by *Curcuma longa* L. (turmeric or *kunyit*), which is widely known as a food coloring ingredient and traditional medicine. The Rubiaceae family is represented by the coffee plant (*Coffea arabica* L.), which is an important commodity in mountainous areas such as Wonosobo. Genu\era such as *Curcuma*, *Amaranthus*, *Capsium* and *Persea* each contribute a species that is often used as a natural food coloring. In addition, some species from the Fabaceae family provide us with species like *Clitoria ternatea* L. (butterfly pea or *telang*) and *Biancaea sappan* (L.) Tod. (sappanwood or *secang*). Local communities often use these renowned, well-known sources of natural dyes, connecting them to their cultural heritage.

Part used

Based on Figure 2 reveals the plant parts used for coloring. From the available data, fruit is the most dominant part used for coloring, with 19 species (36%). Leaves came in second with 15 species (28%), showing the importance of leaves in the preparation of natural dyes. Flowers and bulbs were used by 7 species each, representing 13% of the total. Seed parts were utilized by 3 species (6%), while bark was used by only 2 species (4%). Rhizome was the least used part, with only 1 species (2%). This shows that fruits and leaves are the most utilized parts in the preparation of natural dyes.

Fruits and leaves are the plant parts most commonly used in the manufacture of natural dyes that are not just functional but also stunningly beautiful. Leaves, with their high pigment content like chlorophyll and carotenoids, offer a stunning range of green and yellow dyes. Fruits are also widely utilized for their natural pigment content, such as anthocyanins, which provide red to purple colors. Some fruits, such as dragon fruit or *buah naga* (*Hylocereus undatus* (Haw.) Britton & Rose) and pangi or *kluwek* (*Pangium edule* Reinw.) seeds, are used to produce dyes with brown and red color variations that are truly intriguing (Tamilarasi and Banuchitra 2021).

Life form

Based on Figure 3, the species composition of dye plants consists of four main categories based on their form, namely herbs (49%), trees (26%), shrubs (17%), and vines or lianas (8%). Herbaceous plants dominate as the most commonly used form of dye plants, like pandan (*Pandanus amaryllifolius* Roxb. ex Lindl.) produces green dye from its leaves, and turmeric (*C. longa*), which is well-known as a source of yellow natural dye. Herbaceous plants, like pandan and turmeric, are the most commonly used form of dye plants. They are abundant, with their soft, non-woody stems making them easy to find and fast to grow. This abundance should inspire you to explore the world of natural dyeing. Tree-shaped plants, which account for 26% of the composition, for example, are avocado (*Persea americana* Mill.), which produces green dye from its fruit, and teak tree or *jati* (*T. grandis*), whose leaves can produce a red color. Shrub-shaped plants, meanwhile, occupy 17%, which includes species such as Paper flower or *bunga kertas* (*Bougainvillea glabra* Choisy) which produces red color, and also rubus (*Rubus* sp.), which produces red color from its fruit. In addition, vines or lianas, which account for the smallest proportion (7%) but are nonetheless important in the ecosystem and natural dye industry, such as green grass jelly or *cao* (*Cyclea barbata* Miers) species used in green dyeing. These plants are found in various geographical regions; some are more prevalent in tropical climates, while others thrive in temperate zones. Altitude and climate factors can affect plant growth (Negari et al. 2023; Sulton et al. 2024).

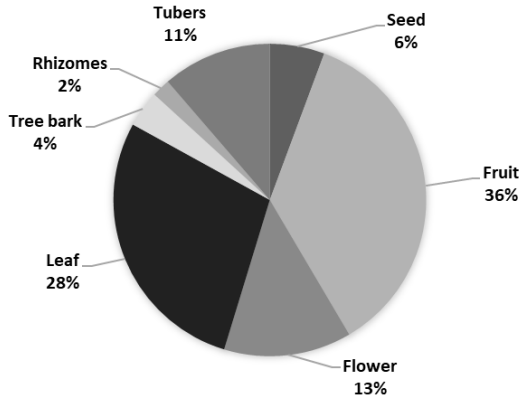

Figure 2. Part used of dye plants in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

Table 2. Composition of coloring plants found in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia, namely Dempel Village, Kalialang Village, Karangsambung Village, and Mergolangu Village

Family	Species name	Common name	Local name	Parts used	Life form	Color	Origin	Extraction	Frequency	Benefits	RFC
Achariaceae	*Pangium edule* Reinw.	Pangi	*Kluwek-pocung*	Fruit	Tree	Black	Wild	Boiled	Rarely used	Food	0.049
Amaranthaceae	*Amaranthus tricolor* L.	Chinese spinach	*Bayam*	Leaf	Herb	Green	Wild	Cooked	Frequently used	Food	0.227
Amaranthaceae	*Beta vulgaris* L.	Beet	*Bit*	Tubers	Herb	Red	Planted	Boiled, blended	Rarely used	Food	0.019
Anacardiaceae	*Mangifera indica* L.	Mango	*Mangga*	Fruit	Tree	Orange	Planted	Blended	Sometimes	Food	0.069
Apiaceae	*Daucus carota* L.	Carrot	*Wortel*	Tubers	Herb	Orange	Planted	Boiled, cooked	Sometimes	Food	0.039
Araceae	*Colocasia esculenta* (L.) Schott	Taro	*Talas*	Tubers	Herb	Chocolate	Planted	Boiled	Rarely used	Food	0.009
Arecaceae	*Cocos nucifera* L.	Coconut	*Kelapa*	Fruit	Herb	Chocolate	Wild, planted	Boiled	Frequently used	Food	0.198
Arecaceae	*Arenga pinnata* (Wurmb) Merr.	Sugar palm	*Aren*	Flower	Tree	Chocolate	Planted	Boiled	Frequently used	Drinks	0.049
Arecaceae	*Areca catechu* L.	Betel-nut palm	*Pinang*	Fruit	Tree	Red	Wild, planted	Chewed	Rarely used	Food	0.029
Asparagaceae	*Dracaena angustifolia* (Medik.) Roxb.	Narrow-leaf dracaena	*Daun suji*	Leaf	Shrub	Green	Wild	Pounded	Rarely used	Food	0.009
Asteraceae	*Lactuca sativa* L.	Red lettuce	*Selada merah*	Leaf	Herb	Red	Planted	Cooked	Rarely used	Food	0.009
Balsaminaceae	*Impatiens balsamina* L.	Garden balsam	*Pacar air*	Flower	Herb	Red	Wild	Pounded	Rarely used	Nail colorant	0.198
Basellaceae	*Anredera cordifolia* (Ten.) Steenis	Madeira vine	*Binahong*	Leaf	Herb	Green	Wild, planted	Boiled, tea	Rarely used	Drinks	0.009
Brassicaceae	*Brassica rapa* L.	Mustard green	*Sawi*	Leaf	Herb	Green	Planted	Cooked	Frequently used	Food	0.019
Brassicaceae	*Brassica oleracea* L.	Red cabbage	*Kol ungu*	Leaf	Herb	Purple	Planted	Cooked	Rarely used	Food	0.009
Cactaceae	*Hylocereus undatus* (Haw.) Britton & Rose	Dragon fruit	*Buah naga*	Fruit	Herb	Purple	Planted	Blended	Frequently used	Drinks	0.207
Caricaceae	*Carica papaya* L.	Papaya	*Pepaya*	Fruit	Herb	Green	Planted	Cooked	Frequently used	Food	0.178
Clusiaceae	*Garcinia mangostana* L.	Mangosteen	*Manggis*	Fruit	Tree	Purple	Planted	Dried	Sometimes	Drinks	0.118
Convolvulaceae	*Ipomoea batatas* (L.) Lam.	Sweet potato, purple yam	*Ubi ungu, ubi kuning*	Tubers	Herb	Purple, Yellow	Planted	Boiled	Sometimes	Food	0.475
Cucurbitaceae	*Cucurbita moschata* (Duchesne) Duchesne ex Poir.	Pumpkin	*Waluh-labu*	Tubers	Vines	Orange	Planted	Boiled	Sometimes	Food	0.356
Cucurbitaceae	*Citrullus lanatus* (Thunb.) Matsum. & Nakai	Watermelon	*Semangka*	Fruit	Herb	Red	Planted	Blended	Rarely used	Drinks	0.009
Euphorbiaceae	*Manihot esculenta* Crantz	Cassava	*Singkong*	Tubers	Herb	White	Wild, planted	Dried	Frequently used	Food	0.019
Fabaceae	*Clitoria ternatea* L.	Butterfly pea	*Telang*	Flower	Herb	Blue	Wild	Boiled, tea	Rarely used	Food	0.069
Fabaceae	*Glycine max* (L.) Merr.	Soybean	*Kedelai*	Seed	Herb	White	Planted	Boiled	Sometimes	Food	0.009
Fabaceae	*Biancaea sappan* (L.) Tod.	Sappanwood	*Secang*	Tree bark	Tree	Red	Wild, planted	Boiled, tea	Rarely used	Drinks	0.009
Lamiaceae	*Tectona grandis* L.f.	Teak	*Daun jati*	Leaf	Tree	Red	Wild, planted	Boiled	Rarely used	Food	0.148
Lauraceae	*Persea americana* Mill.	Avocado	*Alpukat*	Fruit	Tree	Green	Planted	Blended	Rarely used	Drinks	0.178
Lauraceae	*Cinnamomum verum* J.Presl	Cinnamon	*Kayu manis*	Tree Bark	Tree	Chocolate	Planted	Boiled, tea	Rarely used	Drinks	0.009
Malvaceae	*Theobroma cacao* L.	Cocoa	*Coklat*	Fruit	Tree	Chocolate	Wild	Dried	Sometimes	Drinks	0.089
Menispermaceae	*Cyclea barbata* Miers	Green grass jelly	*Cao*	Leaf	Vines	Green	Wild, planted	Boiled	Sometimes	Drinks	0.613
Moraceae	*Abelmoschus moschatus* (L.) Medik.	Musk mallow	*Waron*	Flower	Herb	Red	Wild	Pounded	Rarely used	Nail colorant	0.029

Myrtaceae	*Psidium guajava* L.	Guava	*Jambu*	Leaf	Tree	Red	Planted	Blended	Rarely used	Drinks	0.059
Myrtaceae	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	Clove	*Cengkeh*	Flower	Tree	Chocolate	Planted	Boiled	Sometimes	Drinks	0.108
Nyctaginaceae	*Bougainvillea glabra* Choisy	Paper flower	*Bunga kertas*	Flower	Shrub	Red	Wild, planted	Pounded	Rarely used	Nail colorant	0.019
Pandanaceae	*Pandanus amaryllifolius* Roxb. ex Lindl.	Pandan	*Pandan*	Leaf	Herb	Green	Wild, planted	Pounded, blender	Frequently used	Food	0.633
Passifloraceae	*Passiflora edulis* Sims	Passion fruit	*Markissa*	Fruit	Vines	Yellow	Wild, planted	Raw	Sometimes	Drinks	0.009
Piperaceae	*Piper betle* L.	Betel	*Sirih*	Leaf	Vines	Red	Wild	Boiled, chewed	Sometimes	Drinks	0.227
Piperaceae	*Piper sarmentosum* Roxb.	Wild pepper	*Senggani*	Flower	Shrub	Purple	Wild, planted	Pounded	Rarely used	Nail colorant	0.009
Poaceae	*Cymbopogon citratus* (DC.) Stapf	Lemongrass	*Sereh*	Leaf	Herb	Chocolate	Wild, planted	Boiled	Sometimes	Drinks	0.009
Poaceae	*Oryza sativa* L.	Rice	*Pari*	Seed	Herb	Black	Planted	Burned	Sometimes	Food	0.019
Rosaceae	*Rubus* sp.	Rubus	*Rubus*	Fruit	Shrub	Red	Wild	Pounded	Rarely used	Food	0.009
Rosaceae	*Fragaria ×ananassa* (Weston) Rozier	Strawberry	*Strawberry*	Fruit	Herb	Red	Planted	Blended	Sometimes	Food	0.019
Rubiaceae	*Coffea arabica* L.	Arabica coffee	*Kopi*	Seed	Shrub	Black	Wild, planted	Dried	Frequently used	Drinks	0.287
Rubiaceae	*Uncaria gambir* (W.Hunter) Roxb.	Gambir	*Gambir*	Leaf	Shrub	Chocolate	Wild, planted	Boiled	Sometimes	Drinks	0.019
Rutaceae	*Citrus* sp/	Citrus	*Jeruk*	Fruit	Tree	Orange	Planted	Blended	Frequently used	Drinks	0.089
Rutaceae	*Citrus ×limon* (L.) Osbeck	Lemon	*Lemon*	Fruit	Shrub	Yellow	Planted	Blended	Rarely used	Drinks	0.009
Sapotaceae	*Phyllanthus reticulatus* Poir.	Potato-bush	*Mangsi*	Fruit	Tree	Black	Wild	Pounded	Rarely used	Ink	0.009
Solanaceae	*Capsicum frutescens* L.	Chili pepper	*Cabai*	Fruit	Herb	Red	Planted	Blended	Frequently used	Food	0.356
Solanaceae	*Solanum lycopersicum* L.	Tomato	*Tomat*	Fruit	Herb	Red	Planted	Blended	Frequently used	Food	0.277
Solanaceae	*Nicotiana tabacum* L.	Tobacco	*Mbako*	Leaf	Herb	Chocolate	Wild, planted	Dried	Rarely used	Food	0.019
Theaceae	*Camellia sinensis* (L.) Kuntze	Tea	*Teh*	Leaf	Shrub	Chocolate	Planted	Boiled, tea	Frequently used	Drinks	0.267
Vitaceae	*Vitis vinifera* L.	Grape	*Anggur*	Fruit	Shrub	Purple	Planted	Blended	Sometimes	Drinks	0.009
Zingiberaceae	*Curcuma longa* L.	Turmeric	*Kunyit*	Rhizomes	Herb	Yellow	Planted	Boiled, cooked	Frequently used	Drinks	0.891

Color

This investigation discovered 9 different colors from dye plants used by the community (Figure 4). Red is the most frequently utilized color, which includes 15 species (28%), followed by brown (10 species, 19%) and green (8 species, 15%). Blue is the least common color acquired from plants, accounting for only one species (2%). Sweet potato/purple yam or *ubi ungu* (*Ipomoea batatas* (L.) Lam.) produces two color pigments used by the community, i.e.: yellow and purple. The community commonly uses sweet potato as a culinary coloring. Butterfly pea produces the only blue color in its flowers, which is commonly used as a refreshing drink in the community.

Origin

Figure 5 shows the distribution of the origin of plant species, which is divided into three main groups: Planted (53%), wild (28%), and planted and wild (19%). From these results, it can be seen that more than half of the species are maintained through cultivation (planted), indicating a significant impact of human actions on the distribution of plant species.

These include species such as turmeric, chili or *cabai* (*Capsicum frutescens* L.), sweet potato, etc. A total of 28% of the species are found naturally in the wild, indicating that almost a third of the species still grow without human intervention. Wild plants include species such as betel or *sirih* (*Piper betle* L.), and garden balsam or *pacar air* (*Impatiens balsamina* L.). Meanwhile, 19% of species can be found both in cultivated form and the wild (planted and wild), reflecting a balance between exploitation and conservation efforts for some species. Species in this category, such as cloves or *cengkeh* (*Syzygium aromaticum* (L.) Merr. & L.M.Perry) and green grass jelly, can grow in the wild as well as be specially planted.

Frequency

Figure 6 demonstrates that 23 species (43%) are rarely utilized, 16 species (30%) are sometimes utilized, and 14 species (26%) are frequently used by community. The frequency of use of dye plants varies from frequent use, such as turmeric and pandan, to infrequent use, such as sappanwood for red color. Most of these plants are utilized for food and beverage coloring, while some are explored for broader uses in textile or craft dyes. The predominance of herbs in the composition of dye plants indicates their superiority in availability and ease of utilization. However, the presence of trees, shrubs, and vines also offers further development potential for a more diverse source of natural dyes. This study showed that plants of various morphological types (herbaceous, tree, shrub, and vine) play an important and diverse role in the provision of natural dyes, with the greatest dominance coming from herbs. This diversity in nature's provision of natural dyes is something to be appreciated. The morphological diversity of these plants supports conservation efforts and more sustainable use in the natural color industry (Yadav et al. 2023). The results of research on plant species that can be used as food coloring in the villages of Kalialang, Mergolangu, and Dempel, show that this region has a diversity of plants that are not only useful for food but also produce natural dyes that are safe and environmentally friendly.

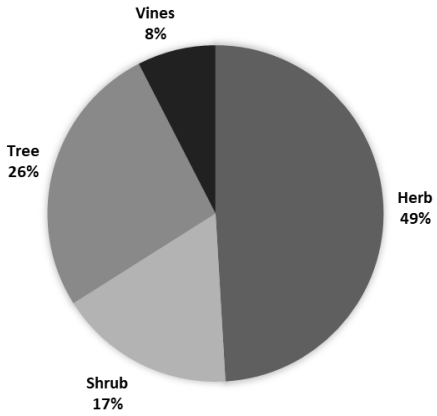

Figure 3. Life form of dye plants in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

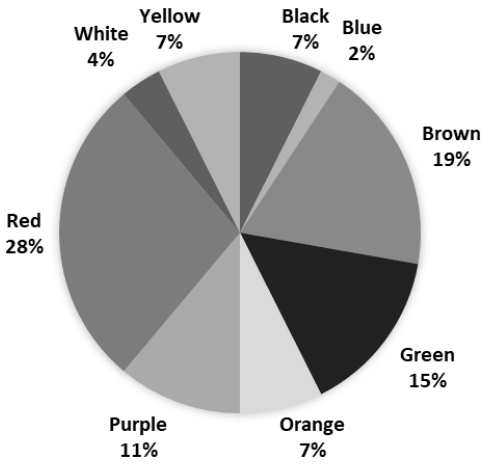

Figure 4. Color diversity of dye plants in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

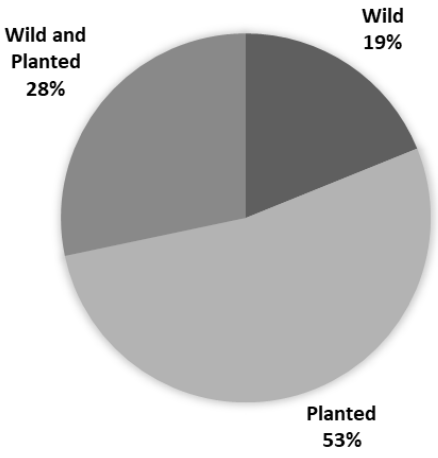

Figure 5. Origin distribution of dye plants in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

Dye plants utilization

The majority of the dye plants in Kalibawang Sub-district are utilized for food and beverage coloring. Food colorings rank highest with 26 species (49%), followed by drink colorings (22 species, 42%), nail polish (4 species, 8%), and ink colorings (1 species, 2%) (Figure 7). Natural plant dyes for food coloring are widely used by the community for traditional and cultural ceremonies, including religious ritual offerings such *merdi dusun* and *sadranan*, as well as traditional offerings at weddings, birth celebrations, and funerals. Turmeric has been widely known as a natural food colorant in traditional culinary practices. Empirical evidence obtained from structured interviews revealed that turmeric is mostly used in the preparation of *nasi kuning* (yellow rice), *opor ayam* (Javanese chicken curry in coconut milk), and *tempe goreng* (fried tempeh), due to its stable pigmentation and cultural prevalence in Indonesian cuisine. We also found the use of the plant as a medium for children's play, especially as a temporary nail polish from the paper flower plant. Our study also identified the use of potato bush as a source of natural ink. This plant species grows wild and is increasingly underutilized in local communities, despite its potential applications.

Extraction

Figure 8 shows that boiling was the most common method (23%, 12 species), followed by blending (21%, 11 species) and pounding (13%, 7 species). Additionally, five species (10%) were prepared as tea, while five species (10%) were dried to obtain color. The dye extraction method usually uses water or other natural ingredients. The dye extraction techniques in Kalibawang remain relatively simple, with water-based methods such as boiling and blending being predominant. Coconut and green grass jelly are traditionally processed through water extraction (boiling). Coconut sap, when thermally reduced, produces coconut sugar—a culturally important sweetener and an important source of income for local communities. Similarly, green grass jelly forms a gelatinous matrix after boiling, which is innovatively used in ethnobotanical practices as a digestive agent and a base for traditional drinks, underlining its dual role in local gastronomy and herbal medicine. The small-scale, household-level use of dye plants in this region explains the limited adoption of modern extraction methods. According to Ballabh and Pullaiah (2017), the preference for simple techniques is influenced by the primary application of these dyes in food and beverages, where minimal processing is favored. Methods like boiling and blending are not only cost-effective but also perceived as healthier due to the absence of synthetic chemicals. Jamaludin et al. (2023) further support this practice, noting that plant-based dyes are preferred for their environmental sustainability and ability to preserve food quality.

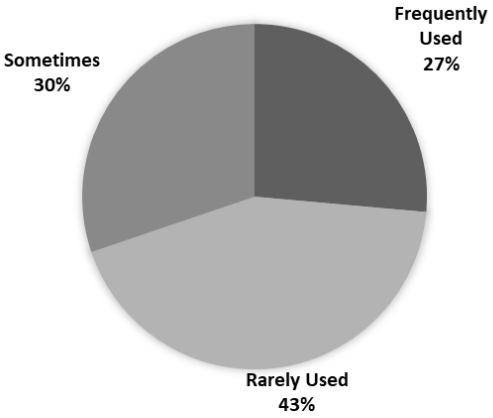

Figure 6. The frequency of use of dye plants in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

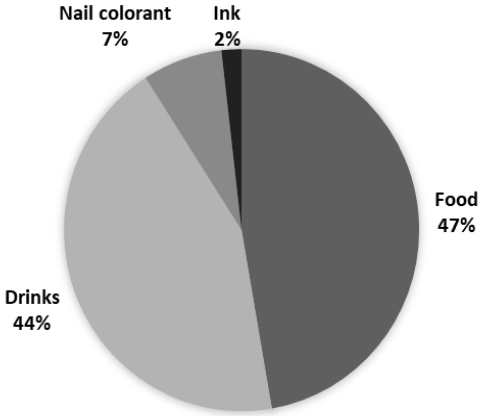

Figure 7. Dye plants utilization in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

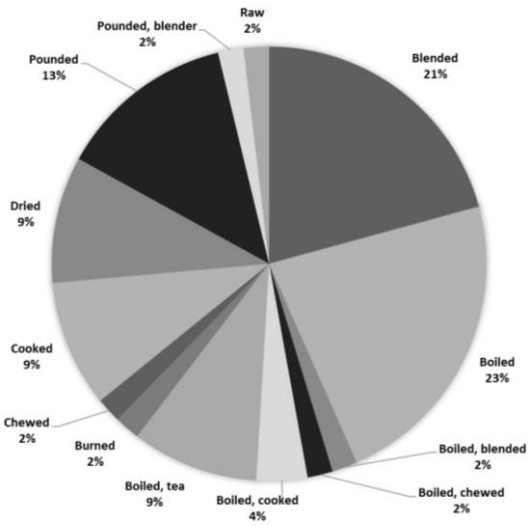

Figure 8. Extraction of dye plants in Kalibawang Sub-district, Wonosobo, Central Java, Indonesia

RFC

The RFC (Relative Frequency of Citation) value in Table 3 is an indicator that describes the level of importance of a plant species based on the frequency of its use by the local community. The higher the RFC value, the more often the plant is used as a natural dye in the life of the Kalibawang community, highlighting their reliance on these plant species. The plant with the highest RFC value is turmeric, with a value of 0.891, followed by pandan with a value of 0.633.

Turmeric has long been the main choice of the Kalibawang community as a natural coloring in food. The curcumin content in turmeric produces a distinctive bright yellow color, giving an attractive appearance to various traditional foods such as yellow rice, *opor* (a traditional cuisine is made from chicken cooked in coconut milk and numerous spices), and wet cakes. Besides beautifying dishes, turmeric also offers health benefits thanks to its safe nature and antioxidant effects. Its abundant availability in Kalibawang is another reason why turmeric is widely used. The plant is easily cultivated in yards or fields without special care, making it a cheap and accessible ingredient for household needs, especially in cooking food.

Meanwhile, pandan is also a plant often used as a natural dye in Kalibawang. Pandan leaves are rich in chlorophyll pigments that produce a soft green color, perfect for enhancing traditional foods such as wet cakes, *jenang* (sticky Indonesian toffee), or drinks. Not only does pandan provide color, but it also produces a distinctive fragrant aroma, enhancing the taste of food. In addition, pandan plants thrive in the Kalibawang environment and can be grown in home yards without intensive care, making it a practical and economical ingredient.

Turmeric and pandan are considered healthier natural dyes than artificial dyes, which often contain harmful chemicals. By utilizing these two plants, people not only maintain the authenticity of the taste and appearance of food but also ensure the health of the family. The combination of benefits, availability, and safety makes turmeric and pandan an important part of the daily life of the Kalibawang community.

Rarity

Table 3 outlines the conservation status of various plant species used as natural dyes based on data from the International Union for Conservation of Nature (IUCN). Only 28 species were recorded on the IUCN Red List. There are a number of species that have Data Deficient (DD) status, such as *Mangifera indica* L., *Brassica rapa* L., *Brassica oleracea* L., *Hylocereus undatus* (Haw.) Britton & Rose, *Camellia sinensis* (L.) Kuntze, *Carica papaya* L., *Garcinia mangostana* L., *Ipomoea batatas* (L.) Lam., *Manihot esculenta* Crantz, *Pandanus amaryllifolius* Roxb. ex Lindl., and *Curcuma longa* L. indicating a lack of sufficient data to assess the level of threat they face. Therefore, further research is needed to more accurately determine their conservation status (Li et al. 2022).

Table 3. Conservation species based on IUCN

Family	Species name	Local name	IUCN	P.106/2018
Achariaceae	*Pangium edule* Reinw.	*Kluwek-pocung*	LC	Not protected
Amaranthaceae	*Beta vulgaris* L.	*Bit*	LC	Not protected
Anacardiaceae	*Mangifera indica* L.	*Mangga*	DD	Not protected
Apiaceae	*Daucus carota* L.	*Wortel*	LC	Not protected
Araceae	*Colocasia esculenta* (L.) Schott	*Talas*	LC	Not protected
Arecaceae	*Arenga pinnata* (Wurmb) Merr.	*Aren*	LC	Not protected
Arecaceae	*Areca catechu* L.	*Pinang*	LC	Not protected
Brassicaceae	*Brassica rapa* L.	*Sawi*	DD	Not protected
Brassicaceae	*Brassica oleracea* L.	*Kol ungu*	DD	Not protected
Cactaceae	*Hylocereus undatus* (Haw.) Britton & Rose	*Buah naga*	DD	Not protected
Theaceae	*Camellia sinensis* (L.) Kuntze	*Teh*	DD	Not protected
Caricaceae	*Carica papaya* L.	*Pepaya*	DD	Not protected
Clusiaceae	*Garcinia mangostana* L.	*Manggis*	DD	Not protected
Convolvulaceae	*Ipomoea batatas* (L.) Lam.	*Ubi ungu, Ubi kuning*	DD	Not protected
Euphorbiaceae	*Manihot esculenta* Crantz	*Singkong*	DD	Not protected
Fabaceae	*Biancaea sappan* (L.) Tod.	*Secang*	LC	Not protected
Lamiaceae	*Tectona grandis* L.f.	*Jati*	EN	Not protected
Lauraceae	*Persea americana* Mill.	*Alpukat*	LC	Not protected
Lauraceae	*Cinnamomum verum* J.Presl	*Kayu manis*	VU	Not protected
Moraceae	*Abelmoschus moschatus* (L.) Medik.	*Waron*	LC	Not protected
Myrtaceae	*Psidium guajava* L.	*Jambu*	LC	Not protected
Pandanaceae	*Pandanus amaryllifolius* Roxb. ex Lindl.	*Pandan*	DD	Not protected
Rubiaceae	*Coffea arabica* L.	*Kopi*	EN	Not protected
Rutaceae	*Citrus ×limon* (L.) Osbeck	*Lemon*	LC	Not protected
Sapotaceae	*Phyllanthus reticulatus* Poir.	*Mangsi*	LC	Not protected
Solanaceae	*Capsicum frutescens* L.	*Cabai*	LC	Not protected
Vitaceae	*Vitis vinifera* L.	*Anggur*	LC	Not protected
Zingiberaceae	*Curcuma longa* L.	*Kunyit*	DD	Not protected

Note: LC: Least Concern. DD: Data Deficient. VU: Vulnerable. EN: Endangered

Some species fall under the Least Concern (LC) category, such as *Pangium edule* Reinw., *Areca catechu* L., *Beta vulgaris* L., *Daucus carota* L., *Colocasia esculenta* (L.) Schott, *Arenga pinnata* (Wurmb) Merr., *Biancaea sappan* (L.) Tod., *Persea americana* Mill., *Abelmoschus moschatus* (L.) Medik., *Psidium guajava* L., *Citrus ×limon* (L.) Osbeck, *Phyllanthus reticulatus* Poir., *Capsicum frutescens* L., and *Vitis vinifera* L. indicating that these species are still relatively safe and do not face major threats. In addition, *Cinnamomum verum* J.Presl (*kayu manis*) has a Vulnerable (VU) status, indicating that although they are not yet critically endangered, they are vulnerable to extinction if threats to their habitat or population are not properly addressed. Other species, such as *Coffea arabica* L., and *Tectona grandis* L.f. are categorized as Endangered (EN), indicating that they are under high threat to survival. None of the species documented in the study area are included in Indonesia's protected species list (P.106/2018). Although IUCN classifies *Cinnamomum verum* (Vulnerable/VU), *Tectona grandis* (Endangered/ EN), and *Coffea arabica* (Endangered/EN), these species are not listed under Indonesian protected species regulations (PP 106/2018).

Discussion

Most widely used plant

The findings of this study indicate that several plant species are employed as dye plants in Kalibawang Sub-district, Wonosobo. There are 53 species, with 37 families. Sapariani et al. (2023) discovered 26 species from 22 families in Raut Muara Village, Sanggau District, which are commonly used as food coloring. The Baiko Yao people of China use 23 species of natural dye plants from 19 families (Hu et al. 2022). The Zingiberaceae family is widely utilized, both in this research and in the study by Sapariani et al. Zingiberaceae is a family of plants that thrive in tropical regions and is extensively cultivated by local communities (Syafira et al. 2024). The most commonly used plants are turmeric, pandan leaves, and green grass jelly leaves. Turmeric, pandan leaves, and *cao* are plants that are most often used as natural coloring sources, especially as food coloring in various regions, especially in the Asian Region.

Turmeric (*C. longa*) is a shallow-rooted Herbaceous plant with thick and fleshy rhizomes (Nwaekpe et al. 2015). Turmeric is popular for its curcumin content, which provides a long-lasting yellow color that is often used as a natural food coloring. In addition to the curcumin content, turmeric also contains 3-5% essential oil and 2.5-6% yellow pigment (Bora et al. 2019). The part that is used as a colorant is the rhizome. In the four villages visited, turmeric is often used as a natural food coloring for their dishes. In Kalibawang Sub-district, Wonosobo, a very famous turmeric-based dish is *tempe kemul*, which is processed fried tempeh with flour, usually mixed with turmeric to give it a yellow color (Figure 9.A). Turmeric has anticancer, antidiabetic, antioxidant, and anti-inflammatory properties in addition to being utilized as a food coloring (Iweala et al. 2023; Nuraini et al. 2024).

Another plant that is widely used by the community is pandan leaves (*P. amaryllifolius*). Pandan plants in Indonesia are known as *pandan wangi* or *pandan rampe* (Dalimunthe 2022). Pandan leaves produce a distinctive green color so they are widely used to make foods such as *jenang* (Figure 9.B). Pandan is processed by boiling to extract the juice and then mixing it with the dough. Pandan is widely used as a food coloring in Southeast Asia. Pandan can also be utilized in medicine, cosmetics, cockroach repellent, and traditional ceremonies (Wang et al. 2024).

In addition to turmeric and pandan leaves, *cao* leaves are also popular in the community for their use as natural dyes. Green grass jelly (*C. barbata*) is very much found in various regions, especially in Indonesia (Sofyan et al. 2020). Three types of *C. barbata* are known to the Indonesian people, namely green grass jelly, black grass jelly, and shrub grass jelly. Because the leaves are thin and limp and easy to squeeze to produce a gel, Indonesian people love *C. barbata*. In Kalibawang Sub-district, Wonosobo, green grass jelly leaves are widely used as a natural colorant for green or black fresh drinks, such as ice jelly drinks (Figure 9.C). The use of green grass jelly leaves as a natural coloring agent is increasingly rare because traditional culture is slowly fading in the community, and the population of green grass jelly is decreasing in the area due to lack of cultivation, and its existence is starting to become difficult to find.

Utilization of plants

They use natural ingredients such as pumpkin or *waluh* (*Cucurbita moschata* (Duchesne) Duchesne ex Poir.) and sweet potato/purple yam for *bolu kukus* or sponge cakes (Figure 9.D), and teak leaves and guava or *jambu* leaves (*Psidium guajava* L.) for *gudeg*, a Javanese food made from young jackfruit (*Artocarpus heterophyllus* Lamk.) and cooked with coconut milk (*Cocos nucifera* L.) and spices, which are usually served in traditional ceremonies (Figure 9.E). Foods that use plants as natural colors are usually served at celebrations and weddings (Luu-Dam et al. 2016). This is an important component of the culinary tradition that has rich cultural significance. Pumpkin and purple yam are used in making sponge cakes to provide orange and purple colors. These ingredients not only add color but also contribute to the nutritional value of the dish.

Meanwhile, teak leaves and guava leaves are also used as natural red color producers to make *gudeg* by steaming young jackfruit along with the leaves until the color turns brownish red. The leaves, in addition to their color-producing properties, are rich in antioxidants, adding a healthful element to the dish. Traditional communities have unique ways of utilizing their natural resources. This tradition is still inherent in the Kalibawang Sub-district, Wonosobo community, which also shows that there is a balance between taste, cultural meaning, and, of course, aesthetics. The use of natural dyes is also a way to respect nature and the heritage of the ancestors. Natural dyes incorporated into food are useful as food protectors because these natural ingredients have many benefits (Echegaray et al. 2023). This also shows that Kalibawang people prefer to use natural ingredients and do not contain synthetic and harmful chemicals, which makes food safer and certainly sustainable for daily life.

Figure 9. Some utilization of natural dye plants in Kalibawang, Wonosobo, Indonesia. A. Turmeric for food, B. pandan leaves for food, C. *Cao* leaves for beverages, D. Pumpkin and purple yam for *bolu kukus* cake, E. *Pacar air* for nail colorant

In addition to being used as natural food coloring, the people of Kalibawang Sub-district, Wonosobo utilize dye plants for beverages. Beyond quenching thirst, these natural dyes enhance the visual appeal of drinks, improve palatability, and provide health benefits. The tradition of using dye plants for beverages has been passed down through generations and remains preserved in Wonosobo, particularly in the Kalibawang Sub-district. The local community believes that certain plants can be brewed into beverages that promote vitality and improve well-being. One notable example is *wedang uwuh*, a traditional herbal drink blended from various plant parts, such as ginger, sappanwood, clove, cinnamon, etc. valued for its therapeutic properties. This practice aligns with the findings of Tsurayya et al. (2025), who observed that *wedang uwuh* is still commonly traded in Wonosobo's traditional markets and widely consumed by the community for its direct health benefits.

Benefits

Wonosobo is an area rich in natural resources, including agriculture (Larasati et al. 2024). Wonosobo's climate tends to be cool because of its location in the mountains and the fertility of the soil, which can support plant growth. Kalibawang Sub-district is located in a hilly area with several mixed gardens and producing forests (Ndofah and Santosa 2023; Herdananta et al. 2024). Mixed-garden areas outperform other types of land uses. Pulungan et al. (2017) found that mixed gardens have a beneficial relationship to enhanced soil nutrients, which has an impact on agricultural sustainability. Rough slopes further increase the risk of landslides. Hence mixed gardens are the best option (Negari et al. 2023). The Kalibawang community uses mixed gardens to grow valuable plants, including dye plants.

The use of turmeric, pandan leaves, and green grass jelly leaves as natural dyes is influenced by various factors, ranging from the availability of raw materials to the traditions of local communities that have been passed down from generation to generation. The majority of Wonosobo's population are farmers, so natural ingredients from plants are very easy to find there and will continue to be cultivated. In addition, their easy availability makes them the right choice that is practical and economical to use as a natural food coloring. The use of the three types of plants as food coloring in Kalibawang Sub-district, Wonosobo is related to the culinary tradition in the area. Many traditional foods from Wonosobo use turmeric, pandan, and green grass jelly as natural dyes. The uses of plants vary for each community, depending on each community's traditional knowledge of the matter. Traditional knowledge is the knowledge that is passed down from one generation to the next (Jamaludin 2023). Likewise, in the community of Kalibawang, the purpose of use and the reasons for use are based on their hereditary traditions, which are not modified due to a lack of environmental education and limited knowledge.

Some plants, in addition to serving as food coloring, can be used as textile dyes. For example, turmeric can be utilized as a fabric dye (Inyom et al. 2024) and an alternative to eosin (Suryawanshi et al. 2017), whilst pandan has the potential as a natural sensitizer for solar cells (Al-Alwani et al. 2017) and a green dye for fabrics

(Berghuis et al. 2024). Because natural dyes yield delicate hues, mordants are required to keep the color pigments in fabrics intact. Color changes will occur when using different types of mordants. Natural mordants, such as alum or plant extracts, are chosen since they are safer for the environment (Singh and Singh 2018). In addition to the type of mordant, light exposure, washing and rubbing methods, and fabric type all have an impact on color fastness (Saeed et al. 2023).

In the four villages, Dempel, Karangsambung, Kalialang, and Mergolangu, plants were use as small dyes for cosmetics and textiles. The use of garden balsam or *pacar air* as a natural nail colorant is still frequently used by children as a medium for playing (Figure 13). According to research (Sapariani et al. 2023), color-producing plants are not only used as food dyes but also as dyes for cosmetics and textiles such as water henna, noni, and henna inai. This research is certainly contrary to this, where color-producing plants are only limited to being used as food coloring and have not penetrated the textile and cosmetic fields. The field of cosmetics and textiles is a strong sector in the industry, given the increasing attention to body image (Guerra et al. 2018). This could be an opportunity to create jobs for local people and improve the region's economy. Better environmental education and the development of environmentally friendly and accessible technologies are needed to address this gap.

The rarity of natural dyes

This research found that several plants are conserved to maintain their existence. Based on the IUCN Red List, some plants are already categorized as Endangered (EN). The International Union for Conservation of Nature (IUCN) Red List is a global authority on the risk of global species extinction (Betts et al. 2019). Endangered (EN) is a category that has the highest risk and requires action to prevent the extinction of the species (Geyle et al. 2018). Plants that fall into this category are *C. arabica* and *T. grandis*. Previous research conducted by Seran et al. (2024) on dye plants in Belu District, Indonesia also found the use of T. grandis (EN) as a traditional fabric dye.

Tectona grandis or teak, a native plant of South and Southeast Asia, has long been introduced to Indonesia since the 14th century and now grows abundantly in central and eastern Java (Verhaegen et al. 2010). Javanese people, including in Kalibawang, consider teak as a valuable asset and often plant it in their yards (Roshetko et al. 2013). Teak is also considered as a family savings, which helps avoid excessive logging considering its long growing time. In addition to its wood for furniture, teak leaves are also used as food wrappers and coloring. This non-timber utilization is a way to preserve the existence of teak in Kalibawang. The agroforestry system practiced in Kalibawang, which integrates teak and pine (*Pinus merkusii* Jungh. & de Vriese) with seasonal crops such as rice and cassava, has been recognized as a sustainable approach to preserving teak populations in Java. Furthermore, teak contributes to soil fertility enhancement and provides significant economic benefits (Pachas et al. 2019; Herdananta et al. 2024). To further optimize conservation efforts, we recommend expanding this agroforestry model by incorporating *C. arabica* and *C. verum*. Both species are currently under conservation concern, and agroforestry presents a viable strategy to ensure their sustainability while maintaining ecological and economic productivity.

Natural dyes challenges

The use of plants as natural dyes does have many advantages because it has health benefits beyond the ability to color (Martins et al. 2016). However, despite the health benefits of natural colorants, the use of plants as colorants has challenges in its application (Li et al. 2022). Inconsistent color in plants can be a challenge because colors in plants have poor stability against heat, light, and pH conditions. In addition, the storage period of natural dyes tends to be short before the dyeing process (Eskak and Salma 2020). Based on interviews the key informants and FGDs, the availability of raw materials is also a challenge, as many coloring plants are seasonal, and the rarity of different plants varies. The last challenge is higher production costs than the use of synthetic dyes because it requires higher costs for the process of cultivating plants and processing them to produce intense colors. The solution to overcome these challenges is to cultivate dye plants with efficient and sustainable cultivation techniques, implement color quality standardization so that colors are better maintained, and establish collaboration between producers, researchers, the government, and stakeholders in order to maintain the availability of dye plants.

Kalibawang Sub-district boasts distinctive community-managed specialty products, notably *leye* (a cassava-based rice analogue) and palm sugar (derived from *Arenga pinnata*), both cultivated and preserved by local communities due to their high economic value. Recognizing the need to maintain product quality and quantity, farmers have implemented conservation measures, primarily through village-level farmer groups that serve as platforms for knowledge exchange, agricultural improvement, and value enhancement while preserving product integrity. Previous research by Herdananta et al. (2024) demonstrates these farmer groups' significant role in developing human capital and supporting local plant conservation initiatives in Kalibawang.

In conclusion, we documented 53 species from 37 families of plants that are used as natural dyes by the people of Kalibawang Sub-district. Turmeric is the most valuable species of dye plants in this area. Especially at traditional ceremonies such as celebrations and weddings, they need to present food colored with natural dyes from plants. This traditional knowledge about natural dyes and how to process them is passed down from generation to generation. However, this traditional knowledge is in danger of being lost due to lifestyle changes and the younger generation's lack of preservation of local culture. Therefore, it is necessary to create awareness to preserve and systematize this traditional knowledge for the younger generation.

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REFERENCES

Affat SS. 2021. Classifications, advantages, disadvantages toxicity effects of natural and synthetic dyes: A review. Univ Thi-Qar J Sci 8 (1): 130-135.

Ahmad M, Sultana S, Fazl-I-Hadi S, Ben Hadda T, Rashid S, Zafar M, Khan MA, Khan MP, Yaseen G.2014. An ethnobotanical study of medicinal plants in high mountainous region of Chail valley (District Swat-Pakistan). J Ethnobiol Ethnomed 10: 36. DOI: 10.1186/1746-4269-10-36.

Al-Alwani MA, Mohamad AB, Kadhum AAH, Ludin NA, Safie NE, Razali MZ, Ismail M, Sopian K. 2017. Natural dye extracted from *Pandannus amaryllifolius* leaves as sensitizer in fabrication of dye-sensitized solar cells. Intl J Electrochem Sci 12 (1): 747-761. DOI: 10.20964/2017.01.56.

Alegbe EO, Uthman TO. 2024. A review of history, properties, classification, applications and challenges of natural and synthetic dyes. Heliyon 10 (13): e33646. DOI: 10.1016/j.heliyon.2024.e33646.

Ballabh B, Pullaiah T. 2017. Ethnic Food Plants and Ethnic Food Preparation in Western and Central Himalayas. In: Pullaiah T, Krishnamurthy KV, Bahadur B (eds). Ethnobotany of India, Volume 4: Western and Central Himalayas. Apple Academic Press, New York. DOI: 10.1201/9781315207391-3.

Berghuis NT, Isnaeni LA, Shaleha KN, Kusumaningrum AT, Maryana E, Kurniawati F. 2024. Extraction of chlorophyll from pandan wangi leaves (*Pandanus amaryllifolius* Roxb.) as natural textile dyes. EduChemia: Jurnal Kimia dan Pendidikan 9 (2): 162-175. DOI: 10.30870/educhemia.v9i2.24963.

Berlin SW, Linda R, Mukarlina. 2017. Utilization of plants as natural dyes by the Dayak Bidayuh Tribe in Kenaman Village, Sekayam Sub-district, Sanggau District. Protobiont 6 (3): 303-309. DOI: 10.26418/protobiont.v6i3.22499. [Indonesian]

Betts J, Young RP, Hilton-Taylor C, Hoffmann M, Rodríguez JP, Stuart SN, Milner-Gulland EJ. 2020. A framework for evaluating the impact of the IUCN Red List of threatened species. Conserv Biol 34 (3): 632-643. DOI: 10.1111/cobi.13454.

Bora P, Das P, Bhattacharyya R, Barooah MS. 2019. Biocolour: The natural way of colouring food. J Pharmacogn Phytochem 8 (3): 3663-3668.

BPS. 2023. Hasil Sensus Pertanian 2023 Kecamatan Kalibawang. Badan Pusat Statistik, Wonosobo.

Dalimunthe A, Nurbaya S, Priltuis N, Ginting P. 2022. Analysis of calcium capacity in bebek (*Anas platyrhynchos-domesticus*) egg cover for the making of toothpaste with natural colors from pandan leaves (*Pandanus amaryllifolius* Roxb). Jurnal Farmanesia 9 (1): 34-40. DOI: 10.51544/jf.v9i1.3427.

Ebrahim S, Mosaad MM, Othman H, Hassabo AG. 2022. A valuable observation of eco-friendly natural dyes for valuable utilisation in the textile industry. J Text Color Polym 19 (1): 25-37. DOI: 10.21608/jtcps.2021.97342.1090.

Echegaray N, Guzel N, Kumar M, Guzel M, Hassoun A, Lorenzo JM. 2023. Recent advancements in natural colorants and their application as coloring in food and in intelligent food packaging. Food Chem 404 (Pt A): 134453. DOI: 10.1016/j.foodchem.2022.134453.

Eskak E, Salma IR. 2020. Study on the utilization of plantation waste for substitution of natural batik dyes. Jurnal Industri Hasil Perkebunan 15 (2): 27-37. DOI: 10.33104/jihp.v15i2.6331. [Indonesian]

Geyle HM, Woinarski JCZ, Baker GB, Dickman CR, Dutson G, Fisher DO, Ford H, Holdsworth M, Jones ME, Kutt A, Legge S, Leiper I, Loyn R, Murphy BP, Menkhorst P, Reside AE, Ritchie EG, Roberts FE, Tingley R, Garnettc ST. 2018. Quantifying extinction risk and forecasting the number of impending Australian bird and mammal extinctions. Pac Conserv Biol 24 (2): 157-167. DOI: 10.1071/PC18006.

Guerra E, Llompart M, Garcia-Jares C. 2018. Analysis of dyes in cosmetics: Challenges and recent developments. Cosmetics 5 (3): 47. DOI: 10.3390/cosmetics5030047.

Herdananta BY, Ibriza NM, Wardha'adlina WA, Sulton MN, Sugiyarto, Budiharta S, Setyawan AD. 2024. Assessing social capital in community forest management in Kalibawang Sub-district, Wonosobo District, Central Java, Indonesia. Asian J Ethnobiol 7: 50-60. 10.13057/asianjethnobiol/y070106.

Hu R, Li T, Qin Y, Liu Y, Huang Y. 2022. Ethnobotanical study on plants used to dye traditional costumes by the Baiku Yao nationality of China. J Ethnobiol Ethnomed 18: 2. DOI: 10.1186/s13002-021-00497-2.

Inyom RM, Oduns CP, Ofoegbu O, Akpan EA. 2024. Extraction, application and assessment of the fastness properties of dyes from turmeric plant (*Curcuma longa*) and its effect on cotton woven fabrics. Intl Acad Res Consort J (IARCJ) 8 (5): 1-31.

Iweala EJ, Uche ME, Dike ED, Etumnu LR, Dokunmu TM, Oluwapelumi AE, Okoro BC, Dania OE, Adebayo AH, Ugbogu EA. 2023. Curcuma longa (Turmeric): Ethnomedicinal uses, phytochemistry, pharmacological activities and toxicity profiles—A review. Pharmacol Res-Mod Chin Med 6: 100222. DOI: 10.1016/j.prmcm.2023.100222.

Jamaludin NA, Ramya AR, Othman R, Hatta FAM. 2023. The use of Malay cultural ethnobotany as natural colourants in eco-friendly dyeing. EHMAP 11: 183-206.

Jan M, Mir TA, Jan HA, Khare RK. 2022. Medicinal plants diversity and their uses for gynecological disorders of District Baramulla, Jammu and Kashmir, India. Vegetos 35: 438-452. DOI: 10.1007/s42535-021-00332-9.

Lakshmi GC. 2014. Food coloring: the natural way. Res J Chem Sci 4 (2): 87-96.

Larasati AD, Abrari FH, Fathoni MFM, Jabbar SA, Arifiani KN, Indrawan M, Sugiyarto, Setyawan AD. 2024. Short Communication: Estimation of aboveground biomass and carbon stock in agroforestry areas of Mergolangu and Karangsambung Villages, Wonosobo, Central Java, Indonesia. Asian J Agric 8 (2): 161-168. DOI: 10.13057/asianjagric/g080210.

Li N, Wang Q, Zhou J, Li S, Liu J, Chen H. 2022. Insight into the progress on natural dyes: Sources, structural features, health effects, challenges, and potential. Molecules 27 (10): 3291. DOI: 10.3390/molecules27103291.

Luong NT, Hop NV, Quy NV, Hoan VM. 2023. Diversity of plant species for food coloring in Vietnam. Nusantara Bioscience 15 (1): 95-104. DOI: 10.13057/nusbiosci/n150112.

Luu-dam NA, Ninh BK, Sumimura Y. 2016. Ethnobotany of colorant plants in ethnic communities in Northern Vietnam. Anthropology 4: 158. DOI: 10.4172/2332-0915.1000158.

Malabadi RB, Kolkar KP, Chalannavar RK. 2022. Plant natural pigment colorants-health benefits: Toxicity of synthetic or artificial food colorants. Intl J Innov Sci Res Rev 4 (10): 3418-3429.

Martins N, Roriz CL, Morales P, Barros L, Ferreira ICFR. 2016. Food colorants: Challenges, opportunities and current desires of agro-industries to ensure consumer expectations and regulatory practices. Trends Food Sci 52: 1-15. DOI: 10.1016/j.tifs.2016.03.009.

Maskun, Assidiq H, Al Mukarramah NH, Bachril SN. 2021. Threats to the sustainability of biodiversity in Indonesia by the utilization of forest areas for national strategic projects: A normative review. IOP Conf Ser: Earth Environ Sci 886 (1): 012071. DOI: 10.1088/1755-1315/886/1/012071.

Mohamad MF, Dailin DJ, Gomaa SE, Nurjayadi M, El Enshasy H. 2019. Natural colorant for food: A healthy alternative. Intl J Sci Technol Res 8 (11): 3161-3166.

Ndofah TA, Santosa PB. 2023. Evaluasi penggunaan lahan mengacu pada indeks potensi lahan dan kesesuaiannya terhadap rencana tata ruang wilayah di Kabupaten Wonosobo. JGISE: J Geospat Inf Sci Eng 6 (2): 87-102. DOI: 10.22146/jgise.91079.

Negari SIT, Ningtyas SRA, Hanun Z, Sulton MN, Kusumaningrum L, Indrawan M, Sugiyarto, Sutomo, Setyawan AD. 2023. Agroforestry suitability evaluation using remote sensing in Jatiyoso Sub-district, Karanganyar District, Central Java, Indonesia. Biodiversitas 24 (12): 6761-6769. DOI: 10.13057/biodiv/d241239.

Novais C, Molina AK, Abreu RMV, Santo-Buelga C, Ferreira ICFR, Pereira C, Barros L. 2022. Natural food colorants and preservatives: A review, a demand, and a challenge. J Agric Food Chem 70 (9): 2789-2805. DOI: 10.1021/acs.jafc.1c07533.

Nuraini A, Rabbani AH, Jagatru AS, Azzahra AN, Azizia MS, Yasa A, Saensouk S, Setyawan AD. 2024. Diversity and use medicinal plants for traditional women's health care in Kalibawang, Wonosobo District, Indonesia. Asian J Ethnobiol 7 (2): 145-155. DOI: 10.13057/asianjethnobiol/y070207.

Nwaekpe JO, Anyaegbunam HN, Okoye BC, Asumugha GN. 2015. Promotion of turmeric for the food/pharmaceutical industry in Nigeria. Am J Exp Agric 8 (6): 335-341. DOI: 10.9734/AJEA/2015/16517.

Pachas ANA, Sakanphet S, Midgley S, Dieters M. 2019. Teak (*Tectona grandis*) silviculture and research: Applications for smallholders in Lao PDR. Austr For 82 (sup1): 94-105. DOI: 10.1080/00049158.2019.1610215.

Pranta AD, Rahaman MT. 2024. Extraction of eco-friendly natural dyes and biomordants for textile coloration: A critical review. Nano-Struct Nano-Objects 39: 101243. DOI: 10.1016/j.nanoso.2024.101243.

Pulungan NA, Utami SNH, Purwanto BH, Sartohadi J. 2017. Analysis of SOM and soil nutrients for sustainable agriculture in hilly areas: Central Part of Bogowonto Catchment, Java, Indonesia. In: Isnansetyo A, Nuringtyas T (eds). Proceeding of the 1st International Conference on Tropical Agriculture. Springer, Cham. DOI: 10.1007/978-3-319-60363-6_19.

Raturi M, Bose D, Mehta J, Saraf D. 2023. Rhododendron arboreum as a sustainable food-grade natural flavouring and colouring agent. Food Humanit 1: 1610-1618. DOI: 10.1016/j.foohum.2023.11.005.

Ribeiro JS, Veloso CM. 2021. Microencapsulation of natural dyes with biopolymers for application in food: A review. Food Hydrocoll 112: 106374. DOI: 10.1016/j.foodhyd.2020.106374.

Roshetko JM, Rohadi D, Perdana A, Sabastian G, Nuryartono N, Pramono AA, Widyani N, Manalu P, Fauzi MA, Sumardamto P, Kusumowardhani N. 2013. Teak agroforestry systems for livelihood enhancement, industrial timber production, and environmental rehabilitation. For Trees Livelihoods 22 (4): 241-256. DOI: 10.1080/14728028.2013.855150.

Saeed A, Hassan K, Sadaf SS. 2023. A review on colour fastness of natural dyed textiles. Pak J Sci Ind Res A: Phys Sci 66 (2): 201-212.

Sapariani, Syamswisna, Mardiyyaningsih AN. 2023. Ethnobotanical study of natural coloring plants in Raut Muara Village, Sanggau Regency. Ekotonia: Jurnal Penelitian Biologi, Botani, Zoologi dan Mikrobiologi 8 (2): 62-71. DOI: 10.33019/ekotonia.v8i2.4455. [Indonesian]

Seran W, Kaho LMR, Pellondo'u ME, Mau AE, Aini Y, Kaho NPLBR, Soimin M. 2024. Diversity and ethnobotany of plants used as natural dye in traditional woven by local community in Belu Regency, Indonesia. Biodiversitas 25 (11): 4415-4424. DOI: 10.13057/biodiv/d251141

Singh S, Singh DR. 2018. Application of natural mordants on textile. Intl J Appl Home Sci 5 (1): 252-260.

Sk MS, Mia R, Haque MA, Shamim AM. 2021. Review on extraction and application of natural dyes. Text Leather Rev 4 (4): 218-233. DOI: 10.31881/TLR.2021.09.

Sofyan A, Priyanti E, Kurnianingsih. 2020. The study of marshmallow's preferences level with the addition of green grass jelly (*Cyclea Barbata* L. Miers). Food ScienTech J 2 (1): 20-24. DOI: 10.33512/fsj.v2i1.8079.

Sulton MN, Aurina DM, Muhammad F, Fadzilah FPA, Hanun Z, Indrawan M, Budiharta S, Supriatna J, Nursamsi I, Setyawan AD. 2024. Predicting the current and future distributions of *Pinus merkusii* in Southeast Asia under climate change. Biodiversitas 25 (3): 1135-1143. DOI: 10.13057/biodiv/d250328.

Suryawanshi H, Naik R, Kumar P, Gupta R. 2017. *Curcuma longa* extract – Haldi: A safe, eco-friendly natural cytoplasmic stain. J Oral Maxillofac Pathol 21 (3): 340-344. DOI: 10.4103/jomfp.JOMFP_62_17.

Syafira F, Nurainas, Syamsuardi. 2024. New record and potential spatial distribution of *Curcuma sumatrana* (Zingiberaceae): An endemic wild turmeric in Sumatra, Indonesia. Biodiversitas 25 (11): 4127-4138. DOI: 10.13057/biodiv/d251112.

Tamilarasi A, Banuchitra M. 2021. Classification and types of natural dyes: A brief review. Intl J Creat Res Thoughts (IJCRT) 9 (11): 527-532.

Tsurayya DA, Saleh DA, Renaldi DR, Rizka DR, Widyaningyas R, Yasa A, Iskandar J, Saensouk S, Setyawan AD. 2025. Herbal medicines sold in Wonosobo Traditional Markets, Indonesia. Asian J Ethnobiol 8: 13-25. DOI: 10.13057/asianjethnobiol/y080102.

Verhaegen D, Fofana IJ, Logossa ZA, Ofori D. 2010. What is the genetic origin of teak (*Tectona grandis* L.) introduced in Africa and in Indonesia? Tree Genet Genomes 6: 717-733. DOI: 10.1007/s11295-010-0286-x.

Wang W, Ren Z, Zheng S, Wu H, Li P, Peng W, Su W, Wang Y. 2024. Botany, phytochemistry, pharmacology, and applications of *Pandanus amaryllifolius* Roxb.: A review. Fitoterapia 177: 106144. DOI: 10.1016/j.fitote.2024.106144.

Yadav S, Tiwari KS, Gupta C, Tiwari MK, Khan A, Sonkar SP. 2023. A brief review on natural dyes, pigments: Recent advances and future perspectives. Results Chem 5: 100733. DOI: 10.1016/j.rechem.2022.100733.

Yamane T. 1967. Statistics: An Introductory Analysis, 2nd Ed. Harper and Row, New York.