Cultural and socio-economic determinants of natural dye usage: A case of African dye plants in Benin

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Research

Abstract

Background: The use of natural dyes in Benin varies across cultural and regional contexts. This study explores traditional knowledge and practices while testing Phillips and Gentry's hypothesis linking plant utility to taxonomic group, growth form, abundance, and size.

Methods: Ethnobotanical surveys were carried out in 31 communes (May-October 2024) with 722 participants selected using Dagnelie's (1998) formula. Data on dye species, categories of use, determinants, and harvesting methods were analysed through informant consensus factor (ICF), fidelity level (FL), use value index (UVi), cultural importance index (CII), and statistical tests including Chi-square and correspondence factor analysis (CFA).

Results: Food-related dye use had the highest ICF (0.98), followed by cosmetics (0.92). *Daniellia oliveri* (Rolfe) Hutch. & Dalziel recorded the highest UVi (1.00), while *Corchorus olitorius* L., *Spondias mombin* L., and *Khaya senegalensis* (Desv.) A.Juss. showed moderate values (0.33-0.50). *Parkia biglobosa* (Jacq.) R.Br. ex G.Don, *Philenoptera cyanescens* (Schumach. & Thonn.) Roberty, and *Sorghum bicolor* (L.) Moench were culturally significant. The dominant uses were food (31.89%) and medicine (24.60%). Influencing factors included ancestral knowledge (21.91%), colour (20.92%), rituals (15.51%), availability (8.57%), and accessibility (8.12%). CFA highlighted socio-cultural variation, while Chi-square revealed gender differences (p = 3.454e-05): women mainly used food dyes, men handicrafts. Occupation was also significant (p = 2.2e-16), with weavers, chiefs, and artisans as key users.

Conclusions: Dye plant use in Benin is diverse and shaped by socio-cultural drivers. Results partly support Phillips and Gentry's hypothesis. Further studies should evaluate species threats and promote sustainable conservation.

Keywords: Producing-dye plants; indigenous dye plants, traditional knowledge; use determinant, Benin

Background

Benin's plant biodiversity forms a significant natural heritage that benefits its people in various ways through the ecosystems they inhabit. These ecosystems, comprising over 51% of shrub and tree savannahs (World Bank Group 2020), house numerous plants essential to the population. Across different domains, several of these plants have demonstrated critical socioeconomic importance, including use in medicine (Ahomadegbe *et al*. 2021, Assogbadjo *et al*. 2011), as fertility (Houmenou *et al*. 2017), and in the provision of non-timber forest products such as fruits, resins, mushrooms, oilseeds and vegetables (Assogbadjo *et al*. 2014). However, the use of these plants for specific applications has gradually declined in favour of artificial substitutes for various reasons (Danthu *et al*. 2016). This trend is particularly pronounced for plants serving as sources of natural dyes and pigments within Benin's biodiversity.

These plants, derived from multiple taxonomic groups, have specific applications as dyes depending on the knowledge base of each sociocultural group (Fagbohoun *et al*. 2014). Conducting ethnobotanical studies on these plants or plant groups is crucial for documenting "how" and "why" communities select and use these plants for their diverse needs (Gaoue *et al*. 2017). This necessity has been demonstrated through research conducted in Benin on specific plants (Adjahossou *et al*. 2009, Adjahossou *et al*. 2019, Akouehou *et al*. 2014, Amouzoun *et al*. 2019, Assi 1983, Fachola *et al.* 2019, Hadonou-Yovo *et al*. 2019), plants with specific uses (Adomou *et al*. 2012, Dansi *et al*. 2008, Dougnon *et al*. 2021, Fagbohoun *et al*. 2014, Fagbohoun & Vieillescazes 2020, Hadonou-Yovo *et al*. 2019, Houmenou *et al*. 2017, Kouchade *et al*. 2017, Koudokpon *et al*. 2018, Sangare *et al*. 2012), or groups of plants (Akpi *et al*. 2019, Dossou *et al*. 2012, Hadonou-Yovo *et al*. 2019, Avikpo *et al*. 2017).

Despite this body of work, studies on natural dyes (Akogou *et al*. 2018, Fagbohoun *et al*. 2014, Fagbohoun & Vieillescazes 2020, Odouaro *et al*. 2024) have revealed significant gaps. They have demonstrated the hidden functionality of these plants beyond those investigated in other studies on plant species in Benin. However, research into natural dyes remains in its infancy. Moreover, the history and determinants of natural dye usage remain largely undocumented in Benin. Existing studies have focused on a limited sociocultural group (Ifangni Commune), primarily examining dyes used by artisans. Yet, as demonstrated by Lawrence (2022), the use of plants can also depend on socioeconomic factors such as gender, ethnicity, age, and market proximity. Expanding these factors across Benin's regions would account for variations in knowledge and their influence on the use of natural dyes.

Additionally, Benin's geomorphological, geological, hydrographic, edaphic, climatic, and demographic diversity explains the variety and fragmentation of vegetation formations and the variability in floristic composition (Ahouandjinou *et al*. 2017). Referring to Phillips and Gentry (1993) certain plant families may not occur in specific geographic locations, yet they possess natural dye properties. This highlights the limitations of previous studies on dye species, particularly regarding local knowledge assessments related to natural dye usage in Benin.

It is therefore essential to investigate the various factors influencing the use of natural dyes to bridge this knowledge gap through an evaluation of local community knowledge, aligned with conservation and valorisation efforts. Specifically, this research will focus on evaluating local knowledge and traditional practices related to natural dye usage and identifying the factors determining usage for dye species. Phillips and Gentry's hypothesis on the utility value of plants, which posits that family, taxonomic group, form, abundance, and/or maximum species size determine a plant's utility value, will also be tested.

Materials and Methods

Study area

The study area for this chapter is Benin, encompassing 31 communes included Ouaké, Djougou, Natitingou, Bassila, Tanguiéta, Kandi, Tchaourou, Kalalé, Gogounou, Sinendé, Ouèssè, Bantè, Savalou, Dassa, Djidja, Za-Kpota, Zogbodomey, Abomey, Ouidah, Lalo, Dogbo, Comè, Abomey-Calavi, Adja-Ouèrè, Porto-Novo, Bonou, Adjohoun, Sakété, Ifangny, Pobè, and Kétou. Figure 1 illustrates the various communes where ethnobotanical data collection was conducted.

Sampling strategy and Data collection

An ethnobotanical survey on dye plants was conducted across the identified communes from May to October 2024, targeting herbalists, artisan dyers, traditional healers, traditional leaders, restaurateurs, and others. We relied on a combination of photographic vouchers, taxonomic keys, and literature verification to ensure accurate species identification. Species were first identified in the field using a photographic catalogue prepared from published sources on African dye plants, and respondents assisted in recognising the species. Photographs of plant parts were then cross-checked with the Analytical

Flora of Benin guide, and all scientific names were standardised using Plants of the World Online (POWO). Prior informed oral consent was also obtained from all participants before interviews were conducted. A structured ethnobotanical survey form containing a questionnaire was developed. To complete the questionnaire, direct interviews were conducted, involving a two-person interaction where one individual shared information with the other (Fagbohoun 2014, Mabika et al. 2013). The objective of this survey was to gather data on various aspects, including the nature, type, and availability of these plants, their areas of application, the sources of knowledge regarding dye usage, the plant parts used for dye extraction, the dye extraction process and factors affecting dye plants selection.

To achieve this, an exploratory study was conducted with 30 randomly selected individuals across four randomly chosen localities. This preliminary study aimed to determine the effective sample size to be considered. The sample size for each locality was calculated using the normal approximation method (Dagnelie 1998):

$$n_i = \frac{U^2_{\left(1-\frac{\alpha}{2}\right)} P(1-P)}{d^2}$$

Where; n_i represents the number of individuals to be surveyed in each locality; $U^2_{\left(1-\frac{\alpha}{2}\right)} = 1{,}96$ is the value of the standard normal variable for a confidence level with $\alpha = 0{,}05$; p = p is the proportion of individuals who are aware of and use natural dyes; and d is the allowable margin of error (d =10 %). In each locality, participants were selected based on the type of activity requiring the use of dyes. In total, 722 individuals were identified as the target group for the survey. The survey was conducted using a digitised form on the KoboCollect tool to facilitate easier data collect.

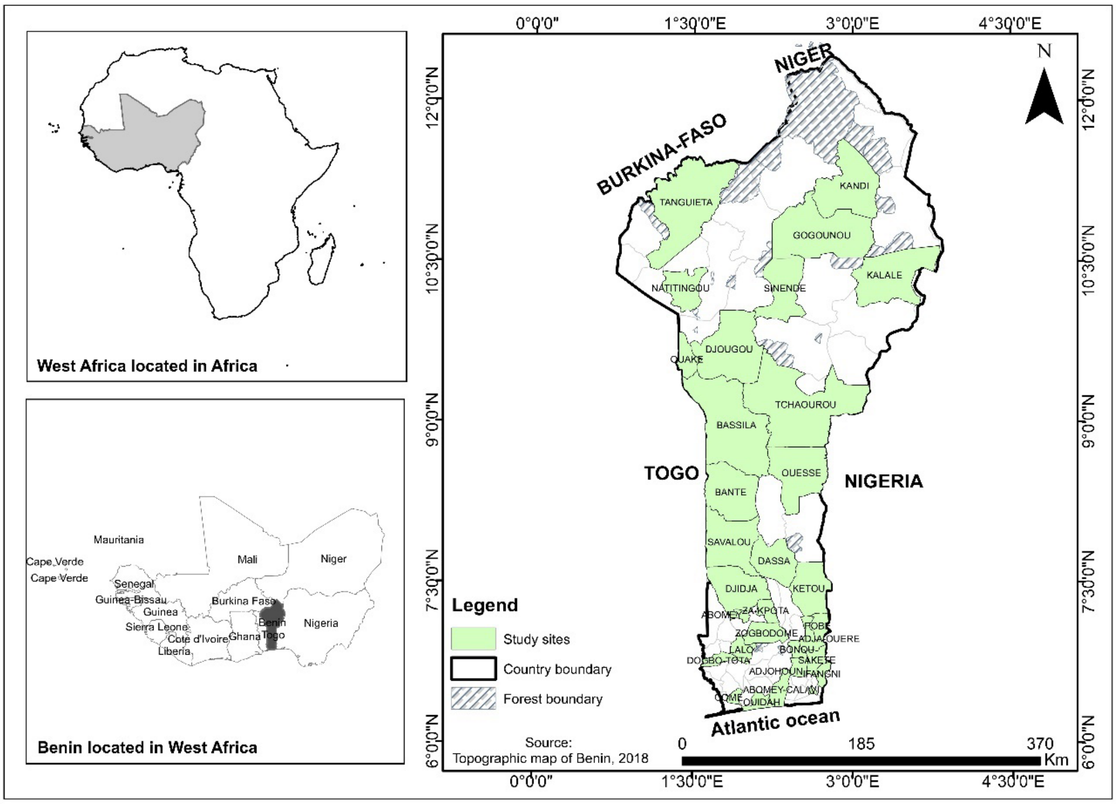

Figure 1. Location of study area

Data Analysis

For data analysis, the software R and Excel spreadsheet were utilised to create various figures and tables. Several indices and tests were calculated to evaluate the local knowledge of populations regarding natural dyes. These indices and tests are listed follows.

Informant Consensus Factor

The Informant Consensus Factor (Trotter & Logan 1986) and later adapted (Heinrich et al. 1998) this indicator enables the analysis and understanding of the consistency of knowledge within an informant group. It helps assess whether the information gathered on the use dyes plants is widely shared or derived from isolated cases. This indicator is expressed by the following formula:

$$F_{ic} = \frac{n_{ur} - n_t}{n_{ur} - 1}$$

With nur the total number of uses reported for each species, and nt represents the number of unique taxa. It ranges from 0 to 1, where a high value is a strong indicator of a high level of informant consensus.

Fidelity Level (FL)

The Fidelity Level (FL) (Friedman et al. 1986) is a quantitative index used to measure the degree of consensus among informants regarding the use of a specific plant species for a particular purpose. It helps to understand which plants are most strongly associated with a specific use within a community. It is calculated using the formular below:

$$FL_{S,U}(\%) = \frac{N_{PS,U}}{N_S} * 100$$

With $N_{PS,U}$ the Number of informants who mentioned species S for a specific use category U, and N_S the total number of informants who mentioned species S for any use.

Use Value Index (UV)

The Use Value Index (Phillips & Gentry 1993) quantifies the importance of each species for each respondent. It is calculated using the following formular.

$$\boldsymbol{UV_s = \sum_i UV_{is} / n_s}$$

With UV_{is} as the number of uses recorded by respondent i for species s, and n_s as the number of respondents mentioning species s.

Cultural Importance Index (CII)

The Cultural Importance Index (CII) (Tardío & Pardo-de-Santayana 2008) is a quantitative measure used in ethnobotany to assess the cultural significance of plant species based on how frequently they are mentioned and for how many different purposes they are used within a community. It is determined by the formular below:

$$CII = \sum_{u=1}^{N} U_u$$

Where **N** is the total number of use categories considered and $\mathbf{U_u}$ the number of informants who mentioned the species for a specific use category u. The normalized version (Thomas 2009) is used to obtain value between 0 to 1, allowing for better comparisons across studies and communities. The normalized version of CII is calculated as:

$$CII_{norm} = \frac{CII}{\mathrm{N} * \mathrm{I}}$$

Where I is the total number of informants interviewed and N × I the theoretical maximum value of CII.

Family Use Value (FUV)

Developed by Stagegaard *et al*. (2002) this index calculates the usage importance of a family of species among others and identifies the most widely used taxonomic family in the production of natural dyes. It is determined by the following formular:

$$FUV = \sum UV_{is} / nf$$

With UV_{is} representing the average use value for each species in the family and nf the number of species in the family.

Plant Part Value (PPV) index

The Plant Part Value (PPV) (Gomez-Beloz 2002) measures the value assigned to a specific part of the plant, as well as the most commonly used part of the plant for natural dyes or other purposes. It is calculated by the following formular:

$$PPV = (\frac{RU[parts\ of\ plants]}{\sum RU})$$

With RU representing the total number of uses reported for each part of the plant, and RU = the total number of uses reported for that plant.

Objective Consensual Value (PC)

The Objective Consensual Value (Byg & Balslev 2001) measures the degree of consensus within a community regarding the use of a plant or group of plants for specific purposes. It is defined by the following relationship:

$$PC_s = \sum P^2u/S$$

With P^2u the number of uses reported for a specific plant within a given category, and S represents the total number of uses reported for all plants within the same category. This value ranges from 0 to 1.

Consensual value of forms of use (CMU)

The Consensual value of forms of use (Monteiro et al. 2006) measures the level of agreement among respondents regarding the form of use of the plant. It is calculated by the following formula:

$$\boldsymbol{CMU = M_x/M_t}$$

With Mx representing the number of citations for a given form of use and Mt the total number of citations for all forms. In order to better understand the relationships between the various variables involved in the conservation of species, certain analyses will be conducted.

Chi-Square Test (χ^2)

The chi-square test (χ^2) is a statistical method used to analyse the independence or goodness of fit between qualitative variables. It determines whether a significant relationship exists between two categorical variables within a dataset.

Two hypotheses were formulated at a 5% significance level:

Null hypothesis (H_0): There is no relationship between the two qualitative variables; they are independent.
Alternative hypothesis (H_1): A significant relationship exists between the two variables; they are dependent.

This test was employed to determine the existence of a relationship between the use of natural dyes and gender, profession, and sociocultural group. Furthermore, the residuals of the chi-square test were used to identify the usage categories that contribute most significantly to the observed association between gender and profession.

Correspondence Analysis (CA)

Correspondence Analysis (CA) is a statistical method used to explore relationships between two qualitative variables by summarising a contingency table graphically. It allows for the visualisation of associations between variable categories in a scatter plot. In this study, Correspondence Analysis was used to identify relationships between usage patterns and sociocultural groups.

Results

Brief history of natural dyeing in Benin

Historical and Cultural Foundations of Natural Dyeing in Benin

In Benin, the art of natural dyeing is a heritage passed down through generations. According to oral traditions collected during our fieldwork, this practice is said to date back to the reign of King Agonglo (1789-1797), a period marked by cultural exchanges and the assimilation of foreign expertise. Several respondents reported that skilled weavers were historically brought to the palace to teach dyeing techniques, which were subsequently transmitted to local craftsmen. These accounts indicate that knowledge of natural dyeing has been historically transmitted through apprenticeships within communities, forming a longstanding tradition that persists today. Natural dyes, particularly indigo, continue to play a role in local cultural identity, ceremonial attire, and artisanal practices.

Philenoptera cyanescens* (Schumach. & Thonn.) Roberty*: A Plant of exceptional shades

Philenoptera cyanescens (Schumach. & Thonn.) Roberty (locally called "Ahoma" in Fon) was cited by 147 participants (20.36% of total) as one of the most emblematic dye plants in Benin's traditional textile practices. According to informants, its leaves are subjected to a meticulous process of maceration and fermentation to produce a deep blue dye, which is particularly used to colour textiles destined for royal and ceremonial garments. Participants emphasised that this natural dye is appreciated not only for its vibrant hue but also for its remarkable durability, which makes it highly valued in cultural and social contexts.

A living tradition

Even today, in various regions of Benin, artisans continue to uphold this heritage. During the ethnobotanical research, several elders and artisans (n = 47) expressed their commitment to preserving this tradition, despite the growing dominance of synthetic dyes. For example, a master dyer from a village in southern Benin (explained: *"This craft is part of our identity. Our ancestors refined it with patience and deep respect for nature. Every colour tells a story and carries a message."* This testimony reflects a wider sentiment among practitioners who regard natural dyeing not only as a technical skill but also as a form of cultural memory and identity.

Challenges and the preservation of this heritage

According to 6.92 % of respondents, the use of natural dyes has declined in recent decades due to the rise of industrial production and changing consumer habits. Nevertheless, participants emphasised that garments made with natural dyes are still highly appreciated, particularly because the process does not involve synthetic pigments, which enhances their cultural and ecological value. Informants also highlighted ongoing local initiatives that seek to revitalise this craft by promoting its environmental benefits and cultural significance. Several participants stressed that raising awareness among younger generations and incorporating these techniques into educational programmes could ensure the sustainability of this unique expertise. In this way, naturally dyed fabrics continue to symbolise Benin's history and identity, embodying the deep connection between culture, nature, and tradition.

Informant Consensus Factor (ICF)

The Informant Consensus Factor (ICF) values reflect agreement among informants on plant use for natural dyes across categories as presented in the Table 1 below. Food plants show the highest consensus (0.98), followed by cosmetics (0.92), medicinal and craft-related uses (0.86), cultural (0.84), and textile dye plants (0.83). The strong ICF values highlight the significance of traditional knowledge, particularly in food, medicine, and cosmetics. Greater species diversity in textile dyes suggests regional variations. These findings underscore the need for conservation and sustainable use of valued plants while reinforcing their cultural and economic importance.

Table 1. Informant Consensus Factor (ICF) Values for plant use in natural dyes across categories

Categories of use	**Informant Consensus Factor**
Food	0,98
Handicraft	0,86
Cosmetic	0,92
Cultural	0,84
Medicinal	0,86
Textile	0,83

Fidelity Level (FL) Index

The Table 2 present the Fidelity Level (FL) Index of plant species used in natural dyeing across categories. Some, like *Afzelia africana* Sm. ex Pers. (100% FL for Crafts) and *Cochlospermum planchonii* Hook.f. ex Planch. (100% FL for Food), are exclusively used in specific fields. Others, such as *Khaya senegalensis* (Desv.) A.Juss., span multiple categories, with the highest FL in Medicinal (87.5%). Overall, plant use varies, with some species highly specialised, while others have broader but less consistent applications in food, crafts, textiles, and medicine.

Table 2. Fidelity level (FL), Use Value (UVi) and Cultural Importance (CII) index of plant species used in natural dyeing across various categories

Species	Family	Fidelity level (FL)						Use Value Index	Cultural Importance Index
		Food	Crafts	Cosmetic	Cultural	Medicinal	Textile	UVi	CII
Afzelia africana Sm. ex Pers	Fabaceae	0.00	100.00	0.00	0.00	0.00	0.00	1.00	0.0003
Annona senegalensis Pers.	Fabaceae	0.00	22.22	0.00	0.00	77.78	0.00	0.33	0.0023
Balanites aegyptiaca (L.) Delile	Annonaceae	0.00	0.00	0.00	100.00	0.00	0.00	0.25	0.0010
Baphia nitida G.Lodd.	Zygophyllaceae	0.00	100.00	0.00	0.00	0.00	0.00	0.06	0.0041
Bridelia micrantha (Hochst.) Baill.	Fabaceae	0.00	0.00	0.00	0.00	57.14	42.86	0.14	0.0018
Cochlospermum planchonii Hook.f. ex Planch	Phyllanthaceae	100.00	0.00	0.00	0.00	0.00	0.00	0.04	0.0064
Cochlospermum tinctorium Perrier ex A.Rich.	Bixaceae	100.00	0.00	0.00	0.00	0.00	0.00	0.14	0.0018
Combretum glutinosum Perr. ex DC.	Bixaceae	0.00	66.67	0.00	0.00	33.33	0.00	0.33	0.0008
Commiphora africana (A.Rich.) Engl.	Combretaceae	0.00	33.33	0.00	0.00	66.67	0.00	0.33	0.0008
Corchorus olitorius L.	Burseraceae	0.00	50.00	0.00	0.00	50.00	0.00	0.50	0.0005
Daniellia oliveri (Rolfe) Hutch. & Dalziel	Malvaceae	0.00	50.00	0.00	0.00	50.00	0.00	1.00	0.0005
Dracaena arborea (Willd.) Link	Fabaceae	0.00	50.00	0.00	50.00	0.00	0.00	0.50	0.0005
Elaeis guineensis Jacq.	Asparagaceae	0.00	0.00	86.67	13.33	0.00	0.00	0.13	0.0038
Flueggea virosa (Roxb. ex Willd.) Royle	Arecaceae	0.00	28.57	0.00	0.00	71.43	0.00	0.29	0.0018
Hymenocardia acida Tul.	Phyllanthaceae	0.00	0.00	0.00	0.00	100.00	0.00	0.17	0.0015
Indigofera suffruticosa Mill.	Phyllanthaceae	0.00	0.00	0.00	0.00	0.00	100.00	0.14	0.0018
Khaya senegalensis (Desr.) A.Juss.	Fabaceae	4.17	0.00	4.17	0.00	87.50	4.17	0.33	0.0061
Lannea barteri (Oliv.) Engl.	Meliaceae	0.00	0.00	0.00	0.00	100.00	0.00	0.13	0.0020
Milicia excelsa (Welw.) C.C.Berg	Anacardiaceae	0.00	75.00	0.00	12.50	12.50	0.00	0.38	0.0102
Newbouldia laevis (P.Beauv.) Seem. ex Bureau	Moraceae	0.00	0.00	0.00	12.50	0.00	87.50	0.13	0.0020
Parkia biglobosa (Jacq.) R.Br. ex G.Don	Bignoniaceae	65.38	3.85	0.00	0.00	0.00	30.77	0.12	0.0066
Paullinia pinnata L.	Fabaceae	0.00	0.00	0.00	100.00	0.00	0.00	0.25	0.0010
Philenoptera cyanescens (Schumach. & Thonn.) Roberty	Sapindaceae	0.00	0.00	0.00	23.81	0.00	76.19	0.10	0.1053
Piliostigma thonningii (Schumach.) Milne-Redh.	Fabaceae	0.00	0.00	0.00	0.00	100.00	0.00	0.25	0.0010
Pterocarpus erinaceus Poir.	Fabaceae	0.00	0.00	0.00	0.00	80.00	20.00	0.25	0.0051

Senna alata (L.) Roxb.	Fabaceae	0.00	0.00	0.00	0.00	90.00	10.00	0.10	0.0025
Senna occidentalis (L.) Link	Fabaceae	0.00	33.33	0.00	0.00	66.67	0.00	0.33	0.0008
Sorghum bicolor (L.) Moench	Fabaceae	58.49	21.70	5.66	0.00	12.89	1.26	0.04	0.0808
Spondias mombin L.	Poaceae	0.00	50.00	0.00	0.00	50.00	0.00	0.50	0.0005
Terminalia leiocarpa (DC.) Baill.	Anacardiaceae	0.00	11.54	0.00	0.00	50.00	38.46	0.12	0.0066
Vachellia nilotica (L.) P.J.H.Hurter & Mabb.	Combretaceae	0.00	70.00	25.00	0.00	0.00	5.00	0.30	0.0051
Vitellaria paradoxa C.F.Gaertn.	Sapotaceae	0.00	50.00	0.00	0.00	50.00	0.00	0.50	0.0005
Vitex doniana Sweet	Lamiaceae	0.00	9.09	0.00	84.85	6.06	0.00	0.09	0.0084
Waltheria indica L.	Malvaceae	0.00	33.33	0.00	0.00	66.67	0.00	0.33	0.0008

Various uses of natural dyes within communities

Natural dyes serve various community needs (Figure 2). The radar chart shows a strong concentration in food (31.89%), reaffirming its central role, followed by medicinal use (24.60%), highlighting its importance in traditional medicine. Handicrafts hold 15.10%, challenging assumptions of their rarity. Cosmetics account for 12.55%, while textiles remain low at 9.33%. Cultural use is the least common (6.53%), showing marginal integration. This uneven distribution suggests usage specialisation, likely influenced by socio-economic factors or limited diversification in dye valorisation.

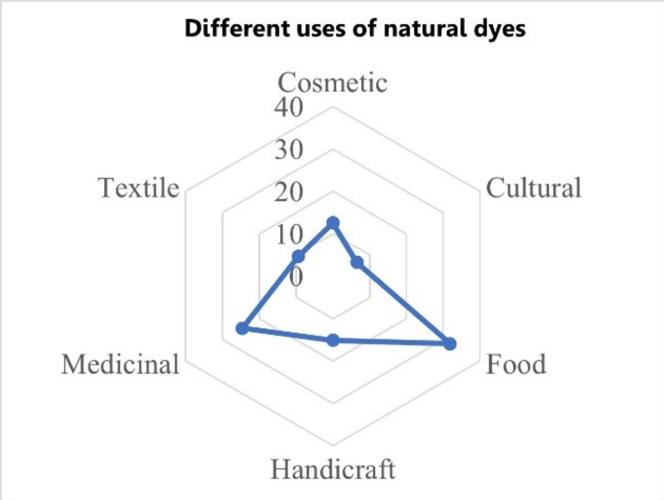

Figure 2. Different uses of natural dyes

Natural dyes serve diverse purposes across multiple domains. *P. cyanescens* (Figure 3a) is central to spiritual practices, its crushed leaves producing a blue pigment believed to enhance the Gou fetish's power (Figure 3b) that is the Vodun deity of iron, war, and protection, embodying power, justice, and the safeguarding of communities in Benin. Similarly, *Paullinia pinnata* L. (Figure 4a) provides a red dye from root maceration in alcohol, seen as equally potent as red oil in energising the Aguè fetish (Figure 4b). Beyond mysticism, these plants shape traditional artefacts. In textile dyeing, *Terminalia leiocarpa* (DC.) Baill. (Figure 5a) offers a stable pigment, used in fabrics like the hunter's woven cloth (Figure 5b), valued for tannins that aid wound healing. *P. biglobosa* (Figure 6a) also plays a role, its bark decoction yielding varied hues depending on mordants (Figure 6b), with naturally dyed textiles preferred by tourists. In food, plant dyes are widely used. The bark of *S. bicolor* (Figure 7a) produces a red pigment integral to culinary applications (Figure 7b), notably in cheese, valued for ease of extraction and potential anaemia treatment.

Figure 3a. Leaves of *Philenoptera cyanescens*. Source : Fieldwork, 2024

Figure 3b. Use of blue dye from *P. cyanescens* for spirituel purpose. Source : Fieldwork, 2024

Figure 4a. Roots of *Paullina pinnata.*
Source : Fieldwork, 2024

Figure 4b. Use of red colorant from roots of *P. pinnata,* an alternative to palm oil.
Source : Fieldwork, 2024

Figure 5a. Leaves of *Terminalia leiocarpa.*
Source : Fieldwork, 2024

Figure 5b. Uses of Brown dye from leaves of *T. leiocarpa* to make hunter' clothes.
Source : Fieldwork, 2024

Figure 6a. Leaves and Bark of *Parkia biglobosa.*
Source : Fieldwork, 2024

Figure 6b. Cotton threads dyed brown with the bark solution of *P. biglobosa.*
Source : Fieldwork, 2024

Figure 7a. Leaves and bark of *Sorghum bicolor.* Source : Fieldwork, 2024

Figure 7b. Use of red dye from *S. bicolor* bark to colour food (cheese). Source : Fieldwork, 2024

Use value and cultural uses of natural dyes

The Use Value Index (UVi) measures the frequency and importance of plant species in natural dyeing (Table 2). *Daniellia oliveri* (Rolfe) Hutch. & Dalziel has the highest UVi of 1.00, indicating it is the most commonly used species. Species like *Corchorus olitorius* L., *Spondias mombin* L., and *K. senegalensis* have moderate UVi values (0.50, 0.33), reflecting their frequent use in various dyeing categories. Other species such as *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. (0.30) and *Milicia excelsa* (Welw.) C.C.Berg (0.38) show lower, yet still moderate, usage rates, indicating their role in specific applications. Species like *C. planchonii* (0.04) and *S. bicolor* (0.04) have very low UVi, suggesting they are rarely used for dyeing. The UVi highlights the relative importance of different species, with only a few being significantly relied upon in the dyeing process.

The Cultural Importance Index (CII) measures the cultural significance of plant species based on their use in various sectors such as food, crafts, medicine, and textiles (Table 3). *S. bicolor* has the highest CII (0.0808), reflecting its notable use in food and crafts. Species like *P. biglobosa* (0.0066) and *K. senegalensis* (0.0061) have moderate CII values, indicating their widespread use in crafts and medicine. *V. nilotica* (0.0051) and *Pterocarpus erinaceus* Poir. (0.0051) are important for crafts and medicinal uses. *P. cyanescens* (0.1053), *S. bicolor* (0.0808) and *M. excelsa* (0.0102) show hight cultural relevance. Several species, such as *A. africana* (0.0003) and *Balanites aegyptiaca* (L.) Delile (0.0010), have low CII, suggesting their use is limited or specialized. The CII reveals how plant species contribute to cultural and medicinal practices, with some playing broader roles and others having niche applications.

Family use value of various natural dye species

The Family Use Value (FUV) reflects the significance of plant families in natural dye use (Table 3). Families such as Asparagaceae and Sapotaceae have high FUV values of 0.5, indicating their significant role in dyeing. Malvaceae follows with a notable FUV of 0.4167. Annonaceae and Burseraceae show moderate FUV values around 0.33. Despite a large number of species, Fabaceae has a lower FUV of 0.2408. Families like Lamiaceae and Poaceae have very low FUVs (0.0909 and 0.0440), indicating minimal use. Overall, these values highlight the most and least important families in natural dye production.

Table 3. Family Use Value (FUV) of Plant families in natural dye production

Family	Number of species	Family value use (FUV)	Family	Number of species	Family value use (FUV)
Anacardiaceae	2	0.31	Lamiaceae	1	0.09
Annonaceae	1	0.33	Malvaceae	2	0.42
Arecaceae	1	0.13	Meliaceae	1	0.33
Asparagaceae	1	0.5	Moraceae	1	0.38
Bignoniaceae	1	0.13	Phyllanthaceae	3	0.2
Bixaceae	2	0.09	Poaceae	1	0.04
Burseraceae	1	0.33	Sapindaceae	1	0.25
Combretaceae	2	0.22	Sapotaceae	1	0.5
Fabaceae	11	0.24	Zygophyllaceae	1	0.25

Plant Part Value (PPV) and Consensual Value of Forms of Use (CMU)

Plant parts used for dyeing vary by species, with values from 0 to 1, where 1 indicates high use. Leaves are most common in *S. bicolor*, *T. leiocarpa*, *V. nilotica*, and *A. africana*, notably from *Annona senegalensis* Pers., *Baphia nitida* Lodd., and *Combretum glutinosum* Perr. ex DC., are also significant. Seeds (*Elaeis guineensis* Jacq.) and flowers (*C. olitorius*) are used less, while roots, trunks, and rhizomes (*S. bicolor*, *M. excelsa*) are rare. Latex and fruits play minimal roles.

The Consensual Value of Forms of Use (CMU) identifies six dyeing methods: decoction, infusion, trituration, maceration, powdering, and fermentation. Decoction is most common (*A. africana*, *S. mombin*), followed by infusion (*Fluggea virosa* (Roxb. ex Willd.) Royle, *Hymencardia acida* Tul.)., *B. nitida* and *C. africana* use trituration, while maceration, powdering, and fermentation are less frequent. Table 4 details the plants and their dyeing methods.

Table 4. Plant parts and dyeing methods: use frequency and preferred techniques for natural dye production

Species	**Plant part value (PPV)**										**Consensual Value of Forms of Use (CMU)**					
	Leaves	Roots	Seeds	Barks	Flowers	Hole plant	Trunk	Rhizome	Latex	Fruits	Decoction	Infusion	Trituration	Maceration	Powder	Fermentation
V. nilotica	0.67	0	0.33	0	0.33	0	0	0	0	0.33	0.15	0	0.1	0	0	0.05
A. africana	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
A. senegalensis	0.5	0	0	1	0	0	0	0	0	0	0.11	0	0.11	0	0	0
B. aegyptiaca	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
B. nitida	1	0	0	1	0	0	0	0	0	0	0	0.06	0.06	0	0	0
B. micrantha	1	0	0	0	0	0	0	0	0	0	0.14	0	0	0	0	0
C. planchonii	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0.04	0
C. tinctorium	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0.14	0
C. glutinosum	1	0	0	1	0	0	0	0	0	0	0.33	0	0	0	0	0
C. africana	1	0	0	0	0	0	0	0	0	0	0	0	0.333	0	0	0
C. olitorius	0	0	0	0	0	1	0	0	0	0	0.5	0	0	0	0	0
D. oliveri	1	0	0	1	0	0	0	0	0	0	0.5	0	0	0	0	0
D. arborea	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
E. guineensis	0	0	1	0	0	0	0	0	0	0	0.06	0	0	0	0.06	0
F. virosa	0.5	0	0	0	0	0.5	0	0	0	0	0	0.14	0.28	0	0	0
H. acida	0	0	0	1	0	0	0	0	0	0	0	0.16	0	0	0	0
I. suffruticosa	0	0	0	0	0	1	0	0	0	0	0	0	0	0.14	0	0
K. senegalensis	0.25	0	0	0.75	0	0	0	0	0	0	0.12	0	0.04	0.04	0	0

L. barteri	0	0	0	1	0	0	0	0	0	0	0	0.125	0	0	0	0
M. excelsa	0	0	0	0.33	0	0	0.67	0	0	0	0.12	0	0.12	0	0.125	0
N. laevis	1	0	0	0	0	0	0	0	0	0	0	0	0.12	0	0	0
P. biglobosa	0	0	0.33	0.33	0	0	0	0	0	0.33	0.07	0	0.03	0.03	0	0
P. pinnata	0	1	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0
P. cyanescens	1	0	0	0	0	0	0	0	0	0	0	0	0.09	0	0	0
P. thoningii	0	1	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0
P. erinaceus	0	0.5	0	1	0	0	0	0	0.5	0	0.05	0.05	0	0.1	0	0
S. alata	1	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
S. occidentalis	0	1	0	0	0	0	0	0	0	0	0.33	0	0	0	0	0
S. bicolor	1	0	0	0.6	0	0	0.2	0	0	0	0.01	0.003	0.01	0.003	0.003	0.003
S. mombin	0	0	0	1	0	0	0	0	0	0	0.5	0	0	0	0	0
T. leiocarpa	0.67	0	0	1	0	0	0	0	0	0	0	0.03	0.07	0.07	0	0
V. paradoxa	1	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0
V. doniana	0.33	0.33	0	0.33	0	0	0	0	0	0	0.03	0	0.03	0	0.03	0
W. indica	1	0	0	0	0	0	0	0	0	0	0.33	0	0	0	0	0

Objective Consensual Value (PC)

The table 5 presented below highlights the plant significance in natural dyeing, with *S. bicolor* being the most important (PC = 0.440). *P. biglobosa* and *T. leiocarpa* also rank high (0.036), while *K. senegalensis*, *P. erinaceus*, and *V. nilotica* hold moderate values. In contrast, *A. africana*, *C. olitorius*, and *V. paradoxa* have low PC values (<0.01), indicating minimal relevance. The results distinguish highly used species from those of lesser importance.

Table 5. Significance of plant species in natural dyeing: Plant Contribution (PC) Values

Species	***PC***	***Species***	***PC***
Vachellia nilotica	0.028	*Khaya senegalensis*	0.033
Afzelia africana	0.001	*Lannea barteri*	0.011
Annona senegalensis	0.012	*Milicia excelsa*	0.011
Balanites aegyptiaca	0.006	*Newbouldia laevis*	0.011
Baphia nitida	0.022	*Parkia biglobosa*	0.036
Bridelia micrantha	0.010	*Paulinia pinnata*	0.006
Cochlospermum planchonii	0.035	*Philenoptera cyanescens*	0.029
Cochlospermum tinctorium	0.010	*Piliostigma thoningii*	0.006
Combretum glutinosum	0.004	*Pterocarpus erinaceus*	0.028
Commiphora africana	0.004	*Senna alata*	0.014
Corchorus olitorius	0.003	*Senna occidentalis*	0.004
Daniellia oliveri	0.003	*Sorghum bicolor*	0.440
Dracaena arborea	0.003	*Spondias mombin*	0.003
Elaeis guineensis	0.021	*Terminalia leiocarpa*	0.036
Fluggea virosa	0.010	*Vitellaria paradoxa*	0.003
Hymencardia acida	0.008	*Vitex doniana*	0.046
Indigofera suffruticosa	0.010	*Waltheria indica*	0.004

Factors determining the use of natural dye in Benin

In Benin, the use of natural dyes is shaped by several key factors, with ancestral knowledge (21.91%) being the most significant (Figure 8). This underscores the importance of traditional practices, passed down through generations, in preserving natural dyeing. Cultural heritage and identity play a vital role, especially in rural and indigenous communities. The second key factor is colour (20.92%), which holds aesthetic and cultural value, with certain hues symbolising deeper meanings in religious and cultural contexts. Rituals and cultural symbols (15.51%) further emphasise the connection between natural dyes and cultural practices. Additionally, availability (8.57%) and accessibility (8.12%) of dyeing materials are crucial, influencing the use of natural dyes where resources are abundant. These factors ancestral knowledge, colour, rituals, and material availability show that natural dyeing in Benin is not just economic but deeply rooted in the cultural and aesthetic identity of the community.

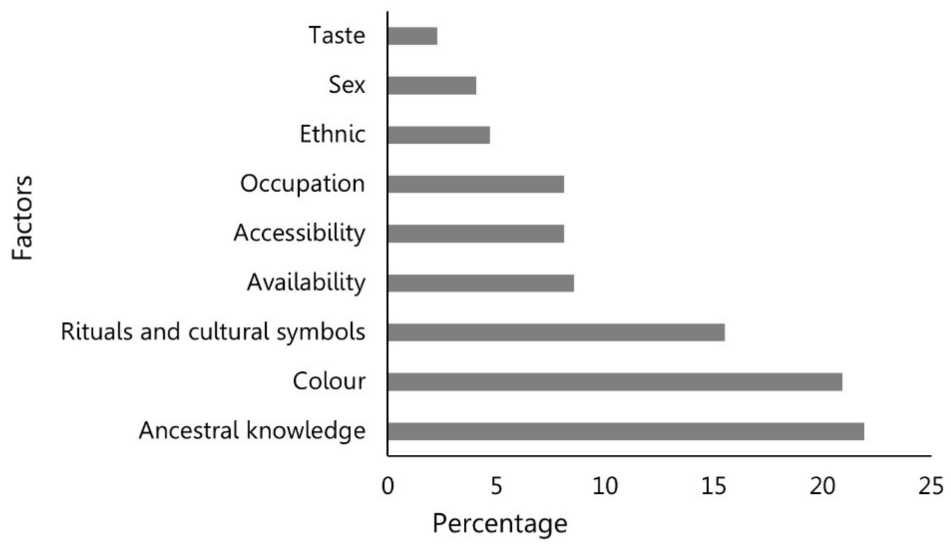

Figure 8. Determinants linked to use of natural dyes

Socio-cultural groups influence on the use of natural dyes

Pearson's Chi-squared test ($\chi^2 = 362$, p-value = 2.2e-16) reveals a significant association between natural dye usage and socio-cultural groups, confirming its strong link to traditional practices. The first two dimensions explain 66.18% of the variance, identifying key patterns in the data. Correspondence Factor Analysis (CFA) shows differences among groups (Figure 9). The Fon, Dendi, and Mahi are highly involved in food, crafts, and traditional medicine, reflecting deeply rooted cultural practices. In contrast, the Autammari, Bo, and Zarma show lower engagement, likely due to different traditions or access to resources. Dyeing for food is most common among the Mahi, Fon, and Mina, while the Fon and Peulh lead in craft and textile dyeing. Medicinal dye use is notable among the Mahi and Dendi. These findings highlight the significant role of cultural heritage in natural dye usage, illustrating how traditions influence resource use. They also emphasise the need to preserve culturally important dyeing practices and ensure sustainable access to essential plant species.

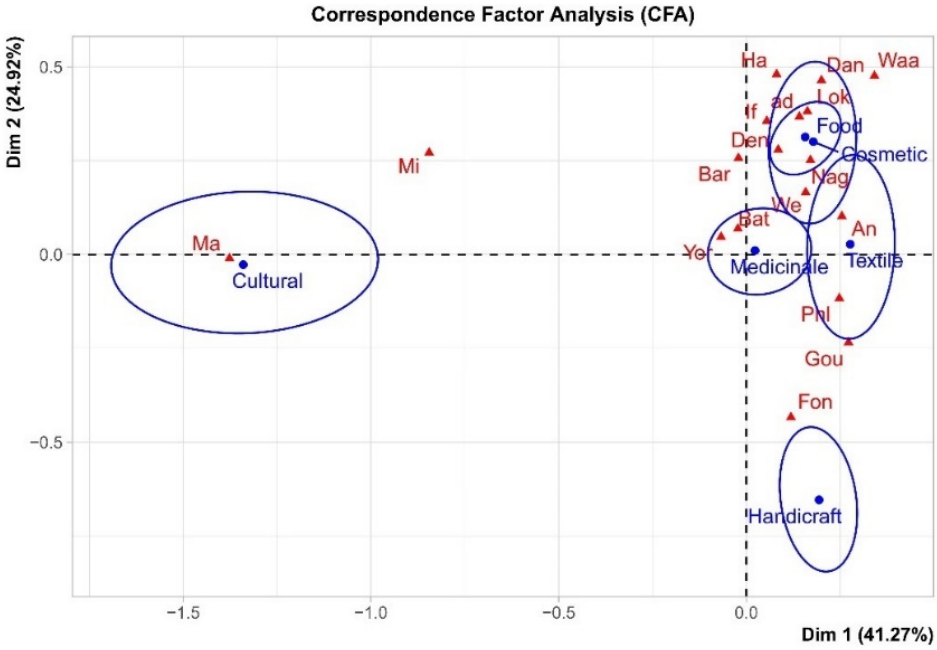

Figure 9. Use of natural dyes across socio-cultural groups

Influence of gender on the use of natural dyes

The Chi-squared test assessed the association between gender and natural dye use, yielding a test statistic of 28.116 (df = 5) and a highly significant p-value (3.454e-05). This confirms a strong link between gender and dye usage, indicating distinct patterns influenced by cultural, professional, or social factors.

The standardised residual analysis presented in the Figure 10 reveals notable gender differences. Women predominantly use natural dyes in food (residual = 2.25) and cosmetics (0.62) but engage less in handicrafts (-1.52) and textiles (-0.75). Conversely, men are more active in cultural (2.29) and handicraft applications (1.09), while their involvement in food (-1.62) and textiles (0.54) is lower than that of women. In medicinal dyeing, women show a slight preference (0.29) over men (-0.21), though the difference is marginal.

These findings suggest that gender plays a defining role in natural dye practices, with women primarily involved in food and cosmetics, while men dominate cultural and handicraft applications. This likely reflects broader socio-cultural traditions and occupational roles, highlighting the need to consider gender dynamics in the conservation and promotion of natural dyeing practices.

Influence of professional activities on the use of natural dyes

The Chi-squared test ($\chi^2 = 312.92$, df = 35, $p < 2.2e-16$) applied on factors (Table 6) had showed a highly significant association between natural dye use and occupation. The strong deviation from expected frequencies rejects the null hypothesis, indicating that dye usage varies significantly across professional groups. A standardised residuals analysis was conducted to determine which occupations contribute most to this association. These findings highlight the influence of professional activities on dyeing practices, emphasising the need to consider occupational roles in the conservation and promotion of natural dye use.

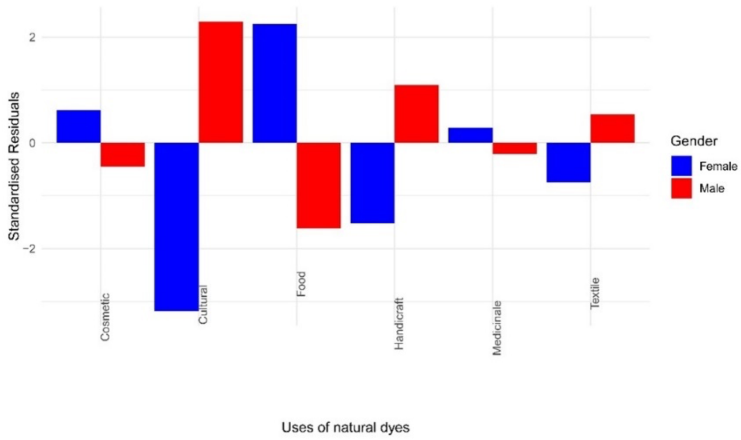

Figure 10. Specific uses differentiated by gender

Table 6. Chi-square test on factors determining the use of natural dyes

Factors	X-squared	df	p-value
Ethnic	362	145	2.2e-16
Gender	28.116	5	3.454e-05
Occupation	312.92	35	2.2e-16

The standardised residuals analysis presented in the figure 11 below confirms strong associations between natural dye use and occupations. Handicrafts are closely linked to craftsmen (3.69), while farmers (-1.25) and herbalists (-1.60) use dyes less. Weavers show the strongest association with textiles (12.19), while craftsmen (-4.20) and farmers (-2.25) use them significantly less. Cultural applications are dominated by traditional chiefs (6.55), whereas weavers (-1.81) and traders (-1.84) are less involved. In cosmetics, craftsmen (2.17) and traders (1.90) use dyes more than expected, while traditional chiefs (-2.63) and weavers (-2.51) use them less. Food-related dye use is higher among farmers (1.94), while weavers (-2.99) use them significantly less. In medicine, herbalists (1.55) have a slightly stronger association, though no major deviations are observed. These findings confirm that natural dye use is occupation-dependent, with weavers leading in textiles, traditional chiefs in cultural applications, and craftsmen in handicrafts and cosmetics.

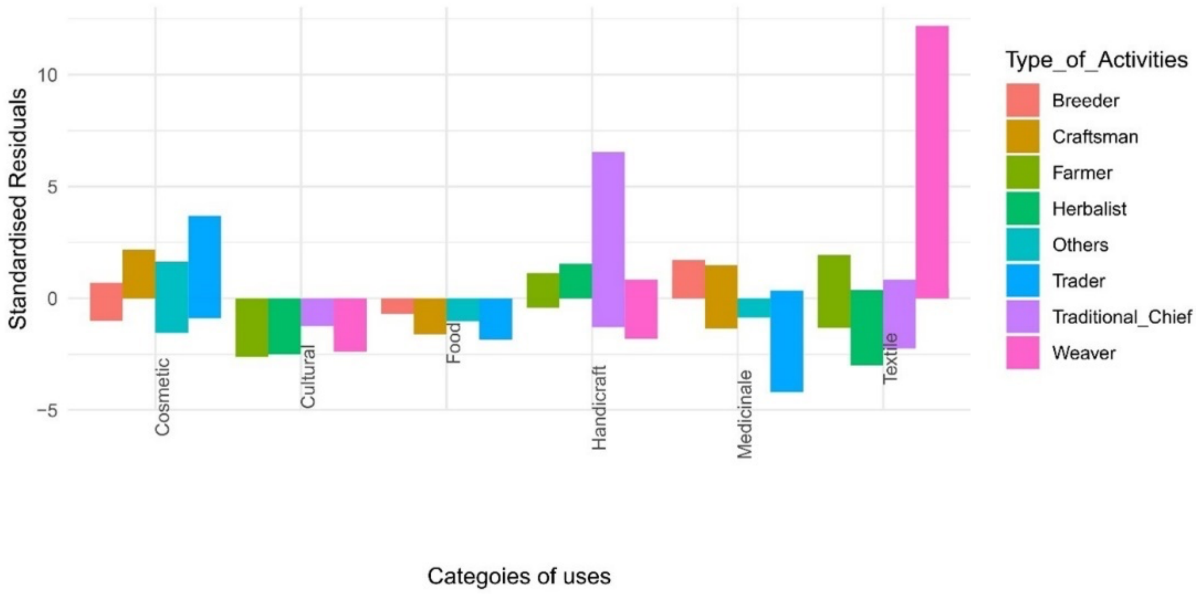

Figure 11. Specific uses differentiated by occupation

Discussion

Ethnobotanical knowledge based of dye plants uses

The high Informant Consensus Factor (ICF) values highlight strong agreement on plant use for natural dyes, particularly in food (0.9), cosmetics (0.86), medicine (0.86), crafts (0.86), culture (0.84), and textiles (0.83). This reflects the importance of traditional knowledge and cultural transmission. Compared to Faruque *et al.* (2018) study in Bangladesh where ICF values for medicinal plants were below 0.8, this study shows a higher consensus, likely due to differing research focuses. Natural dyes are widely used, with food (31.89%) and medicine (24.60%) being the most cited categories. Similar trends were observed in Turkey (Ozturk *et al*. 2013) and India (Chaudhary & Singh 2021) on *Beta vulgaris* L., which contains antioxidants and vitamins. Studies in Benin (Odouaro *et al*. 2024) and Uganda (Wanyama *et al*. 2014) on species such as *S. bicolor, Bixa orellana* L., and *Indigofera arrecta* Hochst. ex A.Rich. reinforce the nutritional and medicinal value of these dyes. This underscores their potential in mitigating synthetic dye-related health risks. Several species, including *C. olitorius, S. mombin*, and *K. senegalensis*, show moderate use values, while *V. nilotica* and *M. excelsa* have lower but still relevant usage rates. Beyond dyeing, many plants provide valuable ecosystem services. *Chromolaena odorata* (L.) R.M.King & H.Rob., for instance, has significant potential in textile dyeing (Ling *et al*. 2022). Unlike studies on dye plants in Africa and beyond, this research did not explore their role in solar energy production. However, studies in Nigeria (Morka 2024) and other African regions (Masua *et al*. 2024) highlight species such as *Mangifera indica* L. and *Senna singueana* (Delile) Lock as promising for solar applications. This calls for further research on their potential in Africa, particularly in Benin. Although cultural applications had lower ICF values, they remain significant in traditional rituals. *P. cyanescens* (ICF = 0.0053), despite its low value, is integral to spiritual practices, producing a blue-violet dye used in Gou fetish ceremonies. Lower consensus may indicate limited awareness of its ritual role or its specialised use within cultural contexts. Taxonomically, dominant dye-producing families include Asparagaceae, Sapotaceae, Malvaceae, Annonaceae, and Burseraceae. Their chemical properties rich in flavonoids, anthocyanins, tannins, and resins enhance their dyeing potential across textiles, cosmetics, and food. While this study identified 18 plant families, past research has reported greater diversity. Andriamanantena *et al*. (2019) in Madagascar and others studies in Turkey, India, Peru, Niger, Morocco, Myanmar, and Benin (Drioiche *et al*. 2021, Fagbohoun *et al.* 2014, Kallo *et al*. 2018, Ling *et al*. 2022, Mostacero León *et al*. 2017, Ozturk *et al*. 2013) documented 20 - 70 families. However, Rashid (2014) in India found similar results, and Fagbohoun *et al*. (2014) in Benin reported fewer families (14), suggesting geographical and methodological differences influence findings. Leaves and bark are the most commonly used plant parts due to their pigment richness and ease of extraction. Although seeds are less frequently utilised, they remain essential for certain dyes. This aligns with research by Ozturk *et al*. (2013), Mabika *et al*. (2013), Fagbohoun *et al*. (2014), Bazié *et al*. (2020), Morka (2024). Extraction methods vary, including decoction, infusion, grinding, maceration, powdering, and fermentation. While the latter methods are less frequent, they remain crucial for specific applications. These findings align with studies by Muhammadu *et al*. (2017), Mansour and Ali (2021), Rahayu *et al*. (2020), Aboudou and Koudouvo (2021), who found decoction and maceration to be the most widely used techniques. These insights reinforce the cultural, medicinal, and technological importance of natural dyes in Benin, emphasising the need for continued research and preservation of traditional dyeing knowledge for local and global applications.

Influence of factor determining the use of natural dye in Benin

The use of natural dyes is shaped by various factors, including ancestral knowledge, cultural symbolism, profession, sociocultural group, gender, and accessibility. This selection is not arbitrary but rooted in tradition, as also noted by Adjahossou *et al*. (2019) and Drioiche *et al*. (2021). Fan *et al.* (2018) further highlight that dyeing practices evolve with environmental conditions, age, and gender.

In this study, sociocultural group, profession, and gender significantly influenced the use of natural dyes ($p < 0.05$). Sociocultural background strongly determines dye use, particularly among the Fon, who have preserved textile dyeing as part of their ethnic identity. In some traditional societies, dyeing techniques and colours are strictly regulated for initiation rites, social status, and religious ceremonies. These cultural norms influence access to knowledge and the continuation of dyeing traditions.

Profession also plays a crucial role. Artisanal dyers, weavers, and designers favour natural dyes due to their expertise and market demand, particularly in ethical fashion. In contrast, professionals in non-textile fields tend to rely on synthetic dyes for convenience, creating disparities in adoption.

Gender further influences dye use. Traditionally, women dominate dyeing in rural and indigenous communities, passing knowledge from mother to daughter. However, men are often more involved in processing and commercialisation. This study found both men and women engaged in textile dyeing, reflecting broader cultural dynamics. Similar findings were reported by Drioiche *et al*. (2021) but contrasting results from India (Teron & Borthakur 2012) and China (Liu *et al*. 2014) suggest that in some regions, dyeing remains an exclusively female activity.

These findings underscore that natural dye use is not purely an individual choice but is shaped by sociocultural, professional, and gender-related factors. Recognising these influences is essential for policies that safeguard and promote traditional knowledge while respecting cultural specificities.

Comparative perspective within Africa

When compared with other African countries, the case of Benin presents both unique and shared characteristics in the use of natural dyes. Similar to findings in Nigeria (Byfield 2002) and Ghana (Acquah & Oduro 2012, Baa-Poku & Enu-kwEsi 2016), dyeing practices in Benin are deeply embedded in cultural symbolism, with particular colours reserved for rituals, social status, or identity. However, Benin is distinctive in the strong ritual role of species such as *P. cyanescens*, which is associated with indigo-dyed cultural objects used in Vodun contexts, including those linked locally to Gou, a use not widely reported elsewhere in West Africa (Fagbohoun & Vieillescazes 2020). In terms of gender, parallels exist with Burkina Faso and Mali, where women play leading roles in dyeing traditions (Luttmann 2010), yet in Benin, men play a more visible role in processing and commercialisation, reflecting broader socio-economic dynamics. Professionally, the persistence of artisanal dyers and weavers in Benin aligns with reports from Uganda (Wanyama *et al*. 2014), where natural dyeing is also linked to local livelihoods and niche markets. These cross-country comparisons highlight that while Benin shares common patterns with other African societies in terms of cultural transmission and gendered knowledge, it also demonstrates unique features, particularly in the ritual and symbolic domains.

Conclusion

The use of natural dye-producing species in Benin is not only an ancient practice but also a heritage passed down through generations within communities. These plants play a crucial role in various sectors, including textiles, food, medicine, cosmetics, and culture, shaping both their significance and the cultural identity of local populations. Although this practice is valued differently across sociocultural groups, it remains influenced by both social and environmental factors that govern the interaction between the human and plant worlds. While these plant species serve diverse purposes, certain ones are prioritised for their specific utility, making them more susceptible to human and/or environmental pressures. Without dedicated conservation efforts, these species face the risk of extinction, even if their current abundance gives a false sense of security regarding their long-term availability. Identifying conservation areas based on human and environmental factor gradients would not only safeguard key African dye-producing species but also preserve the traditional knowledge of local communities. These results provide partial support for Phillips and Gentry's (1993) hypothesis that plant utility is linked to taxonomic affiliation, abundance, size, and growth form. In terms of taxonomic group and family, we observed clear patterns: several families such as Fabaceae (*P. biglobosa*, *P. cyanescens*, *D. oliveri*) and Poaceae (*S. bicolor*) were disproportionately represented among culturally important dye species, consistent with the hypothesis. Regarding abundance and accessibility, frequently encountered species like *C. olitorius* and *S. mombin* showed moderate to high use values, confirming that availability strongly influences dye selection. The hypothesis was also supported for growth form, since trees (e.g., *K. senegalensis*, *D. oliveri*) and lianas (*P. cyanescens*) dominated the repertoire, reflecting the greater utility often attributed to woody species. However, our findings only partially align with the prediction concerning size: while large trees were indeed important, smaller herbs such as *C. olitorius* also held significant roles, particularly in food colouring, suggesting that cultural symbolism and ritual functions can override strict size-related utility patterns. Thus, although abundance, accessibility, family affiliation, and growth form largely conform to Phillips and Gentry's hypothesis, the influence of plant size appears less consistent, highlighting the interplay of cultural, ritual, and symbolic factors in shaping dye plant selection in Benin.

Declarations

List of abbreviations:
ICF: Informant Consensus Factor; FL: Fidelity Level, UVi: Use Value Index, CII: Cultural Importance Index, CFA: Correspondence Factor Analysis, PPV: Plant Part Value, PC: Objective Consensual Value, CMU: Consensual value of forms of use; ad: Adja; Aut: Autammari; Bo: Bo; Dit: Ditammari; Ha: Haoussa; Ag: Agoun; Bar: Bariba; Dan: Dankagoure; Fon: Fon; Ib: Ibo; An: Anii; Bat: Batonou; Den: Dendi; Gou: Goun; Ida: Idaasha; Ife: Ifè; Ma: Mahi; Nat: Natinba; Pe: Pedah; Ta: Tamari; Itc: Itcha; Mi: Mina; Nb: Nberme; Plh: Peulh; Tc: Tchi; Lok: Lokpa; Na: Nagot; Ou: Ouatchi; Se: Semre; Wa: Waama; We: Weme; Yor: Yoruba; Zar: Zarma

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