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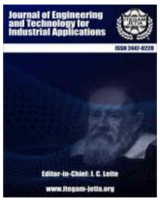

RESEARCH ARTICLE OPEN ACCESS

SYSTEMATIC REVIEW OF COFFEE AND RICE ASH IN PHYSICAL-MECHANICAL PROPERTIES AND CONCRETE DURABILITY

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ABSTRACT

Concrete is one of the most widely used building materials worldwide, but its production generates a high carbon footprint due to the high clinker content in Portland cement. In response, coffee husk ash (CCC) and rice husk ash (CCA) are being investigated as sustainable alternatives to partially replace cement. This paper presents a systematic review of recent studies in Scopus and ScienceDirect, applying selection criteria related to technical relevance, availability of experimental results and incorporation of both ashes in concrete and mortar mixtures. Likewise, a bibliometric analysis is developed using VOSviewer to identify research trends, countries, outstanding authors and predominant keywords. The compiled studies allow us to compare the effect of CCC and CCA on physical properties (workability, density, absorption), mechanical properties (compressive strength, tensile strength and bending) and durability (permeability and resistance to chlorides and sulfates). Overall, the evidence shows that both ashes can be used as supplementary cementitious materials in moderate replacements, valorizing agro-industrial waste and reducing the environmental impact of the concrete, as long as parameters such as fineness, calcination conditions and dosage are controlled to guarantee optimal and sustainable results.

I. INTRODUCTION

Concrete, also called concrete, is one of the most widely used materials and the second most consumed after water [1]. Its manufacture is based on the combination of aggregates with water and Portland cement, whose production was more than four billion tons in 2022, consolidating it as the most widely used binder in construction [2]. Cement production releases carbon dioxide (CO_2) and is recognized as one of the main sources of emissions linked to global warming [3]. The construction sector consumes large volumes of concrete and represents a relevant fraction of GDP, with an impact on greenhouse gas emissions [4]. In view of this, the use of supplementary cementitious materials derived from rice husks is promoted to reduce the clinker content and carbon footprint of concrete, while maintaining adequate structural performance [5].

Concrete can incorporate agro-industrial by-products, such as coffee husks, favoring sustainability by valorizing waste that would otherwise be discarded [6]. According to [7], this process requires an appropriate selection of materials, preliminary tests and adjustments of the mixture based on laboratory results. Studies on ash from silica-rich agricultural residues indicate that they can improve the strength and durability of concrete, reducing its permeability against aggressive agents [8]. Likewise, it has been observed that workability can decrease, mechanical strength tends to increase with curing time [9]. Therefore, it has been shown that agricultural ash without complex treatments, including rice husk ash, can be used as a partial substitute for fine aggregate in mortars, maintaining strengths compatible with conventional cement mortars [10]. In this context, coffee husks (CC) are considered an abundant and potentially polluting agro-industrial waste due to its content of compounds such as caffeine and polyphenols [11].

In addition, its lignocellulosic fraction contains about 53% cellulose and can be transformed into crystalline microcellulose with high crystallinity and thermal stability, reinforcing its potential as a raw material for composite materials and construction products [12]. On a global scale, coffee production is around 10 million tonnes, of which a significant fraction corresponds to husks and other solid by-products that require recovery alternatives [13]. As one of these alternatives, coffee husk ash (CCC) has been incorporated into concrete mixtures, reporting improvements in strength and a reduction in the environmental footprint [14]. By [15] have evaluated CCC on properties such as compressive strength, bending, and hardness, while [16] report additional benefits in the water absorption, density, and thermal performance of concrete elements.

Similarly, the combustion of rice husks generates rice husk ash (ACC), a silica-rich by-product used as supplementary cementitious material. In turn, [17] report that replacements of up to 10% CCA reduce initial strength, but maintain adequate performance at older ages and decrease carbon footprint. In concretes with high recycled aggregate content, contents close to 15% help to recover resistance and improve durability [18], while in permeable concrete, replacements of 5–10% increase compressive and wear resistance without compromising permeability [19]. In addition, CEC has been used in the manufacture of aggregates that reduce the consumption of natural aggregates [20] and as an addition, where replacements close to 25% allow adequate bending strengths to be achieved with environmental benefits [21].

II. METHODOLOGY

SCOPUS and ScienceDirect. In a first stage, specific keywords related to coffee husk ash were used, such as concrete + coffee husk ash and concrete + coffee husk, identifying works on the use of this residue as an addition to improve the physical-mechanical properties and durability of concrete. Given the limited number of studies that met the selection criteria, the search strategy was expanded to include terms associated with rice husk ash, such as concrete + rice husk ash and supplementary cementitious materials + agricultural ash, considering articles that evaluated the effect of one or both ashes on concrete or mortar mixtures. Subsequently, filters were applied by engineering area, topic, type of document and scientific discipline, restricting publications to the period 2021–2025.

The results and search combinations are presented in TABLE 1, where the articles are organized by database, keywords, range of years and type of document. After the purification of duplicate records and the evaluation of the relevance, originality and availability of experimental information, 64 articles were selected for the final synthesis. TABLE 2 presents the distribution of these documents according to the year of publication (2021–2025), the database consulted and the type of ash analyzed, evidencing a growing trend in research related to the use of coffee husk ash and rice husk ash as cementitious additions in concrete.

Table 1: Results of the filtered research.

Database	Year of Search	Keywords	Documents without Filter	Search Filter	Filtered Documents	Selected Documents	Total
Scopus	2021-2025	Concrete AND café AND cáscara OR arroz	1635	Engineering+ Materials Science+ Article	144	10	42
		Coffee Husk + Durability OR Mechanical Properties	118	Engineering+ Materials Science+ Article	38	8	
		Coffee OR Rice AND Husk AND Concrete	2443	Engineering + Materials Science + Article + Properties	972	18	
		husk and rice and corrosion or durability	3050	Engineering + Item + Pollution	399	6	
ScienceDirect	2021-2025	coffee husk AND concrete	946	Engineering+ Building Materials+ Article+ Open Access	64	5	16
		concrete AND coffee AND durability	1843	Engineering+ Building Materials+ Article+ Open Access	105	3	
		coffee husk ash" AND concrete AND "mechanical properties	304	Engineering+ Building Materials and Construction Engineering+ Article+ Open Access	68	8	

Source: Authors, (2026).

Table 2: Distribution of articles by database and year of publication.

Database	**Year Articles Published**					**Total**
	2021	2022	2023	2024	2025	
Scopus	3	7	6	8	24	48
ScienceDirect	0	3	2	3	8	16
Total	3	10	8	11	32	64

Source: Authors, (2026).

A bibliometric analysis was performed with the information collected from the Scopus database, using the following search formula:

(TITLE-ABS-KEY (husk) AND TITLE-ABS-KEY (coffee) OR TITLE-ABS-KEY (corrosion) OR TITLE-ABS-KEY (durability)) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (EXACTKEYWORD, "Durability") OR LIMIT-TO (EXACTKEYWORD, "Coffee Husks") OR LIMIT-TO (EXACTKEYWORD, "Compressive Strength")) AND (LIMIT-TO (LANGUAGE, "English")).

This search process yielded 1635 documents, which were exported and processed in VOSviewer to build a keyword co-occurrence map. The objective was to identify the thematic relationships between terms associated with the incorporation of agro-industrial waste in cementitious materials, with emphasis on "coffee husks" and "rice husk ash" linked to the durability of concrete, as shown in Figure 1. The interpretation of the keyword co-occurrence map generated with VOSviewer allows you to distinguish several thematic clusters. In the central zone, terms such as "durability", "water absorption", "tensile strength" and "rice husk ash" are grouped with words related to "concrete", "mechanical properties" and "sustainable development", which shows a focus of research aimed at evaluating the physical-mechanical performance and durability of concretes modified with ash of agricultural origin.

In parallel, the cluster associated with "coffee husks" is linked to concepts such as "biomass", "biochar", "thermal conductivity" and "reinforcement", which reflect studies on energy recovery and applications in cementitious compounds. Other nuclei are articulated around "fly ash", "geopolymer concrete" and "scanning electron microscopy", highlighting the integration of fly ash, rice husk ash and alkalinely activated systems. Taken together, the map supports the relevance of comparatively analysing coffee husk ash and rice husk ash as supplementary cementitious materials for more sustainable concretes. In summary, the bibliometric analysis shows an integration of approaches that combine materials engineering, environmental sustainability and technological development in the study of coffee husk ash and rice husk ash. However, the map also suggests gaps related to large-scale application and evaluation of the performance of these mixtures under real service conditions.

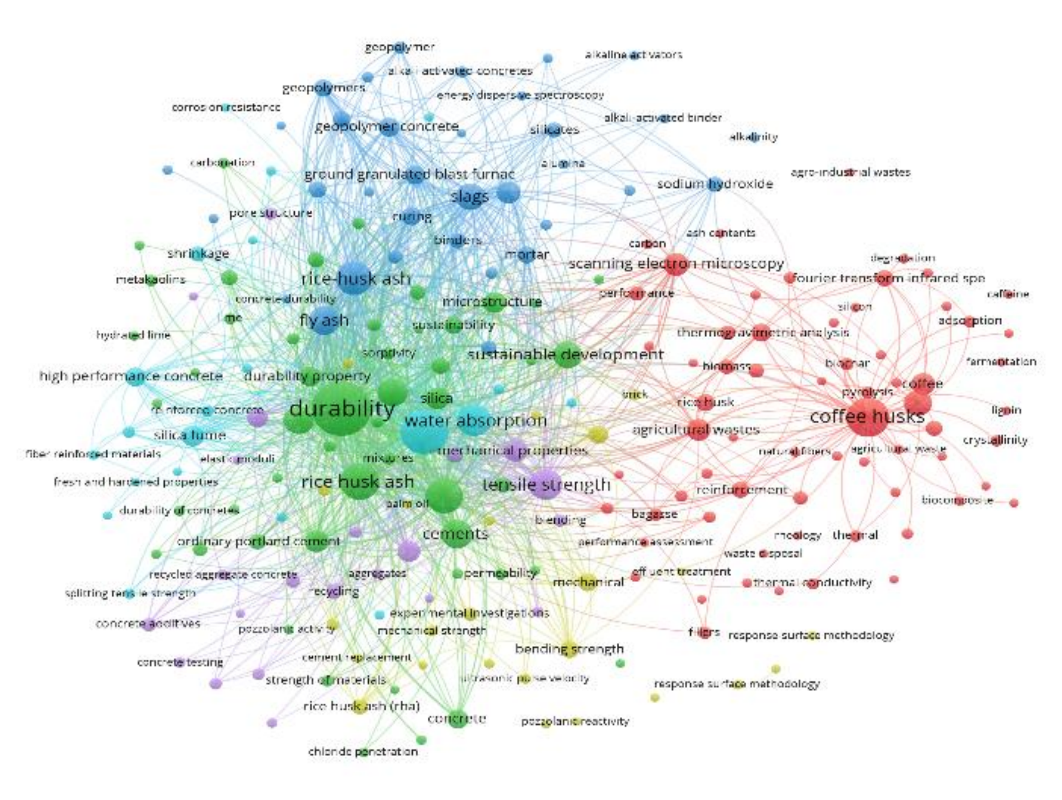

Figure 1: Keyword co-occurrence network map.
Source: Authors, (2026).

III. RESULTS AND DISCUSSIONS

III.1 CONCRETE WITH COFFEE HUSK ASH AND RICE HUSKS

III.1.1Physical Properties

III.1.1.1 Absorption

Water absorption reflects the permeability and durability of concrete; therefore, blends with coffee by-products tend to have higher values due to the high porosity of these residues. In alkalinely activated systems, for example, the progressive replacement of sand with coffee husks increases water absorption and apparent porosity: with 30% husk, absorption reaches ≈19.2% and porosity ≈48.3%, which represents increases in the order of 16.3% and 42% compared to without agro-industrial residue [22]. Similarly, substituting up to 10% of the matrix for coffee husks increases absorption from approximately 17.3 to 23.9% and porosity from ~20 to 40%, while reducing bulk density from 1.94 to 1.69 g/cm³, confirming the highly porous and hygroscopic character of this by-product [23].

On the other hand, rice husk ash behaves in a way that depends on fineness and environmental conditions. In conventional concretes, absorption increases under relative humidity of 31–78 % when using contents of 10–15 % due to its high capillary uptake [24]. However, in moderate additions of 5–10% they reduce open porosity due to the micro-filling effect [25]. This dual behavior is explained by the nanoporosity and high specific surface area of RHA, which can increase or decrease absorption depending on the dosage and the a/c ratio used [26]. Overall, maintaining moderate addition percentages is essential to limit porous connectivity and improve durability.

Table 3: Results obtained for absorption.

Material/system	Residue	% Substitution/Condition	Absorption (%)	Porosity (%)	Main result	Reference
AAB with CC Replaced Sand	CC	30 % arena → CC	≈19,2 %	≈48,3 %	↑Abs ≈16,3 %; ↑P ≈42 % vs control	[22]
Cementitious matrix with CC	CC	0–10% DC → matrix	17,3–23,9 %	20–40 %	↑Abs and ↑P; Density 1.94→1.69 g/cm³	[23]
Concrete with RHA (RH 31–78%)	RHA	10–15% cement → RHA	—	—	↑Abs in Medium-High HR	[24]
Concrete with moderate RHA	RHA	5–10% cement → RHA	—	↓Open porosity	Micro-padding effect, improves durability	[25]
Various Concretes with RHA	RHA	5–20% (depending on the mixture)	—	—	Abs is dosage and a/c (nanoporous) dependent	[26]

Source: Authors, (2026).

III.1.1.2 Workability

Slumping is an essential indicator of the consistency of fresh concrete; Higher values represent more fluid mixtures, although this does not necessarily guarantee better mechanical or durability properties. In this sense, when agro-industrial waste such as ash or bioaggregates of coffee and rice are incorporated, workability usually decreases due to its highwater absorption, great fineness and irregular morphology. For example, [27] they reported that in alkaline activated mortars with coffee husk ash, the flow is reduced as the ash content increases, due to the insoluble fraction that increases the demand for water. Similarly, [28] they observed that substituting up to 15% of cement with a mixture of coffee ash and sugarcane bagasse ash gradually decreases workability, with reductions of about 7% in compaction factor, although within acceptable ranges through adjustments in the water/cement ratio.

Also, in mixtures with rice husk ash (RHA), [29] they report significant slump drops with replacements of 7–14%, especially in mixtures with low A/C ratio, confirming the sensitivity of workability to extreme ash fineness. However, certain treatments can mitigate this loss. When rice husks are used as a pre-saturated bioaggregate, slump variations can be minimal, around 2 mm [30]. Conversely, the combination of RHA with rheological modifiers such as cassava starch increases viscosity and deepens settlement drop [31]. In summary, the incorporation of these residues usually reduces workability, requiring adjustments in the water/cement ratio or the use of superplasticizers to maintain the fluidity of the concrete.

Table 4: Results obtained for workability.

Material/system	Residue	% substitution	Practice	Result	Reference
Alkaline activated mortar	CHA	↑CHA in paste	Flow	↓ Flow with ↑CHA	[27]
Concrete with ash mixture	CHA + other ashes	0–15 % cement	Compaction factor	≈7% ↓ to 15% replacement	[28]
Concrete with RHA	RHA	7–14 % cement	Slump	Marked slump drop	[29]
CC concrete as a saturated bioaggregate	CC	Partial replacement of fine aggregate	Slump	Δslump ≈ 2 mm (almost constant)	[30]
Concrete with RHA + cassava starch	RHA	% RHA + rheological additive	Slump	Slump ↓; Viscosity ↑	[31]

Source: Authors, (2026).

III.1.1.3 Density

The density of concrete is directly related to the porosity and specific gravity of the incorporated materials; As a result, biomass waste often produces lighter mixtures. In this sense, coffee husks have much lower densities than those of mineral aggregates, with values close to 0.16–0.25 g/cm³, which modifies the volumetric behavior of the composite material [32]. This trend is confirmed by looking at its fragile and fibrous microstructure, characterized by abundant voids that reduce the unit mass and classify it as a light component [33]. Consistently, when ash from this shell is incorporated together with polypropylene fibers in 210 and 280 kg/cm² concretes, the density decreases slightly with respect to the standard due to the low specific gravity of both the ash and the synthetic fibers [34].

On the other hand, in reinforced concretes that use rice husk ash as a partial substitute for cement, the density values remain within the typical range of normal concretes, allowing their use in structural elements without significantly altering the dead loads [35]. Overall, the evidence shows that coffee and rice by-products tend to reduce the density of concrete, as long as the dosages are kept controlled to avoid excessive increases in porosity that may compromise the compactness of the material.

Table 5: Results obtained for density.

Material/system	**Waste**	**Density/effect**	**Brief comment**	**Reference**
Coffee husks (dried)	CC	0,16–0,25 g/cm³	Very lightweight component	[32]
CC as a light aggregate	CC	—	Fibrous microstructure, high voids → unit mass ↓	[33]
Concrete 210–280 kg/cm² with CHA + PP fibers	CHA	% CHA + PP	Density slightly ↓ vs pattern	[34]
RHA Reinforced Concrete	RHA	RHA as a partial cement substitute	Density within normal range	[35]

Source: Authors, (2026).

III.1.2 Mechanical Properties

III.1.2.1 Compressive Strength

Compressive strength is the property most influenced by the incorporation of agro-industrial ash. In the case of RHA, its highly reactive amorphous silica allows increases of between 2.4% and 18.7% when 10–20% replacements are used, due to the refinement of the microstructure and the increased formation of secondary C-S-H gel [36]. Likewise, when used in concrete with lower quality aggregates, this ash improves internal cohesion and contributes to the increase of elastic modulus by optimizing the paste-aggregate transition zone [37]. In addition, predictive models based on 348 experimental data indicate that strength reaches its maximum values with replacements between 10% and 30%, with the water/cement ratio and cement content being the most influential variables [38].

On the other hand, research on cementitious alternatives shows that RHA substitutions between 5% and 20% increase resistance from an early age thanks to the high fineness and reactivity of the ash, which favors the closure of pores and the densification of the paste [39]. Finally, in concretes modified with ground coffee residues, it has been observed that moderate replacements close to 10% maintain structural strengths above 20 MPa at 28 days, due to improved alkaline reactivity during curing [40]. Specifically, M30 concretes with combinations of 15% RHA and 15% snail shell ash achieve strengths of up to ≈46 MPa at 90 days, outperforming reference concrete and significantly reducing water absorption [41]. Overall, the results show that agro-industrial ash strengthens mechanical behavior when incorporated in controlled proportions, mainly by reducing porosity and optimizing the microstructure.

Table 6: Results obtained for compressive strength.

Material/system	**Residue**	**% substitution**	**Age**	**Main result**	**Reference**
Concrete with RHA	RHA	10–20 %	28–90 d	fc’ ↑ 2,4–18,7 %	[36]
Concrete with RHA and low-quality aggregates	RHA	10–20 % (typical)	28 d	Improves cohesion and elastic modulus	[37]
Predictive model with RHA	RHA	10–30 %	—	hr' max at 10–30 % RHA	[38]
Alternative Concretes with RHA	RHA	5–20 %	7–28 d	fc' ↑ from an early age	[39]
Concrete with ground coffee	CG	≈10 % replacement	28 d	fc’ > 20 MPa	[40]
M30 Concrete with RHA + Shell Ash	RHA + other ash	15% RHA + 15% shell ash	90 d	fc’ ≈46 MPa	[41]

Source: Authors, (2026).

III.1.2.2 Tensile Strength

The tensile strength of concrete depends largely on the internal cohesion of the matrix and the paste–aggregate link, so the incorporation of coffee husk ash (CHA) can significantly influence this property. Although studies carried out on asphalt mixtures show notable increases in indirect traction, for example, an increase of 35.8% compared to conventional filler and an increase in TSR from 94.58% to 105.03%, values higher than the minimum of 80% required to guarantee resistance to moisture damage, these results show the potential of CHA as a reactive microfiller capable of improving the internal cohesion of the material [42]. In addition, mechanical optimization analyses in cementitious compounds indicate that intermediate dosages of fine agro-industrial residues maximize strength and rigidity, suggesting that moderate use of CHA could strengthen the tensile behavior of concrete without compromising its integrity [43].

In addition, studies with RHA indicate that its densifying effect increases the speed of the ultrasonic pulse and surface hardness, properties closely associated with a greater indirect tensile strength [44] . Added to this is that low proportions of calcined ash at adequate temperatures can improve indirect traction by filling action and increased density. [45]. Even in polymeric matrices, treated coffee husk fibers show significant increases in traction due to optimized matrix-fiber adhesion [46]. Taken together, these results indicate that traction is favored when ash is used in moderate proportions or in balanced combinations, while high replacements reduce performance by increasing porosity and decreasing available cementitious compounds.

Table 7: Results obtained for tensile strength.

Material/system	**Residue**	**% / condition**	**Indicator**	**Result**	**Reference**
Asphalt mix with CHA as filler	CHA	Replacement filler conv.	Indirect traction	↑35,8 %; TSR 94,58→105,03 %	[42]
Cementitious compounds with fine residues	CHA or others	Intermediate dosage	HR and Stiffness	Maximum values in moderated content	[43]
Concrete with RHA	RHA	Low proportions	UPV/Hardness	UPV ↑ and hardness ↑ → indirect traction	[44]
Concrete with calcined ash	Ash CC	Low proportions	Indirect traction	Upgrade by Fill Effect	[45]
Polymeric matrices with DC fibers	CC fibers	Treated fibers	Direct traction	Significant increases for better adhesion	[46]

Source: Authors, (2026).

III.1.2.3 Flexural Strength

The flexural strength reflects the ability of the concrete to redistribute stresses after the initial cracking and is usually increased with moderate substitutions of agro-industrial ash. In concretes with 5–15 % RHA, the maximum performance is achieved at 10 %, achieving values above the control due to the refinement of pores and the higher density of the paste-aggregate transition zone [47]. Similarly, UHPC concretes with up to 40% RHA show significant increases when the ash has fineness < 5 µm, since its high reactivity generates a more homogeneous matrix with less formation of microcracks, which improves the bending capacity of the material [48]. Likewise, concretes modified with coffee husks show increases of more than 18% when obtained by pyrolyzation between 350–450 ℃, favoring internal curing and acting as a micro-filler that limits the early propagation of fissures [49].

In addition, the combined use of CHA with natural reinforcements improves flexional response; for example, mixtures with pineapple leaf fiber and coffee ash reach strengths close to 8 MPa, higher than reference concrete, due to bridging cracks and increasing internal cohesion [50]. Overall, the bending benefits from optimal RHA replacements – around 10% – and the use of coffee residues with natural fibres, as they densify the matrix and raise ductility. However, high replacements reduce stiffness and bending capacity, so controlled dosages are required depending on the type of ash and the structural objective.

Table 8: Results obtained for flexural strength.

Material/system	**Waste**	**% replacement**	**Bending result**	**Comment**	**Reference**
Concrete with RHA	RHA	5–15 %	Maximum performance at 10%	Flexibility > control	[47]
UHPC with very fine RHA	RHA	Up to 40%	Significant ↑ in flexion	Fineness <5 µm → homogeneous matrix	[48]
Concrete with pyrolyzed coffee residues	CG	Optimal content	Flexibility ↑ >18%	Pyrolyzed 350–450 ℃	[49]
Concrete with CHA + Pineapple Leaf Fiber	CHA + fiber	Optimal dosing	≈8 MPa	> flexion that I specify as a reference	[50]

Source: Authors, (2026).

III.1.3 Durability.

III.1.3.1 Freeze Resistance.

Resistance to freeze-thaw cycles is linked to the amount of water retained and porous connectivity. Recent studies show that rice husk ash (RHA), when properly processed and dosed, especially in acid-leached forms, can achieve durability factors greater than 80% after 300–600 F–T cycles. [51], due to matrix densification and critical pore refinement. In binary concretes with 15% ultrafine RHA, increases of 43% in compressive strength at 90 days have been observed, along with reductions of 31% in sorption, 27% in drying shrinkage, and 23% in mass loss due to abrasion[52], indicators of a more stable microstructure against freeze–thaw cycles. Complementarily, the literature reports that replacements of 10–30% of RHA with high amorphous silica and good fineness reduce pore connectivity and delay F–T degradation [53].

On the other hand, coffee waste exhibits more critical hygroscopic behavior. Untreated coffee husks have absorption rates of around 13–14%, higher than those of rice husks, although treatment with NaOH reduces these values by almost half [54]. Specifically, coffee husk biochar achieves an absorption capacity of 4.33 g/g, significantly increasing overall absorption when its content exceeds approximately 3% by volume of the fine aggregate [55]. Overall, while well-processed RHA promotes a denser, more resistant porous network to F–T cycles, coffee residues should be used in moderate proportions or with prior treatment to avoid an excessive increase in water susceptible to freezing.

Table 9: Results obtained for freeze resistance.

Material/system	**Waste**	**% replacement**	**Parameter**	**Result**	**Reference**
Concrete with acid-leached RHA	RHA	Optimal dosage	Durability factor	>80 % tras 300–600 ciclos F–T	[51]
Binary concrete with ultrafine RHA	RHA	15 % cement	90 d: fc’, sorption, shrinkage, abrasion	fc’ ↑43 %; sorption ↓31%; shrinkage ↓27%; mass loss ↑abrasion ↓23%	[52]
Concrete with reactive RHA	RHA	10–30 %	F–T	↓ pore connectivity; slower F–T degradation	[53]
Untreated CC	CC	—	Self-absorption	≈13–14 %; after NaOH ≈ half	[54]
CC biochar in concrete	CC biochar	>3 % vol. fine sand	Self-absorption	4,33 g/g; ↑ Abs global of concrete	[55]

Source: Authors, (2026).

III.1.3.2 Corrosion Resistance.

The corrosion resistance of steel is strongly associated with chloride ion permeability. In concrete with 0–20% RHA and a w/b ratio = 0.35, 20% replacement reduces the RCPT load by 54% and the migration coefficient by 49%, indicating a much denser matrix. [56]. This behavior, incorporated into a Fick diffusion model, shows a notable increase in service life in marine environments. Similar results are observed in mixtures with 10% RHA and bagasse ash, where the RCPT load at 28 days decreases by 58% compared to OPC, reclassifying it as "very low" chloride penetration and showing lower initial absorption and higher electrical resistivity. [57]. Likewise, concrete with around 12% RHA exhibits, after months in chlorides and sulfates, greater resistance to compression and indirect traction and significantly lower permeability than mixtures without ash. [58].

En High-strength concrete that partially replaces cement with PET and sand with RHA, the reference concrete reaches 2550 C (moderate permeability), while combinations with up to 40% RHA as a sand replacement and 15% PET as a cement replacement reduce the load passed by 48%, placing it in the low permeability category. [59]. The improvement is associated with the filling effect of RHA and the action of PET in interrupting ion flow pathways. In terms of AAB mortars with ternary GGBS + RHA + CHA binders, the optimal mixture has lower water absorption, higher UPV speeds, and lower loss of strength when exposed to acid and seawater. [60]Overall, moderate substitutions with RHA alone or combined with polymers or agro-industrial ash significantly reduce chloride ingress and, with it, the risk of reinforcement corrosion.

Table 10: Results obtained for corrosion resistance.

Material/system	**Waste**	**% replacement**	**Test/parameter**	**Result**	**Reference**
Concrete with RHA (a/b=0.35)	RHA	0–20 %	RCPT and migration coefficient	20% RHA → RCPT ↓54%, migration ↓49%	[56]
Concrete with 10% RHA + bagasse ash	RHA + bagasse	10 % RHA + BA	RCPT 28 d	Carga ↓58 % vs OPC → “very low” cloruros	[57]
Concrete with ≈12% RHA	RHA	≈12 % cemento	Exposure to chlorides + sulfates	fc’ y tracción ↑; permeabilidad ↓	[58]
High-strength concrete with PET + RHA	PET + RHA	0–40% sand → RHA, 0–15% cement → PET	RCPT	Control: 2550 C (moderate); optimal mixture → load ↓48% (low permeability)	[59]
Mortar AAB GGBS+RHA+CHA	GGBS+RHA+CHA	Optimal blend	Absorption, UPV, loss of resistance	Lower Abs; ↑UPV; lower loss in acid and seawater	[60]

Source: Authors, (2026).

III.1.3.3 Sulfate Resistance.

Sulfate resistance in concrete with RHA depends heavily on the dosage and refinement of the ash. In M20 concrete with 0–25% RHA, weight loss and strength reduction increase with ash content, reaching the greatest deterioration with 25% replacement in acidic, alkaline, and sulfated environments. [61].In coffee waste, substitutions exceeding 10% of roasted bean ash increase absorption and porous connectivity due to its rough texture and low density. [62]In C25 concrete with coffee husk ash, replacements of around 5% maintain adequate strength levels by preventing an increase in interconnected pores. [63].

Hybrid mixtures with 10% RHA + 5% CHA show an increase of approximately 7% in tensile strength per division, associated with microstructural refinement and greater availability of reactive silica. [64]. Overall, the results indicate that sulfate resistance improves when RHA and CHA are used in moderate proportions, approximately between 5–15%, and with adequate fineness that limits accessible porosity. Conversely, high substitutions with ash of greater roughness and porosity increase the penetration of sulfate solutions and the risk of chemical deterioration.

Table 11: Results obtained for sulfate resistance.

Material/system	Waste	% replacement	Indicator	Result	Reference
M20 concrete with RHA	RHA	0–25 %	Weight loss and fc’	Max. deterioration in 25 % RHA	[61]
Concrete with coffee bean ash	CG	>10 %	Absorption / porosity	Abs and porosity ↑; sulfate resistance ↓	[62]
C25 concrete with CHA	CHA	≈5 % cement	Sulfate status	Maintains adequate resistance (controlled interconnected pores)	[63]
RHA + CHA hybrid concrete	RHA + CHA	10 % RHA + 5 % CHA	fct,split	fct,split ↑≈7 %; better microstructure	[64]

Source: Authors, (2026).

IV. CONCLUSIONS

The systematic review carried out shows that both coffee husk ash and rice husk ash have significant potential as supplementary cementitious materials in concrete, although with different levels of technological consolidation. CCA shows more uniform and favorable behavior, especially when used in moderate replacement percentages and obtained under controlled calcination conditions, since its high amorphous silica content and adequate fineness improve the microstructure of the paste, reduce accessible porosity, and, in many cases, increase compressive and flexural strength compared to reference mixtures. CCC, on the other hand, offers the advantage of valorizing an abundant agro-industrial waste linked to the coffee production chain, but its effect on physical and mechanical properties is more sensitive to the quality of burning, the content of residual organic matter, and the percentage of substitution, so that high doses tend to increase absorption and reduce density and strength, while optimized dosages allow acceptable structural performance to be maintained.

From the point of view of durability and sustainability, the literature reviewed indicates that CCA consistently contributes to improving the resistance of concrete to chloride and sulfate penetration, as well as reducing permeability and the rate of deterioration in aggressive environments, which translates into a potential extension of the service life of structural elements. In the case of coffee waste, its use in the form of ash or biochar partially reduces the clinker content and carbon footprint of the material, but requires greater control of porosity and workability to ensure durable performance comparable to that of CCA-modified concretes. Overall, the results support the use of CCA as a consolidated cementitious addition for more sustainable concretes and position CCC as an emerging alternative that requires further standardization studies, full-scale analysis, and joint evaluation of mechanical performance, durability, and environmental benefits, including the design of hybrid mixtures that combine both ashes.

V. AUTHOR’S CONTRIBUTION

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