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Use of prickly pear (nopal) mucilage in construction applications: research and results

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Abstract

Research on building materials is progressively moving towards the use of more environmentally friendly solutions, with the aim of mitigating the environmental impact of the building sector. This sector, in fact, contributes significantly to global carbon dioxide emissions, being responsible for 37% of emissions globally and 40% in Europe, according to recent data from the Global Buildings Climate Tracker (GBCT). The main objective is to reduce the use of polluting materials, replacing them with alternatives with a lower environmental impact, or improving the performance of traditional materials through the use of natural additives that reduce the use of chemically synthesised substances [1].
In this context, prickly pear mucilage (Nopal), a product of the normal metabolism of mucilaginous cells in the parenchyma of cladodes and other parts of the plant, which has the physiological function of water retention, emerges as a promising natural additive for the formulation of mortars. Several international studies have investigated the application of Nopal in construction materials, highlighting significant improvements in the mechanical, physical and durability properties of mortars and concrete. The use of Nopal mucilage has shown positive effects on the plasticity of pastes, on mechanical resistance, on the reduction of capillary absorption and on the increase in the durability of materials.
This research aims to analyze and summarize the results of the main international experiments on the use of Nopal mucilage as an additive in mortars. Through the identification and analysis of studies conducted globally, we want to understand the potential of this natural material in improving the performance of mortars and in contributing to sustainable development in the construction sector. The results obtained highlight how the integration of Nopal in mortars can represent an effective and sustainable solution, paving the way for further applications and future research in this field.

Keywords
[Sustainable Construction, Biopolymers, Natural Additives, Prickly Pear Mucilage, Nopal, Mortars]

In construction systems, additives are generally defined as products of natural or synthetic origin which, added in small quantities before or during the mixing process, can improve workability, compressive strength, and durability of structures under extreme climatic conditions. Throughout history, additives have varied greatly, as have the techniques for their use, and they have been employed for different functional properties, such as stabilizers, consolidants, adhesives, and binders. Humans have generally always resorted to using materials available in their surrounding environment, such as vegetable gums, tree resins, honey, rice starch, and extracts of mallow leaves and stems.
One of the main advantages of using materials of plant origin lies in their biodegradable qualities, non-toxicity, low cost, the renewability of the resources, and their local availability.

Among the materials being considered as additives for mortars, products of natural origin derived from cacti of the genus Opuntia (commonly known as Nopal or prickly pear), such as mucilage and gum, are recently emerging.

Mucilages and gums have some similarities: they are hydrocolloid substances, amorphous, translucent, and contain monosaccharides, many of which combine with uronic acids. Mucilage, of metabolic origin, forms inside the cells of the prickly pear cladodes (commonly known as "pads") and is produced without harming the plant, while gum is considered a pathological product, formed after the plant has suffered damage due to unfavorable conditions, such as drought or the rupture of cell walls [2]. Both substances present similarities: they are hydrocolloids, amorphous and translucent substances, and contain monosaccharides that combine with uronic acids. They have hydrophilic molecules that can combine with water to form viscous solutions or gels (Jani et al., 2009).

Nopal mucilage is insoluble in organic solvents, alcohols, and ether, and when hydrolyzed, it breaks down into complex organic acids, pentoses, and hexoses [3].

Nopal gum, on the other hand, is mainly composed of complex polysaccharides derived from the degradation of cellulose and hemicellulose in damaged cell walls. This degradation is often caused by environmental or biological stress, such as pest attacks or adverse climatic conditions [2].

Interest in extracting and using prickly pear mucilage as a natural additive is also linked to the possibility of enhancing the value of agricultural waste generated by the cultivation of the plant. In particular, in regions such as Sicily, during the "scozzolatura" phase—a specialized pruning aimed at delaying fruit ripening to obtain a late production—significant quantities of cladodes are generated that require disposal. It is estimated that this operation produces about 6–10 tons of material per hectare, creating an additional burden for the farmer. The use of these residues as a source of mucilage would thus transform a waste product into a useful resource for the construction sector, integrating a circular approach into the production chain and helping to reduce the overall environmental impact of the process [4].

Furthermore, the use of natural materials such as mucilage and gum derived from Nopal offers several advantages, including environmental sustainability, thanks to their biodegradability and non-toxicity, and economic benefits due to their low cost and local availability.

Moreover, the integration of these additives can contribute to improving the mechanical and physical properties of construction materials, while simultaneously promoting more sustainable building practices

1.Extraction processes of Nopal mucilage and gum (AF)

Nopal mucilage and gum, as previously mentioned—originating respectively from metabolic and pathological processes of the Opuntia ficus-indica plant—are substances of great interest for their functional properties in construction materials. Both are hydrocolloids capable of forming viscous solutions or gels, but they differ in chemical composition and extraction methods.

Thanks to its solubility in hot water and gelling properties, mucilage is ideal for improving the cohesion and plasticity of mortars. Gum, with its more complex composition, can provide different characteristics, such as greater resistance to water penetration or improvements in durability.

1.1 Extraction of Nopal mucilage

Mucilage is a viscous substance naturally secreted by Nopal cells without harming the plant. It is a highly branched, fibrous heteropolysaccharide with a molecular weight of about 13×10⁶ g/mol.

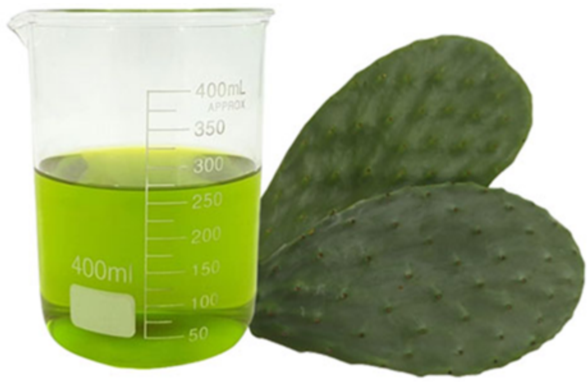
Its composition is primarily D-galactose (20–25%), L-arabinose (35–40%), D-xylose (20–25%), L-rhamnose (7–8%), and galacturonic acid (7–8%) [5].

Thanks to its viscoelastic properties, Nopal mucilage is considered important in the food industry for its ability to form molecular networks and retain large amounts of water.

It also modifies properties such as viscosity, elasticity, texture, and water retention, and it is an excellent gelling, thickening, and emulsifying agent.

The process of extracting mucilage involves the following steps:

1. Cladode harvesting: Young and mature Nopal pads are selected, as mucilage content varies with age and environmental conditions [5].
2. Cleaning: Removal of spines, dust, and impurities to ensure material purity.
3. Cutting and preparation: The cladodes are cut into small pieces to increase the contact surface area.
4. Maceration in water: The pieces are immersed in distilled water at a typical weight-to-volume ratio of 1:2 or 1:3. Maceration lasts from a few hours up to 48 hours.
5. Agitation and heating (optional): Gentle agitation or heating at controlled temperatures may be applied to facilitate extraction.
6. Filtration: The mucilaginous solution is separated from solid residues using filters or sieves.
7. Purification: Any impurities are removed through centrifugation or decantation.
8. Storage: The extracted mucilage can be used immediately or dried for long-term storage.



1.2 Extraction of Nopal gum

Nopal gum forms in response to stress or damage to the plant, such as drought or pest attacks, which cause the rupture of cell walls and the subsequent degradation of cellulose and hemicellulose. Gum is mainly composed of complex polysaccharides, including D-glucose, D-galactose, L-arabinose, L-rhamnose, and glucuronic acid. The gum extraction process is more complex and requires attention to preserve its properties [7]:

1. Identification of affected plants: Plants showing signs of stress or damage, from which gum is exuded, are identified.
2. Gum collection: The gum appears as solidified exudates on the surface of the cladodes. It is collected manually, ensuring that no unwanted plant parts are included.
3. Cleaning: The collected gum is cleaned of external impurities such as dust or plant fragments.
4. Dissolution in water: Unlike mucilage, gum may be less soluble in hot water. Room temperature or slightly warm water is used, possibly with the addition of solubilizing agents.
5. Prolonged agitation: The mixture is stirred for an extended period, ranging from a few hours to several days, to facilitate the dissolution of polysaccharides.
6. Filtration: As with mucilage, filtration is carried out to remove solid residues.
7. Purification: Additional purification steps may include dialysis or selective precipitation with alcohol to remove low molecular weight substances.
8. Drying: The gum solution can be dried to obtain a powdered product, making it easier to measure and incorporate into mixtures.

2. Traditional uses (FF)

According to Gómez (2002), the use of Nopal and its derivatives dates back more than 25,000 years, when humans settled in what is now Mexico [8]. Nopal has represented a fundamental component of Mexico's culture and history, the world's leading producer of this plant, not only in the culinary field but also as a key element in the development of various products. The properties of Nopal mucilage have been exploited in Mexico since pre-Hispanic times for its ability to retain water, interact with fatty substances, and exert a certain emulsifying power; these properties continue to be researched for their potential application, among other areas, in food, medicine, cosmetics, or environmental remediation [9]. It is known that since pre-Hispanic times, Mesoamerican cultures recognized the nutritional and medicinal qualities of the cactus, upon which many of their customs were based. It is likely that, as hunters and gatherers, the ancient peoples of Mexico included Nopal as part of their diet. Excavations carried out in Tehuacán, Puebla, have revealed prickly pear seeds and peels as well as fossilized Nopal fibers. The mucilage extracted from young pads, for example, was used to prepare refreshing and nutritious beverages. Thanks to its ability to form gels and retain water, mucilage was employed as a natural thickener in soups, sauces, and other traditional dishes. It also helped improve the texture of foods and extend their shelf life [10].

In traditional medicine, Nopal mucilage was used for its emollient, anti-inflammatory, and healing properties. It was typically applied to treat burns, wounds, and skin irritations, thanks to its ability to form a protective barrier and promote tissue regeneration. In addition, the ingestion of mucilage was recommended to alleviate gastrointestinal problems such as gastritis, ulcers, and constipation, acting as a soothing agent for internal mucous membranes [11].

The moisturizing and emollient properties of Nopal mucilage also led to its use in traditional cosmetic preparations. It was incorporated into lotions and creams to hydrate the skin, prevent dryness, and reduce signs of aging. In addition, it was used to treat skin problems such as acne and dermatitis, thanks to its antibacterial and anti-inflammatory properties [12].

In Mexico, Nopal mucilage was also traditionally used as a clarifying agent in water intended for consumption. Thanks to its flocculating properties, it can aggregate suspended particles and sediments, facilitating their removal and improving water quality. This natural purification method was particularly important in rural communities with limited access to clean water sources. By the same principle, in agriculture, mucilage was used as a natural agent to improve the soil's water retention. Applied to arid soils, it helped conserve moisture, promoting the growth of crops under adverse climatic conditions. Moreover, it served as a coating for seeds, improving germination and protecting them from pests and diseases [13].

Nopal fibers, combined with mucilage, were also used in the artisanal production of paper and textiles. The mucilage acted as a natural binder, improving fiber cohesion and conferring strength and flexibility to the resulting materials, which were particularly appreciated for their quality and durability [14].

3. Traditional applications in construction materials (FF)

Historically, pre-Columbian civilizations exploited the properties of Nopal gum and mucilage in construction materials: the ancient populations of central Mexico used the juice of the Opuntia ficus-indica cactus in lime-based stucco and mortar formulations [15]. The mixing of these materials dates back 900–1,500 years before our era, with the aim of waterproofing historic buildings.

In Mexico, Nopal mucilage has also traditionally been used in combination with lime because it enhances its adhesive properties and improves its water resistance. Thanks to its adhesive properties, it was used in a manner similar to plaster on adobe and brick walls, as well as a water barrier in stuccos. Pioneering studies by Diana Magaloni in the 1990s indicated that the excellent state of preservation and the brilliance of the pigments in many pre-Hispanic mural paintings could be attributed precisely to the presence of mucilage in the lime [16].

The traditional practice of using prickly pear mucilage as an additive in mortars has been and still is employed to improve the mortar's properties in terms of plasticity, setting time, ductility, and strength. Moreover, it is used as a waterproofing agent, as a reinforcing material in brick production, and as a fixative for pictorial coverings in mural paintings, thanks to its adhesive and cohesive properties.

Nopal mucilage is still used today in the production of ecological paints for the conservation of archaeological heritage. At the INAH, restorers, archaeologists, and architects have recently applied Nopal mucilage as a waterproofing agent for walls and roofs in archaeological areas and historic monuments. The Ministry of the Environment recommends Nopal mucilage as a natural waterproofing agent for walls and roofs of historic monuments, and the Instituto Nacional de Antropología e Historia (INAH) allows the addition of Nopal extract to lime-based mortars for the restoration of historic monuments.

In light of these traditional uses and the beneficial properties attributed to Nopal mucilage and gum, numerous scientific experiments have been conducted to evaluate the effectiveness of these materials as additives in construction mortars. In the following chapter, the most significant studies published in international scientific journals will be examined, investigating modern applications of Nopal mucilage and gum in mortar formulations and other construction materials.

4. Studies and results on the use of Nopal mucilage and gum in the building sector

The use of Nopal mucilage and gum as natural additives in construction materials has been the subject of numerous experiments over the years. These experiments, in line with the traditional uses described above, aimed to improve the mechanical, physical, and durability properties of mortars, adobe, and concrete. These studies confirm the historical knowledge on the use of Nopal, while at the same time providing new perspectives for the conservation of architectural heritage, construction, and the development of more sustainable materials.

Lime mortars (FF)

The results of many studies have confirmed that the addition of Nopal improves the plasticity of the mixtures and helps retain moisture for a longer period, resulting in a slower setting process and more uniform carbonation. According to Magaloni, the monosaccharides in the mucilage promote the increased solubility of calcium hydroxide, which allows for the homogeneous and compact crystallization of calcium carbonate [17].

Diana Magaloni and Tatiana Falcón have also identified the presence of Nopal plant gum as a binder in the mural paintings of various tombs in the archaeological sites of Monte Albán and Suchilquitongo in what is now the state of Oaxaca [13]. Further confirmation comes from studies by Rodríguez-Navarro et al. [18] and Pérez et al. [19], which have noted an improvement in the plasticity of lime pastes with added Nopal mucilage, as well as greater resistance to erosion. Pérez et al., in particular, observed that the addition of Nopal pectin reduces cracking and capillary absorption, increasing the mechanical strength of the mortars. Without the additive, the mortar had an average flow diameter of 160 mm; with the addition of Nopal mucilage, the diameter increased to 175 mm. This ~9% increase in spread indicates greater plasticity of the mixture.

Jáidar [20] used plant extracts in lime mortars and noted that applying the additive after hydrating the lime is more effective, as capillary absorption and water vapor permeability are reduced.

The control mortar, without additives, reaches the initial set time in 90 minutes, while the mortar with plant additive takes 110 minutes. This 20-minute increase quantifies the slowing down of the setting process, indicating more effective water retention and potentially more uniform carbonation.

Pérez et al. [20] conducted research aimed at reducing the curing time of hydrated air lime through the use of Nopal mucilage as an additive. The mucilage was prepared by extraction through high-temperature (90 °C) maceration and constant agitation for 30 minutes, thereby ensuring the solubilization of polysaccharides and the formation of a homogeneous gel.

Chemical investigations into the interaction between mucilage and calcium, conducted through ζ (zeta) potential measurements, acid-base and redox titrations, have shown that the galacturonic acid contained in Nopal pectins plays a key role in the formation of stable chemical complexes with lime. This complexation enhances the reactivity and availability of calcium for the carbonation process, improving the kinetics of hydration and the subsequent formation of carbonate phases.

The experimental samples included aqueous solutions of cactus mucilage at concentrations of 20%, 60%, and 100%, compared to a reference system hydrated by the traditional method (100% aqueous solution without mucilage). Comparative analyses on pastes and mortars, using X-ray diffraction (XRD) and scanning electron microscopy (SEM), confirmed not only an acceleration of the carbonation process, but also improved rheological and mechanical behavior. In fact, the addition of mucilage makes the structure denser and more homogeneous, reduces capillary absorption, and acts as a catalyst in the transformation of lime, minimizing the need for prolonged resting periods of lime putty [21].

Regarding chemical and rheological properties, Rodríguez-González et al. (2021) point out that the thickening and film-forming properties of the mucilage depend on the sugar composition, variety of the cladode, its age, and soil pH. This makes the material extremely adaptable and versatile. However, despite the mucilage's ability to modify the microstructure of lime mortars, no true formation of stable gelling networks is observed, suggesting that the mechanism of action is more complex than a simple gelling process.

Plaster, Clay, and Raw Earth (AL)

Mixtures based on Nopal mucilage combined with plaster and clay have also demonstrated significant mechanical properties. In particular, the study by Perez J. et al. (2022) focused on the application of various stabilizers to clay matrices with the aim of enhancing their mechanical performance. The prepared specimens were subjected to a curing period of 14 and 50 days, after which compression, direct tension, and flexural strength tests were conducted, along with the measurement of ultrasonic pulse velocity (UPV).

The results showed a significant improvement in the mechanical behavior of the mixtures stabilized with plaster and Nopal mucilage, outperforming the control sample in all the experimental tests considered. The evaluation using UPV also revealed greater internal homogeneity of the matrix, indicative of better cohesion and distribution of components. Despite some variability in the behavior of all stabilizers and significant volumetric changes, the experimental evidence indicates that the addition of Nopal mucilage plays a crucial role in increasing the mechanical strength of clay mortars, providing greater robustness and structural uniformity to the material [20].

Adobe and Raw Earth Masonry (SB)

Significant examples of experiments conducted on adobe masonry—i.e., structures made with raw earth—highlight the potential benefits of using vegetal mucilages, including Nopal, in optimizing their physicomechanical characteristics.

In particular, Medina et al. [3] experimented with the use of vegetal gums in adobe, observing a reduction in the water vapor permeability coefficient and an increase in abrasion resistance, using standardized abrasive surface wear tests.

Before applying Nopal mucilage to eroded surfaces, Martínez-Camacho et al. [22] used an alcohol/water solution to lower the liquid's surface tension and facilitate the penetration of mucilage into the porous adobe matrix. This approach allowed for the optimized diffusion of the additive into the surface layers, improving the material's stability and cohesion.

Finally, Torres et al. [23] demonstrated the effectiveness of spraying diluted Nopal mucilage to consolidate friable adobe surfaces. The application led to increased surface stability, as evidenced by surface adhesion tests or microindentation, highlighting the potential of this additive as a natural consolidating agent.

Céspedes and Rivera evaluated the use of Nopal mucilage for the production of artisanal bricks, achieving an increase in compressive strength compared to non-additized bricks from 92.0 kg/cm² to 98.1 kg/cm² [24].

Concrete and Cementitious Mortars (SB, AL)

In the self-compacting concrete (SCC) sector, the research conducted by Ordaya [25] has shown that the introduction of Nopal mucilage into fresh SCC results in a significant increase in flowability, a reduction in blocking resistance, and an improvement in self-leveling compared to the control sample. These effects suggest that Nopal mucilage acts as a natural plasticizer, optimizing the rheological properties of the mixture and facilitating the achievement of the functional requirements of SCC during placement.

Regarding the mechanical properties of hardened concrete, Ordaya also observes that, for mucilage dosages of 0.3%, 0.5%, and 0.7% by weight of cement, compressive strength experiences a slight decrease compared to the standard sample. However, performance remains above the minimum design values, ensuring compliance with structural requirements. Based on experimental evidence, it can be stated that the natural additive maintains its plasticizing function up to dosages of 0.3%, while increasing the concentration to 0.5% performs a role comparable to that of a superplasticizer. In this way, Nopal mucilage proves to be a multifunctional additive capable of optimizing the workability of concrete without significantly compromising its mechanical performance.

Martinez Molina et al. [26] also developed cement-based mortars integrated with dehydrated additives based on Nopal and Aloe Vera to evaluate the effect of these vegetal materials on the physical performance and durability of the conglomerate. The mixtures, prepared with different replacement percentages (0%, 1%, 2%, and 4%) relative to cement, were subjected to a series of experimental tests aimed at objectively defining their properties.

Among the characterization methods adopted were:

- Determination of total void content, through porometric analysis, to understand the impact of additives on the microstructure of the cement matrix;
- Compressive strength measurement, according to standardized procedures (e.g., EN 12390-3), to evaluate the effect of replacement materials on mechanical characteristics;
- Ultrasonic wave propagation, to analyze the density and internal homogeneity of the specimen, as well as any defects or microcracks, using standards such as ASTM C597;
- Electrical resistivity under saturation conditions, to investigate the mortar's ability to resist ionic current passage, thereby assessing the likelihood of reinforcement corrosion phenomena and long-term durability.

The results highlighted that the use of dehydrated Nopal showed higher potential than Aloe in improving the physical characteristics of the mortar, reducing porosity, increasing mechanical strength, and providing greater long-term durability. These observations indicate that the addition of dehydrated Nopal can be considered a promising strategy for optimizing the performance of cement-based mortars, promoting more sustainable approaches in the use of natural resources in construction [27].

In the study by Darwin Sergio Agüero-Hualcas et al. [28], the influence of adding Nopal (N) and Aloe Vera (AV) extracts on the physical and mechanical properties of structural concrete exposed to saline environments was analyzed. The replacement percentages, based on the weight of cement, were as follows: Nopal at 2%, 6%, and 10%; Aloe Vera at 0.5%, 1.5%, and 3%; combined mixtures of Nopal + Aloe Vera at 2%N + 0.5%AV, 6%N + 1.5%AV, and 10%N + 3%AV.

Experimental results showed that the optimal mixture, in terms of mechanical properties, was the one with 2%N + 0.5%AV. This combination achieved a compressive strength of 443.4 kg/cm² at 28 days and 445.4 kg/cm² at 56 days, as well as a tensile strength of 41.4 kg/cm² at 28 days. Flexural strength also showed higher values, with 66.4 kg/cm² at 56 days and 70.9 kg/cm² at 90 days. Additionally, the concrete's corrosion resistance was improved, with a maximum reduction in corrosion rate of 0.22 mm/year. The use of this combination of additives resulted in a more compact cement matrix, reducing the carbonation rate and increasing durability and strength over time.

The analysis of rheological behavior (via slump test) showed that, with increasing percentages of extracts, the mixture becomes progressively more workable. Concurrently, the measurement of the concrete's unit weight exhibited a decreasing trend compared to the control mixture, in accordance with regulatory specifications, indicating a reduction in overall density in favor of better workability of the mixture.

From a mechanical standpoint, the mixture additive with 2%N, 0.5%AV, and the combination 2%N+0.5%AV showed the most favorable results. Compared to the control, compressive strength increased by 70.34% at 28 days and by 38% at 56 days; tensile strength grew by 43.25%, while flexural strength increased by 36.33% at 56 days and by 32.37% at 90 days.

The evaluation of the carbonation phenomenon revealed particularly positive results, with a significant reduction in the carbonation front advancement rate compared to the standard mixture. The formulation with 2%N+0.5%AV showed a lower carbonation rate, equal to 0.04 mm at 90 days and 0.08 mm at 180 days, indicating a lower potential degradation of the reinforcement in the long term.

It was therefore possible to define optimal percentages for each extract and their combination: 2% for Nopal, 0.5% for Aloe Vera, and 2%N+0.5%AV for the hybrid mixture. These proportions ensure an improvement in workability, mechanical characteristics, and a significant reduction in carbonation rate.

Experimental results suggest that the use of Opuntia ficus-indica and Aloe Vera in cementitious structural systems exposed to aggressive environments (such as saline ones) can provide a natural and effective solution to increase the corrosion resistance of concrete and the steel within it, while simultaneously enhancing the mechanical performance and durability of structures [28].

Giovene Perez Campomanes et al. conducted a study aimed at evaluating the effect of adding Nopal mucilage (6% by weight of cement) on the mechanical properties and impermeability of concrete blocks, using computer tools (TIA Portal, Factory IO) and adopting the Peruvian technical standard E-070 for performance characterization.

Experimental results showed a significant increase in compressive strength, reaching 101.81 kg/cm², equivalent to an increase of 61.65% compared to the control material. This improvement is attributable to the favorable chemical-physical interaction between Nopal mucilage and the cement matrix, which optimizes the microstructure of the block.

Regarding water absorption, the addition of mucilage resulted in a reduction of up to 21.81%, bringing the overall absorption down to 8.14%. This effect is due to the formation of oxalates derived from the mucilage, which provide a protective barrier against atmospheric agents and limit the entry of moisture into the porous structure.

From a regulatory standpoint, blocks additive with 6% mucilage far exceed the minimum requirement of 50 kg/cm² set by the Peruvian standard E-070, making them a competitive solution for constructing homes in rural areas. The increase in material density, observed following the reduction in pore content, further confirms the beneficial effect of the additive on the compactness and durability of concrete blocks [29].

Torres-Acosta et al. analyzed the effect of adding Nopal gel to concrete by partially replacing the mixing water with varying percentages (4%, 8%, 15%, and 30%) of mucilage. Durability tests were conducted over extended time intervals (30, 90, 180, and 400 days) and included evaluations of saturated electrical resistivity (ρS), total void content (TV%), capillary absorption (effective porosity, εEF), compressive strength (fc), and rapid chloride permeability (RCP), along with SEM micrographic analyses. The use of mucilage derived from Nopal exudates (eNm) led to a significant increase in the durability index (up to 20%), with a reduction in TV% and εEF and an increase in the ρS/fc ratio. Additionally, the RCP index was reduced by up to 30%, indicating lower chloride penetration and, consequently, greater resistance to reinforcement corrosion [30].

Experiments on the Use of Mucilage as a Water Repellent and Anti-corrosive (SB, AL)

The use of Nopal mucilage and gum as water repellents and waterproofing agents is confirmed by several experimental studies, which highlight how these natural additives can enhance the durability and resistance of materials against moisture.

The study by Demetrio Castelán Urquiza et al. (2022) focused on creating a prototype waterproofing agent based on Nopal mucilage to be applied to construction materials (e.g., red clay bricks) to reduce internal moisture in buildings. Various mix designs were tested, involving the addition of water, alum stone, lime, soap, and/or salt. The most performing mixture, containing Nopal mucilage, water, alum stone, lime, and soap, achieved an average water absorption of only 4.33%, thanks to the formation of sealed pores that limit the material's permeability. Conversely, the absence of alum stone in other formulations resulted in higher absorptions (6.83% or 7.50%), confirming the importance of this component in reducing moisture penetration [31].

Carolin Ivette Rocabruno Valdés et al. (2019) analyzed the influence of adding Nopal mucilage on the electrochemical properties of reinforcing steel in concrete, testing three different mucilage concentrations with Nopal-water ratios of 1:1, 1:2, and 1:3. The specimens were subjected to compressive tests after 28 days of curing, while the electrochemical properties were monitored up to 270 days through open-circuit potential (OCP) measurements, electrochemical noise (EN), and linear polarization resistance (LPR).

The results indicated a reduction in compressive strength in the samples containing Nopal mucilage at 28 days. However, on the electrochemical side, the initiation of the corrosion process on the steel was delayed, and the corrosion rate was lower in the additive-containing samples compared to the control. The mixture with a 1:3 Nopal-water ratio stood out for higher compressive strength values. Furthermore, during the curing process, all samples with Nopal mucilage exhibited comparable trends, showing a rapid increase in noise resistance (Rn) and polarization resistance (Rp) values. These parameters suggest that the presence of mucilage ensures internal conditions that favor the passivation of steel, maintaining the corrosion rate between negligible and low throughout the duration of the test.

The correlation between Rn and Rp data, characterized by a coefficient of 0.695, confirms the consistency of the electrochemical measurements and the validity of the analysis. The sample with a 1:3 Nopal-water ratio recorded the best electrochemical performance, with an efficiency of 86%, achieved through a mucilage maceration process for 48 hours with heating at 95 °C. These results demonstrate the ability of Nopal mucilage to slow the initiation of corrosion and maintain optimal conditions for steel protection in concrete, opening up interesting prospects for the use of natural additives in the durability of infrastructures [32].

Conclusions (FF)

The analysis and synthesis of the research conducted on the use of Nopal mucilage and gum as natural additives in mortars and other construction materials have highlighted the effectiveness of these vegetal biopolymers in improving various physicomechanical and durability properties. Specifically, the addition of Nopal mucilage to cementitious, lime-based, and clay matrices has been shown to increase plasticity, slow down the setting process, promote more uniform carbonation, reduce capillary absorption, total void content, and permeability, enhance compressive, tensile, and flexural strength, as well as improve the corrosion resistance of reinforcements.

Experimental tests have demonstrated how Nopal mucilage can function both as a plasticizer and a superplasticizer, modulating the workability and rheological characteristics of mortars depending on the concentration used. Additionally, the chemical-physical interaction between Nopal polysaccharides and the inorganic matrix allows for the formation of more compact and cohesive microstructural frameworks, with tangible effects on long-term durability.

The use of Nopal mucilage as an additive in construction settings is not limited to improving mechanical performance but also appears to include effective water-repellent action, providing protection against moisture and reinforcement corrosion. In this way, it would be possible to optimize the lifecycle of materials, reduce the need for maintenance interventions, and contain environmental impact by integrating a circular approach that can valorize agricultural waste generated from the cultivation of Opuntia ficus-indica.

The applicative versatility of Nopal mucilage, combined with its simple extraction, local availability, low cost, and non-toxicity, makes this natural additive a promising option for sustainable architecture and heritage conservation, as well as for the construction of new, more durable and eco-friendly structures.

The gathered evidence suggests the need for further research to optimize dosages, extraction methods, and interactions with other types of binders, in order to expand the field of application and consolidate knowledge on this interesting vegetal material.

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