

Organic Stabilizers of Plant Origin in Archaeological Structures: Influence of Cactus Mucilage in the Making of Sacrificial Mortars

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Abstract

Today we have a wide variety of raw earth stabilizers, both of natural origin (animal, mineral or plant) and artificial. Thanks to them it is possible to provide greater stability to the earth that needs it, through physical, mechanical or chemical mechanisms. However, selecting the most suitable stabilizer for each type of earth remains a challenge, due to the variability in the nature of the substrate and its adaptation to climatic conditions. For this reason, it is essential to carry out previous studies and tests, both in the laboratory and in situ, that allow us to understand and optimize its properties. This research focuses on the use of plant-based stabilizers and their influence on the properties of raw earth. In particular, the effects of different mucilages from the plant species *Opuntia* spp., *Austrocylindropuntia subulata* (Mühlpfrdt. Backbg) and *Opuntia huaquapensis* (Bravo) are analyzed through experimental studies. The research includes, on the one hand, the laboratory evaluation of the adhesion capacity of these compounds on three types of supports: brick, raw earth and stone; and, on the other, field experimentation, where these substances have been integrated into mortars and coatings. The results of this study will contribute to the understanding of their potential as natural stabilizers in raw earth construction.

Keywords: natural mortars; biopolymer adhesion; earth stabilization; raw earth

1. Introduction

Raw earth constructions are structures especially exposed to severe deterioration because the materials they are composed of are easily degradable in nature. That is why, since ancient times, materials have been incorporated with the aim of stabilizing the earthy material.

Within the wide range of possible stabilizers for raw earth, the *Cactaceae* family has had a role of interest in the American continent (Alanís and Velasco, 2008).

Fortunately, many of these plant stabilizers have survived to our time, not only through archaeological evidence, but also through collective memory. This fact has demonstrated, among other characteristics, the sustainability and retratability that characterizes many of these natural materials.

However, the methodology and proportions of some of them may present a series of problems, mainly due to the lack of records. For all these reasons, for some decades now, within the field of heritage conservation and restoration, research

has been carried out both in the laboratory and in the field, with the aim of integrating these plant stabilizers as a more sustainable alternative.

2. Objective

The study presented here is part of a doctoral research, whose objective is the study of sacrificial mortars of earth added with mucilage of cactus species for its application in the conservation work of archaeological structures in the Cochasquí Archaeological Park, Ecuador.

Firstly, the evaluation of the earthy material prepared in the laboratory is presented and the adhesion resistance of raw earth mortars with the addition of mucilage from cacti: *Opuntia huaquapensis* (Bravo) and *Austrocylindropuntia subulata* (Mühlenpfordt) Backeb., together with reference mortars, is evaluated.

3. Methodology

3.1. Preparation of test tubes

3.1.1. Preparation of earthy material

To approach the characteristics of *chocoto* (earth rich in soil used in construction and its maintenance), commercial materials have been used.

3.1.1.1. Volcanic tuff

Volcanic tuff from Burés Profesional was used, with a granulometry that initially ranged between 0 and 6 mm.

The STD was subsequently screened in the laboratory of Architecture of the UPV to obtain a granulometry of less than 2 mm.

3.1.1.2. Clay material

The black refractory paste (PRNF) from the Barcelona company Sio-2 was selected. It contains 40% chamotte and particles ranging between 0-0.5 mm. Table 1 shows some interesting characteristics of this material.

Table 1 – *Technical data of interest* (O. Medina, 2024).

Refractory paste (PRNF)	
Humidity	Drying shrinkage
21%	7.0%

3.1.2. Incorporation of vegetable gums

The extraction system carried out to obtain the mucilage was by maceration at room temperature for 72 hours. This system was selected after the evaluation of the kinematic viscosity (η) at different temperatures and times (Medina, Carrascosa & Osete, 2022). The fragments and cladodes were collected from mature and healthy plants. Immediately upon collection, they were washed, de-thorned and peeled, using deionized water in a 1:1 (v/v) ratio for wood processing. Once the mucilage or gums were obtained, they were applied with their mother concentration, which we refer to as 100% and also at other dilutions: 75% and 50%.

3.1.3. Prepared test tubes

The specimens made of raw earth are grouped into three groups: the reference group (REF), the HUA group, and the group AUS in the proportions: 50, 75 and 100% (Table 2).

4. Instrumentation and evaluation tests

4.1. The earthy material intended for study

4.1.1. Granulometric study

The commercial tuff used had to be sieved to reach a maximum particle size of 2 mm, according to the characteristics of *chocoto* earth.

The granulometric study consists of separating the material into granulometric fractions by means of a series of sieves and their quantification by weighing. For this purpose, a total of 11 test sieves were used that meet the specific regulations for this purpose (Standards: EN 933-2, ISO 3310-1 and ISO 3310-2).

Table 2 – Test tubes studied (Medina, 2024).

Group	Subgroups	Acronym
1	Raw earth rich mixed with water	REF
2	Raw earth rich mixed with mucilage from <i>Opuntia huajuapensis</i> (Bravo), diluted 50% in water	HUA50
	Raw earth mixed with mucilage from <i>Opuntia huajuapensis</i> (Bravo), diluted 75% in water	HUA75
	Raw soil mixed with mucilage from <i>Opuntia huajuapensis</i> (Bravo), obtained directly from the maceration 1:1 (w/w)	HUA100
3	Raw earth mixed with mucilage from <i>Austrocylindropuntia subulata</i> (Mühlenpfordt) Backeb., diluted 50% in water	AUS50
	Raw earth rich mixed with mucilage from <i>Austrocylindropuntia subulata</i> (Mühlenpfordt) Backeb., diluted 75% in water	AUS75
	Raw earth rich mixed with mucilage from <i>Austrocylindropuntia subulata</i> (Mühlenpfordt) Backeb., obtained from the mash 1:1 (w/w)	AUS100

The mass of the particles retained in each of the sieves is represented as a percentage of the initial mass used. The values are obtained following the following formula where:

$$y = 100 \sqrt{t/D} \quad (1)$$

y = Represents the percentage that passes through the sieve of diameter t; t = It is the opening of the sieve and D = Maximum aggregate size.

These values are represented graphically to obtain the corresponding granulometric curve of the material.

4.1.2. Plasticity test

It consists of a very simple test that determines the quality of the earthy material, classifying it according to its properties in clay, sandy or clay-sandy earth. To carry it out, the material is moistened and molded into a cylinder with a diameter of 1.5 cm. It is then held in the air and the length of the detached fragment is measured. According to the length obtained, the material is classified into: sandy: 0 - 5 cm, sandy-clay: 5 - 15 cm and clay: 15 cm or more. For this study, three cylinders were made with different proportions of clay and volcanic earth: 1:2, 1:3 and 1:4 (v:v).

4.1.3. Dry strength test

It consisted of making a series of earth discs 3 cm in diameter and 1.5 cm thick. These were dried for 48 hours and subsequently broken manually to qualitatively estimate their fracture resistance. 5 discs were made in two different proportions of clay and volcanic earth: 1:2 and 1:3 (v:v).

4.2. Evaluation of the mechanical properties of earth blocks with and without the addition of mucilage

4.2.1. Determination of adhesion resistance

This laboratory test can evaluate the adhesive strength between earth test tubes with and without additives on different substrates: fired brick, raw earth and stone. In the following figure (Fig. 1) you can see the appearance of the test specimens.



Fig. 1 – Specimens made on raw earth supports. (Medina, 2024).

Table 3 – Fractions collected in each of the sieves (Medina, 2024).

Sieve	Retained weight	% Retained	% Retained Accumulated	% Passing	% Fuller
64	0,00	0,00	0,00	100,00%	100,00%
32	0,00	0,00	0,00	100,00%	100,00%
16	0,00	0,00	0,00	100,00%	100,00%
8	0,00	0,00	0,00	100,00%	70,71%
4	0,00	0,00	0,00	100,00%	50,00%
2	347,60	63,52	63,65%	36,35%	35,36%
1	126,10	23,09	86,74%	13,26%	25,00%
0,5	32,70	5,99	92,73%	7,27%	17,68%
0,25	12,40	2,64	97,16%	4,63%	12,50%
0,125	9,80	1,79	98,57%	2,84%	8,84%
0,063	7,70	1,41	99,84%	1,43%	6,27%
Tray	6,90	1,26		0,16%	0,00%
Final weight	545,20				
Initial weight	546,10				

To carry out the test, a layer of raw earth 1 cm thick was applied to each support and given a circular shape 5 cm in diameter. After drying, a 5 cm diameter metal disc or pad is adhered to the layer of earth using an epoxy resin. After the resin has cured, the disc is coupled to a Neurtek Instruments KN-10 adhesion meter with which a traction force is applied. This test ends at the moment in which the clay specimen detaches from the surface or fragments, recording the force used for this (kilograms of force) and the type of breakage: adhesive or cohesive, according to the specifications of the UNE-EN 1015-12:2016 regulations. The results are obtained using the following formula:

$$f_u = F_u / A \quad (2)$$

Where the adhesion resistance (f_u) is achieved through the relationship between the recorded breaking load (F_u) and the surface area (A), being expressed in Mpa.

5. Results and discussion

5.1. Granulometric study

As can be seen in Table 3, from the 8 mm sieve, 70% of the total screened weight is counted, approximately 50% and 35% in the 4 and 2 mm

sieves respectively. 25% of the particles are concentrated on the 1 mm mesh sieve. The following apertures corresponding to 0.5 mm, 0.25 mm, 0.125 mm and 0.063 mm collect 17.68, 12.5, 8.84 and 6.27% respectively. The sum of these percentages results in a granulometric modulation of 6.341%.

Figure 2 represents the granulometric distribution obtained for the tuff compared to the Fuller adjustment, which corresponds to an optimal granulometry to achieve greater compaction of the material, with a continuous distribution of particle sizes.

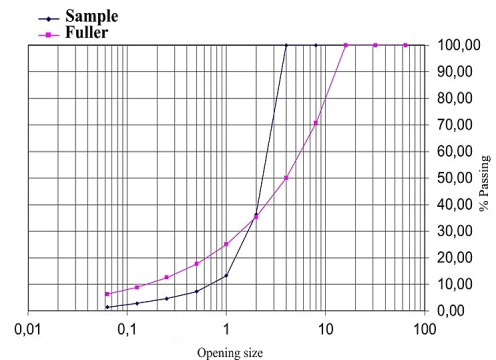


Fig. 2 – Distribution of the granulometry of the tuff to be experimented and comparison with the Fuller adjustment (Medina, 2024).

As can be seen, the analysis indicates that the granulometry of the tuff sample does not fit perfectly to the Fuller model. These imbalances indicate that the tuff is deficient in fines (clay), so the incorporation of these is necessary to achieve greater compaction of the material. Between 0.5 mm and 2 mm, the sample curve and the Fuller curve are quite similar, which indicates that in this fraction the material has a granulometric distribution closer to the theoretical model. From 2 mm to approximately 4 mm, the sample follows the trend of the Fuller curve relatively well, although with slight deviations.

5.2. Plasticity test

The results obtained from the cylinder corresponding to the 1:3 ratio (clay-tuff), were located between the clay and clay-sandy ranges, obtaining measurements between 14 and 15 cm. For the 1:2 ratio (clay-tuff), measurements greater than 16 cm were obtained, corresponding to a clay earth and in the 1:4 ratio (clay-tuff), within the sandy values.

5.3. Dry strength test

The discs could not be pulverized with fingers. It was also difficult to break them with one hand. Therefore, according to earth selection manuals (Morales et al., 1993 and Minke, 2008), they could respond to a medium-high resistance. This type of behavior would respond to the clay character of the earth. Regarding the proportions studied: 1:2 and 1:3 (clay:tuff), no appreciable differences have been found in terms of their dry mechanical behavior.

5.4. Determination of adhesion resistance

5.4.1. Adhesion on fired brick support

The results obtained on this support were previously published along with other trials (Medina & Carrascosa, 2022). However, to facilitate comparison with other media, the data recorded at the time is presented again below. The following graph (Fig. 3) represents the values in Mpa of three independent tests carried

out for each of the material types. As seems to be characteristic of this type of tested gums (Medina & Carrascosa, 2022; Medina et al., 2022), the results are very heterogeneous. Furthermore, the adhesion levels recorded are so weak that some test tubes do not reach the minimal sticking values (less than 0.05 Mpa).

The highest levels (0.06 MPa) correspond to both test tubes without mucilage (REF-1A) and other test tubes with different percentages, being: HUA100-2A, AUS50-3A, AUS75-1A and AUS100-3A. Regarding the lowest records, they are recorded for the test pieces: HUA100-2A, AUS50-1A and 2A and AUS100-1A. It should be noted that the most homogeneous behavior was that observed for the AUS50 specimens, which would indicate that the presence of 50% mucilage helps to homogenize the mechanical behavior of the material.

The type of breakage observed in all cases was cohesive failure, which consisted of the separation of the earth disks from the brick support, leaving remains of the earth mortars in the incisions of the latter. The specimens that left the most remains (the circumference of the discs is perfectly drawn) on the brick support were: the REF, AUS50 and AUS75 subgroups. With a more discontinuous shape, it is followed by HUA75 and AUS100. Regarding the HUA100 subgroup, specimens 1 and 3 leave very few remains, barely drawing the circumference and leaving few remains in the incisions of the brick. On the other hand, in test tube 2, traces of earth remain in all the incisions and the circumference of loose earth is perfectly drawn. Finally, the HUA50 subgroup is the one with the least traces of earth on the support.

5.4.2. Adhesion on raw earth support

In this case, a superficial breakage of the raw earth support occurs, even in the reference specimens. Furthermore, in the latter (REF-1A, 2A and 3A), they did not register any adhesion

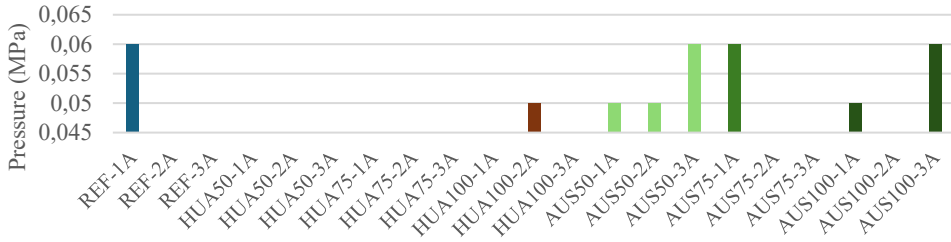


Fig. 3 – Results obtained from adhesion resistance on fired brick support (O. Medina, 2024).

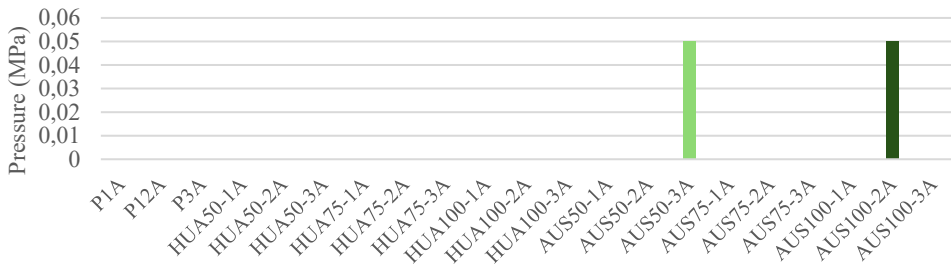


Fig. 4 – Results obtained on the adobe support (Medina, 2024).

strength, like the HUA family, made with the mucilage of the *Opuntia Huajuapensis* (Bravo) cactus. Strength values could only be recorded for two specimens of the *Austrocylindroopuntia subulata* (AUS) family: one made with 50% mucilage (AUS50-3) and another made with 100% mucilage (AUS100-2), both with 0.05 MPa (Fig. 4). The breaks observed correspond to superficial failures of the substrate, that is, the earthy support, without notable distinctions between the experienced groups.

5.4.3. Adhesion on raw earth support with a layer of mucilage

The incorporation of a layer of mucilage prior to placing the specimens on the surface of raw earth does not reveal significant changes either, as seen in Figure 5. Some values are recorded for two of the families studied and also in the reference specimens. In the latter, the REF-2A specimen reaches 0.05 MPa, compared to 0.06 MPa in HUA75-2A (*Opuntia huajuapensis*) and AUS75-3A (*Austrocylindroopuntia subulata*). Both

records coincide in the concentration of mucilage, being 75%. But like the previous case, the mortar-support adhesion values obtained must be higher than those recorded. This is because the support fails in the vast majority of discs, with the exception of the test specimens: HUA100-2, AUS100-2. HUA50-1 and REF-1, which could be considered 100% adhesive failures. The support failure occurs 100% in the specimens: AUS75-1, HUA75-1, 2 and 3 and REF-3. At 75% in the test pieces: AUS100-1 and 2 and AUS50-1. At 50% in the specimens: AUS100-3 and AUS75-2 and 3. For the rest of the specimens, the percentage of earth support removed after the test does not exceed 20%, so these breaks in the support make it impossible to know the exact results of adhesion resistance.

5.4.4. Adhesion on stone support

On a stone support, differences can be seen with respect to the other supports, since for the reference specimens (REF) no values are recorded in the equipment (indicative of a resistance lower than the minimum: 0.05 Mpa),

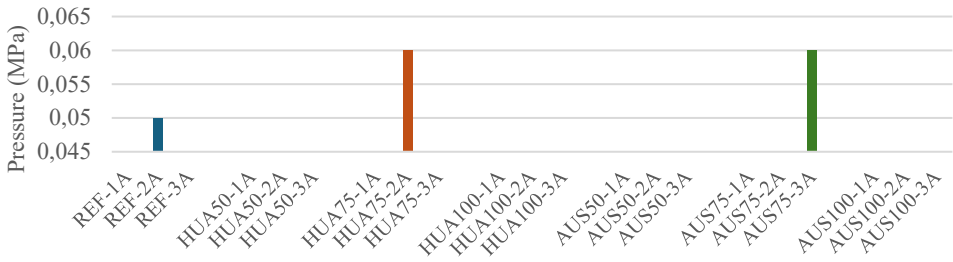


Fig. 5 – Results obtained on the adobe support with an intermediate layer of mucilage (Medina, 2024).

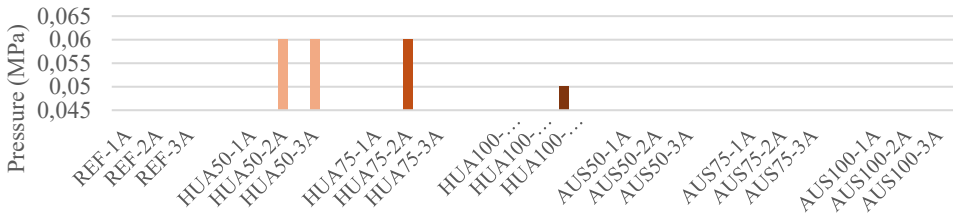


Fig. 6 – Results obtained on stone support with a layer of mucilage (Medina, 2024).

while for the specimens made with one of the mucilage families (HUA) numerical values of adhesion resistance have been recorded (Figure 6). In this case, two specimens at 50% (HUA50-2A and 3A) and one at 75% (HUA75-2A) are the ones that show superior resistance results (0.06 MPa) and HUA100-3A, the one with the lowest value (0.05 MPa). This suggests an increase in the internal cohesion of the material associated with the presence of mucilage. Regarding the separation of the clay discs from the support, some earthy particles from the discs can be seen in the latter, while in the mortar some whitish particles from the surface of the stone material can be identified.

6. Conclusions

The results obtained reflect the complexity of the interaction between plant stabilizers and the different supports analyzed. In general, the adhesion resistance of raw earth mortars added with mucilage has been low in all tests, although certain patterns have been identified that allow relevant conclusions to be drawn:

- Influence of the granulometry and plasticity of the material: The volcanic tuff used does not completely fit Fuller's theoretical model, which could have affected the cohesion and compaction of the material. However, the plasticity tests show that the 1:3 ratio (clay-tuff) presented intermediate values between clay and clay-sandy plasticity, suggesting that this ratio could optimize the workability of the mortar.
- Mechanical behavior of dry mortars: The mortar discs demonstrated a medium-high dry strength, without significant differences between the proportions of clay evaluated. This suggests that the cohesion of the material depends to a greater extent on the granulometric composition and the drying process than on the type of stabilizer added.
- Adhesion resistance on different supports, Burnt brick: The highest adhesion values were obtained compared to other supports, although the results were heterogeneous. The breaks were cohesive, in the brick and stone supports,

which indicates that the internal resistance of the mortar is lower than its adhesion capacity to the support.

- Adhesion resistance on different supports, Raw earth: Adhesion was significantly lower and no resistance values were recorded in most of the specimens, except in some formulations with *Austrocylindropuntia subulata*, which could suggest a slight improvement in the internal cohesion of the mortar. In this case, the earth support has few remains of the mortar, and the mortar has superficial remains of the stone support attached.
- Adhesion resistance on different supports, Stone: Only mortars with *Opuntia huajuapensis* showed measurable adhesion values, although these were very low. With the incorporation of a layer of mucilage, no significant improvements in adhesion were observed, although the specimens with a concentration of 75% of mucilage recorded slightly higher values.

Regarding the effects of mucilage on adhesion, although previous studies have pointed out the stabilizing potential of cacti mucilage, in this work its effect on adhesion has been limited and highly variable.

It was observed that the specimens with 50% mucilage showed a more homogeneous behavior, which suggests that this concentration could favor a better distribution of the stabilizer within the mortar.

7. Final considerations

The results suggest that, although mucilages from *Opuntia huajuapensis* and *Austrocylindropuntia subulata* can influence some properties of raw earth mortars, their effect on adhesion is limited. The variability in the results can be influenced by factors such as the heterogeneity of the material, the texture of the supports and the variability in the collection and processing of mucilage.

To improve the effectiveness of these stabilizers, it is recommended to carry out additional studies by adjusting the granulometric composition of the mortar and exploring other application methods.

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References

- Medina, O., & Carrascosa, B. (2022). Evaluación de la resistencia mecánica de morteros de tierra cruda estabilizados con gomas obtenidas de plantas de la familia cactaceae. In O. Rodríguez & A. Jiménez (Coords.), *Adobes & cia. Estudios multidisciplinares sobre la construcción en tierra desde la prehistoria hasta nuestros días* (pp. 177–186). Editorial Universidad de Sevilla.
- Medina, O., Carrascosa, B., & Osete, L. (2022). Effects of the use of the plant mucilage on the physico-mechanical properties of raw earth structures. In C. Mileto, F. Vegas, V. Cristini, & L. García-Soriano (Eds.), *Vernacular Heritage: Culture, people and sustainability* (No. 2, pp. 987–994). Editorial Universitat Politècnica de València.
- UNE-EN 933-2. (2022). *Parte 2: Determinación de la granulometría de las partículas. Tamices de ensayo, tamaño nominal de las aberturas. Ensayos para determinar las propiedades geométricas de los áridos*. AENOR.
- ISO 3310-1. (2016). *Test sieves. Technical requirements and testing. Part 1: Test sieves of metal wire cloth*.
- ISO 3310-2. (1990). *Test sieves. Technical requirements and testing. Part 2: Test sieves of perforated metal plate*.
- UNE-EN 1015-12. (2016). *Parte 12: Determinación de la resistencia a la adhesión de los morteros de revoco y enlucido endurecidos aplicados sobre soportes. Métodos de ensayo de los morteros para albañilería*. AENOR.