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Blues from Tikuna/Magüta Masks and a Still Unknown Blue Colorant in Technical Art History and Conservation Science

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Abstract: Blue is one of the most challenging colors for humans to produce and one of the most important colors in art history. Literature from the Tikuna/Magüta culture, from the Amazon Forest, suggests the use of chemical reactions between the juice of the naïcü fruit and iron to produce a blue colorant still unknown among technical art historians and conservation scientists. Additionally, the coloring materials from the Tikuna/Magüta people were never chemically investigated. Therefore, this manuscript presents the investigation of blue colorants from twenty-two Tikuna/Magüta masks and one stamp used to decorate similar items. Collections from four museums, from the USA and Brazil, were examined, and Raman spectra indicated the presence of Prussian blue, phthalocyanine blue, indigo, ultramarine, crystal violet, amorphous carbon, anatase, and barium sulfate (or lithopone). Although the unknown blue colorant was not detected in this campaign, the authors hypothesize the chemical composition and reactions involved in its production by considering the chemistry of naïcü and anthocyanins. The continuation of this work with community-based participatory research (CBPR) approaches is also discussed, justifying why reproduction was not considered in this work and supporting a more socially responsible and inclusive practice in technical art history and conservation science.

Keywords: indigenous art history; technical art history; naïcü; community-engaged research; plant-based dyes; anthocyanin dyes; Raman spectroscopy

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1. Introduction

The Amazon Forest is renowned for its human, cultural, and biological diversities. The artistic and cultural creations of the Amazonian people are deeply rooted in the region's natural surroundings, which serve as conduits for transmitting cultural narratives, spiritual beliefs, and ecological wisdom. The materials used by the Indigenous people hold invaluable insights into the cultural connections with the environment and the intricate ecological knowledge that has sustained their communities for centuries. However, to date, the paint and coloring materials created and used in this region remain under-studied [1]. Delving into the study of these colorants offers a unique opportunity to understand, appreciate, value, and respect their creative processes and heritage.

Specifically, the Tikuna/Magüta people have been using many colors in their cultural items, such as blues, greens, yellows, and reds, in creating their material culture. Inhabiting near the borders of Brazil, Peru, and Colombia, the variety of their materials becomes evident through the account of a Tikuna/Magüta artisan, who describes the use of 65 "colors" (or colorants, as interpreted by the authors of this manuscript) from several natural sources, such as seeds, flowers, leaves, roots, barks, and mud [2]. An example of their abundance of coloring materials is those present in masks used as part of the Tikuna/Magüta female

initiation rituals [3,4]. Additionally, studies have reported that it is the paints that give meaning to the masks, highlighting their importance: "when they do not have paint, it [the mask] is of no use" (p. 163, authors translation) [5].

Blue is one of the most challenging colors for humans to produce and has a profound importance in art history. Before ancient civilizations learned how to produce colorants, the use of blue was limited by the availability of natural resources like plants and minerals. Examples of plant-based materials are indigotin (from *Indigofera tinctoria*), genipocyanin (from *Gardenia jasminoids* and *Genipa americana*), and ventilein (from *Ventilago goughii*) [6]. Examples of natural inorganic materials are azurite and lapis lazuli. However, over time, humans learned how to mimic nature by synthesizing naturally occurring molecules or creating new compounds like Maya and Egyptian blues. Maya blue, for example, was produced by the ancient Maya civilization and is known for its exceptional durability and vivid color, which has survived centuries in artifacts and mural paintings [7]. The pigment is a complex formed by combining indigo dye with zeolitic clay minerals such as palygorskite or sepiolite. Objects painted with Maya blue were often of great significance, as the pigment was associated with important rituals and deities, highlighting the cultural relevance of the objects adorned with this vibrant material. Investigating ancient pigments is crucial for understanding the cultural practices of past civilizations and gaining insights into technological advancements, trades, rituals, and artistic achievements. Additionally, the investigation of pigments from different civilizations helps connect the broader narrative of human innovation in artistic and cultural practices.

In South America, plants like *Licania macrocarpa* Cuatrecasas [8], Cartelhana [9], *Cybistax antisyphilitica*, *Llangua*, *Sami*, and *Twi kshanate* [10], among others, including *Indigofera suffruticosa* Mill., have been used to produce blue colorants. Specifically, the Tikuna/Magüta people have prepared blue colorants using plant-based sources like bure or buré (*Calathea loeseneri* Macbride) [2], anil (*Indigofera suffruticosa* Mill.) [11], and "native strawberry" (without supplementary details in the referenced source) [2] for centuries. Dark blue or bluish-black hues have been prepared by using *Genipa americana* L. [12], which is also known as jenipapo, and the fruits from pacová [13]. Pacová is also known by the Indigenous name na'i^{n}ku. The term na'i^{n}ku appears to be interchangeable with naikú, naiku, naïku, nai'ku, naike, naicu, naïcü, naico, and na ico, and all these terms have been used to describe plants whose fruits are utilized for extracting dyes with purple, blue, black, and "chocolate" colors. Additionally, some of these terms seem to refer to specific plants. For example, naiku, naike, or nai'ku have been used to refer to the specie *Renealmia alpinia* [14–20], naiku also to *Renealmia alpinia* (Rottb.) Maas [21], and naico to *Renealmia* sp. (p. 30) [12]. Pacová has been linked to *Renealmia alpinia* [22], *Renealmia cernua*, *Renealmia exaltata*, *Renealmia petasites* [15], and *Renealmia petasites* Gagnep. [23]. These plants are from the family *Zingiberaceae*, genus *Renealmia* L.f., and many of their species could have been available to and used by the Tikuna/Magüta people.

The fruit of naïcü (the term chosen for use in this manuscript) is of particular interest due to references in the literature that point towards the use of chemical reactions to produce a blue colorant still unknown among technical art historians and conservation scientists. Curt Nimuendajú (p. 42), a German ethnologist and anthropologist (see more below), describes that "the juice of one fleshy fruit (T., na'i^{n}ku) furnishes a dark violet which, upon contact with iron, changes into a clear blue" [24]. This indicates the likelihood of a chemical reaction to create a still unknown organometallic blue colorant. Creutzberg (p. 69) [18], when writing about nai'ku, notes that by boiling or incorporating salts, a more durable paint can be produced, and when combined with soap, it takes on a blue hue. Gruber [13], albeit without detailing the resultant color, depicts the mixture of pacová with iron in the paint production practices of the Tikuna/Magüta people.

Except for anil and jenipapo [1], a survey of the literature reveals a dearth of scientific investigations into the aforementioned blue colorants used by the Tikuna/Magüta people, including the still unknown blue derived from naïcü. This gap in knowledge impacts the art historical understanding of Indigenous material choices, the appreciation

of Tikuna/Magüta cultural items, which are present in museums worldwide, and the conservation steps needed to preserve these items. Therefore, this work aims to chemically investigate blue colorants present in Tikuna/Magüta masks, expecting to find chemical fingerprints of such an unknown blue. Masks selected from the collections of the Magüta Museum located in Benjamin Constant (Brazil), the Museum of Archaeology and Ethnology (MAE) from the University of São Paulo (Brazil), the Peabody Museum of Archaeology and Ethnology from Harvard University (USA), and the Fowler Museum from the University of California, Los Angeles (USA) were investigated.

2. Materials and Methods

2.1. The Investigated Items

Curt Nimuendajú (1883–1945) was a German researcher who arrived in Brazil in 1903. Nimuendajú conducted ethnographic trips in 1929, 1941, 1942, and 1945 in order to study the Tikuna/Magüta people and their material culture [25]. As most of the Nimuendajú's trips were conducted in the 1940s, it was decided that the items considered for this research (Figures 1–4) would be contemporary with this and were all collected (albeit by other researchers) from the 1940s onward, meaning that at least some were produced in that decade or earlier. Additionally, another criterion for object selection was having visibly well-preserved blue colors. Naïcü is rich in anthocyanins [26], which are well-known to be unstable molecules. However, as naïcü was described as being mixed with iron to produce a new compound with still unknown chemical stability, it was supposed, in this first phase of the project, that the naïcü-derived blue might be stable, leading to the choice to investigate well-preserved blue colors.



Figure 1. Tikuna/Magüta items from the MAE. Reference numbers: RG 8649, RG 10034, RG 8716, RG 9984, RG 8753 (2), RG 8753, RG 8889, RG 8892, RG 8894, RG 8898, RG 8902, RG 8710, RG 8764, RG 9454, and RG 10098 (by Ader Gotardo); credits: Museu de Arqueologia e Etnologia da Universidade de São Paulo.



Figure 2. Tikuna/Magüta item 996-24-30/11694 from the Peabody Museum; credits: Gift of Richard E. Schultes, 1996. Courtesy of the Peabody Museum of Archaeology and Ethnology, Harvard University, 996-24-30/11694. No photo is available from item 47-8-30/5627.



Figure 3. Tikuna/Magüta item X64.965 (by Thiago Sevilhano Puglieri and Christian De Brer) from the Fowler Museum; credits: ©Photo courtesy of the Fowler Museum at UCLA; Tikuna/Magüta.



MM374 **MM383** **MM384** **MM385** **MM387**

Figure 4. Tikuna/Magüta items from the Magüta Museum. Reference numbers: MM374, MM383, MM384, MM385, and MM387 (by Thiago Sevilhano Puglieri); credits: Thiago Sevilhano Puglieri.

It is worth noting that for the Tikuna/Magüta people, the term mask is related to the part that covers the head and the body (p. 105) [27], so all the items investigated here were considered masks or part of them. Only one item from the MAE collection, RG 10896, is a stamp used to decorate masks.

From the MAE (Figure 1), the considered items were collected by Harald Schultz (1909–1965) in 1958 (RG 8649, RG 8710, RG 8716, RG 8753, RG 8753 (2), RG 8764, and RG 10896) or 1956 (RG 8889, RG 8892, RG 8894, RG 8898, RG 8902, RG 9454, and RG 9984). It is important to note that the collection dates do not necessarily reflect the actual production dates of the items; the same is true for the items from the Peabody and Fowler Museums. For mask RG 10034, no date information was found. Other details from these items can be found in the Supplementary Materials.

From the Peabody Museum (Figure 2), two items were investigated, and both were collected by Richard E. Schultes (1915–2001), a Harvard professor, ethnobotanist, and conservationist [28]. One of the items was collected in 1946 (47-8-30.5627) in Leticia, Colombia, and the other in 1958 (996-24-30.11694) in Rio Loretoyacu, Amazonas, Colombia. They were received by the museum in 1947 and 1996, respectively [29]. Other details from these items can be found in the Supplementary Materials.

From the Fowler Museum (Figure 3), mask X64.965 was selected. This item was collected by Peter T. Furst (1922–2015), a cultural anthropologist from Germany who worked at UCLA, the State University of New York, the University of Pennsylvania, and the Museum of Indian Arts and Culture [30]. This item entered the Fowler Museum collection in the 1960s.

From the Magüta Museum (Figure 4), items MM374, MM383, MM384, MM385, and MM387 were selected. This collection was created with the participation of the Tikuna/Magüta people, and the museum is located in Benjamin Constant, Amazonas State, Brazil, close to the area where Nimuendajú conducted his research [31]. This collection was created between 1988 and 1991 (p. 100), and the masks are from the end of the 1980s (p. 105) [27]. However, the overpainting of some of the Magüta Museum's items (p. 163) has been reported [27]. Therefore, items with potential overpainting, as determined by visual examination using visible light and UV radiation, were not considered for this research.

2.2. Chemical Investigation

All the samples were investigated using Raman micro-spectroscopy. Raman spectra were collected with Renishaw inVia Microscopes (Wotton-under-Edge, UK) (with nominal spectral resolutions of about 4 cm^{-1}), employing a Leica DM2500 M or a Leica DMLM microscope (Leica Geosystems AG, Heerbrugg, Switzerland) equipped with a CCD camera using a 785 nm (diode laser, 1200 L/mm grating) laser line. The laser line was focused onto the samples by a ×50 Leica objective (NA 0.50, 8 mm working distance), and the laser power was kept below values that could degrade the sample. The microscopes were coupled to

a Renishaw Peltier-cooled CCD array detector. The Raman spectra were analyzed and manipulated using the Renishaw WiRE® 3.1 software and OriginPro® 2022b software.

3. Results and Discussion

This section is divided into three parts. The first concerns the investigation of blue colorants found in the Tikuna/Magüta masks. The second is devoted to discussing the continuation of this research through community-based participatory research (CBPR) and the justification of why reproduction was not considered in this work. The third is related to the hypotheses behind the unknown blue.

3.1. Blue Colorants from the Tikuna/Magüta Masks

The masks considered in this manuscript are ceremonial items, and it is of the utmost importance to remember that, as per their wishes, specific knowledge about the Tikuna/Magüta people must not be disclosed to ensure their balance with the surroundings and protect their well-being (p. 127) [2]. For example, scientific investigations can reveal Indigenous knowledge, which can be disclosed by publishing the results. In this work, consent for sampling and analytical investigation was requested from Tikuna/Magüta representatives and the institutions holding the collections. Regarding the publication of the results, consent was obtained from a Tikuna/Magüta representative leadership before publishing them. Additionally, this manuscript solely discusses coloring materials previously made public. The authors are grateful to the Tikuna/Magüta people for all the support given to this project.

Raman micro-spectroscopy results show the presence of Prussian blue, phthalocyanine blue, indigo, and ultramarine as blue colorants in the investigated samples. In some instances, the synthetic dye crystal violet or amorphous carbon was also found. Anatase and barium sulfate (or lithopone) were found in low concentrations in a few items. All the results are summarized in Table 1, and Figure 5 shows representative Raman spectra of the main colorants with their main bands highlighted.

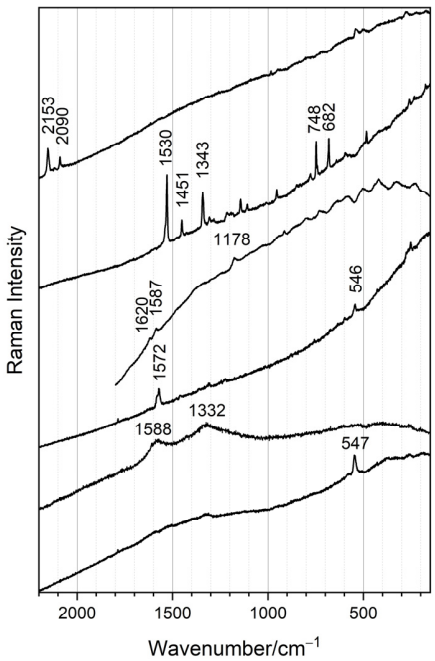


Figure 5. Representative Raman spectra (785 nm) of each colorant identified in this research. From the top to the bottom: Prussian blue, phthalocyanine blue, crystal violet, indigo, amorphous carbon, and ultramarine.

Table 1. Summary of results.

Museum	Item's Identification	Main Raman Bands/cm^{-1} and Attributed Colorants
Fowler Museum	X64.965	547, 584 (ultramarine)
Peabody Museum	47-8-30/5627	253, 546, 598, 1226, 1310, 1572, 1582 (indigo, sample 1) 1332, 1588 (amorphous carbon, sample 2)
	996-24-30/11694	1572, 1582 (indigo)
Museum of Archaeology and Ethnology (MAE)	RG 10034	176, 235, 259, 485, 594, 641, 681, 748, 780, 833, 848, 953, 1008, 1108, 1143, 1160, 1185, 1194, 1214, 1307, 1341, 1430, 1451, 1528 (phthalocyanine blue)
	RG 10896	915, 1178, 1587, 1620 (crystal violet)
	RG 8649	275, 504, 531, 2090, 2153 (Prussian blue) 542 (ultramarine) 142 (anatase)
	RG 8716	1572, 1582 (indigo)
	RG 8753	2092, 2154 (Prussian blue)
	RG 8753-2	277, 533, 2091, 2153 (Prussian blue)
	RG 8764	1573, 1583 (indigo)
	RG 8889	2092, 2155 (Prussian blue) 544 (ultramarine) 987 (barium sulfate and/or lithopone) 143 (anatase)
	RG 8892	280, 2091, 2154 (Prussian blue) 144 (anatase)
	RG 8894	2089, 2149 (Prussian blue) 144 (anatase)
	RG 8898	2093, 2154 (Prussian blue) 143 (anatase)
	RG 8902	544 (ultramarine)
	RG 9454	2090, 2152 (Prussian blue) 252, 544, 1225, 1248, 1310, 1572, 1582 (indigo) 1325, 1597 (amorphous carbon) 144 (anatase)
	RG 9984	278, 2091, 2152 (Prussian blue) 543 (ultramarine) 145 (anatase)
	RG 8710	282, 505, 533, 2092, 2154 (Prussian blue) 1325, 1599 (amorphous carbon)
Magüta Museum	MM374	175, 258, 484, 594, 642, 681, 748, 782, 833, 848, 954, 1008, 1109, 1144, 1185, 1195, 1217, 1308, 1343, 1451, 1530 (phthalocyanine blue)
	MM383	484, 682, 748, 954, 1109, 1144, 1308, 1343, 1451, 1530, 1539 (phthalocyanine blue)
	MM384	175, 259, 484, 594, 682, 748, 780, 954, 1109, 1144, 1185, 1195, 1217, 1308, 1343, 1451, 1530 (phthalocyanine blue)
	MM385	176, 235, 259, 484, 495, 596, 642, 681, 748, 783, 833, 848, 954, 1008, 1109, 1132, 1144, 1158, 1186, 1196, 1217, 1308, 1343, 1429, 1451, 1530 (phthalocyanine blue)
	MM387	175, 259, 484, 594, 682, 748, 780, 954, 1109, 1144, 1185, 1195, 1217, 1308, 1343, 1451, 1530, 1539 (phthalocyanine blue)

The presence of Prussian blue was identified mainly by the bands at ca. 2153 and 2090 cm^{-1}, attributed to $1A_g$ and E_g ν(CN) stretching vibrations, respectively [32]. The presence of indigo was indicated mainly by the bands at ca. 1582 and 1572 cm^{-1}, attributed to symmetric A_g stretching vibrations of ν(C=O), ν(C=C), and ν(C-C) modes [33]. Indigo spectra acquired were also compared to the ROD00176 Raman spectrum from the Infrared and Raman Users Group (IRUG) database. Ultramarine was indicated by its most intense band due to lazurite at ca. 545 cm^{-1}, attributed to the symmetric stretching vibration of radicals S^{3-} [34]. Phthalocyanine blue was identified mainly by the presence of bands at ca. 1530, 1451, 1343, 748, and 682 cm^{-1} [35], and the presence of crystal violet was verified by the bands at ca. 1620, 1587, 1178, and 915 cm^{-1} [36,37]. Amorphous carbon was identified by its two characteristic broad features at ca. 1575 and 1320 cm^{-1}, assigned to the G and D bands, respectively [38]. The presence of anatase was suggested by the observation of its most intense band at ca. 143 cm^{-1}. Anatase presents a high scattering cross-section, and because only low-intensity bands were observed, the results suggest that it is from a natural mineralogical impurity [39]. The presence of barium sulfate or lithopone was indicated by their most intense band at ca. 987 cm^{-1}. Lithopone could be differentiated from barium sulfate by the observation of a medium-intensity band at ca. 342 cm^{-1} [40]. However, the low concentration and the luminescence background present in the spectra did not allow their differentiation.

Naturally derived ultramarine, or its source, lapis lazuli, contains minerals like calcite, diopside, pyrite, sodalite, and wollastonite, in addition to the main chromophore, lazurite. Even after purification to remove these associate minerals, calcite usually remains present. Additionally, natural ultramarine usually produces fluorescence bands in the Raman spectra when employing 785 nm laser wavelength [41]. Because neither calcite nor fluorescence bands were observed in the Raman spectra in this investigation, the results indicate the use of synthetic ultramarine. Differentiating synthetic from natural indigo is not trivial with Raman spectroscopy [42], and the results obtained here did not allow their distinction.

Prussian blue, a Fe^{3+} ferrocyanide, is the only compound identified here that could potentially be the chemical product from the reaction between naīcü and iron. However, as discussed in Section 3.3, there is no evidence of naīcü being a source of cyanides to form Prussian blue. Prussian blue was first synthesized in 1704 (p. 302), and ultramarine in the early 19th century (p. 302) [43]. Copper phthalocyanine blue, although discovered at the beginning of the 20th century, was introduced and described as an artists' material at the end of the 1930s (p. 284) [43]. Indigo was first synthesized and commercially produced at the end of the 19th century [42], and crystal violet is an early synthetic organic dye used since the 19th century [44].

Although it is reported that some Tikuna/Magüta communities insist on using natural colorants in the masks (p. 164) [5], most of the colorants identified here are likely synthetic. This is not a surprise, given that in the 1940s, Nimuendajú reported the loss of the Tikuna/Magüta's traditional material culture to more or less one-third [31]. Furthermore, the replacement of natural colorants with synthetic ones by the Tikuna/Magüta people was also documented elsewhere [45]. These results reinforce the expected transformations in the Tikuna/Magüta artistic practices and serve as a warning of the potential loss of their former traditional material knowledge, emphasizing the need to increase scientific investigations in this area.

In some instances (items RG8649, RG8889, RG9454, and RG9984), more than one blue colorant was found in the same sample. In others (items RG9454 and RG8710), blue colorant(s) were mixed with amorphous carbon. Assuming that all these materials are original to the items, the use of a wide range of blue colorants alone or mixed with other materials suggests that the artists had the intention of achieving specific blue hues. Additionally, since materials in Indigenous ceremonial items are usually intertwined with spiritual meanings, the use of specific colorants could also be related to spiritual reasons, which still needs to be investigated in collaboration with the community.

The Tikuna/Magüta masks are made of bark trees called tururi and obtained from several types of trees. Specifically, about the myths and meanings, in Tikuna/Magüta mythology some masks, for instance, come ready-made from the tururi trees, as in the myth of the "man who killed his wives" (p. 384, authors translation). In this myth, the character who will avenge his sisters' death brings masks to the enemy brother-in-law's party, which were obtained simply by arrowing the tururi tree. This specific tree, known as tüerumaũ, is believed to also give rise to jaguars and hawks (p. 384–385). In addition to the paints in the masks, the human bodies underneath them are also colored, and this superposition of painted bodies and masks is critical in their culture (p. 386) [3]. For example, in the myth about the jaguar Torama rü ai, a young man decided to wear a jaguar mask for one of the young girl's parties. He painted his body with watery clay before wearing it. However, because he was supposed to paint it also with açafroa (which is likely curcuma), he metamorphosed into a jaguar (p. 94–97) [46]. The Tikuna/Magüta people also use other materials to paint their bodies when wearing the masks, like jenipapo and urucum, and the paintings have the power of reversibility (p. 97) [46]. As already mentioned, the paints are also what give meaning to the masks (p. 163) [5]. Still, these material choices and meanings have yet to be systematically explored in the context of technical art history.

For example, it is reported that replacing natural colorants with synthetic ones changes the masks' value at the moment of exchange with food and drink (p. 171) [5]. However, the role and significance of coloring materials are unclear when considering a broader understanding of the values and meanings of colors, natural resources, and coloring techniques in terms of social, environmental, spiritual, and cultural interconnectedness. About blue, for instance, a follow-up of this research is to understand what are the meanings associated with such a color, with the different natural materials used to produce different blues, and with the nature's transformations the Tikuna/Magüta people perform by chemically reacting, for example, naïcü's juice with iron.

Concerning the blue colorant prepared from naïcü with iron, unfortunately, it was not found in this work. Its reproduction in the laboratory, its acquisition from the Tikuna/Magüta community, or the investigation of degraded items would be the most natural ways to proceed in conventional technical art history or conservation science approaches. However, in this work, none of them were chosen, and this choice, together with the hypothesis behind the naïcü blue, is discussed in the next two sections.

3.2. Community-Based Participatory Research (CBPR) as a Continuation of This Research

A few reasons could explain why the naïcü blue was not detected in this research. Firstly, it may not have been used to decorate the investigated items. Secondly, it could have been used, but because it may be chemically unstable, it is now degraded, and Raman micro-spectroscopy did not detect potential degradation products. Additionally, if present, its concentration could be below the detection limit of the technique employed here.

In conventional technical art history and conservation science approaches, three main pathways would be considered to proceed with this investigation: (1) The researcher obtains a sample of the blue from the Tikuna/Magüta community and investigates it in the laboratory using different analytical techniques; (2) The researcher procures the raw materials and attempts to reproduce the blue in the laboratory for analytical investigation; (3) The researcher investigates degraded masks from museum collections to search for traces of degradation products that could be related to the unknown blue; all the options would consider the publication of results in scientific journals. More than one option could be considered simultaneously, but all are usually investigator-driven and academically-centered approaches that generate benefits mainly to the researchers and their scholarly fields. Some of those options consider community engagement, but Indigenous members usually participate as subjects or sources of materials, and their needs are often not considered in the formulation of research questions or the use and dissemination of the results. To help explore more socially responsible and inclusive practices in technical art history

and conservation science, the authors of this manuscript decided to investigate alternatives, such as community-based participatory research, CBPR, to proceed with this investigation.

Only a few examples of community-engaged research (CER) involving the scientific investigation of Indigenous sacred and ceremonial items are available in the literature; for instance, see [47–49]. However, fields like conservation, archaeology, health, and education have been exploring CER for a long time, and they are valuable sources of case studies and methodological frameworks. CER can be seen as a continuum from community-driven to investigator-driven research (p. 3, chapter 1) [50], from more to less collaborative. Many approaches exist within such a continuum, and the authors of this manuscript have chosen to proceed with CBPR. CBPR aims to "create an effective translational process that will increase bidirectional connections between academics and the communities that they study" (p. 3, chapter 1) [50], having social justice and empowerment at its foundation. The community has a broad participation, from the formulation of research questions and hypotheses to data collection, interpretation, use, and dissemination. It considers power-sharing with the community members, promotes mutual learning and reciprocity, is based on the community's resources and strengths, considers the sustainability of the outcomes, and disseminates results for all partners and interested parties. Details are outside this manuscript's scope, but the readers can learn more about CBPR in texts like those by Hacker and Atalay [50,51]. Additionally, our CBPR experience should result in a specific publication about the method in the context of technical art history.

The Tikuna/Magüta people are a living culture, producing colorants from natural sources, and there is no reason not to consider their participation in this research. In 2023, in collaboration with community members, we mapped some of their needs related to their cultural heritage and started exploring how technical art history and conservation science can engage with them for mutual benefits. Within a CBPR project, it is possible to consider research actions with more or less community engagement. For example, the results of this manuscript are part of an action closer to researcher-driven research but connected to other actions (still in their initial phases) with more extensive community participation. Thus, when considering the reciprocity principle of CBPR, it would not be reasonable to reproduce or request the Tikuna/Magüta people to prepare the naïcü blue for this manuscript, and therefore, for the researchers' benefit, without having a well-developed action that can also directly benefit the community. Additionally, naïcü is not readily available, and it is impossible to access the Amazon Forest and collect native plants for research without proper authorization.

Therefore, to continue this research, a fourth option is proposed and considered: that the researchers and community work together to prepare and chemically investigate the naïcü blue. However, to guarantee mutual benefits, the results should be shared only after the research group has at least one well-developed action plan that will directly address at least one of the community's needs by using the scientific results. This option is proposed as an alternative to increase the social impacts of research in technical art history and conservation science, and it is not expected to replace the others. For example, the Tikuna/Magüta people are living and producing their colorants, but this may not be the reality for other cultures. Therefore, the methodological approaches need to be defined case by case. The challenges, risks, and benefits of CBPR also need to be considered, and they will be addressed in a future publication.

3.3. Hypothesis behind the Still Unknown Blue Colorant

Concerning the chemical nature of the unknown blue, it can at least be hypothesized in this manuscript. Naïcü refers to plants from the family *Zingiberaceae*, genus *Renealmia* L.f. One of the plants attributed to the term naïku is *Renealmia alpinia* (Rottb.) Maas [21], and the peel of its fruit is rich in anthocyanins, with lower amounts of flavonoids and phenolic compounds and minor amounts of carotenoids [26]. Anthocyanins are derivatives of flavylium compounds, and although there are eighteen basic structures, the most common are pelargonidin, cyanidin, delphinidin, peonidin, petunidin, and malvidin (p. 252) [52].

For the pericarp of *Renealmia alpinia* (Rottb.) Maas, cyanidin-3-O-glucoside and delphinidin-3-O-glucoside are reported (Figure 6) [53].

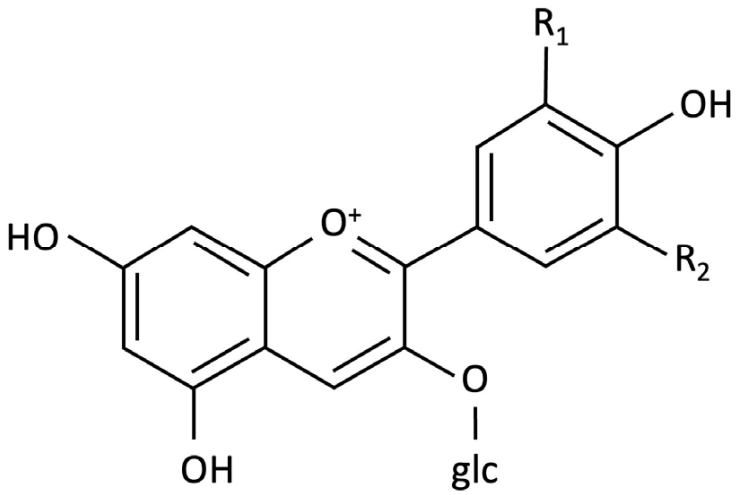


Figure 6. Chemical structures of cyanidin-3-O-glucoside (R_1 = OH, R_2 = H) and delphinidin-3-O-glucoside (R_1 = OH, R_2 = OH); glc = glycoside.

Anthocyanins were employed in cultural heritage items for millennia to produce watercolors and paints and to dye textiles, with hues ranging from red to blue [54–56]. Humans have been reacting anthocyanins with metal ions, such as aluminum ions, achieving mostly violet and purplish hues. Regarding blue hues, the use of anthocyanins in arts and cultural heritage is described mainly by their extraction from nature, not by human-made chemical processes with iron ions, as in the case of the Tikuna/Magüta people. There are only a few instances where similar blue systems with iron are described, and their chemical composition and analytical identification were also not explored. One work reports the use of hollyhock (*Althaea rosea* (L.) Cav.) flowers (p. 251) [55] to dye, and another the use of piñon (*Pinus edulis*) pitch and sumac (*Rhus trilobata*) withes with leaves (p. 66) [57].

Supposing that the blue prepared from naïcü is indeed the result of the chemical reaction between iron ions and anthocyanins, the Tikuna/Magüta people have been mimicking one of the strategies that nature uses to fix the blue color, which is complexation with metallic ions. The blue in hydrangea, for instance, is attributed to a complex of Al^{3+} with delphinidin-3-O-glucoside and the copigment 5-O-caffeoylquinic [6]. For petals of *Commelina communis*, the blue hue is attributed to a structure composed of the anthocyanin malonylawobanin, the flavone flavocommelin, and ions Mg^{2+} in a ratio of 6:6:2 [6]. Similar supramolecular structures were proposed for *Salvia patens* and *Salvia uliginosa* (with anthocyanins, flavones, and ions Mg^{2+}), and *Centaurea cyanus* and *Nemophila menziezii* (with anthocyanins, flavones, and ions Fe^{3+} and Mg^{2+}). Other plants for which blue was related to the presence of anthocyanins and Fe^{3+} are *Corydalis ambigua* and *Meconopsis grandis* [6]. The effect of iron ions has also been investigated in similar systems [58], and a study evidenced that the chemical reactions between ferric chloride and cyanidin-3-glucoside and delphinidin-3-glucoside result in the formation of blue chelate complexes [59]. Therefore, it is reasonable to expect the formation of anthocyanin–Fe^{3+} chelates of cyanidin-3-O-glucoside and delphinidin-3-O-glucoside for the blue produced by the Tikuna/Magüta people, resulting in structures similar to those proposed in Figure 7. This reasoning will form the basis for future investigations including the community, as detailed above.

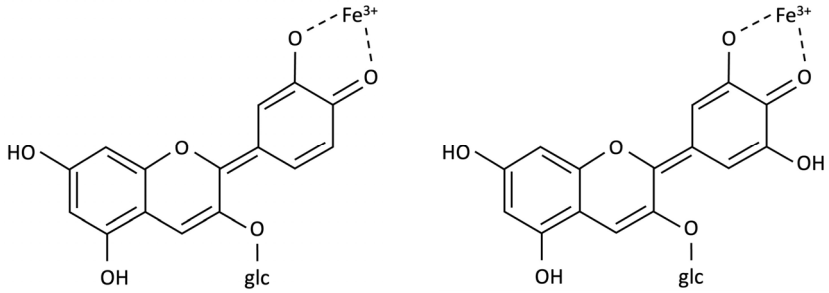


Figure 7. Representation of the potential chelates in the blue pigment prepared by the Tikuna/Magüta people by mixing fruits from naïcü with iron. (**a**) is from cyanidin-3-O-glucoside and (**b**) from delphinidin-3-O-glucoside; glc = glycoside. Not all the Fe^{3+}–ligand chemical bonds are represented in this figure.

4. Conclusions

The use of a single blue colorant (ultramarine, indigo, phthalocyanine blue, crystal violet, or Prussian blue) or a mixture of blue colorants (Prussian blue and ultramarine or Prussian blue and indigo—in addition to black) by the Tikuna/Magüta people in their female initiation ritual masks evidences their artistic knowledge and intention to achieve specific shades of blue, which could also be attributed to spiritual reasons. The results also evidence the replacement of natural colorants with synthetic ones and the potential loss of former Tikuna/Magüta traditional material knowledge, a warning for the urgent need to investigate their past and present painting practices. The urgency is also due to the fact that many of the natural Tikuna/Magüta colorants present in museums are already degraded, and the documentation of their materials and techniques is scarce and sometimes ambiguous. The replacement of materials, the loss of former traditional knowledge, and the possible low chemical stability of former colorants may be related to the non-identification of the unknown blue in this research.

Although a few traditional approaches from technical art history and conservation science could be considered to continue this research, the authors propose an alternative with a paradigm shift to prioritize the people culturally and spiritually connected to the items instead of prioritizing the material understanding and the researchers. The proposed approach involves community engagement through CBPR and aims to help promote more socially responsible and inclusive practices in technical art history and conservation science based on examples from fields like conservation, health, and archaeology. Because there are no systematic CBPR studies in technical art history and conservation science, much work needs to be performed regarding case studies and the development of methodologies and ethical considerations.

In addition to investigating the materiality related to the Tikuna/Magüta coloring practices, it is also important to understand, for example, the meanings of the colors, of the materials used in their coloring practices, of the chemical reactions they performed when transforming nature, and of the replacement of natural colorants by modern ones. These kinds of inquiries are relevant both in art history and conservation, and the engagement of the Tikuna/Magüta community as collaborators is fundamental in answering them.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/heritage7090222/s1, **Table S1.** Additional information from the Tikuna/Magüta items from the Museum of Archaeology and Ethnology from the University of São Paulo (MAE, Brazil). Photos: RG 8649, RG 8710, RG 8716, RG 8753, RG 8753 (2), RG 8764, RG 8889, RG 8892, RG 8894, RG 8898, RG 8902, RG 9454, RG 9984, RG 10034, and RG 10896 (by Ader Gotardo); credits: Museu de Arqueologia e Etnologia da Universidade de São Paulo. The items' descriptions were obtained from the MAE's collection website (http://sophia.mae.usp.br) accessed on 2 March 2024; the English descriptions are the authors' translation. **Table S2.** Additional

information from the Tikuna/Magüta items 996-24-30/11694 and 47-8-30/5627 from the Peabody Museum of Archaeology and Ethnology from the Harvard University (U.S.A.). Photo: credits: Gift of Richard E. Schultes, 1996. Courtesy of the Peabody Museum of Archaeology and Ethnology, Harvard University, 996-24-30/11694. The items' descriptions were obtained from the Peabody Museum's collection website (https://collections.peabody.harvard.edu/collections) accessed on 2 March 2024.

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