LEX LOCALIS-JOURNAL OF LOCAL SELF-GOVERNMENT
ISSN:1581-5374 E-ISSN:1855-363X
VOL. 23, NO. S6(2025)

IDENTIFICATION OF COLOR RANGES PRODUCED WITH INORGANIC PIGMENTS FROM THE CUZCO AREA - PERU

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Summary
Mineral pigments extracted from the immediate territory have been used throughout history in the architecture and mural paintings of Cuzco in Peru. This study aims to characterize the visual aspect in the NCS color notation system of the paintings produced from inorganic pigments extracted from quarries in the city of Cuzco. These are compared according to their crushing process by sedimentation (MS) or ball milling (MG) and according to three types of dosages at 10%, 40%, and 60%, using polyvinyl acetate (PVA) as a binder for the mixture. The results indicate that most of the color ranges obtained are reddish (Y20R to Y80R) with the exception of a greenish yellow (G90Y), have low to middle blackness (10 to 50) and low chromaticcness (<=30). The use of MS compared to MG process alters the visual aspect of paintings in an unpredictable way in 40% of the cases, with independency of the dosage. Although the PVA content does not result in significant changes in the perception of hue, blackness levels, or chromaticness in more than 50% of the samples, it slightly influences certain pigment and extraction method combinations. It was observed that paints with higher proportions of PVA, especially in pigments processed by sedimentation (MS), tend to exhibit more reddish Hues and less blackness compared to those obtained by ball milling (MG). Furthermore, increased PVA often intensifies chromaticcness in some samples, such as M-01 and M-07, highlighting its role as a regulator of the visual properties of the coatings.

Key words: inorganic pigments, color ranges, Cuzco quarries, NCS, polyvinyl acetate.

INTRODUCTION

The use of natural earth pigments in South America dates back to ancient Qosqo, the capital of the Inca empire, which included present-day Peru, Ecuador, Colombia, parts of Argentina, and Chile (1200 to 1532 AD). Evidence of rock paintings from the pre-Inca period exists, and these pigments represent a direct link to the societies that inhabited the study area. The paintings offer a unique glimpse into the worldview, beliefs, and daily activities of the pre-Columbian cultures that left their mark on the region, including representations created with mineral and vegetable pigments (Hostnig, 2004).

Although Inca architecture is known for its stone materials, some examples of pigment use can be found in the ceramics of the Qeros, such as ceremonial wooden vessels painted with natural pigments, but the most notable richness is in textile production, which was enhanced with colors derived from vegetable and mineral pigments (Wright et al., 2014).

In the field of architecture, it is interesting to observe the use of pigments in religious mural paintings. The church of Andahuaylillas in Cuzco, known as the Sistine Chapel of America, is recognized for its 17th-century frescoes, which exemplify mestizo baroque art in Latin America. Notably, the entrance fresco titled "The Path to Heaven and Hell" represents the allegory of good and evil (Cohen Suárez, 2013). The fresco of Andahuaylillas is one of the earliest preserved examples of the role of

colonial Andean murals in teaching the Catholic religion. The pigments used included metals like gold and silver, derived from minerals such as ochre or natural earths that impart earthy and warm colors. Additionally, malachite, along with green earths, contributed to the landscapes' hues, as did natural pigments like indigo and cochineal.

In identifying Cuzco art throughout history, three important periods can be recognized: the pre-colonization period, the colonial period, the republican era, and the present day. In all of these, mineral pigments have played a significant role in various artistic expressions.

Rock art in the Cuzco valley prior to colonization.

The rock paintings of Cuzco are a valuable testament to the history and culture of the ancient civilizations of the region. Some of the pigments commonly include iron oxide, which is used to produce reddish and ochre colors; charcoal used to make black paint; and copper sulfate, which is used to create blue and green dyes (Guffroy, 2015). Ancient artists also employed a variety of techniques, including brushes made from natural materials such as plant fibers or animal hair, and applied paint directly with their fingers or with tools made of bone or sHue (National Institute of Culture, 1986). These paintings served ritual or communicative functions and reflect the beliefs and experiences of ancient civilizations. Furthermore, rock images might have served as a way to delimit territory or record important events (Lumbreras, 2015).

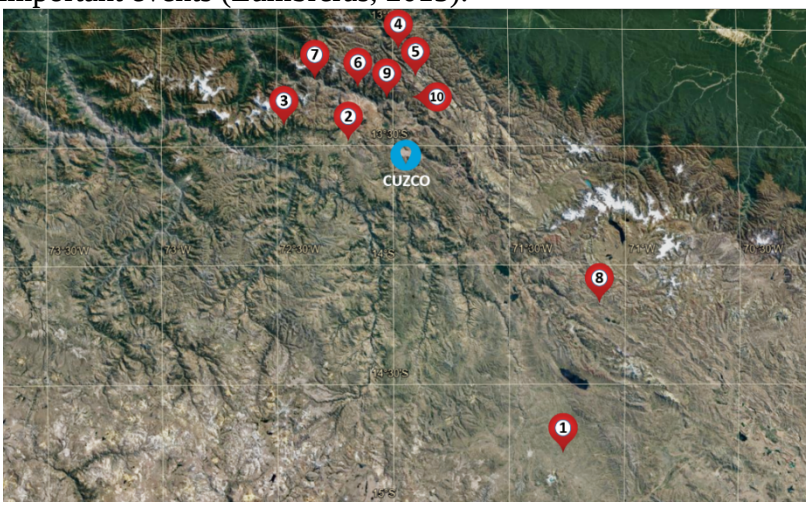

Figure 1. Location of rock paintings in the Cuzco Region (1. *Espinar*, *2. Intiyoq Maraskay*, *3. Llamachayoq Qapa*, *4. Llamayoq*, *5. Banderayoq*, *6. Inkapintay*, *7. Kechuqaqa*, *8. Intimarkana*, *9. Chichero, and 10. Yucay.*

The recorded existence of inorganic pigments used in cave paintings in the Cuzco region primarily encompasses the Andean region, concentrating in the area known as the Sacred Valley of the Incas, covering cities such as Yucay, *Intiyoq Maraskay* (Ccorca), *Intimarkana* (Combapata), *Banderayoq* (Calca), *Kechuqaqa* (Ollantaytambo), *Inkapintay* (Urubamba), among others (Figure 1). The motifs of the cave paintings in the Cuzco valley include representations of South American camelids both individually and in groups, geometric figures, possibly representing the sun and stars, and even humanoid figures like those found in the district of Ccorca (Figure 2).

Figure 2. Representation of motifs in the cave paintings present in Cuzco

Note: The cave paintings in the Cuzco Valley are documented at the National University of San Antonio Abad of Cuzco.

Colonial Paintings

The paintings of the Cuzco School have a rich history and tradition in the use of color (Figure 3). Artists from Cuzco used a variety of pigments to create their art (Girard, 2023). These pigments come from soils, plants, minerals, and insects. One of the most commonly used pigments is ochre, which is obtained from clay deposits rich in iron oxides (Balta Campbell, 2009).

Figure 3. Mural painting of the Cuzco School. From left to right, above: façade with mural painting of the Church of Andahuaylillas, mural painting in the coffered ceiling of the Church of Huaro, Baroque mural painting on the walls of the Church of Andahuaylillas. Below: The three murals correspond to the walls of the Church of Huaro, showcasing the technique of the Baroque painter Tadeo Escalante and other unidentified artists.

The scanning electron microscopy (SEM) tests conducted by Balta Campbell were applied to samples of colonial Andean paintings from Cuzco. Red, ochre, and base colors with variations were detected. Chemical elements such as sulfur, metallic mercury, lead, aluminum, silicon, chlorine, calcium, iron, carbon, and oxygen were recorded in various samples (Balta Campbell, 2009). Among the highlighted inorganic pigments is Vermilion (Paria or llimpi), extracted from mines in the central highlands of Peru. This pigment was mixed with white lead pigment and applied over a layer of yellowish ochre to enhance the skin Hues in the paintings. White lead (albayalde), imported from Spain but also mined in southern Peru, was also used. Other mentioned pigments include azurite, indigo, hematite (almagre) characteristic of the red soils of Cuzco, and yellow ochre (quellu) present in the representations of flowers and vases as depicted in figure 4 (Siracusano & Maier, 2005).

Figure 4. Mural painting of the Cuzco School

Note: The mural paintings of the Cuzco School found in the San Bernardo House depict religious scenes, such as the life of Jesus and the saints, as well as landscapes and portraits of important figures from the 17th century.

Paintings from the Republican period

During the Republican period of Cuzco, many artists continued to use earth pigments in their works to connect with the traditional and ancestral techniques of Cuzquenian painting. These pigments came

from different parts of the region and were used to create the various colors depicted in canvases and murals. A notable example of the use of soil pigments from Cuzco is the work "The Bound Indian" by the renowned Cuzquenian painter Juan José Bueno. In this piece, Bueno used the color of the earth to represent the image of a bound native, symbolizing the oppression of the time and the struggle for freedom. The ochre and earthy colors of the painting provide a sense of authenticity and a connection to the land of Cuzco (De Mesa, 1982).

Another relevant example is the work of painter Rafael Santa Cruz titled "Cuzquenian Landscape." In this painting, Santa Cruz utilized earth-Hue pigments to represent the diverse colors of Cuzquenian nature, such as the greens of the fields and the ochres of the mountains. These pigments impart a sense of roots and authenticity to the landscape, capturing the essence of the area. The ochre provides warm Hues and brown shades that are used to depict landscapes, figures, and architectural elements in republican paintings. In addition to ochre, pigments from manganese-rich clays were also employed. The use of Siena provided the yellow and ochre Hues used to represent skin, fabrics, and other elements in Cuzco paintings Mujica (2012). Red cinnabar, obtained from mercury, was also utilized to achieve intense red shades using the tempera technique (Figure 5).

Figure 5. Representations of religious scenes by the Baroque painter Tadeo Escalante. Left: mural painting "The Triumph of Death" or "The Dance of Death" from the Gospel in the church of San Juan Bautista de Huaro. Right: "The Last Judgment" belongs to the Cuzco School, (1802).

The Production of Artisan Paintings Today

Currently, there are initiatives in different South American countries to produce paints from mineral pigments obtained from the surrounding territory. This allows, on the one hand, to recover the chromatic identity of a place and favour the color palettes typical of local tradition, as well as to provide an opportunity to stimulate the local artisanal economy. In Ecuador, there are experiences of ecological and economic alternatives for the production of artisan paintings, focused on the production and application of colored earths, aimed at preserving architectural heritage and enhancing contemporary buildings. Experiences were gathered from local builders who applied colored earths for the artisanal production of paints, thereby identifying and safeguarding the traditions, techniques, and materials of the region. The typical historical colorimetric palette of exterior walls of heritage buildings was cataloged; similarly, paintings were reproduced with chromatic approaches to the originals (Amaya Ruiz et al., 2018).

There are experiences of ecological and economic alternatives to the protection of adobe walls using earth colors. Ana Aracelia Quiteño (2018), a civil engineer from the Faculty of Engineering and Architecture at the Pontifical Catholic University of El Salvador, conducted the research. The study's purpose was to experiment with colored soil by mixing it with lime and polyvinyl acetate to produce ecological and economical paints in various shades. To achieve this, soil samples from different regions of western El Salvador were collected, tested, and analyzed to determine their chemical and mineral composition. Once the sifted earth was obtained, a variety of natural colors were produced consisting of a base, a binder and colored earth. Water was used as the vehicle, while slaked lime and

polyvinyl acetate served as the binders. Additionally, the use of earth Hues contributes to the preservation of the community's culture and identity through traditional materials and techniques (Quiteño, 2018).

It is evident, therefore, that natural pigments have been integral to the artistic manifestations of the Cuzco region in Peru throughout its history, spanning pre-colonial, colonial, and republican periods, with examples of mural paintings and architecture of undeniable artistic value. Currently, there are initiatives aimed at reviving the use of local mineral pigments in the production of artisanal paints, although these have been developed in countries other than Peru. The production of artisanal paints could represent an ecologically sustainable alternative for the economic development of local communities in Cuzco. However, there is no colorimetric characterization study of the paints that could be obtained from such mineral pigments. Therefore, the objective of this article is to carry out a colorimetric characterization in Natural Color System (NCS) of the colors obtained from mineral pigments extracted in the Cuzco area in Peru, using different extraction and dosage systems.

MATERIALS AND METHODS

This section describes (1) the characteristics and location of the quarries in the Cuzco valley from which pigment samples were extracted, (2) the process of extraction and preparation of the pigments, (3) the process of paint manufacture, and (4) the colorimetric characterization in NCS.

1. Pigment quarries located in the Cuzco valley

The city of Cuzco is characterized by a diverse geomorphology, allowing it to possess a variety of soil quarries with inorganic pigments that offer a wide range of colors. This research produced a series of 13 paints using these pigments.

One of the most notable minerals in the geology of Cuzco is iron oxide, which appears as hematite and goethite present in the south of the city, characterized by the production of semi-industrial bricks for the construction sector. These minerals create the red and ochre Hues used in the region's traditional paints. In addition to iron oxide, other inorganic minerals have been found, such as copper oxide, which has green and blue hues located southeast of the city in the area known as ENACO, and manganese oxide, which has black and brown Hues found in the peripheral area of the city (community of Pumamarca).

Found in the geology of the city of Cuzco, these inorganic pigments were used by pre-Columbian cultures in the area, such as the Incas. Extracted from nearby mines, these pigments are processed to create artistic colors.

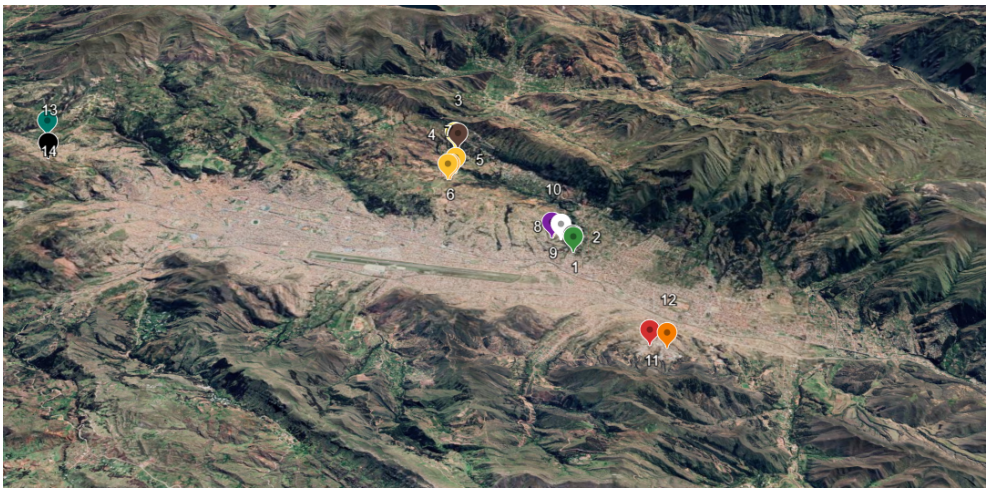

Figure 6. Location of quarries in the Cuzco Valley

2. Extraction and Preparation of the Pigment

Once the designated extraction point is identified, samples are collected following the steps outlined below:

I. Surface cleaning of the selected area to remove organic matter, such as roots, stems, leaves, and other elements that could alter the pigment's color.

II. Excavation of the surface layer of the ground to remove impurities caused by exposure to

environmental factors such as rain and sun, as well as the presence of animals and other agents that significantly influence the contamination of the samples.

III. Sample extraction using manual means, such as a pick and shovel, with the extracted fragments stored in a polypropylene bag to ensure their preservation during transport.

IV. Coding of the extracted samples by assigning unique identifiers for precise tracking.

For the pigment preparation process, various stages were followed to ensure the consistency and quality of the final product, and precise protocols were implemented for their handling and processing. The following stages were developed for this purpose:

I. *Natural drying:* The samples were placed on plastic surfaces to prevent moisture absorption and were exposed to sunlight and local climatic conditions for a period of 3 days.

II. *Coarse grinding:* The grinding process was carried out using traditional tools, such as a hammer and/or mallet, to reduce the particle size to no more than two centimeters.

III. *Sieving:* In the sieving process, ASTM sieve mesh number 20 was used with an opening of 850 μm (micrometers) or 0.85 mm. This mesh was precisely selected, considering the specific dimension of the opening, to allow the controlled passage of particles smaller than the established value. Sieving, as a method of granulometric separation, involves applying vibrations to the mesh, which facilitates the passage of smaller particles while retaining those whose size exceeds the opening.

After the general sieving, the samples are divided into two groups, weighing them in 1 kg samples that will undergo two methods of pigment extraction: the first called sedimentation (MS) and the second obtained through ball milling (MG).

Sedimentation (MS): In this method, the goal is to achieve the pigment with the highest integrity and quality, for which a liquid grinding process is carried out. This procedure begins with the addition of a precise proportion of 3 liters of water and 1 kg of sample in a container. Next, mechanical disintegration is performed using a stainless-steel Cowles disk, which is coupled to a galvanized threaded rod of 3/8". This rod is secured to the rotor of a motor, initiating a crushing process that lasts for 15 minutes. Upon completion of the crushing process, the mixture is allowed to rest for 24 hours. During this phase, a natural decantation occurs, where pigment particles settle at the bottom while organic matter remains on the surface. Subsequently, water containing organic matter is extracted using a 1/2" levelling hose. This device allows for the selective absorption of the contaminated liquid, leaving only the pigment intact. Finally, the wet mixture is poured into galvanized trays, which are then placed in a dehydration oven to remove residual moisture and sediment the pigment. The oven operates continuously for two days at a temperature of 100°C, allowing for gradual and controlled dehydration. At the end of this process, the final percentage of pigment is obtained, exhibiting optimal characteristics, ready for application.

Ball Milling (MG): This procedure is carried out by introducing 100g of sample into the container of the ball milling equipment, which contains 12 porcelain balls. Once the container is sealed, it undergoes the milling process for periods of 20 minutes each time until a powdered sample is obtained, which is then screened through sieve No. 4. At the end of each milling period, the porcelain balls are removed, and the pigment is weighed until specific groups of 1 kg of pigment are formed.

Once the milling of each sample is completed, general cleaning of the balls and container is performed using 100g of quartz sand, which is rotated for periods of 20 minutes. This process is repeated until it is observed that the pigment does not adhere to the walls of the container and the surfaces of the balls. The contents are poured through a mesh that retains the balls while allowing excess material to pass; once completed, the milling process is repeated with the next color sample. The result is the production of the pigment that will be used in paint manufacturing (Figure 7).

Figure 7. Pigments obtained by sedimentation and bead milling

3. Design and Production of Paint

The paint production was formulated using water as a diluent, inorganic pigment, and polyvinyl acetate as a synthetic binder, along with potable water as a binding agent.

The production process consisted of the following steps:

I. Calculation of Pigment Yield: Prior to weighing each of the samples, the samples were homogenized using a "Cowles" mechanical agitator adapted to a drill at 2800 rpm for 10 minutes. Subsequently, the samples were weighed, placed in a dehydrator oven for 24 hours, and weighed again to calculate the pigment yield in each dispersion.

II. Preparation of the Dispersions: Each dispersion was homogenized again using a "Cowles" mechanical agitator adapted to a drill at 2800 rpm for 10 minutes.

III. Addition of solvent (water): According to the proportions designed in the experiment, 1 part of pigment was mixed with 30% water as a solvent. The mixing was performed using stainless steel paddles with star-shaped blades, also made of the same material, which help to liquefy the pigment and convert it into an aqueous solution.

IV. Addition of binders: The dosing was planned under serial repetitions considering two blocks: the first with pigments obtained from sedimentation (MS) and the second from milling (MG); each was mixed volumetrically, altering the proportion of the synthetic binder. These were gradually added using a "Cowles" mechanical stirrer adapted to a drill operating at 2800 rpm, over a period of 15 minutes (Table 1).

V. Measurement of viscosity: After completing the mixing of the pigment dispersion, the viscosity was measured using a Ford cup viscometer, with an estimated time between 14 and 16 seconds. If the viscosity does not meet the specification—specifically, if the sample takes less than 14 seconds—it indicates that the mixture lacks the appropriate viscosity. In this case, 10 ml of water is added and mixed again. If the desired viscosity is still not achieved, the process is repeated, adding 10 ml each time until the required viscosity is reached. If it exceeds 16 seconds, this indicates that the mixture is very fluid, so adjustments should be made by adding 10g of pigment at a time until reaching the required viscosity time of 14 to 16 seconds.

VI. Storage: The paints were stored in five-liter containers.

VII. Application of Paint: For the application of the samples, test pieces measuring 25cm x 50cm were cut from 4 mm thick Superboart ST fiber cement sheets. A first layer of sealer made from stretched acrylic latex resin (brand CPP) was applied to these test pieces; it took 4 hours to dry. After drying, a wall primer made from stretched acrylic latex resin (brand CPP) was applied. Following an additional 2 hours of drying, the surface was smoothed with #180 sandpaper, repeating the process until the desired finish was achieved. Once the test pieces were sanded, they were cleaned with a dry brush to remove any dust, and then the first layer of paint was applied using a #22 brush in one

direction. After the first layer was applied, it was left to rest for 4 hours before applying the second layer of paint, thus completing the process. This procedure was repeated for each color and each dosage scheduled in the research.

The proportions of the thinner varied depending on the characteristics of the pigments and paint formulations, making it impossible to define them a priori. The proportions were determined by viscosity.

4. Colorimetric characterization of the samples:

The colorimetric identification of the samples was conducted through visual comparison by 3 expert observers with normal color vision, illuminating the samples with a D65 illuminant in a Verivide light booth and utilizing the NCS Atlas 2050. The Natural Color System (NCS) is a perceptual color model based on the theory of opposite perceptual colors, which identifies colors according to their *blackness* in percentage, their *chromaticness* in percentage, and their hue, based on the position of the color on a color wheel with 4 main hues and 9 intermediate hues.

RESULTS

Table 2 describes the color notation of the various samples in NCS, based on the dosages of polyvinyl acetate (20%, 40%, and 60%) and whether the pigments were obtained through sedimentation (MS) or villa milling (MV). Figure 8 provides a visual approximation of the colors of the analyzed samples.

SAMPLE	**Polyvinyl Acetate Dosage**					
	MS 20%	**MG 20%**	**MS 40%**	**MG 40%**	**MS 60%**	**MG 60%**
M-01	S 2005-Y50R	S 1010-Y30R	S 2005-Y50R	S 1010-Y30R	S 3010-Y70R	S 1020-Y20R
M-02	S 0505-Y50R	S 1005-Y30R	S 1005-Y30R	S 1005-Y30R	S 1005-Y30R	S 1005-Y30R
M-03	S 2030-Y20R	S 2030-Y20R	S 3030-Y20R	S 2040-Y20R	S 3040-Y30R	S 3040-Y20R
M-04	S 1010-Y30R	S 2005-Y40R	S 1010-Y30R	S 2005-Y40R	S 1010-Y30R	S 2005-Y40R
M-05	S 2030-Y20R	S 1010-Y20R	S 2020-Y20R	S 2020-Y20R	S 1020-Y10R	S 3040-Y20R
M-06	S 4020-Y70R	S 4020-Y70R	S 5020-Y60R	S 4020-Y70R	S 5020-Y70R	S 4020-Y70R
M-07	S 2005-G90Y	S 2005-G80Y	S 2005-G90Y	S 3010-G80Y	S 2005-G90Y	S 3010-G90Y
M-08	S 1010-Y20R	S 1005-Y20R	S 2020-Y10R	S 2010-Y20R	S 3020-Y10R	S 3020-Y10R
M-09	-	-	-	-	-	-
M-10	S 2030-Y30R	S 2040-Y20R	S 2040-Y30R	S 2040-Y30R	S 3040-Y30R	S 2040-Y30R
M-11	S 2030-Y20R	S2020-Y20R	S 2030-Y20R	S 2020-Y20R	S 3030-Y20R	S 2030-Y20R
M-12	S 3010-Y60R	S 3010-Y60R	S4010-Y50R	S 4010-Y50R	S 4010-Y50R	S 4010-Y50R
M-13	S 8005-Y20R	S 8005-Y20R	S 8005-Y20R	S 8005-Y20R	S 8005-Y20R	S 8005-Y20R
M-14	S 4020-Y70R	S4020-Y80R	S 4020-Y70R	S 4020-Y80R	S 4020-Y80R	S 4020-Y70R

Table 1. Characterization of visual appearance according to NCS, considering the binder addition dosages (polyvinyl acetate) at 20%, 40%, and 60%, compared by type of grinding (MS = Sedimentation; MG = Villa Milling). Sample M-09 was not included as the pigment did not form paint.

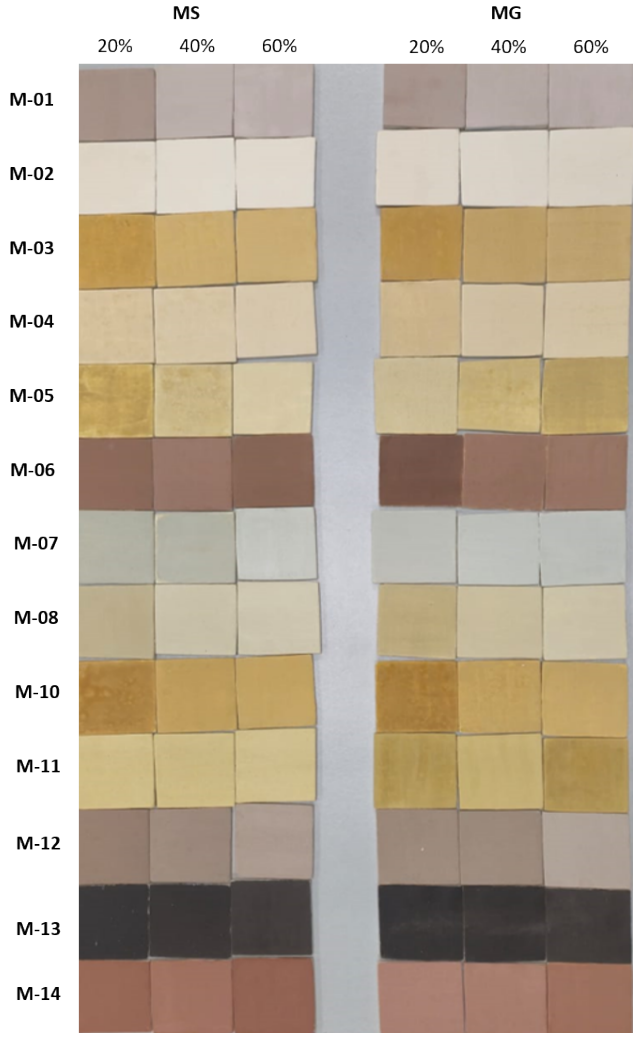

Figure 9. Graphical comparison of samples with the addition of polyvinyl acetate at 20%, 40%, and 60% between paints derived from pigments by sedimentation (MS) and ball mill grinding (MG).

ANALYSIS OF RESULTS

After obtaining the colorimetric characteristics of the colors in NCS, a comparison was made of the MS sedimentation samples (MS) and the ball mill grinding samples (MG)to determine if there were perceptible differences in the colorimetric characteristics of the colors based on the pigment extraction method. Similarly, a comparison was made to determine perceptible differences in the colorimetric characteristics of the colors based on the concentrations of polyvinyl acetate (PVA) at 20%, 40%, and 60%. For each pair of samples, the difference in blackness (ΔS), difference in chromaticness (ΔC), and difference in hue (ΔH) were obtained according to the extraction method (MS, MG) and the concentrations of PVA.

Results according to the pigment extraction method MS-MG

Previous research indicates that the visual characteristics of paint color are related to the particle size of the pigments it contains (Cardoso, 2020). Thus, the mineralogical composition of the pigments can be a primary factor influencing aggregate stability and optical properties. In this context, the pigment extraction method MS and MG might influence the color notation in NCS.

Considering the pigment extraction method MS-MG, when making the 39 comparisons of the 78 samples studied, we observe that, regarding the blackness, in 24 ΔS=0, in 8 ΔS=+10, in 1 ΔS=+20, in 5 ΔS=-10, and in 1 ΔS=-20. It is observed, therefore, that in more than 50% of the samples, the color blackness is not altered by the pigment extraction method MS or MG (Table3).

Regarding color chromaticness, of the 39 comparissons, 23 showed ΔC=0, 4 showed ΔC= +5, 3 showed ΔC=+10, 1 showed ΔC=+20, 4 showed ΔC=-5, 3 showed ΔC=-10, and 1 showed ΔC=-20. Thus, it is observed that in 50% of the samples, the chromaticness of the color is not affected by the pigment production system MS or MG.
Regarding the color hue, of the 39 comparisons, 22 showed ΔH=0, 8 showed ΔH=-10R, 3 showed ΔH=+10R, 2 showed ΔH=+10Y, 3 showed ΔH=+20R, and 1 showed ΔH=+50R, indicating varying distances from the primary colors R and Y in the NCS color circle. It is observed that in 52% of the samples, the color Hue remains unaltered by the pigment extraction methods MS or MG.
Considering all of this, it is observed that most of the paintings do not show differences in their colorimetric variables NCS hue, blackness, or chromaticness, regardless of whether the pigment was obtained using the MG ball milling method or the MS sedimentation method. However, there are samples such as M01, M04, M05, and M07 that do exhibit greater differences depending on whether MS or MG is employed (table 3).

Sample	**Δ (MS - MG)**	**Polyvinyl acetate content**			**Observation**
		20%	**40%**	**60%**	
M-01	Δ S	**+10**	**+10**	**+20**	$S_{MS} > S_{MG}$ in all dosages
	Δ C	**-5**	**-5**	**-10**	$C_{MS} < C_{MG}$ in all dosages
	Δ H	**+20R**	**+20R**	**+50R**	Content of R, MS > MG in all dosages
SM-02	Δ S	**-10**	0	0	$S_{MS} > S_{MG}$ in a dosage of 20%
	Δ C	0	0	0	$C_{MS} = C_{MG}$ in all dosages
	Δ H	**+20R**	0	0	Content of R, MS > MG in a dosage of 20%
M-03	Δ S	0	**+10**	0	$S_{MS} > S_{MG}$ in a dosage of 40%
	Δ C	0	**-10**	0	$C_{MS} < C_{MG}$ in a dosage of 40%
	Δ H	0	0	**+10R**	Content of R, MS > MG in a dosage of 60%
M-04	Δ S	**-10**	**-10**	**-10**	$S_{MS} < S_{MG}$ in all dosages
	Δ C	**+5**	**+5**	**+5**	$C_{MS} > C_{MG}$ in all dosages
	Δ H	**-10R**	**-10R**	**-10R**	Content of R, MS < MG in all dosages
M-05	Δ S	**+10**	0	**-20**	$S_{MS} > S_{MG}$ in a dosage of 20% y $S_{MS} < S_{MG}$ in a dosage of de 60%
	Δ C	**+20**	0	**-20**	$C_{MS} > C_{MG}$ in a dosage of 20% y $S_{MS} < S_{MG}$ in a dosage of de 60%
	Δ H	0	0	**-10R**	Content of R, MS < MG in a dosage of 60%
M-06	Δ S	0	**+10**	**+10**	$S_{MS} > S_{MG}$ en dosificación de 40% y 60%
	Δ C	0	0	0	$C_{MS} = C_{MG}$ in all dosages
	Δ H	0	**-10R**	0	Content of R, MS < MG en dosificación de 40%
M-07	Δ S	0	**-10**	**-10**	$S_{MS} > S_{MG}$ in a dosage of 40% y 60%
	Δ C	0	**-5**	**-5**	$C_{MS} < C_{MG}$ in a dosage of 40% y 60%
	Δ H	**+10Y**	**+10Y**	0	Content of R, MS > MG in a dosage of 20% y 40%
M-08	Δ S	0	0	0	$S_{MS} = S_{MG}$ in all dosages
	Δ C	**+5**	**+10**	0	$C_{MS} > C_{MG}$ in a dosage of 20% y 40%
	Δ H	0	**-10R**	0	Content of R, MS < MG in a dosage of 40%
M-10	Δ S	0	0	**+10**	$S_{MS} > S_{MG}$ in a dosage of 60%

	Δ C	**-10**	0	0	$C_{MS} < C_{MG}$ in a dosage of 20%
	Δ H	**+10R**	0	0	Content of R, MS > MG in a dosage of 20%
	Δ S	0	0	**+10**	$S_{MS} > S_{MG}$ in a dosage of 60%
M-11	Δ C	**+10**	**+10**	0	$C_{MS} > C_{MG}$ in a dosage of 20% y 40%
	Δ H	0	0	0	Content of R, MS = MG in all dosages
	Δ S	0	0	0	$S_{MS} = S_{MG}$ in all dosages
M-12	Δ C	0	0	0	$C_{MS} = C_{MG}$ in all dosages
	Δ H	0	0	0	Content of R, MS = MG in all dosages
	Δ S	0	0	0	$S_{MS} = S_{MG}$ in all dosages
M-13	Δ C	0	0	0	$C_{MS} = C_{MG}$ in all dosages
	Δ H	0	0	0	Content of R, MS = MG in all dosages
	Δ S	0	0	0	$S_{MS} = S_{MG}$ in all dosages
	Δ C	0	0	0	$C_{MS} = C_{MG}$ in all dosages
M-14	Δ H	**-10R**	**-10R**	**+10R**	Content of R, MS < MG in a dosage of 20% y 40% y MS > MG in a dosage of 60%

Table 3. Comparison of results between MS and MG samples with the addition of polyvinyl acetate at 20%, 40%, and 60%

Results according to the dosage of polyvinyl acetate (PVA)

Considering the three doses of PVA at 20%, 40%, and 60%, when making the 52 comparisons of the 78 samples, we observe that, regarding the blackness variation, in 67.31% of the comparisons, when the PVA increases, the blackness does not register any variation. In 28.85% of cases, when the PVA increases (samples MG 3, 5, 7, 8, and 12; MS 3, 6, 8, 10, 11, and 12), the blackness decreases, and in the remaining comparisons (3.85%), the blackness increases.

Regarding the chromaticness variation, in 75% of cases there is no chromaticness variation; in 21.15% of cases, when PVA increases, chromaticness decreases (samples MG 1, 3, 5, 7, 8, and 11; MS 2, 3, 8, and 10); and in 3.85% of cases chromaticness increases. This effect is slightly more evident in MS compared to MG.

The results obtained for the variation in hue show that, in most cases (69.23%), the increase in PVA concentration does not lead to significant changes in hue. However, specific trends are observed depending on the pigment extraction method. In 19.23% of the cases (M-01, M-03, M-06, M-10, M-14), the hue in the pigments obtained by MS tends to shift towards yellow as the PVA content increases, while in the pigments obtained by MG, the hue generally remains stable. In 11.54% of the cases (M-05, M-08, M-12), both in MG and MS, the hue shifts towards red with the increase of PVA, indicating that certain pigments have a greater tendency to intensify warm hues under the influence of the binder. Finally, in 3.85% of the cases (M-07), a particular behaviour is observed in MG, where the hue shifts away from yellow towards green, while in MS it remains constant. These results suggest that the impact of PVA on hue depends both on the extraction method and the inherent characteristics of each pigment, highlighting the need for further studies to better understand the interactions with the binder.

Sample	**Δ**	**Content PVA**				**Observación**
		MG		**MS**		
		40%-20%	**60%-40%**	**40%-20%**	**60%-40%**	
M-01	ΔS	0	0	0	+10	If PVA increases in MG, S does not vary, while in MS, S increases

		0	0		If PVA increases, in MG, C decreases, while in MS C increases
	ΔC		-10	**+5**	
		0	0		If PVA increases in MG, H approaches Red, while in MS, H approaches Yellow
	ΔH		+10R	-20R	
		0	-5	0	If PVA increases, in MG, S remains unchanged, while in MS, S decreases.
	Δ S		0		
		0	0	0	If PVA increases, both in MG and MS, C does not change
M-02	Δ C		0		
		0	+20R	0	If PVA increases, in MG, H does not change, while in MS, H approaches Red
	Δ H		0		
		0	-10	0	If PVA increases, both in MG and MS, S decreases.
	Δ S		-10		
		-10	0	-10	If PVA increases, both in MG and MS, C decreases
M-03	Δ C		0		
		0	0	-10R	If PVA increases, in MG, H does not change, while in MS, H approaches yellow
	Δ H		0		
		0	0	0	If PVA increases, both in MG and MS, S does not change.
M-04	Δ S		0		

	Δ C	0 0	0	0	If PVA increases, both in MG and in MS, C does not change
	Δ H	0 0	0	0	If PVA increases, both in MG and MS, H does not change
M-05	Δ S	-10 -10	0	+10	If PVA increases, in MG, S decreases, while in MS, S increases
	Δ C	-10 -20	+10	0	If PVA increases, in MG, C decreases, while in MS, C increases.
	Δ H	0 0	0	+10R	If PVA increases, in MG, H does not change, while in MS, H approaches Red.
M-06	Δ S	0 0	-10	0	If PVA increases, in MG, S remains unchanged, while in MS, S decreases.
	Δ C	0 0	0	0	If PVA increases, both in MG and MS, S does not change.
	Δ H	0 0	+10R	-10R	If PVA increases, in MG, H does not change, while in MS, H at lower proportions of PVA approaches Red, while at higher

					proportions it approaches Yellow
M-07	Δ S	-10	0	0	If PVA increases, in MG, S decreases, while in MS, S remains unchanged.
	Δ C	-05	0	0	If PVA increases, in MG, C decreases, while in MS, C remains unchanged.
	Δ H	0	-10Y	0	If PVA increases, in MG, H moves away from Yellow to Green, while in MS, H remains unchanged
M-08	Δ S	-10	-10	-10	If PVA increases, both in MG and MS, S decreases.
	Δ C	-10	-10	0	If PVA increases, both in MG and MS, C decreases.
	Δ H	0	+10R	0	If PVA increases, both in MG and MS, H approaches Red
M-10	Δ S	0	0	-10	If PVA increases, in MG, S remains unchanged, while in MS, S decreases
	Δ C	0	-10	0	If PVA increases in MG, C does not change, whereas in MS, C decreases
	Δ H	-10R	0	0	If PVA

					increases, in MG, H approaches Yellow, while in MS, H remains unchanged
M-11	Δ S	0	0	-10	If PVA increases, in MG, S remains unchanged, while in MS, S decreases
	Δ C	0	0	0	If PVA increases, in MG, S decreases, while in MS, S remains unchanged
	Δ H	0	0	0	If PVA increases, both in MG and MS, H does not change
M-12	Δ S	-10	-10	0	If PVA increases, both in MG and MS, S decreases
	Δ C	0	0	0	If PVA increases, both in MG and MS, C does not change.
	Δ H	+50R	+10R	0	If PVA increases, both in MG and MS, H approaches red
M-13	Δ S	0	0	0	If PVA increases, both in MG and MS, S does not change
	Δ C	0	0	0	If PVA increases, both in MG and MS, C does not change
	Δ H	0	0	0	If PVA increases, both

					in MG and MS, H does not change.
		0	0	0	If PVA increases, both in MG and MS, S does not change.
	Δ S	0			
		0	0	0	If PVA increases, both in MG and MS, C does not change.
M-14	Δ C	0			
		0	0	-10R	If PVA increases, in MG, H does not change, while in MS, H approaches yellow
	Δ H	0			

Table 4. Comparison of results of variation in blackness, chromaticcness, and hue among samples based on percentages of polyvinyl acetate added at 20%, 40%, and 60%.

Graphic representation of the samples with more colorimetric variations

The study of the colorimetric properties of the samples, considering the MG-MS pigment extraction system and the variation in PVA content, has shown that there are generally minimal variations in hue (H), blackness (S), and chromaticness (C) in the NCS system. However, a number of samples exhibit somewhat more variation, specifically M-01, M-04, M-05, and M-07, which are illustrated in Figures 10 and 11.

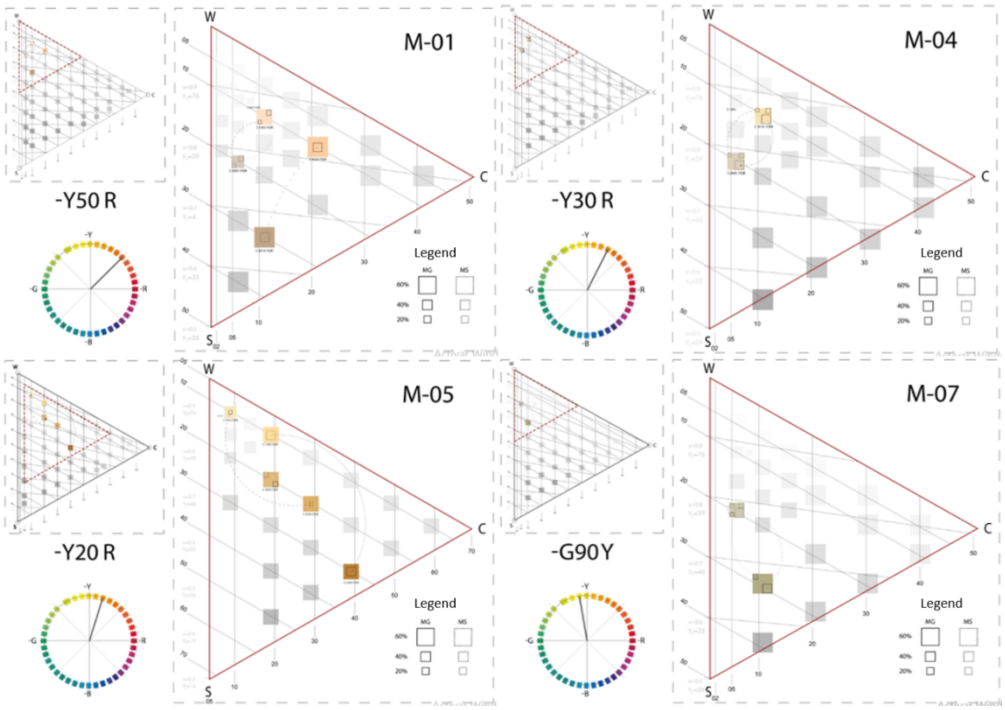

Figure 10. Colorimetric comparison of samples obtained through sedimentation (MS) or ball milling (MG), based on their PVA content at 20%, 40%, and 60%, indicating their hue, blackness (S), and chromaticness (C) in NCS.

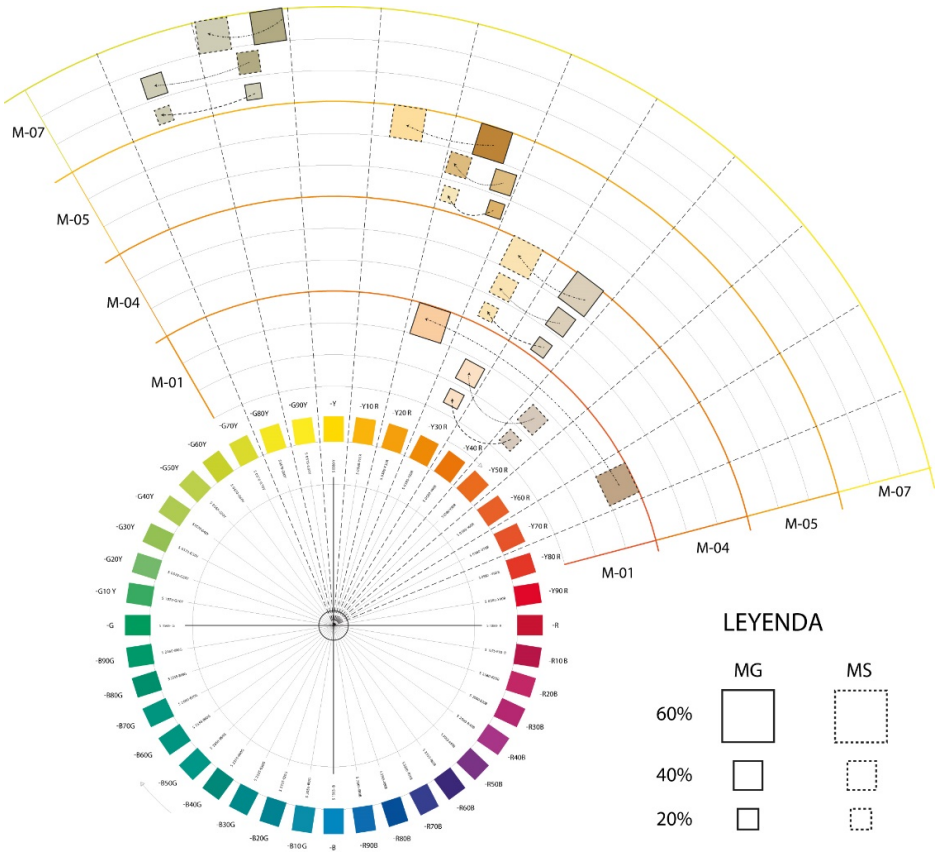

Figure 11. Color variation of the samples M-01, M-04, M-05 and M-07, according to NCS

CONCLUSIONS

In Cuzco, there is a rich and extensive tradition in the use of pigments derived from local soils, as evidenced in its pre-Columbian, colonial, republican stages, and currently as experiences of ecological and economic alternatives for the production of local artisanal paint.
Therefore, the objective of this research was to conduct a colorimetric characterization in NCS of the colors obtained from inorganic pigments extracted from the Cuzco valley in Peru, using two crushing methods (sedimentation and ball milling) and PVA as a binder in 3 proportions (20%, 30% and 40%). The methodology consisted of four stages: (1) identifying the characteristics and location of the quarries in the Cuzco valley, including registration processes and georeferential location, surface cleaning, and pigment extraction; (2) selecting and preparing the pigments by manual crushing to separate organic matter and inappropriate elements, which were subsequently divided into two forms of pigment extraction: one by sedimentation until passing through sieve number 4 (MS), and the second by ball milling sieved through mesh No. 200 (MG); finally, (3) producing the paint using polyvinyl acetate as a synthetic binder in proportions of 20%, 40%, and 60% applied to each type of pigment extraction in series of 3 repetitions, and (4) conducting colorimetric characterization in NCS. From the identification of the perceptual color characteristics of the paintings with natural pigments from the Cuzco Valley in NCS, it can be concluded that:

- Regarding NCS Hue: The identified hue primarily encompass the red-yellow range (Y20R to Y80R), with some exceptions in greenish hues (G90Y). This range highlights the predominance of iron and chromium oxides in the pigments used, which are on the roots of the warm and earthy colours characteristic of the Cuzco region.
- Regarding NCS blackness: Most of the samples analysed exhibit levels of blackness ranging from low to medium, with values fluctuating between 10% and 50% according to the nomenclature of NCS.
- Regarding NCS chromaticness: The samples present low to medium chromaticness, with values ≤30% in the NCS. This behaviour indicates that the colours obtained maintain a moderate character, suitable for applications seeking a balance between saturation and naturalness, while preserving a chromatic palette representative of the Cuzco environment and cultural heritage.

With regard to the pigment processing methods MS (sedimentation) compared to MG (grinding), we have observed that:

- Regarding hue: It is observed that in 56% of the samples, the color Hue remains unaltered by the pigment extraction methods MS or MG. MS tend to shift the hue towards yellow in 26% of the cases and to Red in18%.
- Regarding blackness: In 62% of the analyzed samples, no significant alterations in blackness were found due to the production method of the MS or MG pigment. However, variations were identified in the remaining 38%, with differences of up to ±20 ΔC. A slight trend towards increased blackness (+10 to +20 ΔC) was observed in 23% of the cases when using MS instead of MG.
- Regarding NCS chromaticness: In 59% of the analyzed samples (23 out of 39), no variation in chromaticness was observed (ΔC=0), indicating that the pigment production system MS or MG did not affect this parameter. However, in the remaining 41% (16 out of 39), variations were recorded: 21% of the samples (8 out of 39) exhibited a moderate change (ΔC=±5), 15% (6 out of 39) showed a more pronounced shift (ΔC=±10), and 5% (2 out of 39) presented the highest chromatic deviation (ΔC=±20). These results demonstrate that while chromatic stability is maintained in more than half of the cases, the pigment production system can induce measurable alterations in nearly half of the samples, with deviations reaching up to 20 chroma units.

With respect to the PVA content in paint formulations, we have observed that:

- Regarding hue: The influence of PVA on the hue depends both on the pigment extraction method and its intrinsic characteristics. In most cases (69.23%), the increase in PVA concentration does not result in significant variations; however, specific patterns are

identified. In samples M-01, M-03, M-06, M-10, and M-14 (19.23%), the pigments extracted by MS tend to shift towards yellow as the PVA content increases, while in MG, the hue remains stable. In contrast, in samples M-05, M-08, and M-12 (11.54%), both in MG and MS, the hue shifts towards red, indicating an intensification of warm hues with increasing PVA. A particular behaviour is observed in sample M-07 (3.85%), where in MG, the hue moves away from yellow towards green, while in MS, it remains unchanged. These findings suggest that the chromatic stability of the pigments in the presence of PVA is not uniform and is conditioned by both the extraction method and the pigment composition, highlighting the need for further studies to better understand these interactions.

- Regarding blackness: The findings suggest that the increase in PVA concentration generally does not alter the blackness in most samples (67.31%). However, in specific cases (28.85%), a reduction in blackness is observed, particularly in samples MG 3, 5, 7, 8, and 12, as well as MS 3, 6, 8, 10, 11, and 12, indicating a possible interaction between the polymer and certain pigments. In a smaller proportion of cases (3.85%), an increase in blackness occurs, suggesting that the effect of PVA may depend on the specific pigment composition. These variations highlight the need for further analysis to determine the underlying mechanisms influencing blackness.
- Regarding chromaticness: The increase in the concentration of PVA generally maintains the chromaticness in most samples, with 75% showing no variation. However, in 21.15% of cases when PVA increases, a decrease in chromaticness is observed, particularly in samples MG 1, 3, 5, 7, 8, and 11, as well as MS 2, 3, 8, and 10, suggesting a possible interaction between the polymer and specific pigments. Just in a very small proportion of cases (3.85%), chromaticity increases with PVA. Furthermore, this effect appears to be slightly more pronounced in the MS samples compared to MG, suggesting that the extraction method may influence the pigment's response to the polymer concentration.

Ultimately, not the pigment extraction method MS-MG neither the PVA content seem to significantly impact the majority of the colorimetric properties of the paints. However, slight variations in hue, blackness, and chromaticness were identified in specific cases. These differences, present in a smaller percentage of the samples, do not alter the overall consistency of the obtained colour palettes, which faithfully reflect the mineral richness of the pigments from Cuzco. The results confirm that both the processing method and the PVA content allow for the formulation of paints with a stable and representative palette, contributing to the recovery and enhancement of local chromatic heritage and offering practical applications in conservation and contemporary design.

The analysis of Cuzco's pigments transcends the technical to become a bridge towards understanding the history and cultural identity of the region. The colour palette obtained, translated into the standardized NCS system, not only allows for the cataloguing and preservation of traditional color ranges but also integrates them into contemporary projects that respect and reinforce collective memory. These colours, linked to the natural resources of the territory, represent a direct connection between architecture, landscape, and the social expressions of Cuzco, highlighting their relevance in the construction of a cultural identity. This study opens the door to future research that could explore the application of these pigments in new materials, advanced conservation techniques, or even their impact on the psychological and emotional perception of the built environment.

Acknowledgments

We extend our gratitude to the Carolina Foundation, the Polytechnic University of Valencia, and the Andean University of Cuzco for funding the doctoral scholarship that led to this contribution.

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