

UV-Visible-NIR Camouflage Textiles with Natural Plant Based Natural Dyes on Natural Fibre against Woodland Combat Background for Defence Protection

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Abstract

Natural plant based natural dyes (NPND) is a common source of woodland combat background (CB). Swietenia Macrophylla, Mangifera Indica, Terminalia Arjuna, Corchorus Capsularis, Camellia Sinensis, Azadirachta Indica, Acacia Acuminata, Areca Catechu and Cinnamomum Tamala were powdered/extracted and dyed-coated-printed with leafy design on cotton textiles and tested against woodland CB under the reflection engineering of ultraviolet (UV)-visible (Vis)-near infrared (NIR) spectrum and photographic technique of Vis imaging. The reflection properties of NPND treated and untreated textiles were experimented by UV-Vis-NIR spectrophotometer from 220 nm to 1400 nm. A field trialling of NPND treated woodland camouflage textiles was also investigated, located at Madhupur forest, Tangail, Dhaka, Bangladesh. The imaging properties such as CIE L*, a*, b* and RGB (red, green, blue) of NPND treated textiles were trialled by digital camera against tree stem/bark, dry leaves and green leaves of woodland CB. Therefore, a colorful matching with woodland CB (natural plant Shorea Robusta Gaertn, a common tree of woodland CB) was verified by Vis camera imaging and UV-Vis-NIR reflection mechanism. UV-protection property of Swietenia Macrophylla treated fabric was also investigated by diffuse reflection for defence clothing. Therefore, simultaneous 'camouflage textiles in UV-Vis-NIR' and 'UV-protective' property of Swietenia Macrophyllatreated fabric has been investigated for NPND materials-based textiles coloration (dyeing-coating-printing) which is a new concept for camouflage formulation of NPND-dyed-coated-printed textiles in terms of ecofriendly camouflage materials.

Introduction

Natural plant based natural dyes (NPND) materials are being introduced as 'green dyes' and 'green mordanting' for textile coloration¹. NPND materials²⁻⁷ are common source of woodland combat dye for textile coloration and presently being commercialized in home and abroad, but the concept of NPND based camouflage coloration is an innovative approach for combat application in defence textiles. The main plants of woodland CB are Swietenia Macrophylla, Mangifera Indica, Terminalia Arjuna, Corchorus Capsularis, Camellia Sinensis, Azadirachta Indica, Acacia Acuminata, Areca Catechu, Cinnamomum Tamala, Shorea Robusta Gaertn etc.² The analytical/optical assessment technology of camouflage textiles assessment⁸⁻¹² is still a new approach in camouflage textiles technology for defence textiles rather than field trialling method for concealment, detection, recognition and identification (CDRI) of defence target signature¹³. Spectral reflection of woodland CB has been considered by researchers^{14, 15} but the spectral reflection versus camouflage assessment technique is still a new technology and ongoing platform of camouflage research^{9, 12}. Simultaneous spectrum of ultraviolet-visible-near infrared (UV-Vis-NIR) reflection is a newly applied optical technology for assessment of UV-Vis-NIR camouflage textiles technology in terms of CDRI¹⁰. Hence NPND materials-polyaziridine crosslinker-UV-Vis-NIR reflection-Vis imaging versus combat engineering-color engineering-woodland CB-optical assessment-ImageJ engineering is a new approach of environment friendly materials for camouflage textiles technology, an application for defence protection. In literature, there is lacking of study related to NPND

camouflage materials and its right application for camouflage textiles as nature-friendly source of NPND materials.

Materials, formulations and methodology for camouflage textiles with NPND materials

Exemption note of NPND materials collection and approval for textile coloration. Table 1, a minimum amount of NPND materials including ‘agricultural waste’¹ were collected from non-commercial/commercial sources applied for non-commercial application. NPND application for camouflage textiles is an academic platform of research to propose a practicability for broader scale implementation in terms of ecofriendly source of camouflage materials. All experiment of NPND materials were conducted with accordance to relevant regulations and guidelines. Therefore, permission of NPND sample collection is not required. This exemption is supported by ‘3.1.2, assessment requirement’ for collection of NPND materials quoted as below, registered research located in Australia:

“A permit is not required to collect native plant material from private land, unless: the species for collection are listed threatened species or form part of a threatened ecological community under the environment protection and biodiversity conservation (EPBC) Act, under such circumstances a Commonwealth permit may be required”¹⁶.

Experimental preparations in general. Table 1, nine-NPND materials of woodland CB were collected, washed, dried, powdered/grinded and extracted by water medium. Three-dimensional method of textiles coloration was applied to signify the feasibility of NPND-camouflage coloration of dyeing, coating and printing. In terms of maximum and minimum reflection, standardized white and black background was used for comparison between target object, dyed-coated-printed textiles and selected woodland CB.

Coating and printing with NPND on cotton fabric. Table 2, a composite paste of Tubassist Fix 104W, a crosslinking agent of polyaziridine¹⁷; NK binder, acrylonitrile copolymer^{18, 19}; F53 glitter paste, acrylic copolymer and selected NPND-powder was formulated for coating and printing paste. Therefore, S/J knitted cotton fabric was coated with wooden scrubber and printed with rubber scrubber. Figure 1 identifies the complete coloration/preparation process of printing. Figure, 1a shows the formulated recipe of polyaziridine encapsulated NPND¹⁷-Swietenia Macrophylla; Figure, 1b, 1c means the trailing conditions of printing; Figure, 1d shows the formulated recipe of grinded dry leaves of polyaziridine encapsulated NPND¹⁷-Corchorus Capsularis; Figure, 1e, 1f means the trailing conditions of NPND-Corchorus Capsularis printing on cotton fabric; Figure, 1g, 1h shows the pictorial image of NPND-Swietenia Macrophylla and NPND-Corchorus Capsularis printed fabric after curing.

Mordant free coloration and NPND-mordanting of natural dyeing with NPND on natural fibre. Nine individual NPND was formulated for mordant free coloration on cotton fabric for camouflage textiles. An exhaust method of NPND coloration process was applied for camouflage coloration on cotton fabric. 150 GSM, 100% cotton knitted fabric (scoured, bleached) was washed with 2% detergent. 5g powdered Swietenia Macrophylla (wood/stem) was boiled with 1.5 litre water at boiling temperature, run

time 120 min in an open bath and continuous method. 10g cotton fabric was dyed for 90 min in an open bath at boiling temperature and followed a continuous method of coloration. A post mordanting technique was applied with the seed of *Areca catechu* in terms of NPND-mordanting¹. Similarly, a mordant free coloration with processed tea leaves was continued by water medium: water 2.5 litre, processed black tea 25g, Taza, Uniliver Bangladesh Ltd.; extraction, and dyeing time 120 minutes in an open bath at boiling temperature and followed a continuous method of coloration. Correspondingly, *Mangifera indica* (leaves), *Terminalia arjuna* (bark), *Corchorus Capsularis* (leaves), *Camellia sinensis* (modified leaves powder), *Azadirachta indica* (leaves) with *Areca Catechu* (NPND-mordant/bio-mordant), *Acacia acuminata* (seed), *Cinnamomum Tamala* (leaves) were formulated for NPND dyeing on cotton fabric, separately noted in table 1 and 2.

Fabrication and groundwork process of field trialling against woodland CB; NPND treated fabrication and field trialling of nine color combination. Figure 2 (a-l), fabrication of nine color combination of NPND against standardized black and white fabric as low reflection and high reflection chromatic hue. a = standardized white fabric, b = *Swietenia Macrophylla* dyed fabric, c = *Mangifera Indica* dyed fabric, d = *Terminalia Arjuna* dyed fabric, e = *Corchorus Capsularis* dyed fabric, f = standardized black fabric, g = *Camellia Sinensis* dyed fabric, h = *Corchorus Capsularis* dyed fabric, i = *Azadirachta Indica* treated fabric with *Areca Catechu*, NPND-mordanting/bio-mordanting, j = *Acacia Acuminata* dyed fabric, k = *Swietenia Macrophylla* treated fabric with *Areca Catechu* NPND-mordanting/bio-mordanting, l = *Cinnamomum Tamala* dyed fabric. Hence, nine color-NPND was dyed on cotton fabric, cut in small pieces and stitched for measurement of optical reflection under natural illumination and Vis imaging principle against woodland CB. Figure 7a, 7b; a garment of NPND-nine color combination was made and trialled for field experimentation of camouflage target signature against woodland CB during February-March 2022 under natural illumination (sunlight) of morning day light, located at Madhupur forest, Tangail, Dhaka, Bangladesh¹³.

NPND-*Swietenia Macrophylla* coated and printed fabrication with single color chromatic hue. Figure 2 (m-n), *Swietenia Macrophylla* wood powder was coated with solid color design and printed with single color leafy design matching with woodland CB. Figure 7c, 7d; a single color coated and printed garment of *Swietenia Macrophylla* was trialled for field experimentation of camouflage target signature against woodland CB during February-March 2022 under natural illumination (sunlight) of morning day light, located at Madhupur forest, Tangail, Dhaka, Bangladesh¹³.

NPND-*Corchorus Capsularis* coated and printed with single color chromatic hue. Figure 2 (o-p), *Corchorus Capsularis* leaves powder was coated²⁰ with solid color design and printed with single color leafy design for woodland CB. Figure 7e, 7f; a single color coated and printed garment of *Corchorus Capsularis* was trialled for field experimentation of camouflage target signature against woodland CB during February-March 2022 under natural illumination (sunlight) of morning day light, located at Madhupur forest, Tangail, Dhaka, Bangladesh¹³.

Kubelka-Munk (K-M) diffuse theory of UV-Vis-NIR reflectance spectroscopy.

Equ.1, validation of diffuse reflectance using Kubelka-Munk (K-M) theory of scattering between target signature and woodland CB. For camouflage assessment in laboratory stages, K-M theory is a theoretical reference for diffuse reflectance in UV-Vis-NIR spectrum.

$$K/S = \frac{(1-R_{\infty})^2}{2R_{\infty}} \quad \text{Equ. 1}$$

Reflectance (R) is inversely proportional to the light scattering co-efficient (S) and s value is inversely proportional to the particle size of treated textiles and the materials of woodland CB⁸.

Sampling procedure for UV-Vis-NIR spectrophotometer. Sampling procedure for measurement in UV-Vis-NIR spectrum was conducted under constant reflection of barium sulfate as 100% reflectance materials. Powdered sample and round cut of fabric was placed on standardized glass vial for reflection spectra. In Figure, 3a = powder of *Swietenia Macrophylla*, 3b = powder of *Areca Catechu*, 3c = cut pieces of raw knitted fabric before dyeing, 3d = cut pieces of *Swietenia Macrophylla* dyed fabric without mordanting, 3e = cut species of *Swietenia Macrophylla* dyed fabric with *Areca Catechu* (NPND-mordant/bio-mordant).

Scanning condition of UV-Vis-NIR spectrophotometer. UV-Vis-NIR spectrophotometer, named UV-2600 spectrophotometer was used for diffuse reflectance from 200 nm to 1400 nm. This machine was a set-up with integrating sphere. A film plate of standardized barium sulphate was scanned as reference of 100% reflection material in room temperature shown in figure 4.

Image engineering and Vis image analysis. A photograph of NPND dyed, coated and printed cotton fabric in the form of stitched garments against woodland CB was captured and considered as real image of object-background reflectance in visible range. Nikon Coolpix s2500, Nikon Corporation, Japan; 74163447 was used to capture photograph under selected distance of 7 ft and 14 ft. ImageJ software was used for Vis image analysis. Chromatic deviation of target signature against woodland CB was analysed by three dimensional color space mechanism of CIE $L^* = 0$ (black), $L^* = 100$ (white), $+a^*$ (red), $-a^*$ (green), $+b^*$ (yellow), $-b^*$ (blue) and RGB (red, green, blue) trichromatic technique of grey (white-black) chroma saturation²¹.

Results And Discussion

Assessment of UV-Vis-NIR camouflage properties of *Swietenia Macrophylla* dyed fabric against woodland CB materials for concealment of target signature. Figure 5, the reflection% of UV-Vis-NIR

spectrum obtained from the standardized barium sulphate, Swietenia Macrophylla dyed fabric without mordanting, Swietenia Macrophylla dyed fabric with NPND-mordanting, undyed knitted fabric against the materials of woodland CB. The reflection% of raw Swietenia Macrophylla and Areca Catechu was scanned as the materials of NPND and woodland CB. The reflection deviation of UV from 220 nm to 375 nm is found from 5% to 35% but the reflection was found symmetrical. The variation of reflection in Vis from 412 nm to 685 nm is marked as 5% to 60% but the reflection was shown symmetrical. The NIR reflection is recorded from 25% to 80% from 716 nm to 1398 nm. A symmetrical C-O and O-H group stretching has been exhibited from 1305 nm to 1398 nm and 778 nm to 871 nm. The C-O strength is comparatively more vibrated in NIR spectrum. For chromatic explanation of UV to Vis range, the deviation of chromatic reflection is minor in UV and Vis region due to optical scattering and chromatic matching in terms of established chromatic assessment in Vis region related to violet (400-450 nm), indigo (450-500 nm), green (500-550 nm), yellow (550-600 nm), orange (600-650 nm), red (650-700 nm). Chromatic intensity by reflection % in UV to Vis range from 220 nm 592 nm is comparatively lower due to higher absorption. The reflection% is gradually increased from 530 nm to 871 nm. From 901 nm, chromatic reflection starts to stabilize into straight direction due to lower absorption under continuous stretching vibration. The key features of reflection% have been found a harmonized direction in the entire area of graphical stage from 220 nm to 1398 nm. Hence the entire reflection% of Swietenia Macrophylla dyed fabric has been demonstrated a graphical matching in UV-Vis-NIR compared with raw Swietenia Macrophylla and raw Areca Catechu which is signified as camouflage property under symmetrical properties of woodland CB. The compositional structure of cellulosic cotton and cellulosic structure of woodland CB has also been found symmetry in NIR reflection% from 716 nm to 1398 nm. The reflection% of raw Areca Catechu was comparatively straight due to hard surface of Areca Catechu particle. Hence the darker chromatic hue of reddish tone of Swietenia Macrophylla wood (inner side) coated/dyed/printed fabric is correlated with the Swietenia Macrophylla tree of woodland CB due to similarities of existing phytochemical properties of chromatic reflection such as tannin, lignin, flavonoids etc. The molecular vibration of Swietenia Macrophylla in NIR has been excited associated with C=O, C-H, O-H and N-H bonds due to presence of lignin, cellulose, hemicellulose and phenolic compound. Hence the stretching vibration is comparatively increased in NIR rather than UV-Vis range. The symmetrical stretching of O-H bond has been found due to cellulosic properties of Swietenia Macrophylla-wood and cotton fabric. Consequently, C=O and C-H stretching was also observed due to existing hemicellulose both in cotton fibre and Swietenia Macrophylla²². The supporting information of UV-Vis-NIR camouflage assessment from 220 nm to 1400 nm has been attached in table 1-12 which are sequentially remarked as reflection (%) of standardized barium sulphate, Swietenia Macrophylla dyed fabric without mordanting, Swietenia Macrophylla dyed fabric with mordanting, undyed knitted cotton fabric, raw Swietenia Macrophylla and raw Areca Catechu.

Optical assessment of UV-protection property of Swietenia Macrophylla dyed fabric. Figure 6; possibly, the reflection of raw cotton fibre is critically uncommon due to high exposure of UV light from 220 nm to 282 nm. It may happen because of acceleration of yellowness and whiteness chroma, increased light energy, therefore fabrics looks exceptionally brighter, hence the reflection looks accelerated more than

100%. The UV parameters from 220 nm to 406 nm was also remarked based on UV reflection spectra²³. UV protection of UV-A and UV-B is comparatively lower of *Swietenia Macrophylla* treated fabric due to minimum percentage of reflectance, from 20% to 30%. Optical properties of light are related to transmission, absorption and reflection. According to established theory of energy, absorptivity + reflectivity + transmittance = 1. Therefore, the total expected absorption and transmittance will be around 70%. Natural illumination of UV is generally classified by UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (below 280 nm) although UV-C was not measured in this experiment. The reflection of UV-A and UV-B of *Sweitenia Macrophylla* treated fabric was analysed by UV spectrum exposed in figure 6. The significant variation of UV reflection was observed between NPND dyed fabric and undyed knitted cotton fabric. UV protection of *Sweitenia Macrophylla* dyed fabric was found 20% to 30%. The supporting information of UV-optical properties has been attached in table 1-2.

Vis imaging of NPND treated target signature against woodland CB, *Shorea Robusta Gaertn* under natural illumination. Figure 7, a combat engineering and digital camera imaging was applied for Vis-range camouflage textiles assessment. Under partial assessment; b, d, f located target signature have been found camouflage against the materials of woodland CB such as tree stem/bark, green leaves, dry leaves of *Shorea Robusta Gaertn*. Accordingly; a, b, c, d, e, f located target signature have been found color matching against woodland CB. The chromatic hue of NPND-nine color combination has minor difference of reflection compared with tree stem/bark, green leaves, dry leaves of *Shorea Robusta Gaertn*. Therefore, NPND-dyed-coated-printed textiles have been found minor difference of chromatic reflection against woodland CB under natural illumination.

Target signature of NPND-nine color combination-dyed fabric/garment against woodland CB, *Shorea Robusta Gaertn*. Figure 7a and 7b, target signature of dyed fabric with nine color combination; 7a, target distance was kept 7 ft from NPND treated target signature against woodland CB; 7b, target distance was kept 14 ft from NPND treated target signature against woodland CB. The reflection mechanism of dyed fabric with nine color combination (figure 2) was almost matched with woodland CB (*Shorea Robusta Gaertn*) compared with standardized black and white color fabric.

Target signature of NPND- *Swietenia Macrophylla*-coated-printed fabric/garment against woodland CB, *Shorea Robusta Gaertn*. Figure 7c and 7d, target signature of *Swietenia Macrophylla* coated and printed fabric; 7c, target distance was kept 7 ft from NPND treated target signature against woodland CB; 7d, target distance was kept 14 ft from NPND treated target signature against woodland CB. The coated and printed fabric with *Swietenia Macrophylla* was trialled with field experimentation against *Shorea Robusta Gaertn*, woodland CB and the target signature was found chromatic matching against woodland CB referred to figure 7, 8, 9. The reddish chromatic hue of *Swietenia Macrophylla* coated part of garment was completely matched with the combat bark of *Shorea Robusta Gaertn* due to matching of phenolic pigment, anthocyanin of *Swietenia Macrophylla* treated textiles.

Target signature of NPND-*Corchorus Capsularis*-coated-printed fabric/garment against woodland CB, *Shorea Robusta Gaertn*. Figure 7e and 7f, target signature of *Corchorus Capsularis* leaves coated and

printed fabric; 7e, target distance was kept 7 ft from NPND treated target signature against woodland CB; 7f, target distance was kept 14 ft from NPND treated target signature against woodland CB. The coated and printed fabric with *Corchorus Capsularis* was trialled with field experimentation against *Shorea Robusta Gaertn*, woodland CB and the target signature was also remarked as chromatic matching against woodland CB referred to figure 7, 8, 9. The greenish chroma of *Corchorus Capsularis* leaves coated part of garment was completely matched with the green leaves of *Shorea Robusta Gaertn*, possibly the well matching of green pigment named chlorophyll compound. Furthermore, existing protochlorophyll, anthocyanin and catechin in NPND may be the vital reason of reflection matching between woodland CB and target object of coated/printed NPND textiles.

ImageJ analysis of NPND treated and untreated target signature against woodland CB, *Shorea Robusta Gaertn* under natural illumination. Figure 8A, raw image of NPND-dyed-coated-printed garment has been placed against *Shorea Robusta Gaertn*, woodland CB; and figure 8B, 8C and 8D are remarked for the chromatic hue of CIE L^* , a^* , b^* when $Aa = Ba = Ca = Da$; $Ab = Bb = Cb = Db$; $Ac = Bc = Cc = Dc$; $Ad = Bd = Cd = Dd$; $Ae = Be = Ce = De$; $Af = Bf = Cf = Df$ shown in figure 8. Therefore, white-black/grey breakdown of CIE L^* , a^* , b^* of object and background have been found camouflage shown in figure 8 (Ba, Ca, Da ; Bb, Cb, Db ; Bc, Cc, Dc ; Bd, Cd, Dd ; Be, Ce, De ; Bf, Cf, Df compared with raw image of target signature against *Shorea Robusta Gaertn*, woodland CB shown in figure 8 (Aa, Ab, Ac, Ad, Ae, Af). Similarly figure 9A; raw image of NPND-dyed-coated-printed garment has been positioned against *Shorea Robusta Gaertn*, woodland CB; and RGB chromatic hue has been denoted as blue color shown in figure 9B, green color shown in figure 9C and red color shown in figure 9B when $Aa = Ba = Ca = Da$; $Ab = Bb = Cb = Db$; $Ac = Bc = Cc = Dc$; $Ad = Bd = Cd = Dd$; $Ae = Be = Ce = De$; $Af = Bf = Cf = Df$ shown in figure 9. White-black/grey breakdown of RGB chromatic hue has also been shown camouflage shown in figure 9 (Ba, Ca, Da ; Bb, Cb, Db ; Bc, Cc, Dc ; Bd, Cd, Dd ; Be, Ce, De ; Bf, Cf, Df) compared with raw image of target signature against woodland CB revealed in figure 9 (Aa, Ab, Ac, Ad, Ae, Af). Figure 8 ($Aa, Ab, Ba, Bb, Ca, Cb, Da, Db$) and figure 9 ($Aa, Ab, Ba, Bb, Ca, Cb, Da, Db$); dry leaves, seeds, tree bark and wood of NPND materials have presency of tannin (polyphenolic compound) which creates strong complex with OH group of cellulosic cotton fabric. Tannase is the main element of tannin. Tannase may be responsible for matching NPND-color formation of camouflage textile applications against woodland CB²⁴. The chromatic reflection of dry leaves, green leaves, tree bark and wood of woodland CB, *Shorea Robusta Gaertn* are related to chlorophyll/phytochemical in terms of green pigmentation/reddish chromatic hue²⁵. The reflection of NPND dyed-coated-printed textiles have been found almost similar reflection of woodland CB as dry leaves, green leaves, tree bark and wood are the key materials of woodland CB, *Shorea Robusta Gaertn*^{24, 25}. Therefore, possible chromatic matching of phytochemicals exists between NPND dyed-coated-printed garment and woodland CB, *Shorea Robusta Gaertn*. These phytochemicals are classified as swieteniamacrophyllanin; catechine; 1,3 dihydroxy 2 methylanthraquinone; tannin and gallotannic acid which are chemically structured in figure 10. Furthermore, *Areca Catechu* is a NPND-mordanting agent which has the property of color sensitizing. *Areca Catechu* has coloring agents and color improvement agents due to remaining tannin, gallic acid, catechin, alkanoids, gum, etc. Existing gallotannic acid in *Areca Catechu* is a pigment, it may be responsible for color sensitizer as NPND-mordanting for NPND

applications on textile substances^{26, 27}. Figure 8 (Ac, Ad; Bc, Bd; Cc, Cd; Dc, Dd) and figure 9 (Ac, Ad; Bc, Bd; Cc, Cd; Dc, Dd); the reddish chromatic hue of *Swietenia Macrophylla* is related to “reddish pale compound” named Swieteniamacrophyllanin has the tendency for reddish chromatic hue of coated cotton textiles as source of NPND. *Swietenia Macrophylla* coated fabric has been found exact matching against woodland CB, *Shorea Robusta Gaertn*²⁸. Similarly figure 8 (Ae, Af; Be, Bf; Ce, Cf; De, Df) and figure 9 (Ae, Af; Be, Bf; Ce, Cf; De, Df); “greenish hue” of *Corchorus Capsularis*-dry leaves has also been observed color matching against woodland CB, *Shorea Robusta Gaertn* due to matching of chlorophyl and existing phytochemicals such as tannin and catechine of polyphenol group. Hence a crosslinking of NPND powder-polyaziridine-acrylonitrile copolymer-acrylic copolymer-cellulose may be formed to create a symmetrical chromatic hue of coated and printed textiles against woodland CB. This NPND formulation can be implemented for nature-friendly camouflage materials.

Concluding remarks

NPND dyeing process can be replaced by coating/printing in terms of higher percentage of NPND deposition/leafy design development on fabric surface which may have more symmetry between defence target object (camouflage treated textiles) and the materials of woodland CB, this formulation may be a new model of NPND formulated camouflage textiles for concealment of target detection for defence applications in terms of ecofriendly dyes; and NPND-mordanting process for NPND based natural coloration and defence applications. The phenolic and tannin reflection between *Swietenia Macrophylla* treated fabric and raw *Swietenia Macrophylla* have not been found any significant difference in terms of UV-Vis-NIR spectrum from 220 nm to 1400 nm which may signify a symmetrical matching of optical reflection between *Swietenia Macrophylla* treated textiles and woodland CB. The minor deviation of chromatic reflection between woodland CB, *Shorea Robusta Gaertn* and *Swietenia Macrophylla* dyed-coated-printed textiles have also been found in field trailing. *Swietenia Macrophylla* bark has been remarked as good coloration properties applicable for dyeing-coating-printing and the reflection properties are suitable for camouflage coloration against woodland CB; and waste-NPND powder of wood processing industries may be a good source of combat-NPND. Hence, there is possibility for development of NPND treated camouflage coloration for defence protection (such as defence clothing/temporary tents for combat location/combats nets for defence applications) against woodland CB, preferred textile technology is coating for maximum deposition of NPND on cotton textiles. Furthermore, NPND coated/printed/dyed fabric may be used for manufacture of UV protective clothing for defence protection of simultaneous ‘camouflage textiles’ and ‘UV-protective textiles’. An ecofriendly concept of natural coloration was applied in addition to mordant free coloration and/or NPND-mordanting/bio-mordanting without applications of any synthetic mordant, therefore coating/printing method of NPND treated textiles have been found more efficient for camouflage coloration. NPND-dyed-coated-printed textiles can be formulated for defence clothing, protection net/tent in CB. For photographic reflection of coated and printed textiles as target object and selected woodland background as target woodland CB; coated textile is more suitable but a combination of coated-printed-NPND textiles or dyed-printed-NPND textiles can be recommended for making a leafy design on fabric against woodland CB in terms of defence clothing.

NPND coated textiles is more suitable technique for symmetrical reflection between woodland CB and NPND coated textiles. For example: coating of net and tent for defence protection against woodland CB. Hence, there is enormous possibilities of research on natural coloration but the concept of NPND based camouflage textiles is a new experimentation for applications in defence textiles and an ecofriendly formulation of NPND coloration. Although NPND-mordanting has been opined in this experiment but the application of synthetic mordant may enhance the functional activity of tannase for more dye-fibre crosslinking of NPND based textile coloration. Hence, NPND-natural dyes-natural mordant-natural fibre-cotton can also be implemented/extended for ecofriendly production of fashionable garments specially for production of kid's garments/medical textiles in terms of users friendly/protection textiles.

Declarations

Declaration of conflicting interests

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Data availability

All data generated or analysed during this experimentation are included in supplementary information file, Table 1-12, supporting information.

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Tables

Tables 1 to 2 are available in the Supplementary Files section

Figures

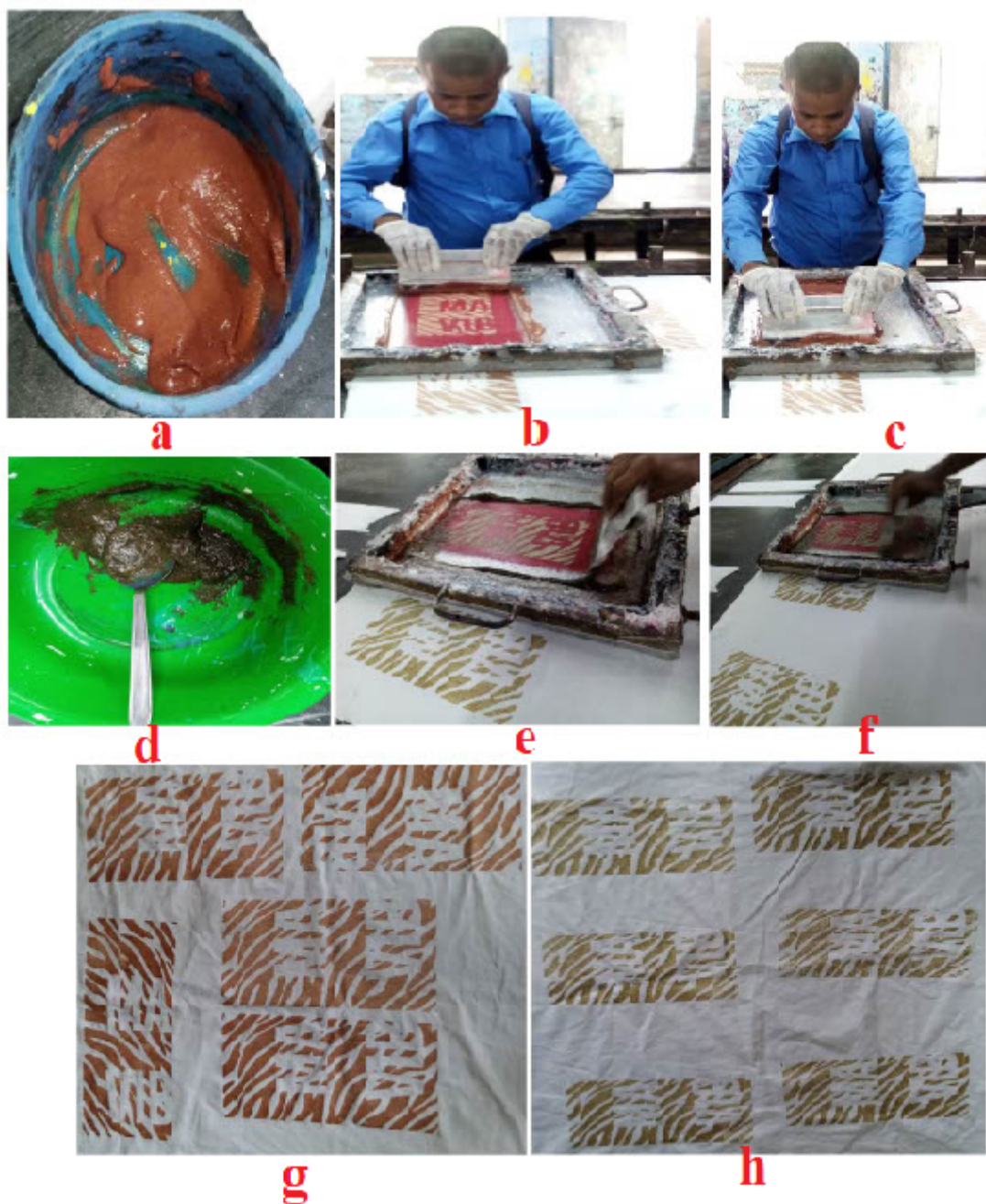


Figure 1

A preparation and laboratory work process of printing with NPND-*Swietenia Macrophylla* and NPND-*Corchorus Capsularis*.

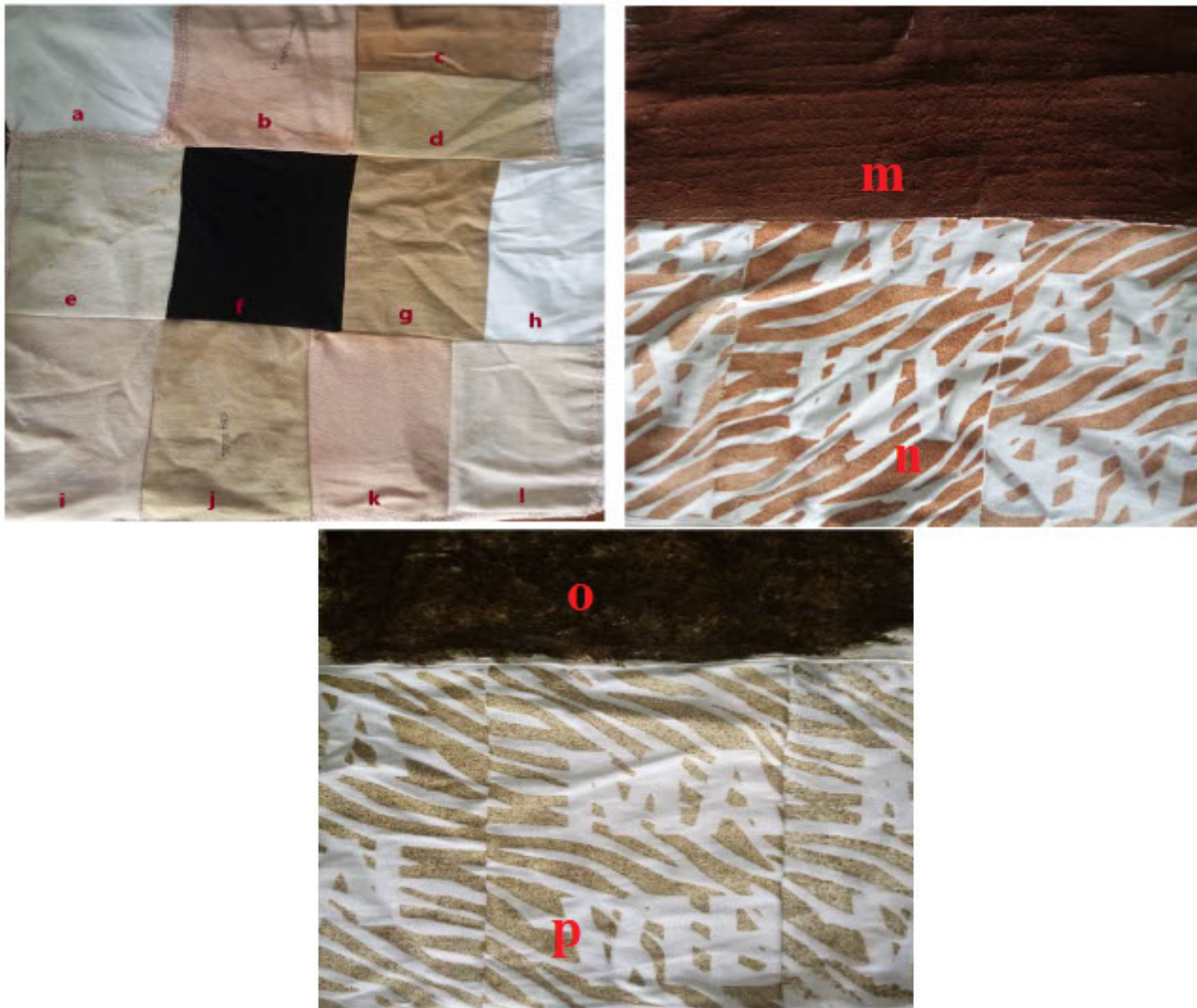


Figure 2

Dyed cotton fabric with solid color design (a-l), coated cotton fabric with solid color design (m, o) and printed cotton fabric with leafy design (n, p).

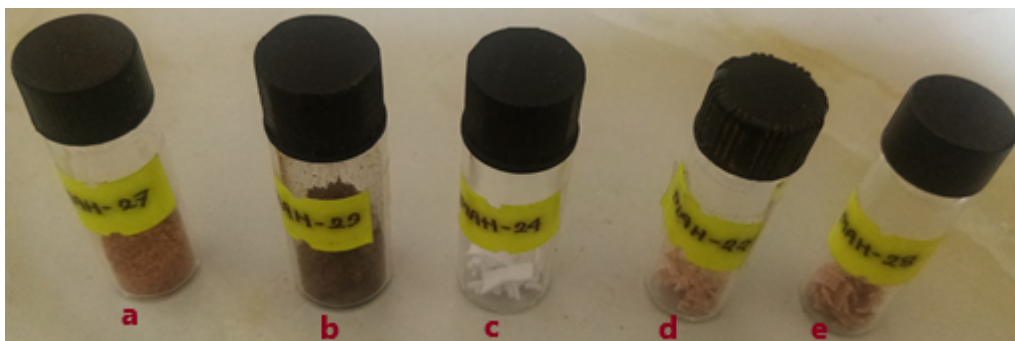


Figure 3

Samples of NPND-powdered materials (a, b); cut pieces of undyed cotton fabric (c) and cut pieces NPND-dyed cotton fabric (d, e) for measurement with sample port of UV-Vis-NIR spectrophotometer.

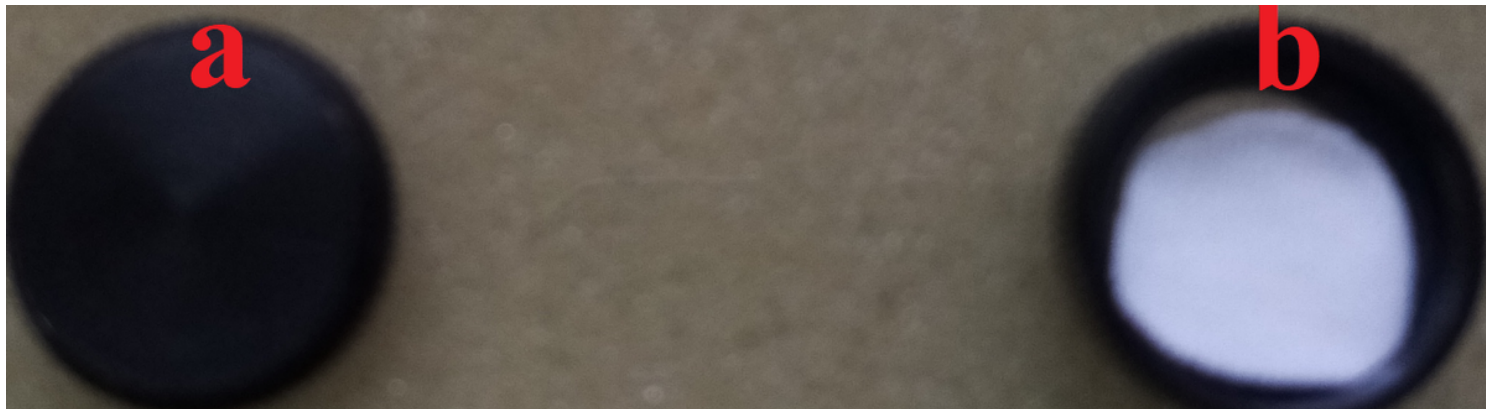


Figure 4

Blank sample port of UV-Vis-NIR spectrophotometer (a), standardized barium sulphate placed on sample port (b).

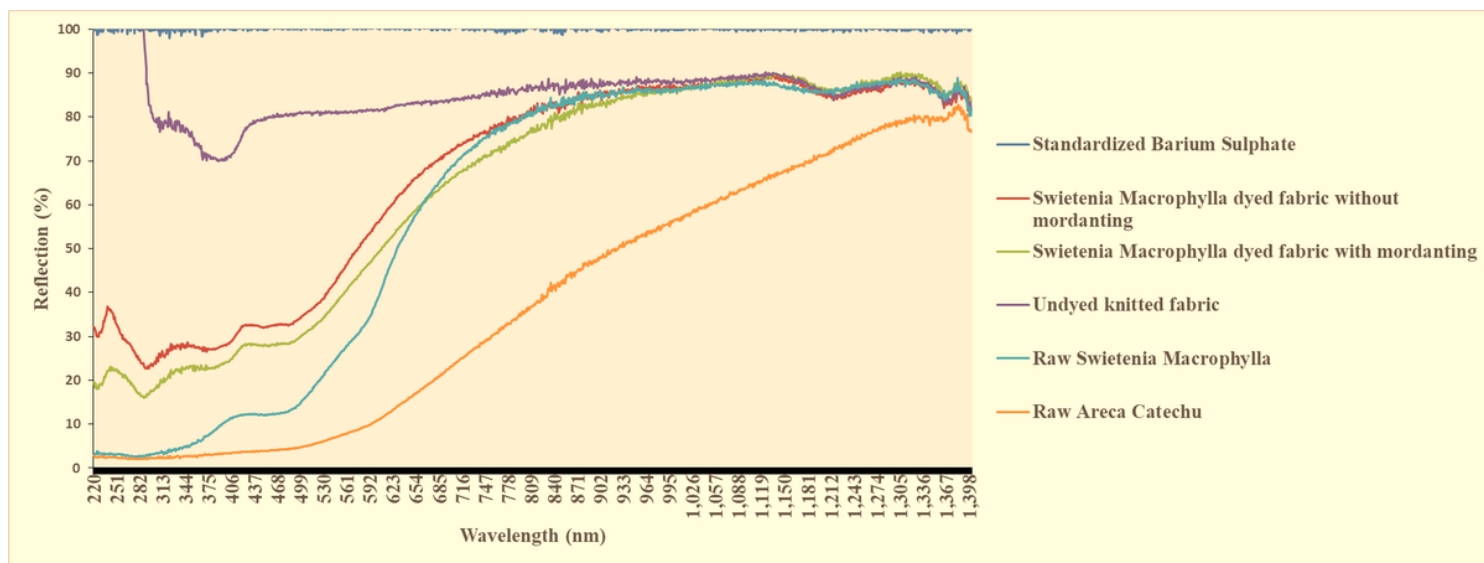


Figure 5

UV-Vis-NIR reflection spectra of undyed cotton fabric, dyed cotton fabric and NPND raw materials of woodland CB against standardized barium sulphate.

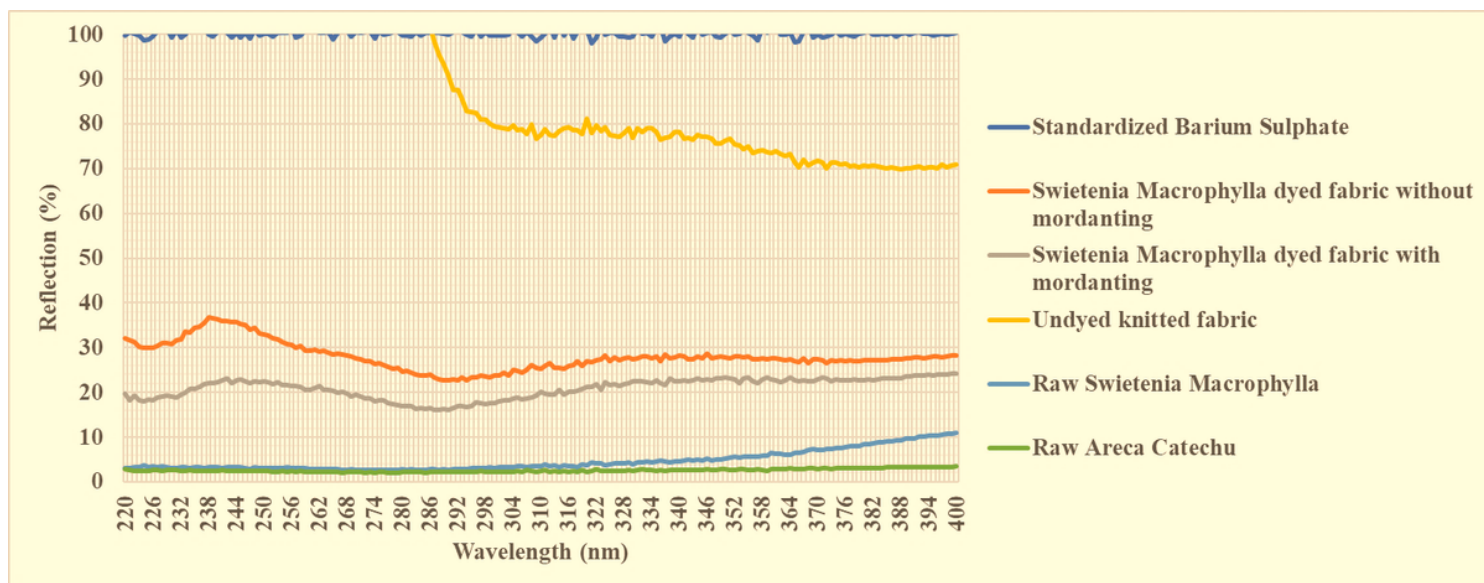


Figure 6

UV-reflection of *Swietenia Macrophylla* treated fabric, untreated fabric and raw *Swietenia Macrophylla*.



Figure 7

NPND-dyed (a, b)-coated-printed (c, d, e, f) target signature against *Shorea Robusta Gaertn*, woodland CB; captured from two selected distance; a, c, e and b, d, f.

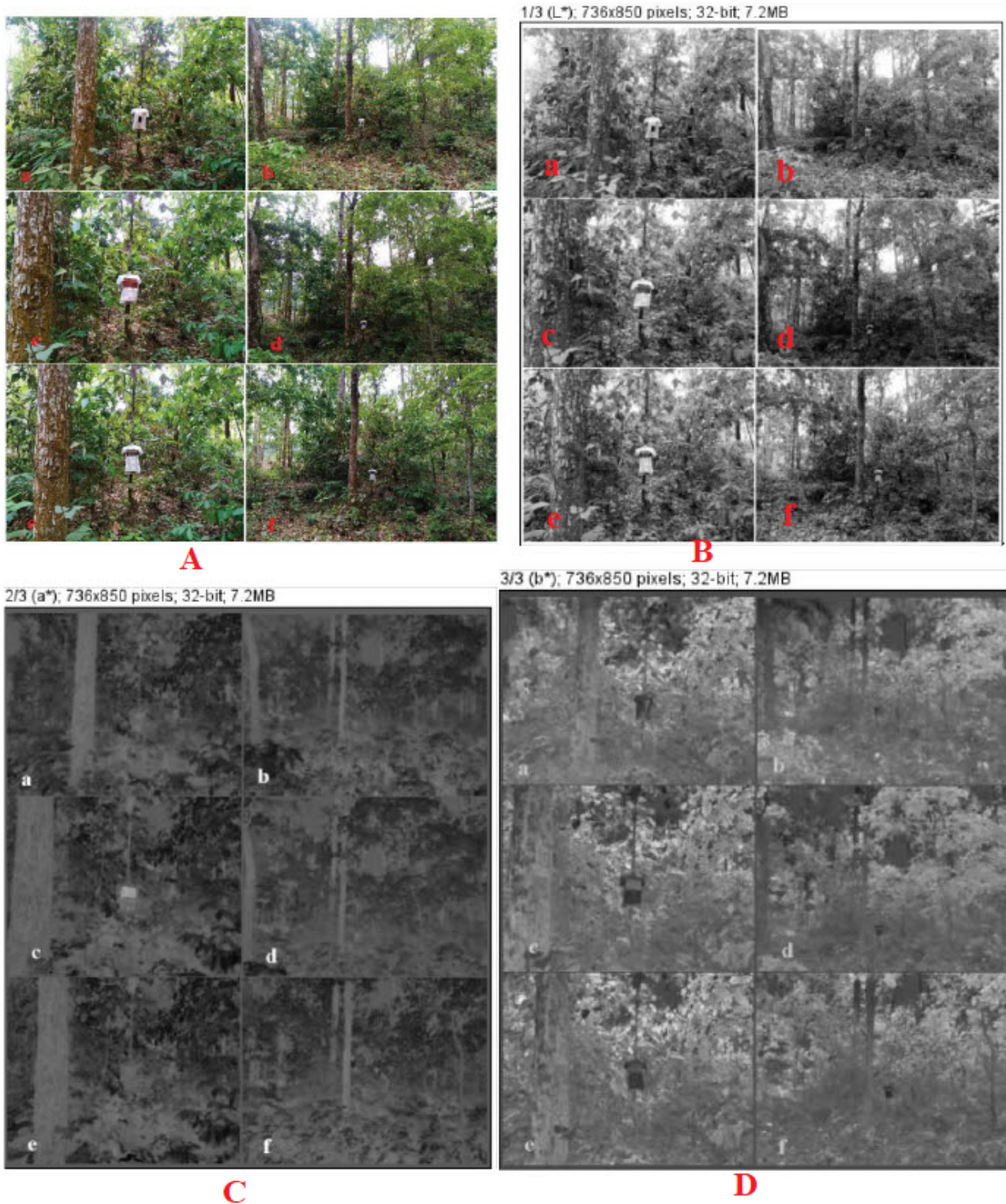


Figure 8

Chromatic breakdown of CIE L^* (B), a^* (C), b^* (D) against chromatic hue of raw image A, Vis image of target signature against woodland CB when $Aa = Ba = Ca = Da$; $Ab = Bb = Cb = Db$; $Ac = Bc = Cc = Dc$; $Ad = Bd = Cd = Dd$; $Ae = Be = Ce = De$; $Af = Bf = Cf = Df$.

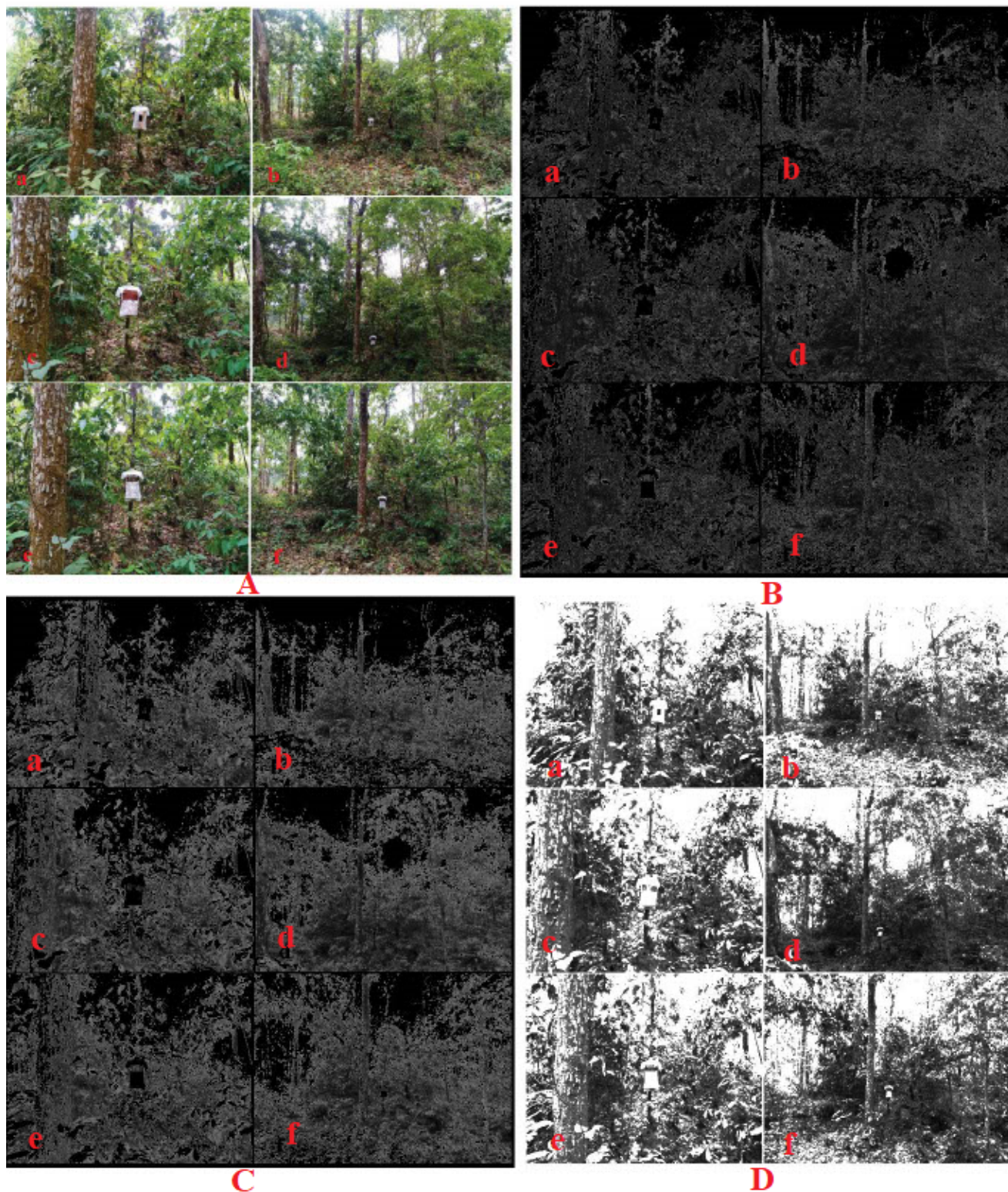


Figure 9

Chromatic breakdown of blue (B)-green (C)-red (D) against chromatic hue of raw image A, Vis image of target signature against woodland CB when $Aa = Ba = Ca = Da$; $Ab = Bb = Cb = Db$; $Ac = Bc = Cc = Dc$; $Ad = Bd = Cd = Dd$; $Ae = Be = Ce = De$; $Af = Bf = Cf = Df$.

Supplementary Files

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