Natural additives as reinforcement for mortars: comparative evaluation of gypsum-based plasters with pistachio shells and orange peels

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Abstract. This research explores the use of waste from agriculture and food production (agro-food waste) as a green additive in building gypsum plasters. The focus is on lightweight mortars made with bio-based materials, aiming for a solution that aligns with green building principles and circular economy practices. Current research prioritizes examining the physical and mechanical properties of these bio-based mortars. These mortars often have high porosity and lower weight, making them good thermal insulators and sound absorbers. While not yet widely used in construction, they hold promise as a sustainable alternative with performance comparable or even exceeding conventional plasters in thermal and acoustic insulation. In particular, the cultural premises of this study refer to the shared identity between Sicily and Tunisia, focused by a recent strategic cross-border cooperation project CUBÂTI, Culture du bâti de qualité: recherche, innovation et entreprise pour la durabilité, funded by Italy-Tunisie Programme 2014-2020. In fact, the present experimental research has focused on two materials easy to find in these countries, applying a replicable method to other regions in the Mediterranean area. In this study, the performances of gypsum-based plasters with pistachio shells and orange peels as additives were evaluated. Several tests were carried out on the developed materials to optimize their mix design, verify their mechanical and physical properties and the results of the comparative investigations showed interesting results in terms of mechanical resistance, thermal conductivity and reduction of water absorption.

1 Introduction

We can define waste as any material that has not been fully used such as waste from domestic, agricultural, or industrial processes. Over recent decades, waste production has surged, encouraged by economic and industrial advancements, population expansion, and urban sprawl. The escalation in waste generation has exacerbated disposal challenges, compounded

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by the proliferation of harmful waste types detrimental to the environment. From an environmental perspective, the escalating volume of waste generated serves as an indicator of Earth's resource depletion. In the specific field of agri-food systems, Circular Economy models can reduce the amount of food loss and waste generated in the supply chain by using them as a new resource [1]. In the case of fruits and vegetables, loss and waste account for 45% in the whole supply chain, being the processing stage responsible for up to 18% of losses [2]. Therefore, new challenges and opportunities have been planned to reduce Food Loss and Waste (FLW), providing greater efficiency when using natural resources [3]. The waste-to-resource approach faces challenges related to FLW management considering the technological, financial, institutional and regulatory aspects [4].

Different innovative options are available to process by-products in animal feed [5,6]. Recent technologies allow to produce materials and energy [7] from food residues [8]; this is consistent with the waste-to-resource approach [9].

Another sector with a high environmental impact is construction, as building materials are one of the main factors influencing the overall environmental impact due to their production, transport, use and end-of-life. To reduce this problem, a number of strategies have been identified such as the use of environmentally friendly materials, the use of local materials and the encouragement of circular economy practices [10]. Bolden et al. [11] in their work investigated the strengths and weaknesses of the practice to support the construction industry in developing effective policies regarding the use of waste and recycled materials as construction materials.

According to the Waste Framework Directive (2008/98/EC), "recycling" is "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for their original or other purposes". If recycling, re-use or other processing operations result in 'secondary raw materials' being obtained from waste, this is again a 'recovery' operation (Dir 2006/12/EC).

To date, research is focused on investigating the possibility of using as additives in construction products Recycled Aggregates (AR) from the reuse of Construction and Demolition Waste or natural materials with possible advantages such as low environmental impact, lower energy demand, low cost, large-scale availability, biodegradability and good insulation and mechanical properties. A. A. Sundarraj and T. V. Ranganathan in their studies investigated the possibility of using cellulose, extracted from agro-industrial waste, as reinforcement for the building materials industry [12].

Current research on bio-based lightweight mortars mainly focuses on physical properties (workability, density and porosity, etc.) and mechanical properties (compressive strength, tensile strength and elastic modulus, etc.). Generally, bio-based aggregates possess high porosity and lightweight properties, which is an advantage that differs significantly from normal weight aggregates, contributing to the special functional properties of bio-based lightweight concrete, such as thermal insulation and sound absorption properties.

Currently, various bio-based aggregates have been successfully added to the mix design of mortars such as date seeds [13], coconut shells [14-16], bamboo [17] and apricot shells [18] or seashell [19] Other studies focused on composites using rice straw [20] rice husk [21], bagasse, i.e. the residue from the grinding and pressing of sugar cane [22], corn cob [23,24], pineapple leaves [25,26], coffee chaff [27], coffee grounds [28], sunflower seeds [29,30] durian peel and coconut coir [31], peanut shell [32,33], walnut shells [34] and Opuntia. Most of these products have not yet been industrialised and put on the market, but they represent a sustainable alternative for the green building sector, with performance values that are often comparable to commercial products and in some cases better, with particular reference to thermal and acoustic insulation properties [35].

Some research has also shown how natural fibers can effectively contribute to increasing the mechanical resistance of mortars. Wu et al. demonstrated, for example, how miscanthus fibers, a common grass, improve the compressive and flexural strength of cement mortar by 82.7% and 26.9%, respectively, due to reduced porosity [36].

On the other hand, bio-based lightweight aggregates consist of carbohydrates and are porous, so they are particularly sensitive to changes in ambient humidity; as a result, they may have a negative impact on the durability of mortars, particularly on water-related properties such as drying shrinkage and freeze-thaw resistance. However, studies have shown that the heat treatment of bio-based admixtures can significantly reduce the shrinkage of the mortar, increasing its freeze-thaw resistance due to reduced micro-cracking and porosity.

But the outcomes are not always positive, e.g. the studies by Nguyen et al. [37] found that the freeze-thaw performance of mortars admixed with seashells is significantly lower than the same mortars without admixtures, due to the dissociation of the calcium carbonate present in the shells.

Citrus fruits, for example, are the main processed fruits in the world and generate large quantities of by-products, which can be reused for new productions, as can be read in the work compiled by P. Chavan et al. [38] Consequently, citrus peels, especially orange peels, are also beginning to be used in the construction industry. Vitale [39] produced panels by subjecting wet and dry orange peels to a thermocompression process and found that the best performance was shown by panels with 100% wet orange peels. The results of the study showed that orange peels could be used as a thermal insulation material.

Understanding territorial dynamics assumes an important role in the dissemination of the circular economy, oriented towards recovery and waste minimisation, and must be associated with studies, of an experimental nature, on the characteristics and quality of materials Pani et al. [40-42].

The present study, implemented in the frame of the CUBÂTI “Culture du bâti de qualité: Recherche, Innovation et Entreprise pour la Durabilité” project, starts from the identification of waste from the agrifood sector in two Mediterranean countries, Sicily and Tunisia, which can be used as an additive in mortars for the production of plasters, with the dual objective of valorising waste and improving the performance of traditional mortars.

This research, therefore, focuses on the manufacturing of gypsum-based plasters, a traditional local material [43] widely used as plaster in Sicily and Tunisia, as in the entire Mediterranean basin, due to its low cost and good fire resistance [44] added with various types of citrus fruit waste; including orange peels, lemon pressing waste and *pastazzo*, and pistachio shells. These additives were used to try to overcome the limitations presented by gypsum such as brittleness, high water absorption and low thermal insulation properties [45]. Various tests were performed on the produced materials to verify their mechanical and physical properties and the results of the comparative investigations showed interesting results.

Starting from a wider research study regarding the assessment of several mix designs combining different agro-food wastes i.e., pistachio shells [46], orange peels, *pastazzo*, wood fiber, and different base mortars i.e., gypsum and clay, the results of the selection and comparison of the most promising samples is presented in this article.

2 Materials and Methods

2.1 Method and phases

The project is structured into four phases: in a first phase, the materials to be used to make the mortars were identified; in particular, gypsum from the Trapani area in Sicily, citrus peels and pistachio shells waste from local Sicilian production, were chosen.

The second phase envisaged the production of test specimens with different aggregate grain size, in order to verify how this affected the workability and spreadability of the plasters, followed by a curing phase, consisting of storing the test specimens for 7 days at a temperature of 23 ± 2 °C with relative air humidity of 50 ± 5% and subsequent drying to a constant mass at a temperature of 40 ± 2 °C in accordance with standard UNI EN 13279-2. Following the curing process, in the third phase, preliminary tests were carried out to assess the performance characteristics of the mortars produced and to define the product attributes.

2.1.1 Gypsum

Gypsum is a mineral that can be found in nature in two different forms, namely as anhydrous calcium sulphate ($CaSO_4$) and dehydrated calcium sulphate ($CaSO_4 \cdot 2H_2O$). A certain amount of water of crystallization is present in the crystals in the second case, which distinguishes the two forms [47]. From a chemical perspective, the material occurs in different forms depending on the concentration of water crystallization.

Gypsum is a white mineral that can have colours ranging from grey to reddish, depending on the type and quantity of impurities present as well as the degree of purity. When anhydrous calcium sulphate is found in the quarry, the material that is extracted does not need to be crushed again to become powder, which is what happens when sulphate dehydrate is present. In addition, in the case of sulphate dihydrate, there is a burning phase for the complete or partial removal of the mineral's water of crystallization, which defines the gypsum's technical properties and application. In the course of firing, once it reaches 128 °C, the chalky rock loses about 6 per cent of its water of crystallisation: a semi-hydrated calcium sulphate is thus formed ($CaSO_4$ -(1/2)H_2O, which has a setting time of between 1 - 4 minutes), which, when it comes into contact with water, transforms back into the starting material. Between 150 °C and 180 °C, the water of crystallisation is completely eliminated and the soluble anhydrite $CaSO_4$ (α) begins to form, the setting time of which is about 20 minutes: above 180 °C, this transformation significantly increases its speed. If firing is carried out above 250 °C, insoluble anhydrite $CaSO_4$ (β) is formed. At higher temperatures, the formation of insoluble anhydrite continues, and at 1200 °C, CaO + SO_3, or calcium monoxide (quicklime) and sulphuric anhydride are formed. Following firing, a second grinding process takes place, which is necessary to obtain a homogenous product that is easy to use and guarantees successful installation. Generally, fired gypsum is finely ground to a grain size of between 150 and 600 μm. Commercially available construction plasters consist of semi-hydrated gypsum or soluble anhydride or a mixture of these.

The gypsum used in this study is a powdered product based on hemihydrate gypsum classified according to the European standard EN 13279-1[48] as A1/A2/A3/7.

2.1.1 Citrus waste

Oranges are the most cultivated fruit in the world and account for about 50-60% of the total citrus fruit production. Every year, more than 76 million tonnes of oranges are consumed worldwide [49] and processing generates a huge amount of waste, mostly consisting of peels. By-products derived from citrus waste are mainly used for energy production, nutrient sources or pharmaceutical, food and cosmetic industries. However, their use in the construction sector was only studied by Vitale in 2021 for the production of thermally compressed panels that yielded interesting results in terms of thermal insulation [50]. The chemical composition of citrus fruit peel, in general, is influenced by external climatic conditions, the method of cultivation and ripening, and the type of fruit. However, according to the literature, it is mainly composed of cellulose, pectin, sugar, acids, lipids, mineral elements, essential oil and vitamins [51-54]. The citrus waste used in this work are orange peels sorted and prepared, dried and ground at the Euro-Mediterranean Institute of Science and Technology in Palermo using an electric grinder. The size obtained from grinding is shown in Fig. 1.

2.1.2 Pistachio shells

Based on data from FAOstat (2020) [55], the United States, Turkey, and Iran produced 1,239,007 tons of pistachios annually in 2018, accounting for 90% of the global production. Approximately 300 thousand tons of nuts are produced annually in Italy overall. Based on ISTAT statistics from 2017 [56], the country's pistachio areas span no more than 4000 hectares, yielding a production of slightly less than 4,000 tons, with Sicily accounting for the majority of this production. Pistachio shells are currently burned or disposed of in landfills because they have no practical industrial use or substantial commercial value [57].

Between 51% and 69% of the weight of the fruit is composed of the pistachio shell [58]. Furthermore, because of its high cellulose structure, the pistachio shell loses weight during the heating phase by about 75–80% [59,60]. Pistachio shells are a type of biomass that mostly consists of 30-55% cellulose, 20-32% hemicellulose, and 12-38% lignin [61,62]. Their size and form are similar to those of pellets. Because of their great elasticity and mechanical resistance, the pistachio shells utilized in this work were processed using a high-power electric grinder (2.5 kW) with a high number of laps (36,000 r/min for 1 min). The product obtained after the grinding operation was sieved to separate the various grain sizes obtained [46] (Fig. 2).

Fig. 1. Orange peel with dimensions < 0.5 mm

Fig. 2. Pistachio shell grain sizes < 0.5 mm

2.2 Samples preparation and mix design

A UNI EN 13279-2 compliant mixer with a steel cup and mixing blade that was coupled to an electronic control system for speed and rotation was utilized for specimen preparation and production activities.

In compliance with EN 13279-2, the shaking table method was used to assess the consistency of fresh mortar. By measuring the mortar's spread, the test establishes the consistency of the material. The apparatus is made up of a circular table with a shaft that is fixed on a strong frame and allows for the application of vertical shocks with a standard energy determined by the shaft's stroke. To ensure regular filling, the mortar is compressed with a pestle and placed into a bronze cone that is positioned in the centre of the circular table. After 10 to 15 seconds, the cone is raised, and 15 shocks are given in that time. The mortar's spreading, or its diameter measured in millimetres, is then measured at the conclusion. According to standard UNI EN 13279-2, a spread of between 160 and 165 mm (with a tolerance of ± 5 mm) must be adopted to ensure good workability of the mortar to be used for plastering.

The mixes were formed in steel moulds that had been appropriately released agent-treated on the walls. The specimen was taken out of the mould as soon as it attained the desired level of strength. They were then kept for seven days in a curing chamber at a temperature of 23° ± 2° C and a relative humidity of at least 50% ± 5%. They were then dried at 40 ± 2 °C until they reached a consistent mass. The samples were allowed to cool to room temperature after drying.

Every sample was categorized using a distinctive nomenclature, catalogued, and documented. The samples reported in Table 1 were taken for the evaluation of each mix.

Table 1. Samples made with their relative dimensions and the tests carried out on each of them.

Mix	Dimension	Samples Nr	Test
GS	16x4x4	9	Mechanical tests and water absorption
	10x10x0.5	1	Adhesion tests
	4x4x4	6	Mechanical compression tests and water absorption
	20x20x2	1	Thermal conductivity tests
GAsLfS	16x4x4	9	Mechanical tests and water absorption
	10x10x0.5	1	Adhesion tests
	4x4x4	6	Mechanical compression tests and water absorption
	20x20x2	1	Thermal conductivity tests
GSPf	16x4x4	9	Mechanical tests and water absorption
	10x10x0.5	1	Adhesion tests
	4x4x4	6	Mechanical compression tests and water absorption
	20x20x2	1	Thermal conductivity tests

Legend: G: gypsum; S: sand; As: fine orange peels; Ps: fine pistachio shells; Lf: sawdust.

2.3 Testing activities

The produced samples underwent various tests to characterize the mix designs and assess the performance in comparison to the mortars that were not added. Evaluations were conducted on the mechanical resistance, water absorption and thermal conductivity.

2.3.1 Mortar spreading measurement

To determine the consistency of the fresh mortar, the shake table method was adopted in accordance with UNI EN 1015-3 /2007.

The test determines the consistency of the mortar by measuring its spreading (Fig. 3). For the purposes of good workability of the mortar to be used for plasters, it is necessary to adopt a spreading which can vary from 140 to 180 mm (with a tolerance of ± 10 mm) as prescribed by the UNI 998-1 standards [60].

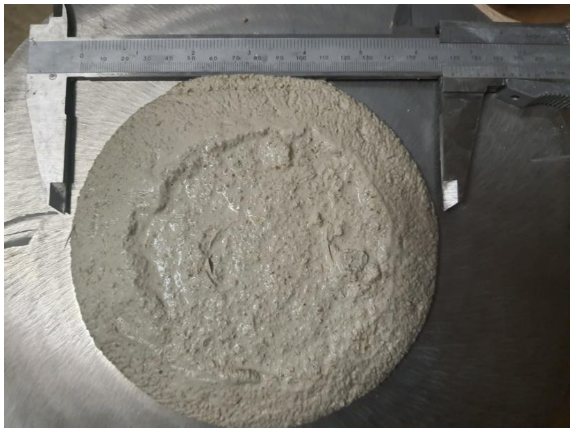

Fig. 3. Example of mortar spreading measurement.

2.3.2 Mechanical Properties

Following the realisation of the samples with the different mix designs, after waiting for a suitable curing period of 7 days, a series of tests were carried out to assess the mechanical strengths of the manufactured specimens. All samples were then subjected to flexural and compression tests as prescribed by UNI EN 13279-2.

2.3.3 Water absorption tests

Water circulation measurement using capillarity absorption were conducted to confirm each mortar mix design's capacity to absorb water as well as how this behaviour was preserved over time. The water absorption/desorption test measures the increase in mass of a stone material specimen in contact with deionized water per unit of surface as a function of time. This test is used to determine the capillarity of a mortar, as defined by the UNI 10859:2000 standard [63]. Three samples of each sort of mortar mix design, each measuring 16 cm x 16 cm x 4 cm, were inspected for the test. Once the samples had dried completely, they were put in a basin and submerged in water to a depth of 5 mm, with filter paper discs keeping them from touching the base (Fig. 4). Throughout the entire test, the water level remained consistent. Following a damp cloth swab, the specimens were weighed at various intervals (10, 20, 30, 60, 240, 360, 1440, 2880, and 4320 min). The time intervals were then changed in accordance with the requirements in the standard UNI 10859:2000 for stone materials to evaluate the behavior of gypsum. The coefficient of water absorption by capillarity, or the slope of the straight line joining the points that represent the measurements made at the intervals, might be calculated from the weight data. The following formula was used to calculate the imbibition coefficient, which was determined in accordance with CNR BU standard n. 137/92 (Regulations on aggregates–Determination of the imbibition coefficient) [64].

$$Ci_i = \frac{m_{1,1} - m_{2,1}}{m_{2,1}} \cdot 100$$

Where $m_{1,i}$ indicates the mass expressed in grams of wet material for the reference specimen, and $m_{2,i}$ indicates the mass expressed in grams of dry material.

Fig. 4. Example of water absorption test

2.3.4 Thermal conductivity measurements

In order to assess the thermal characteristics of the various mix designs and confirm whether the addition of biobased aggregates improved thermal insulation, thermal conductivity measurements were conducted. Thermal conductivity is defined as the capacity of a material with a surface area of 1 sqm to transmit heat through a thickness of 1 m between two opposite surfaces with a temperature difference of 1K and it represents a measure of the heat transmission capacity of materials.

The tests were conducted by means of the thermofluximeter ISOMET 2114, a commercial portable microprocessor-controlled instrument for direct measurement of the thermal conductivity coefficient of materials, distributed by the Applied Precision s.r.o., in Bratislava, Slovakia. The ISOMET 2114 can be alternatively equipped with—a needle probe for unconsolidated and composite materials and a surface probe for solid consolidated and composite materials. It ensures a relative measurement inaccuracy of ≈ 5% for a measurement spanning from 0.015 to 0.700 W/mK [65]. For this study goal, samples measuring 20 cm x 20 cm x 2 cm were prepared and for each of them 10 measurements were performed, using the surface probe and a measurement range of 0.04 - 0.3 W/mK, with a built-in memory and calibration constants stored in the memory.

3 Results and discussion

3.1 Mechanical properties

As required by UNI EN 13279-2, flexural and compression tests were performed on each specimen. The results of tests that were carried out are listed in Table 2.

It was observed that the majority of the pistachio biobased mix designs demonstrated higher compression resistance (4.14 MPa) when compared to a standard gypsum mortar plaster without biobased aggregates 2.56 MPa (GS). This improvement in mechanical performance was attributed to the pistachio shells' elastic nature.

Table 2. Results of mechanical tests

Sample	Flexion test [MPa]	Compression test [MPa]	N° samples	Variability
GS	2.64	2.56	9 (16x4x4) + 6 (4x4x4)	±1%
GAsLfS	0.84	2.80	9 (16x4x4) + 6 (4x4x4)	±4%
GSPf	1.95	4.14	9 (16x4x4) + 6 (4x4x4)	±3%

3.2 Water absorption tests

The outcomes of the capillarity absorption tests demonstrate the different imbibition capacities of the mortars due to the presence of aggregates in varying grain sizes. The amount of water absorbed in the first 240 minutes increased quickly for each type of mortar. The test was terminated for all samples after 4320 minutes since the weight seemed to have stabilized by then, ascribable to the high absorbent gypsum matrix.

From the test results it can be seen that the samples containing orange peel are slightly worse, while the samples with the addition of pistachio shells reduce the capacity of water absorption by capillarity. This is due to the natural water repellence of pistachio shells which improve the final performance of the gypsum mortar. Table 3 reports the imbibition coefficient values for the various tested samples.

Table 3. Imbibition coefficient values for the various samples tested

Sample	Imbibition coefficient	N° samples
GS	45.54	9 (16x4x4) + 6 (4x4x4)
GAsLfS	48.57	9 (16x4x4) + 6 (4x4x4)
GSPf	44.09	9 (16x4x4) + 6 (4x4x4)

3.3 Thermal conductivity measurements

Measured thermal conductivities are reported in Table 4. The gypsum mortar without additives sample revealed a thermal conductivity of 0.531 W/mK. Compared to that, both the developed biobased mix designs combining gypsum with organic waste source additives improved the thermal conductivity with an over 60% decrement, returning values equal to 0.231 W/mK in the pistachio shells added mortar case, due to the similarity with wood behaviour, and 0.167 W/mK in the orange peels one.

As a practical example, it was carried out an evaluation of the overall thermal transmittance of a typical air-cavity wall made of hollow brick, by assuming the three different mortars as inner and outer plaster layers, and the needed insulation panel thickness for complying with the Italian regulation in force (DM 26/6/2015) with reference to the requirements set for the two Sicilian hottest climate zones (A and B). In case it was used the gypsum mortar without additives, the wall would have an overall thermal transmittance (U value) of 0.77 W/m^{2}K, so requiring a 5 cm EPS panel while, with the pistachio shells added mortar the U value would be 0.71 W/m^{2}K, thus requiring a 4 cm EPS panel, and finally with the orange peels the U value would be 0.68 W/m^{2}K, so requiring a 3 cm EPS panel.

Table 4. Average thermal conductivity values for the various samples tested.

Sample	Average Thermal Conductivity [W/m·K]	N° samples	Variability
GS	0.531	1 (20x20x2)	±0.3%
GAsLfS	0.167	1 (20x20x2)	±0.5%
GSPf	0.231	1 (20x20x2)	±0.4%

3.4 Further economic and environmental implications

From the economic perspective, one of the most interesting aspects is linked to the low cost of gypsum plaster (8-10 euro/sqm) compared to plasters made of hydraulic lime or cement (16-30 euro/sqm). In the case of the tested plasters, despite the increase in performance achieved with orange peels or pistachio shells, there is no increase in cost, as they are derived from waste, not by synthesis. Furthermore, their transformation is simple and economical to implement and has a low environmental impact because it does not require chemical processes or high temperatures.

A first assessment, for the above, of the cost-effectiveness of producing and using these materials highlights their high potential for commercialization and wider industry adoption in the eco-building sector. In order to proceed with industrial production, for orange peels in particular, it would, however, be necessary to verify the stability of the dry mixture over time and define precise parameters on the methods of storage of the aggregate and the material in bags.

According to Istat, in Sicily both the production of pistachios and oranges are facing an increasing trend. In 2023, 4121 tons of pistachios and 1108390 tons of oranges were produced in Sicily. Considering that the pistachio shell is around the 51% of the total weight, every year over 2100 tons of shells could be produced in Sicily and so, potentially, about 4000 tons of mortar. Similarly, considering that the orange peel is around the 14% of the total weight, every year 155175 tons of peels could be produced in Sicily and become secondary materials for the construction chain. The EU Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and in Italy the Legislative Decree 152/2006 "Regulations on environmental matters" regulate, among others, agricultural wastes management by promoting the development of a circular economy through reuse, recycling and recovery activities. The law establishes that the disposal and possible marketing of agricultural wastes can be carried out by stipulating an agreement either with the public service or authorized private companies. Hence, although the regulation and the research are pushing a reuse of agricultural waste in other applications, there are still some issues related to the higher costs that the agricultural companies should afford for commercializing the waste and to the lack in the regulation, which is currently more focused on reuse of waste as biomass for the energy production rather than as additive for the construction sector.

Another important aspect regards the environmental impact of the mortars processing. One of the most widely adopted and comprehensive methods for the quantitative analysis of the environmental impact of a building product, from the material extraction toward its disposal, is the Life Cycle Assessment (LCA). The official definition of the LCA was provided by The Society of Environmental Toxicology and Chemistry (SETAC) in 1990 and claims "Life-Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extracting and processing raw materials; manufacturing;

transportation and distribution; use, re-use, maintenance; recycling, and final disposal" [66]. Although the LCA is a powerful tool, able to support the improvement of the processing phase by identifying critical hotspots, its application is quite difficult due to tailored and accurate data lack, especially in case of biowaste materials addition in conventional mortars [67]. Pedreño-Rojas et al. assessed the life cycle environmental impact of 1 ton of gypsum manufactured in Andalusia to develop gypsum plasters, comparing the processes of natural gypsum and that from recycled plasterboards, reporting that a halving of some impact categories could be obtained [**Erro! Fonte de referência não encontrada.**].

Therefore, based on that study findings and considering that the adopted agricultural wastes in the biobased mixes developed in this study are around the 10% of the total weight, although a more accurate study should be carried out, in first analysis and with high caution, it can be estimated that their use could imply at least a 5% reduction of environmental impacts compared to the only gypsum mortar.

4 Conclusion

The mechanical resistance, thermal conductivity and imbibition capacity of two mortar mix designs with different biobased aggregates were assessed and their performances compared to one without additives.

Based on the mechanical test results, it can be concluded that both new mix designs with natural additives demonstrated a higher compression resistance than the mortar without additives due to their natural good mechanical resistance and elasticity. To be noted that the higher values of resistance came by plaster with the pistachio shells.

Moreover, the capillary absorption tests demonstrate that the addition of pistachio shells reduces the capacity of water absorption.

Improved thermal conductivity values were measured for the pistachio added gypsum mortars and, even better, for the orange ones, compared with the not added gypsum mortar, providing promising insights in terms of thermal insulating plasters production for building energy retrofit.

The conducted research activities show that utilizing agro-food chain waste materials can improve the physical performances of conventional mortars, together with the first economic and environmental analysis which gave promising insights on potential advantages to be deepened in further studies.

Biobased materials are becoming more and more appealing for a variety of uses, including building, because they are abundant, less expensive, biodegradable, and produce fewer greenhouse gas emissions when processed. However, there is a dearth of information regarding the efficiency and cost of this process. The research activities are progressing to investigate the chemical implications or microscale analysis. Additional research could improve this study by analysing other qualities, such as durability, fire resistance, sound absorption, production chains, and costs, in order to support the industrialization phase.

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