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Manufacturing of building materials using agricultural waste (sugarcane bagasse ash) for sustainable construction: towards a low carbon economy. A review

Oluwatoyin Joseph Gbadeyan[a], Lindokuhle Sibiya[a], Ncumisa Mpongwana[a], Linda Z Linganiso[b], Ella Cebisa Linganiso[c] and Nirmala Deenadayalu[a]

[a]Department of Chemistry, Durban University of Technology, Durban, South Africa; [b]Microscopy and Microanalysis Unit, University of the Witwatersrand, Johannesburg, South Africa; [c]Molecular Sciences Institute, School of Chemistry, University of the Witwatersrand, Johannesburg, South Africa

ABSTRACT

Cement production processes contribute to around 5% of carbon emissions globally and increase yearly. To cut 5% of global emissions, alternative materials to substitute cement concentration in building materials must be sourced. This review identified some agricultural waste, such as sugarcane bagasse ash (SBA), palm leaf ash, and rice husk ash, with potential materials for partial substitution or replacement for cement. It also discusses the influence of incorporating agricultural waste on critical properties of building materials such as bricks, interlocks, concrete, and pavements. Adding these agricultural wastes could increase bricks' strength by 65% and reduce unit weight by 25%. It also improves bio bricks' compressive strength, water resistance, and bulk density. Optimising agricultural waste-loading-producing building materials is critical to their performance and must be considered for developing brick materials with improved properties. The review established that 50% of cement concentration could be replaced with SCBA, or hybridising rice husk ash, agricultural olive waste (AOW), sugarcane leaf waste ashes (SLWA), and rice husk (RH). This suggested that 100% of cement is achievable by exploring hybridising SCBA, a combination of rice husk, (AOW), (SLWA), and (RH) to develop a sustainable material without compromising the required properties for construction application. Incorporating agricultural waste is a viable way to develop more cost-effective and sustainable building materials with no cement content, resulting in a 5% global emission cut and a low-carbon environment.

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Bricks; CO_2 emissions; construction sector; sugarcane bagasse ash

1. Introduction

Bricks are utilised as construction materials worldwide (Phonphuak and Chindaprasirt 2018). Most of these bricks are formulated with a significant amount of cement, and the production process and transportation of cement often contribute to the CO2 emissions of cement (He et al. 2019; Nie et al. 2022). Consequently, they are identified as primary producers of anthropogenic CO2 emissions that negatively impact the environment, contributing to climate change and global warming (Ofosu-Adarkwa, Xie, and Javed 2020). These challenges made scholars look at reducing the amount of cement in bricks by using alternative materials such as sugarcane bagasse ash in ceramics, burnt clay bricks, mortar, and concrete mixes, to name a few (Phonphuak and Chindaprasirt 2018). These studies targeted carbon footprint reduction to have a low-carbon environment.

On the other hand, sugar industries process a high volume of waste during production. These wastes, including molasses, wastewater, sugarcane bagasse, and organic pulp (ash), have been used as raw materials to produce other value-added materials (Nawaz et al. 2021) to reduce further waste generated from sugar industries. However, an increase in the volume of organic pulp left behind after juice extraction (ash) produced by the sugar industry sectors raised the demand for ecologically acceptable reuse and practical disposal methods for sugarcane bagasse ash (Rajput and Gupta 2016). Using these wastes as raw materials for developing new products may help waste reduction, resulting in pollution reduction. Singh and Kumar (2015) suggested that utilising this organic pulp or solid waste as a reinforcement component of construction material, such as bricks, is one of the viable approaches for its management. Incorporating these wastes to develop sustainable construction materials such as concrete, bricks, and interlock components may be a feasible solution to environmental pollution and the high costs of construction materials.

Notably, sugarcane bagasse ash is generated from two sources during the burning of sugarcane with pozzolanic material characteristics that could be used as a partial replacement for cement. The first is bottom ash, collected straight from the bottom of the boilers, and the second is fly ash, acquired by cleaning the chimney gases (Sales and Lima 2010). Although ordinary Portland cement is the most commonly used construction material globally, alternative materials such as blast furnace slag, fly ash, and silica fume are some industrial wastes considered potential cement substitutes (Ganesan, Rajagopal, and Thangavel 2007).

CONTACT Oluwatoyin Joseph Gbadeyan toyin2good@gmail.com Department of Chemistry, Durban University of Technology, Durban, South Africa

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Furthermore, cement, commonly used as a traditional raw material for building, uses large amounts of energy and contaminates the air, water, and land. As a result, new sustainable materials are required to fulfill the ever-increasing demand for building materials (Rautray et al. 2019). Therefore, this review discusses over seventy available literature on the adverse effects of cement production on the ecosystem and the possibility of replacing cement with agricultural waste. These agricultural wastes include but are not limited to sugarcane bagasse, peanut husk, corn stalk, sugarcane leaf waste, rice husk ash, eggshell particles, and agricultural olive waste agriculturally based. This information was sourced from online articles, theses, books, conference proceedings, and report analyses. These were accessed via Google Scholar, Science Direct, ResearchGate, and Google Search. The review defines sugarcane bagasse and sugarcane bagasse ash and compares their chemical composition from different literature and their contribution to pozzolanic reactions. It analysed the possibility of replacing sugarcane by-products and other agricultural waste for construction materials development. The effect of incorporating a single waste and combining two or more wastes for partial substitution of cement in construction material was evaluated. The loading ratio effect of sugar bagasse and other agricultural waste on the partial replacement of cement in construction materials was discussed.

Moreover, the hybridising effect of agricultural waste and eggshell nanopowder for substituting cement concentration in concrete and bricks was reported. Furthermore, it identified traditional stabilisers for construction materials and their combination with sugarcane bagasse ash to produce sustainable bricks. The effect of incorporating bagasse on cement-based brick properties, such as water absorption, compressive strength, bulk density, and unit weight of construction material, was evaluated. Using a combination of fly ash and sugarcane bagasse ash as a stabiliser in bricks and other construction materials was discussed.

1.1. The negative impact of cement production

Cement manufacturing harms the environment. During cement manufacture, two distinct sources of carbon dioxide emissions are generated. The first and most notable source is the combustion of fossil fuels to power the rotary kiln, which emits around 3/4 ton of CO2 per ton of cement produced (Micheal and Moussa 2021). According to Micheal & Moussa's study, the cement sector is responsible for over 5% of worldwide carbon emissions. Similarly, the chemical process of calcining limestone into lime in the cement kiln is the second largest source of CO2. With these two sources, 1.25 tons of carbon dioxide is released into the atmosphere for every ton of cement produced and pollutes the environment (Dawoud, Micheal, and Moussa 2020).

Concrete and cement production also generate many air pollutants, such as nitrogen oxides, sulphur dioxides, carbon oxides, and dust, the most visible pollutant (Blois and Lay-Ekuakille 2021). From 1 ton of cement manufactured, 1 163.3 kg of particulate dust pollution is created. Most of these are caused by loading or packaging cement, grinding cement clinker, cement manufacture, and raw material handling Dawoud et al. (2020). However, using fossil fuels for producing concrete and cement, transportation emits other pollutants into the atmosphere. Another issue with cement and concrete manufacturing is water contamination. Water from equipment cleaning is frequently thrown into batch plant settling ponds, where the deposited particles end up in the ocean or streams (Abou Hussein and Sawan 2010; Dawoud, Micheal, and Moussa 2020).

2. Sugarcane bagasse

Sugarcane bagasse is the fibrous, non-biodegradable residue left after extracted sugarcane juice. It is one of the sugar industry's most significant solid waste streams (James & Pandian 2017). Approximately 7 million tonnes in South Africa are produced annually (Davidson et al. 2006). The sugar industry frequently uses bagasse as fuel, which produces sugarcane bagasse ash when burnt at high temperatures. Sugarcane bagasse is produced in large quantities in many countries as a waste product. For each ton of sugarcane bagasse burnt, 25–40 kg of SCBA is produced (Sales and Lima 2010). It is a valuable 'waste' material used in ceramics, biomass ash filters, concrete, and, most recently, compressed earth blocks as a stabiliser (Umamaheswaran, Batra, and Bhagavanulu 2004; Teixeira et al. 2008). Incorporating this waste into construction materials such as bricks, interlocking, and concretes will help reduce environmental pollution and the weight and cost of these materials. However, during sugar cane and sugar production harvesting, the waste generated, such as sugar bagasse and ashes, is managed by either land fields or burning, emitting carbon dioxide into the atmosphere, resulting in air pollution and climate change. The following section discusses the devastating effect of burning on the ecosystem.

2.1. The negative effect on the environment of burning sugarcane bagasse

Because agricultural activities depend on climatic conditions, climate change and agriculture are inextricably linked. When one considers the feedback effect of agriculture on climate change, the relationship between climate change and agriculture becomes even more complicated. Agriculture does play a significant role in climate change (Fofack and Derick 2020). Global climate change has long threatened sustainable development, necessitating global cooperation to meet the net-zero emissions target (Han et al. 2022). It should be emphasised that agriculture is primarily responsible for the atmospheric release of N2O and CH4 and produces more than half of the world's non-CO2 gas emissions (Fofack and Derick 2020). Since no one-size-fits-all remedy for environmental harm exists, more rapid and successful domestic actions are needed to restrict carbon emissions (Han et al. 2022). Many developing countries are hampered by ineffective waste management regulations, which harms the environment and air quality of these countries (Priyadarshini 2015). Meanwhile, these challenges need urgent attention to achieve a low-carbon environment.

The inadequate methods for waste management in dealing with the waste created during sugarcane harvest resulted in a large volume of residues during the season, prompting

farmers to burn the residues for disposal (Priyadarshini 2015). Burning sugarcane bagasse leaves during harvesting season has negative effects on the environment. The adverse effects include air quality degradation and the emission of harmful combustion products such as volatile organic compounds (VOCs) and carbon monoxide (CO), which harm public health and accumulate black clouds. It contaminates the environment and damages the soil microbial diversity due to fly ash production (Alavéz-Ramírez et al. 2012; Rajput and Gupta 2016). In addition, sugarcane and waste fertilisers turn into nitrate, reducing water oxygen content and negatively impacting aquatic animals (Priyadarshini 2015).

Similarly, pollution caused by agricultural waste significantly impacts the environment. The fire that results from burning sugarcane bagasse leaves produces a variety of hazardous pollutants that contribute to various health problems, including respiratory and lung diseases. Furthermore, fertiliser and pesticide pollutants drain into groundwater, where drinking water is sourced, triggering many health issues and contributing to the blue baby syndrome (Micheal and Moussa 2021). Nowadays, in some countries, there is federal legislation prohibiting the burning of sugarcane 'straw', and most of the harvesting is done with machines. Despite considerable advances in reducing the waste created during sugarcane harvest and large volumes of residues during the season and sugar production, large amounts of waste lie in the environment, causing different pollution and leading to global warming. Biorefinery and circular economic concept has been one of the most effective ways to reduce this waste. One of these concepts is using this waste as a feedstock to develop new material that meets societal needs. Sugarcane bagasse and ashes are waste created during sugarcane harvest and sugar production, which comes in tons. Several authors (Kazmi et al. 2017; Madurwar, Mandavgane, and Ralegaonkar 2014; Phonphuak and Chindaprasirt 2018; Tonnayopas 2013) investigated the chemical composition of sugarcane bagasse ashes and confirmed their suitability as an alternative to cement based on their chemical composition and properties.

2.2. Comparison of the chemical composition of sugarcane bagasse

It is well known that bagasse ash is high in silica, alumina, and iron oxide. This chemical composition of bagasse ash reported by various researchers shown in Table 1 proved that silica is the prominent component of bagasse ash's chemical properties. Despite being far less abundant than alumina and iron oxide, which are the significant components of bagasse ash composition, they contribute to pozzolanic reactions.

The chemical composition of SBA was determined through X-ray fluorescence (XRF). The XRF analysis shows that the major components in the SBA were silicon dioxide, aluminium oxide, calcium oxide, and iron (III) oxide. These chemical compositions classify ash (Concrete and Aggregates, 2013; Mahmood et al., 2018). According to ASTM C 618 (Mahmood et al., 2018), when sugarcane bagasse ash has a minimum of 70% of a combination of silicon dioxide, aluminium oxide, calcium oxide, and iron (III) oxide, they are classified as F. On the other hand, sugarcane bagasse ash has a minimum of 50% combination of silicon dioxide and aluminium oxide are classified as C Therefore, all the chemical composition requirements of sugarcane bagasse ash extracted from different studies reviewed in Table 1 fall within ASTM C 618's Class F, except for chemical composition requirement sugarcane bagasse ash reported by Tonnayopas (2013), which is less than 50%.

Furthermore, the chemical composition of SCBA reported by Kazmi et al. (2017) and Phonphuak and Chindaprasirt (2018) are slightly similar, except for percentages of MgO, SO3 reported by Kazmi et al. (2017), which are not in Phonphuak and Chindaprasirt (2018) findings. While the chemical compositions of SCBA reported by Tonnayopas (2013) and Madurwar et al. (2014) are different from the chemical compositions of SCBA by Kazmi et al. (2017) and Phonphuak and Chindaprasirt (2018)by a wide margin. The change observed in the chemical compositions may be attributed to different climate conditions and soil where the sugarcane plant was grown (Laftouhi et al., 2023)

Similarly, the difference between SCBA minerals present in SCBA presented in Table 2 may linked to different climate conditions and soil where the sugarcane plant was grown.

Furthermore, it could be seen that different studies discovered different minerals for SBA samples. However, minerals such as quartz, cristobalite, and carbon-based materials dominated the SBA composition, proving uniformity. The difference in the mineral may be attributed to different sources of sugarcane bagasse and different process procedures used for producing sugarcane bagasse ash. Therefore, before considering

Table 1. Different chemical compositions of SBA from different authors.

Author(s)	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	TiO_2	MgO	P_2O_5	SO_3	MnO	LOI
(Tonnayopas 2013)	38.31	2.84	10.76	3.36	1.77	0.21	0.94	0.90	0.45	0.23	40.21
(Batool, Masood, and Ali 2020)	22.00	5.00	64.25	3.50	1.00	0.17	0.16	0.10	-	0.16	-
(Kazmi et al. 2017)	86.77	1.79	2.55	2.72	0.46	-	0.79	-	0.12	-	10.12
(Phonphuak and Chindaprasirt 2018)	88.03	2.31	2.55	3.67	0.32	-	-	-	-	-	10.57
(Mamatha, Narayana, and Kumar 2017)	87.50	3.8	2.56	4.9	0.47	-	0.68	-	-	-	8.27
(Salim, Ndambuki, and Adedokun 2014)	73	6.7	2.8	6.3	2.4	-	3.2	4.0	-	-	0.9
(Saranya et al. 2016)	66.89	29.18	1.92	-	-	-	0.83	-	0.56	-	0.72
(Madurwar, Mandavgane, and Ralegaonkar 2014)	59.50	2.40	14.75	3.34	-	-	2.11	-	0.92	-	8.90
(Schettino and Holanda 2015)	85.55	2.29	1.21	1.21	1.33	0.20	-	3.01	2.28	0.08	-
(Shafiq et al. 2016)	77.25	6.37	4.05	4.21	2.34	0.58	2.61	0.58	0.11	0.27	
(Priya and Ragupathy 2016)	71.0	1.9	3.4	7.8	8.2	-	0.3	-	-	0.20	
(Grau et al. 2015)	85.5	5.3	1.3	2.1	10.38	-	-	-	-	-	
(Abdulkadir, Oyejobi, and Lawal 2014)	72.85	1.07	9.96	6.96	6.76	-	6.49	-	-	-	4.233
(Zhang et al. 2020)	76.16	8.38	2.32	2.71	3.97	0.42	-	-	0.24	0.13	2.46

Table 2. Minerals present in sugarcane bagasse ash, according to different authors.

Author(s)	Minerals found in sugarcane bagasse ash
"Teixeira et al. (2011), Sales and Lima (2010)"	"Quartz"
"Ganesan et al. (2007)"	"Quartz, cristobalite"
"Alavez-Ramırez et al. (2012)"	"Quartz, cristobalite, carbon"
"Madurwar et al. (2014)"	"Amorphous silica"
"Tonnayopas (2013)"	"Quartz, calcite, microcline, feldspar"
"James and Pandian (2016)"	"Quartz, cristobalite, calcium carbonate"
"Faria et al. (2012)"	"Quartz, cristobalite, hematite, mullite, calcium phosphate, potassium carbonate"

incorporating sugarcane bagasse ash as a partial replacement for cement, its minerals and chemical composition must be investigated to determine its suitability.

2.3. Potential utilization of sugarcane bagasse ash as a cement replacement in building material

The possibility of substituting cement with sugarcane bagasse ash in building materials such as concrete and brick has been explored by numerous researchers (Basika, Kigozi, and Kiggundu 2015; Modani and Vyawahare 2013; Prasanth et al. 2015; Thomas et al. 2021).

Prasanth et al. (2015) studied the impact of incorporating bagasse ash, lime, fly ash, cement, and quarry dust into compressed mixed bricks. These additives were all added, and the strength of the composite brick was measured. The maximum strength of all combinations was determined to be 10% cement. However, a 5% bagasse ash composite earth brick was discovered to have strength comparable to a 10% lime-stabilised earth brick. This finding is consistent with Saranya et al. (2016) studies. However, different materials are combined for developing bricks in these studies.

Furthermore, Salim et al. (2014) introduced sugarcane bagasse ash and sandy loam soil into compressed earth blocks development. The sandy loam soil blocks were produced with 3%, 5%, 8%, and 10% bagasse ash loading before being compacted and cast into 285 mm X 145 mm X 95 mm blocks and cured for 14, 21, and 28 days. After curing, they were subjected to compressive strength and shrinkage crack tests. The results revealed that adding 10% bagasse ash to a sandy loam soil block increased strength by 65%—a 7% reduction in shrinkage cracks after adding 10% bagasse ash-modified soil blocks was obtained. This property improvement may be attributed to the pozzolanic reactions of sugarcane bagasse ash.

Furthermore, the partial replacement of cement with bagasse ash as fine aggregate in concrete was explored further by (Modani and Vyawahare 2013). Untreated bagasse ash was partially substituted in the proportions of 0%, 10%, 20%, 30%, and 40% by volume of fine aggregate in concrete. Fresh concrete tests, such as the compaction factor test and the slump cone test, were performed. Similarly, hardened concrete tests were carried out, such as compressive strength and split tensile strength. The results demonstrated that 10% bagasse ash could be a fine aggregate substitute.

Basika et al. (2015) looked into bagasse ash as a cement substitute in the building industry. The chemical properties of bagasse ash samples were collected and evaluated. The compressive strength of mortars containing conventional Portland cement and SCBA was investigated. As cement replacement, SCBA was examined with varying amounts of 0 %, 10%, 15%, 20%, 25%, 30%, and 40%. Three duplicates were made and tested, with bagasse ash substituting regular Portland cement in the above proportions. At a test age of 28 days, the findings demonstrated that regular Portland cement might be substituted with SBA up to 20% without altering the compressive strength of the mortar.

Priyadarshini (2015) explored the impact of using bagasse ash and silica fumes as an additive instead of cement in concrete blocks. Two concrete mix ratios were investigated: bagasse ash was used to substitute cement up to 30% by weight, with silica fumes as an additive. The hollow cast blocks were investigated for compressive strength and water absorption. According to the results of the tests, up to 10% bagasse ash replacement with silica fume admixture produced performance equivalent to the control specimens.

Another study by Ganesan et al. (2007) found that the compressive strength of concrete samples increases at lesser concentrations of bagasse ash but decreases as bagasse loading increases. They replaced cement with 5% –20% bagasse ash and evaluated concrete samples for compressive strength, splitting tensile strength, water absorption, chloride penetration, and chloride diffusion after 7, 14, 28, and 90 days. The addition of 10% bagasse resulted in improved compressive strength. The compressive strength decreases to the value of the control specimen after % bagasse addition. However, superior compressive strength was obtained after adding 5% bagasse. The compressive strength of the 20% bagasse ash concrete specimen was equivalent to the 14-day compressive strength of the control specimen after seven days. A similar pattern was observed when evaluating a 20% bagasse ash sample's compressive strength compared to a control specimen from the next curing period. This finding demonstrates that including bagasse ash results in high strength in concrete in the early days of testing. The authors determined that a 20% replacement of cement with sugarcane bagasse ash is achievable without affecting the characteristics of concrete Amin et al. (2020).

Thomas et al. (2021) thoroughly reviewed sugarcane bagasse ash's physical and chemical characteristics. The review looked into the performance of concrete with varied amounts of sugarcane bagasse ash and assessed the qualities of fresh and hardened concrete. The study's findings point to an improvement in the performance of sugarcane bagasse-contained concrete; strength gains were observed due to increased pozzolanic reactions, low heat of hydration, and reduced permeability, which may have been caused by the addition of bagasse ash to refine the concrete's pores. It was established in this review

that construction material with 20% SCBA offered improved compressive strength and lower density, suggesting that 20% of cement content can be replaced with SCBA.

Moussa (2022) investigated the influence of incorporating 0.5 wt.%, 1.5 wt.% and 2.5 wt.% SBA on the compression stress and crushing load of fire clay bricks under 0.2 MPa/sec loading speed. Suitable and acceptable compressive strength for bricks, according to ESS 4763/2006, is within 1–8 MPa. The compressive strength of fire bricks shown in Figure 2 proved that all the bricks meet standard strength irrespective of SBA loadings. However, a slight linear reduction in compressive strength was observed with a corresponding increase in SBA addition after burning. This slight drop in strength proved the burning of SBA fibre, resulting in drop resistance to external compression force. However, achieving the compressive strength required for bricks at 2.5 wt% SBA fibre loading could only replace cement at that low percentage, and the aim of reducing air pollution will not be attained. In this regard, Tonnayopas (2013) conducted a study on the effect of loading sugarcane bagasse ash on the properties of clay biobricks. The mixing ratio adopted was from 1:5 wt% clayey soil to 5 wt% of sugar cane bagasse ash, which was sintered at an optimal temperature of 1050℃ and later subjected to a hydraulic press. Thermal stability, water absorption, compressive strength, and bulk density of sugar cane bagasse ash-made biobrick samples were investigated. A linear improvement in compressive strength was observed at the loading of sugarcane bagasse ash up to 30% and declined at 50% loading. This performance depicts that loading sugarcane bagasse ash at 30% exhibited a higher strength of 43 MPa. The loading of smaller particle sizes of sugar cane bagasse ash offered better strength in the study than (Micheal and Moussa 2022) reported. This performance may be attributed to the high service area, homogeneous dispersion, and inherent properties of ash incorporated.

Considering Tonnayopas (2013) and (Micheal and Moussa 2022) on improving biobrick's compressive strength by incorporating sugar cane bagasse ash and sugar cane bagasse, it could be concluded that the loading of sugar cane bagasse ash is more effective in terms of loading ratio and strength. This discovery has led to rigorous studies on the effect of loading sugarcane bagasse ash on the compressive strength of bricks. Tonnayopas's (2013) study proved that sugarcane bagasse ash could substitute 30% of cement to develop brick with improved compressive strength.

Danso (2015) explored the influence of loading sugarcane bagasse fibre on soil block properties such as density. They discovered that the reinforced soil blocks' average dry density decreased with increased sugarcane bagasse fibre concentration (Han et al. 2022; Hakeem; Amin et al. 2022). A decrease in bulk density with a corresponding increase in sugarcane bagasse ash loading was observed from 20 wt.% to 50 wt.%. The decrease can be attributed to sugarcane bagasse ashes' lightweight and bulk density. The high loading of sugarcane bagasse ashes eventually reduces the overall density of biobricks. Kazmi et al. (2016) study also confirmed that sugarcane bagasse ashes loading positively affected bulk density. This output signified that the loading of sugarcane bagasse ashes improves compressive strength and reduces the weight of the biobrick.

Similarly, Minhaj et al. (2016) confirmed that incorporating rice hub ash or sugarcane bagasse ashes reduces biobrick weight by approximately 6%. Madurwar, Mandavgane, and Ralegaonkar (2015) developed and investigated the feasibility analysis of sugarcane bagasse ashes bricks. They reported that the brick produced with the combination of sugarcane bagasse ashes was lighter in weight, meeting the necessary standard. The investigation by Micheal and Moussa (2022) showed that the unit weight reduced as sugarcane bagasse ashes concentrations increased. A reasonable 7% reduction in weight observed impacts the weight of the structure and foundation size. The reduction in bricks' unit weight after incorporating sugarcane bagasse ashes may be attributed to the lightweight of naturally sourced material.

Furthermore (Saad Agwa et al. 2022), confirmed the growing interest in sugarcane bagasse cane (SCBA), a byproduct from sugar industries, as a partial replacement for cement to reduce air pollution. They provide information on studies where sugarcane bagasse influenced construction materials due to their pozzolanic characteristics. The effect of treating SCBA before incorporation on concrete physio-mechanical and microstructure properties was evaluated. Similarly, the incorporation of treated sugarcane bagasse as a cement alternative with eco-friendly concrete properties was provided. This literature confirmed that sugarcane bagasse's percentage loading, heating, or milling treatment determines the quantity of concrete slump. It also advised that the 5%-10% ratio of treated SCBA is the optimum for cement replacement and offers better mechanical properties than rice (Saad Agwa et al. 2022) as shown in Table 3.

The influence of incorporating SCBA to substitute cement concentration on the compressive strength of building materials such as concrete and bricks reported by different authors is compared in Table 2 and Figure 1. Different compressive values with the same sugarcane bagasse ash loading were discovered. The performance may be attributed to the difference-based material used in these studies. For instance, Salim et al. (2014) introduced sugarcane bagasse ash into sandy loam soil to develop compressed earth blocks. Priyadarshini (2015) used bagasse ash and silica fumes as an additive instead of cement in concrete blocks. However, building materials with 10% bagasse ash incorporation exhibited superior compressive strength irrespective of the based materials. This implied that 10% bagasse ash incorporation may be the optimum loading for improved compressive strength of concrete bricks with the based material used in the reviewed literature. The optimum incorporation of sugarcane bagasse ash for substituting cement in building materials from more studies was further compared and illustrated in Figure 2.

Figure 2 shows comparative studies conducted by different authors on the compressive strength of bricks without bagasse ash and biobricks with different optimum loading concentrations of sugarcane bagasse ash (4–30 %). Notably, the optimised concentration of bagasse ash exhibited superior compressive strength than bricks without bagasse ash. Furthermore, Tonnayopas's (2013) study shows that SCBA can substitute 30 % cement to develop brick with superior compressive strength. This performance may be attributed to interfacial bonding provided by bagasse ash and the

Table 3. Minerals present in sugarcane bagasse ash, according to different authors.

SCBA Loading (%)	Type of building materials	Compressive strength @ 28 day (MPa)	Reference	SCBA Loading (%)	Type of building materials	Average Compressive strength @ 28 day (MPa)	Reference
0	Compressed	2.19		0		22.36	
3	Bricks	2.3	Salim, Ndambuki, and Adedokun (2014)	10	Concrete	**23.85**	Modani and Vyawahare (2013)
5		2.3		20		21.9	
8		3.15		30		19.17	
10		**3.92**		40		14.7	
0		1.945		0		28.31	
10		2.533	Basika, Kigozi, and Kiggundu (2015)	5		**33.38**	Ganesan et al. (2007)
15	Concrete	**3.125**		10	Concrete blocks	**33.38**	
20		2.556		15		32.06	
25		1.43		20		27.86	
30		1.118		25		26.14	
40		0.783		30		25.07	
0		8.02				32	
10		**7.48**	Priyadarshini (2015)	10		**34**	Amin et al. (2020)
20	Concrete	6.75		20		30	
30		5.35		30		28	

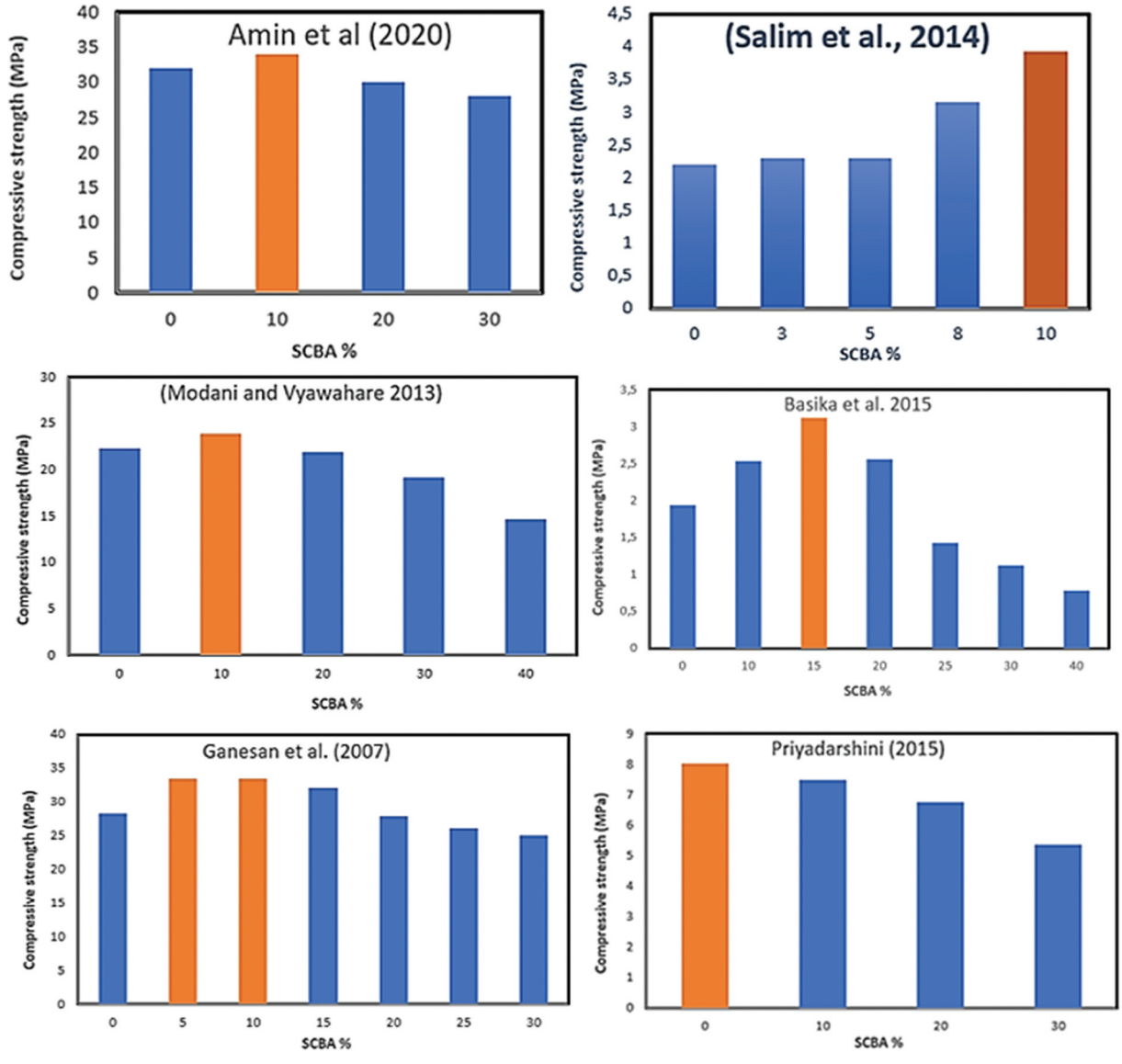


Figure 1. The loading effect bagasse ash on compressive strength of building materials.

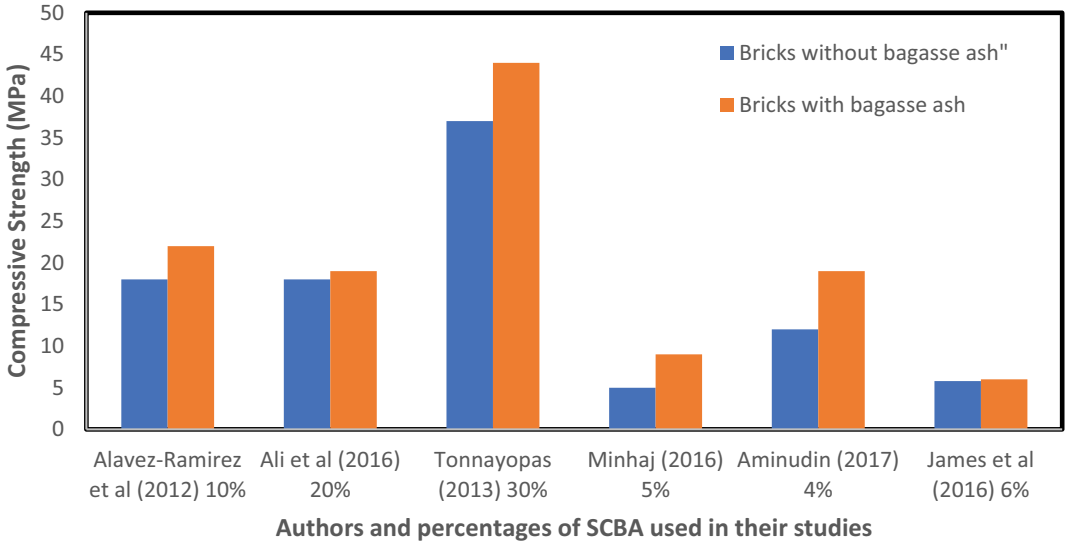


Figure 2. Compressive strength results result of optimum loading of bagasse ash from other authors.

compatibility of components for developing bricks, leading to a structural formation that improves compressive strength.

2.4. Combination of agricultural waste for substituting cement concentration in construction materials

Recently, cement processes have been identified as highly contaminating (Abd-Elrahman et al. 2023). This discovery led to numerous research on reducing cement usage in construction towards achieving a low carbon environment. Numerous agricultural waste such as peanut husk ash (PHA), combination of nano eggshell (NES) and SCBA, rice husk, agricultural olive waste (AOW), sugarcane leaf waste ashes (SLWA), and rice husk (RH), SBA and corn stalk ash CS, rice straw ash (RSA) and nano sesame stalk ash (NSSA), and rice straw ash (RSA) and palm leaf ash (PLA) showed in Figure 3 have been explored to replace cement in brick production (Abd-Elrahman et al. 2023; Hakeem et al. 2022a; Maglad et al. 2023).

2.4.1. The combination of nano eggshell (NES) and SCBA

(Amin et al. 2022) introduce nano eggshell for reducing slump, which reduces water absorption and improves the strength and stiffness of concrete produced using sugarcane bagasse cane (SCBA). Combining nano eggshell (NES) and SCBA was used as cementitious materials to reduce cement content in the fabricated high-strength concrete. SCBA loading ratio ranges from 5%- 20 %, and NES concentrations ranging from 2.5% to 7% were considered a partial replacement for cement. The high-strength concrete with improved mechanical properties, a dense form without porosity and crack, was achieved after 5% NES and 15% SCBA loading. This depicts that incorporating nano eggshells is a viable way to improve construction materials at a high loading above 10%, as suggested by (Saad Agwa et al. 2022).

2.4.2. The combination of rice husk, agricultural olive waste (AOW), sugarcane leaf waste ashes (SLWA), and rice husk (RH)

Abd-Elrahman et al. (2023) supplement 50% cement with a combination of rice husk, agricultural olive waste (AOW), sugarcane leaf waste ashes (SLWA), and rice husk (RH) for developing sustainable Ultra High-Performance Concrete (SUHPC). These wastes were incorporated at different percentage weights ranging from 0% to 50% to determine the effect of loading this waste at different percentages and optimal concentrations. The mechanical, physical, and chemical properties of the developed sustainable ultra-high-performance concrete produced using different SLWA, RH, SLWA, and AOW concentrations were evaluated. SUHPC, with 25% SLAW and 25% RH loading, used to replace 50% content, exhibited more than 19 MPa tensile strength, 27 MPa flexural strength, and 155 MPa compressive strength.

Furthermore, replacing ordinary Portland cement with RH reduces water absorption to $1.45 \times 10 - 6$ cm/s and decreases chloride permeability to 220 Coulombs. The improved properties of SUHPC with 25% SLAW and 25% RH loading show that a combination of SLWA, RH, SLWA, and AOW can replace cement concentration in construction materials by 50%. However, total cement replacement is needed to eliminate the cement industry's environmental pollution. Therefore, the present result is not yet satisfactory. Achieving construction material without cement concentration required more research to identify potential biobased additives with similar properties to materials that construe cement. Besides, many underutilised agricultural wastes, such as biomass and shell, are yet to be fully explored for this application.

2.4.3. Incorporation of peanut husk ash (PHA)

(Abd-Elrahman et al. 2023) investigated the possibility of partial replacement of cement with peanut husk ash (PHA) for developing sustainable construction materials (ultra-high-strength concrete (UHSC).

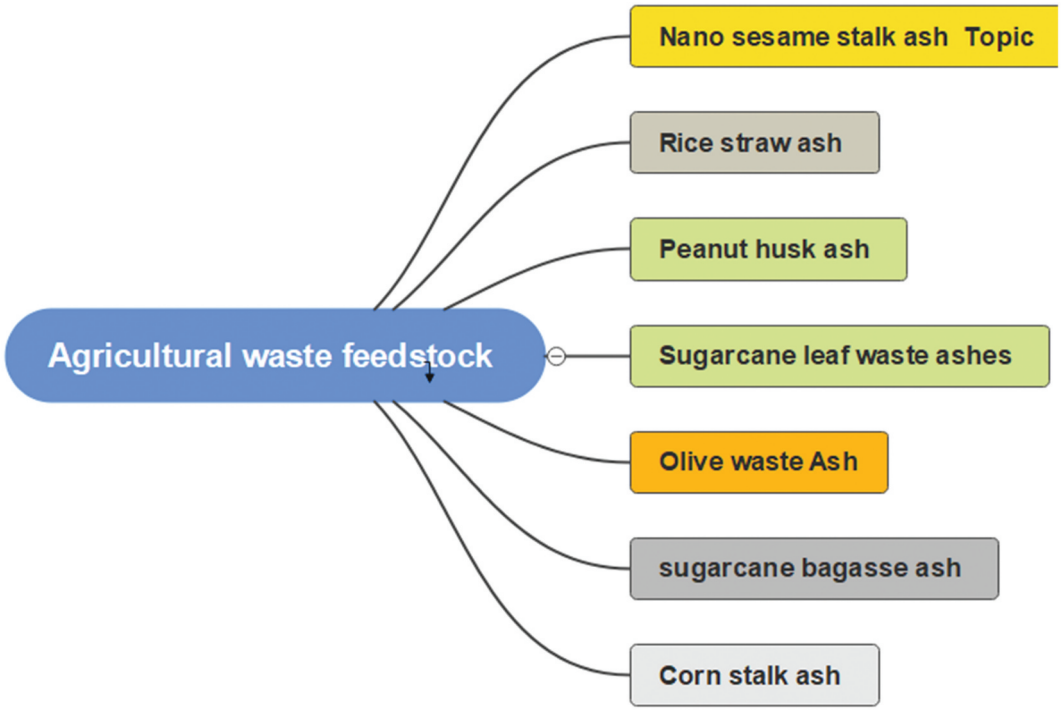


Figure 3. The investigated agricultural waste feedstock for substituting cement in building materials.

Before this investigation, this agro-based industrial waste was treated at different temperatures ranging from 400 to 700 °C. The heat-treated PHA used substitute ordinary Portland cement (OPC) at different weight percentages (2.5, 5.0, and 7.5%) in UHSC. The mechanical, physical, and microstructure characteristics of the developed UHSC were evaluated to determine the optimum replacement of cement using PHA in UHSC. UHSC with 5% PHA treated at 600 °C was optimised as a partial substitution of OPC to produce UHSC with high mechanical properties. This study confirmed that using PHA to manufacture UHSC may reduce brick cost and pollution by 5%. Although using PHA has been proven to have the potential to substitute cement in brick formulation, the partial replacement rate of 5% is meagre. The research considered a composite approach for further reducing cement replacement percentages in construction materials by combining different agricultural waste (Hakeem et al. 2022b, 2022a; Maglad et al. 2023).

2.4.4. Combination of SBA and corn stalk ash CSA

The increase in agricultural waste due to expansion in agricultural production globally, making proper disposal of the waste challenge increases research in combining agro-based waste in construction material to reduce cement content further (Maglad et al. 2023). investigates the effect of using SBA and corn stalk ash CSA on UHSC properties. These burned waste residues were incorporated as a pozzolanic material to partially replace cement in UHSC fabrication. SBA of loading weight percentages ranging from 10 wt.% – 30 wt.% at an increase of 10 and CSA loading of 2 wt.%, – 8 wt.% at an increase of 2 were considered. The influence of incorporating SBA and CSA on workability, compressive strength, splitting flexural strength, tensile strength, and modulus of elasticity of UHSC properties was investigated. The effect of loading SBA and CSA on UHSC resistance to chloride ion penetration and water sorptivity and permeability also were investigated.

In Figure 4, UHSC with SBA 20% and CSA 4% offered compressive and flexural strengths higher than 205 and 27 MPa investigated after 28 days, confirming that 24% of cement mass replacement by SBA 20% + CSA 4% is achievable. Besides, increasing the SBA and CSA to 30% and 8% reduces water permeability to 0.95 (cm/sec) and chloride permeability to 140 coulombs. This output shows that 38% of cement mass can be replaced by combining SBA and CSA to produce UHSC with higher resistance to water and chlorine permeability.

2.4.5. Rice straw ash (RSA) and nano sesame stalk ash (NSSA)

The possibility of combining treated rice straw ash (RSA) and nano sesame stalk ash (NSSA), which are by-products from bioenergy production, to serve as cement partial replacement in HSC formulation was evaluated by Hakeem et al., (2022a). Thermal properties and microstructure RSA and NSSA were investigated to determine their suitability for cement replacement in HSC. Cement concentrations were substituted with different ratios of RSA ranging from 10%-30% and NSSA from 0%- 10%. High-strength concrete with various combinations of RSA and NSSA at different loading percentages was fabricated and dried for 7, 14, and 28 days. The effect of different NSSA and RSA cast concentrations using different weight percentages and drying days on HSC properties was evaluated. Physio-mechanical properties such as compressive strength, slump investigation, indirect flexural, tensile strength, and stiffness of developed HSC were investigated. The treatment positively affects RSA and NSSA by removing the materials' impurities, unburned organic matter, and carbon. It was discovered that an increase in ash substitution results in the

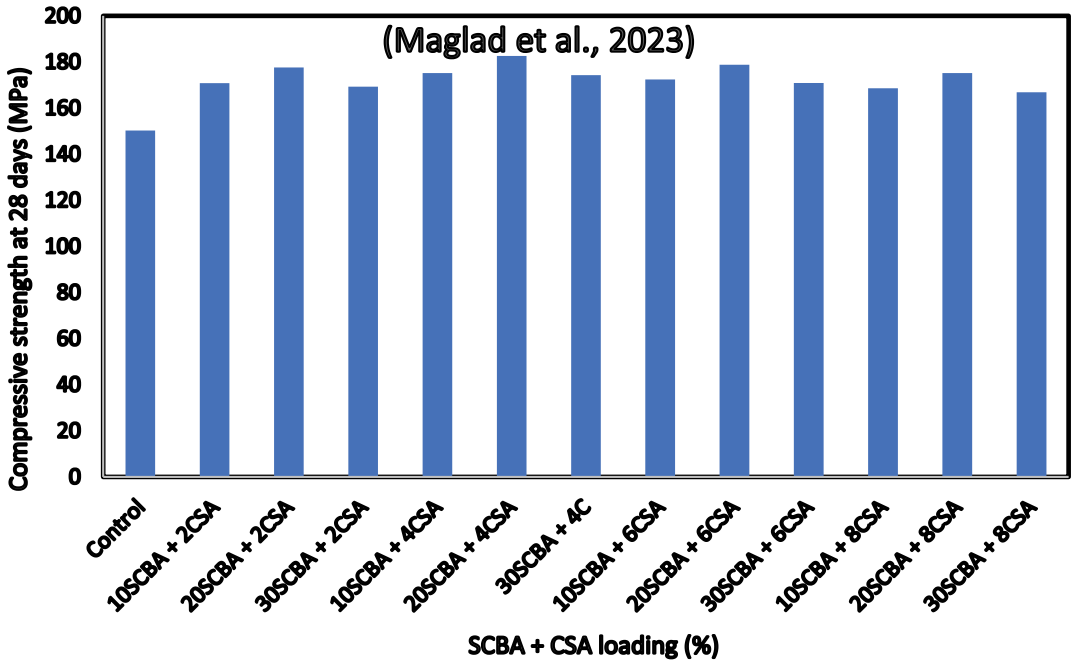


Figure 4. Compressive strength of UHSC with different concentration of SBA and corn stalk ash that partially replace cement content.

properties and workability of HSC. However, HSC with 20% RSA and 2.5% NSSA and 20% RSA and 5% NSSA exhibited the highest compressive strengths of 88.9 and 90.7 MPa. Additionally, HSC with 20% RSA and 2.5% NSSA offered improved splitting flexural strength (10.7 MPa), tensile strength (7.3 MPa), and elastic modulus (38600 MPa). These improved properties of HSC proved that agricultural waste, such as a combination of RSA and NSSA, could substitute 25% of cement in High-strength concrete.

Similarly, Hakeem et al., (2022b) combined rice husk and olive waste ashes to develop high-strength concrete and investigated their properties. It was discovered that a combination of rice husk and olive waste ashes could substitute 25% cement concentration in high-strength concrete. Furthermore, there is a significant increase, considering the 5% cement substitution in

HSC achieved by Abd-Elrahman et al. (2023) after the incorporation of a single agricultural waste and 25% observed by Hakeem et al., (2022a) and b that combines two agro-based wastes, proving the synergistic effect of combining two agro-based wastes to replace cement in building materials. Despite this 25% partial replacement of cement in construction material, the results are not yet satisfactory, as 100% replacement is needed to eliminate cement production pollution.

2.4.6. Rice straw ash (RSA) and palm leaf ash (PLA)

Amin et al. (2022) considered and investigated rice straw ash (RSA) and palm leaf ash (PLA) as partial substitutions for cement in ultra-high-performance concrete (UHPC). The effect of pozzolanic of this waste material on UHPC properties was investigated. Materials the microstructure and the fresh, mechanical, and physical properties of UHPC. These wastes were incorporated separately and hybridised at different percentages ranging from 10%-50%; the UHPC with an optimum concentration of 20% of either RSA or PLA offered 20% partial replacement of cement as they exhibit low density, improved durability, and mechanical properties that are better than the control that has 100% cement concentration. Significantly, the incorporation of 20% RSA and 20% PLA exhibited 188.5 MPa and 185 MPa investigated after 28. Hybridising of RSA and PLA offered a significance of 40% by weight, which may be the current high cement replacement percentages. Although there is a significant achievement in the partial replacement of cement in construction materials, 100% replacement is yet to be accomplished. Therefore, more research on potential agricultural waste and their combination for total cement replacement is required for a low-carbon environment.

2.4. Effect of adding sugarcane bagasse the bulk density, water absorption, and unit weight

Aside from the compressive strength of building materials, some critical properties, such as density, unit weight, and water absorption, need to be studied to confirm the suitability of the materials. Researchers investigated the effect of adding sugarcane bagasse on brick properties. Herein, the review of the kind of literature where the effect of adding sugarcane bagasse on brick properties is discussed.

2.4.1. Bulk density

The introduction of sugarcane bagasse ash into biobricks development has been reported as a viable way of reducing the Bulk density of biobricks, which could be directly linked with sugarcane bagasse ash's lightweight. Tonnayopas (2013) studied loading sugarcane bagasse ash on clay biobricks properties, where partial replacement sugarcane bagasse ash-made biobrick samples were investigated for bulk density. A sharp decrease in Bulk density with increased sugarcane bagasse ash was observed. Similarly, Danso (2015) explored the influence of loading sugarcane bagasse fibre on soil block properties such as density. They

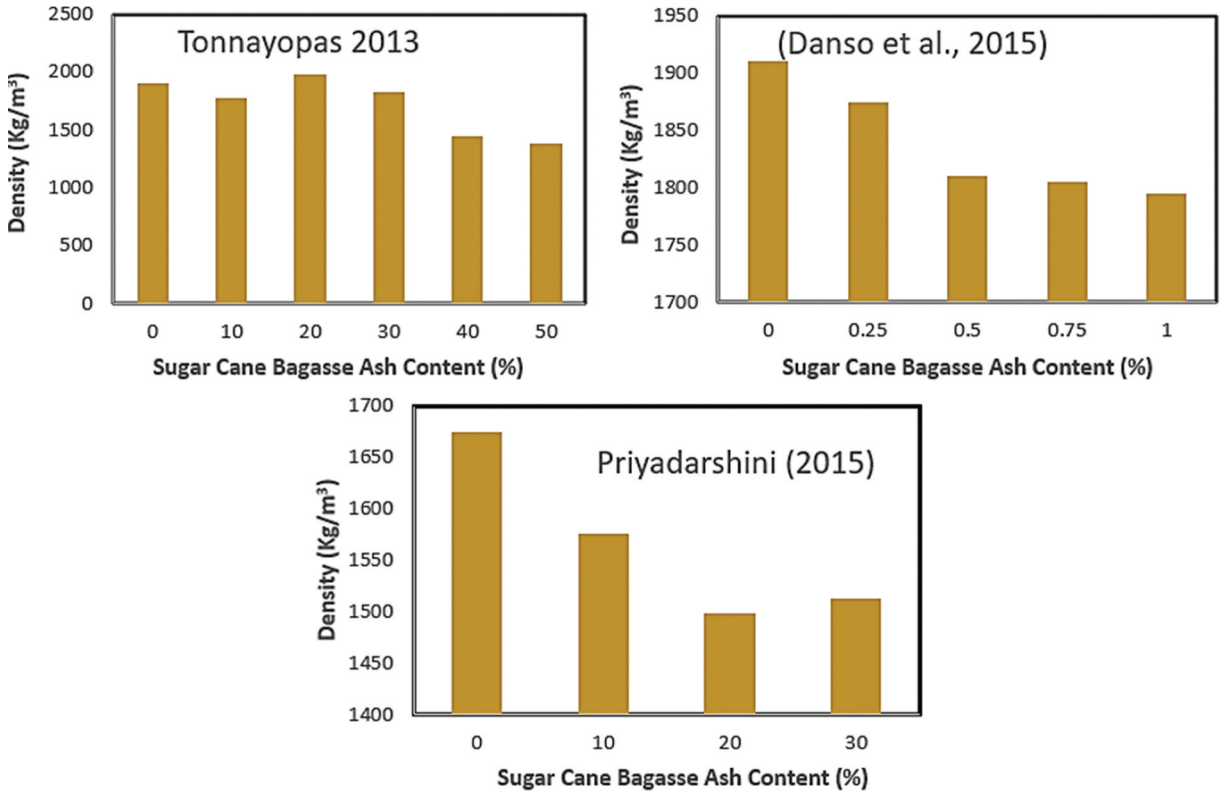


Figure 5. Bulk density of brick with different weight percentage of sugarcane bagasse ash.

discovered that the reinforced soil blocks' average dry density decreased with increased sugarcane bagasse fibre concentration (Hakeem et al. 2022b; Hakeem, Amin et al. 2022)

The bulk density of bricks compared in Figure 5 proves that including SCBA in bricks is a viable way to reduce the density of building materials. Irrespective of the based materials, a decrease in brick density with increased incorporation of SCBA was observed. Considering the result of Tonnayopas 2023, A decrease in bulk density with a corresponding increase in sugarcane bagasse ash loading was observed from 20 wt.% to 50 wt.%. Similarly, linear reduction in density with increased loading of SCBA up to 20 wt.% and insignificant density increase afterwards was observed in Priyadarshini's (2015) result. The decrease in bulk density can be attributed to the lightweight and bulk density of sugarcane bagasse ashes incorporated, which eventually reduces the overall density of biobricks.

2.4.2. Unit weight

Ali et al. (2016) increased the incorporation of bagasse ash to 20%, 25%, and 30%. They investigated their loading impact on the initial rate absorption, density, size, compressive strength, and water absorption of compressed cement-stabilised earth blocks. The soil blocks prepared with 20%, 25%, and 30% bagasse ash as a substitute for cement were dried for 7, 14, and 28 days, respectively. It was reported that adding bagasse ash increased water absorption but slightly decreased at a concentration of 20% bagasse ash. The addition of bagasse ash decreased the block's weight marginally. This implies that a lighter brick with moderate water absorption could be developed with 20% bagasse ash.

Similarly, Minhaj et al. (2016) confirmed that incorporating rice hub ash or sugarcane bagasse ashes could reduce biobrick weight by approximately 6%. Madurwar, Mandavgane, and Ralegaonkar (2015) developed and investigated the feasibility analysis of sugarcane bagasse ashes bricks. They reported that the brick produced with the combination of sugarcane bagasse ashes was lighter in weight, meeting the necessary standard. The investigation by Micheal and Moussa (2022) showed that the unit weight reduced as sugarcane bagasse ashes concentrations increased. A reasonable 7% reduction in weight observed impacts the weight of the structure and foundation size. The reduction in bricks' unit weight after incorporating sugarcane bagasse ashes may be attributed to the lightweight of naturally sourced material. Similarly, Kazmi et al. (2016) study also confirmed that sugarcane bagasse ashes loading positively affected bulk density. This output signified that the loading of sugarcane bagasse ashes reduces the weight of the biobrick.

2.4.3. Water absorption

The water absorption of clay brick is often interpreted as its durability. These bricks are primarily developed in Egypt, and their properties are controlled by *Egyptian* Standard Specification (***ESS***) (Moussa, Micheal, and Dawoud 2020). When clay brick absorbs water, the durability of the brick is reduced (Demir, 2009). Consequently, limiting water absorption in the brick body is pivotal because the lesser the amount of water absorbed "by the brick, the higher its quality. A good quality brick should not absorb over 20% of its weight in water. In general, the water absorption of clay bricks reduces as the sintering temperature rises and the bricks become stronger. Because of the increased water absorption, clay bricks are

unsuitable and degrade the wall strength (Phonphuak & Thiansem, 2011).

Kazmi et al. (2017) discovered that adding SBA to brick specimens increased their water absorption. SCBA absorbed 24% of its weight in water. The porous nature of SCBA may be responsible for increasing water absorption. According to Saleem et al. (2017), the water absorption of burnt clay bricks is enhanced with SCBA and RHA wastes. For example, after adding 10% SCBA, 24% absorption was detected, whereas brick specimens without SCBA showed 17% absorption. This reduction in water absorption implies that incorporating SBA reduces construction materials' water absorption properties.

According to Ganesan et al. (2007), water absorption upsurges with SCBA concentration after 28 days of curing. This output may be because SCBA is finer than OPC and has a hygroscopic characteristic. After 90 days of cure, the water absorption values decreased significantly (50%), confirming the positive effect of incorporating water absorption properties of bricks. Minhaj et al. (2016) investigated the effect of incorporating waste rice hug and SCBA on burnt clay bricks bulk density. The mixing ratio of waste rice hug and SCBA to clay was 100:5 waste rice hug and SCBA. Adding rice hug ash increases the water absorption of burnt clay bricks by 17%.

Similarly, bricks SCBA exhibited a water absorption rate 21% higher than burnt clay bricks. Evaluating the effect of loading waste rice hug and SCBA on burnt clay bricks water absorption revealed that incorporating SCBA reduces water absorption rate. However, the addition of waste rice hug increases it. This performance proves that incorporating SCBA is an effective way to reduce water absorption of construction materials.

Moussa (2022) evaluated the effect of incorporating 0.5 wt. %, 1.5 wt.% and 2.5 wt.% sugarcane bagasse on fire clay properties. The sugarcane bagasse and clay were mixed using a rotary mixer, and water was added to give plasticity to the blend. The blend was poured into a plank mould to form a cavity and dried under ambient temperature for 48 hours. The biobrick was sent for burning at a commercial brick manufacturer and later immersed in water for 4 hours – the initial weight before and after immersion was taken. According to the reported result, it was observed that water absorption of the developed biobrick increased with a corresponding increase in SCB incorporation from 0.5 wt.% to 2.5 wt.%, as shown in Figure 1. According to Moussa et al. (2020), the ESS 4763/2006 absorption of normal weather (NW) clay bricks should not exceed 25%.

Saranya et al. (2016) used a mixture of bagasse ash and rice husk ash to make stabilised bricks without additional binder. The researchers used a mixture of bagasse ash and rice husk ash in equal proportions ranging from 5% to 30% in 5% increments in the experiment.

The bricks were tested for water absorption and density of the cast brick for various combinations. The brick material with 5% bagasse ash and 5% rice husk ash exhibited superior water resistance and reduced bulk density. This performance may be due to the homogenous dispersion of bagasse ash and rice husk forming an interlocking structure that offers improved strength and water permeability. However, a small amount of these agro-based materials waste was added, whereas a large amount is needed to produce lightweight bricks. The authors suggested combining bagasse ash with rice husk ash up to 20% in the brick's construction, which may lead to lightweight bricks, with lightweight being an added benefit. However, the water absorption of the brick increased with a corresponding increase in bagasse ash and rice husk ash loadings. Therefore, a working brick with improved strength and lightweight can be developed using small incorporation of bagasse ash and rice husk.

3. Using bagasse ash, limestone, and fly ash as stabilisers in building material formulations

The stabiliser is one of the main components of brick, which helps the rigidity and size stability of bricks. According to Sherwood (1993), soil stabilisation is the preparation of soils to boost their strength and durability until they are entirely acceptable for construction. Afrin (2017) confirmed that soil stabilisation is the process of blending and combining elements with soil to improve specific properties of the soil. This stabilisation method may include combining soils to create a desired gradation or mixing commercially available additives that may modify the gradation, texture, or plasticity of the soil or act as a binder for the cementation of the soil. Mechanical stabilisation, additive stabilisation, and modification are all examples of stabilisation.

3.1. Biobrick with limestone

Lime is produced by burning limestone at temperatures above 9000 degrees Celsius. Since the olden days, lime has been utilised as a stabiliser and is now employed to produce compressed stabilised earth blocks. Because lime interacts with clay to generate a binder when mixed with a pozzolana, it stabilises buildings with clayey soils (rice husk ash, fly ash, blast furnace slag). Combined lime-cement stabilisation may improve long-term strength, which cannot be obtained with cement or lime alone. Nagaraj et al. (2014) employed a combination of cement and lime stabilisers for compressed stabilised earth blocks (CSEBs). A mixture of 6% cement, 2% lime, 4% cement, and 4% lime was utilised in the experiments. A long-term high strength was achieved for the brick at a ratio of 4% cement to 4% lime. Because the cement stabilises the sand component and the lime helps stabilise the clay portion, the combination of cement and lime proved advantageous. The strength and durability of sugarcane bagasse bricks may be improved by adding lime as a stabiliser (Nagaraj et al. 2014). In this section, the stabiliser and its process are defined, and the traditional materials, such as cement and lime, are discussed to achieve the stability of construction materials. The incorporation effect of this commonly used material on brick properties was identified to be effective at small loading. The following section discusses the feasibility of reducing cement and lime in construction **materials** by introducing agricultural waste, such as bagasse ash, as a partial replacement to reduce cement content further. Achieving this cement content reduction may reduce cement industries' carbon emissions and environmental pollution.

3.2. The effect of adding sugarcane bagasse ash into lime and fly ash stabilized blocks

Prasanth et al. (2015) studied the impact of incorporating bagasse ash, lime, fly ash, cement, and quarry dust into compressed mixed bricks. These additives were all added, and the strength of the composite brick was measured. The maximum strength of all combinations was determined to be 10% cement. However, a 5% bagasse ash composite earth brick was discovered to have strength comparable to a 10% lime-stabilised earth brick. This finding is consistent with Saranya et al. (2016) studies. However, different materials are combined for developing bricks in these studies.

James and Pandian (2016) confirmed that bagasse ash possesses the potential to improve the performance of lime-stabilised blocks. Their study incorporated bagasse ash to enhance the stabilised block's compressive strength and water absorption. A superior strength was achieved after 8% bagasse ash was incorporated. However, this improved it could not meet the Indian standards for the minimum strength of the class 20 block. These researchers study the investigation relationship between compressive strength and bagasse ash content. This study revealed that a minimum incorporation of 9.5% bagasse ash was required to accomplish class 20 block strength, proving the positive effect of incorporating bagasse ash on the block's mechanical properties.

The use of lime and sugar cane bagasse ash as chemical stabilisers in compacted soil blocks was explored by Alavéz-Ramírez et al. (2012). The blocks were manufactured using a combination of 10% lime and 10% sugarcane bagasse ash and were dried for 7, 14, and 28 days respectively. Afterwards, the stabilised blocks were tested in dry and saturated temperatures for compression and flexure testing. The experiment results suggest that adding bagasse ash to lime-stabilised blocks significantly improved the performance of the stabilised blocks.

Lima et al. (2012) and James and Pandian's studies contradicted the loading amount of bagasse ash on the block specification. In Lima et al. (2012) study, a block with 9.5% bagasse ash was established to have the required properties for the block, while James and Pandian recommended 8% bagasse ash. This contradiction may be attributed to standard specifications for different countries.

Besides, James et al. (2016) examine the effectiveness of ordinary Portland cement stabilised soil blocks modified with sugarcane bagasse ash. For stabilising the soil blocks that were rehabilitated with 4%, 6%, and 8% bagasse ash, two different cement concentrations of 4% and 10% were used. All the blocks were cast to the same density and water content and wet-cured for 28 days. The compression, water absorption, and efflorescence testing were carried out according to Bureau of Indian Standards (BIS) regulations. The experiment results revealed that adding bagasse ash to the blocks improved the performance, with higher compressive strength. The addition of bagasse ash reduced the cement concentration by 4%, allowing the product to fulfill the specifications' minimum strength criteria. On the other hand, adding bagasse ash resulted in a slight increase in water absorption. Bagasse ash also performed better at a lower cement level of 4% than at a higher cement level of 10%.

Naibaho et al. (2015) investigated the use of bagasse ash to reduce the amount of cement in stabilised blocks. Three stabilised blocks with different loading of 5%, 15%, and 25% were evaluated to increase compressive strength and reduce water absorption to produce a cost-effective stabilised block. The findings showed that adding 25% bagasse ash exhibited the highest compressive strength but increased water absorption. The findings revealed that using 25% bagasse ash in manufacturing could reduce cement concentration when developing stabilising bricks, and using bagasse ash reduces production costs by 32.48 %".

Madurwar et al. (2014) investigated the use of bagasse ash to improve the effectiveness of quarry dust-lime stabilised bricks. X-ray fluorescence assays were used to determine the chemical makeup of the materials. Bagasse ash was subjected to thermogravimetric examination, demonstrating its thermal stability up to 650 degrees Celsius. The results obtained for this study indicated that a mixture of 50% bagasse ash, 30% quarry dust, and 20% lime exhibited superior compressive strength of any combination. Bagasse ash bricks absorbed more water than conventional and fly ash bricks. However, no efflorescence was found on any bagasse ash brick combinations. X-ray analysis was used to determine the chemical composition of the components. This study demonstrated that bricks can be developed without cement concentration. This study demonstrated that bricks can be developed without cement concentration. Although lime accounting for a low concentration of materials combined to develop this brick has a toxic element, another challenge is feedstock availability and sustainability. Producing biobased construction material by sourcing another biobased calcium oxide to replace lime will help alleviate these challenges. It will also lead to the development of construction materials without cement content. Developing construction materials from a combination of these suggested materials will reduce carbon emissions generated by cement industries and help reduce environmental pollution.

The inclusion of fly ash with sugarcane bagasse ash in biobricks development has been investigated extensively by Shair (2020). The study compared the conventional method of fabricating interlocking with stabilised soil blocks (ISSBs) and using sugar bagasse ash as the principal stabiliser in bricks and other construction materials. It was discovered that sugar bagasse ash substituted up to 20% of the cement content in interlocking soil-stabilised blocks.

Shair (2020).

Detroja (2018) explored the possible application of clay and fly ash in clay brick. According to the compressive strength test findings, up to 20% bagasse ash strength is sufficient. As a result, employing only up to 20% bagasse ash is preferable. Adding more than 20% bagasse ash increases water absorption and decreases bricks' compressive strength and hardness.

Prasanth et al. (2015) studied the impact of incorporating bagasse ash, lime, fly ash, cement, and quarry dust into compressed mixed bricks. These additives were all added, and the strength of the composite brick was measured. The maximum strength of all combinations was determined to be 10% cement. However, a 5% bagasse ash composite earth brick was discovered to have strength comparable to a 10% lime-

stabilised earth brick. This finding is consistent with Saranya et al. (2016) studies. However, different materials are combined for developing bricks in these studies.

3.3. Bagasse ash as a substitute for fly ash and lime in fly ash bricks

Kulkarni et al. (2013) studied the possibility of using bagasse ash as a substitute for fly ash and lime in fly ash bricks. In the construction of bricks, bagasse ash was used to substitute fly ash up to 60% by weight and lime up to 20% by weight in increments of 10% and 5%, respectively. The bricks were evaluated for compressive strength and water absorption after 7, 14, and 21 days of curing. It was discovered that replacing fly ash with bagasse ash decreased the strength of the stabilised block as the bagasse ash percentage increased. On the other hand, all combinations have higher strength than the minimum required for class 30 blocks. It was determined that replacing 10% bagasse ash for fly ash resulted in a strength closest to that of the control sample, with a strength variation of less than 5%.

4. Findings

The review presents cement as one of the most used binders in construction materials. It also discovered that the production process of cement significantly contributes to global carbon emissions. Furthermore, this study revealed that 5% of global emissions could be reduced by substituting cement concentration in construction materials with alternative materials such as agricultural and industrial waste. The finding of this study proved that incorporating RSA and PLA can substitute 40% cement concentration in building materials. Similarly, adding sugarcane bagasse ash is an effective way to successfully replace 50% of the cement content in construction material. It also proved that loading a combination of sugarcane bagasse ash, rice husk ash, and agricultural olive waste (AOW) can replace 50% cement concentration. It was discovered that the effectiveness of replacing cement with agricultural depends on the compatibility of these water with based material such as type of sand, additives and other aggregate, which determine the properties of construction material. Additionally, chemical or mechanical treatment of agricultural waste before use is critical to their performance construction materials.

5. Conclusion

The possibility of replacing cement in construction materials to reduce greenhouse gas emissions has been reviewed successfully. This review discovered that construction material without cement concentration is achievable by exploring a combination of biobased waste to achieve a low-carbon economy and safer environment. Agricultural a waste, such as sugarcane leaf waste ashes, cornstalk ash, peanut husk ash, rice straw husk, and sugarcane bagasse ash, can substitute cement concentration in construction material at different incorporating ratios. This review also suggests that a combination of sugarcane bagasse ash (50%), rice husk (25%), and agricultural olive waste (25%) could be used to develop construction materials without cement, which may lead to sustainable construction and eliminate 5% of global emission from cement manufacturing companies.

6. Recommendations for future studies

It is evident from the comprehensive review that additional research is needed before SBA can be incorporated into bricks for sustainable construction. Hence, here are a few recommendations for future work. The impact of sugarcane bagasse ash on the modulus of rupture and initial rate of absorption of bricks requires further investigation to encourage interlocking stabilised bricks. Furthermore, an essential indicator of a masonry unit's lateral resistance is its modulus of rupture, which should also be considered for future study. The initial absorption rate is a crucial quality control factor because too dry bricks may absorb water from the mortar, resulting in structural flaws. The aspect of brick production needs to be examined further to control the curing rate and water absorption.

Additionally, experiments with varying replacement ratios for cement can be encouraged regarding other mineral and chemical admixtures. Further studies can be conducted when admixtures are exposed to hot temperatures to investigate the effect of extreme temperatures. This finding indicates that bagasse ash could replace more cement in construction materials by changing the methodology or combination processes. The review established that 50% of cement concentration could be replaced with a combination of agricultural waste, but 100% replacement is yet to be accomplished. Madurwar et al. (2014) fabricated construction material without content using 50% bagasse ash, 30% quarry dust, and 20% lime. However, the properties of the material developed in this formulation offered are yet to meet the standard. Therefore, more research focus studies on identifying potential agricultural waste and their combination for cement total replacement should be considered for future work.

Abbreviation

AOW	Agricultural olive waste
Al_2O_3	Aluminium oxide
BIS	Bureau of Indian Standards
CaO	Calcium oxide
CH_4	Methane
CSA	Corn stalk ash
CO	Carbon monoxide
CO_2	Carbon dioxide
CSEBs	Compressed stabilised earth blocks
ESS	Egyptian Standard Specification
Fe_2O_3	Iron(III) oxide
HSC	High-strenght concrete
PHA	Peanut husk ash
K_2O	Potassium oxide
LOI	Loss On Ignition
MgO	Magnesium oxide
MnO_2	Manganese dioxide
NES	nano eggshell
N_2O	Nitrous oxide
NSSA	Nano sesame stalk ash
NW	Normal weather
OPC	Ordinary Poland Cement

P_2O_5	Phosphorus pentoxide
RH	Rice husk
RSH	Rice straw husk
SCB	Sugarcane bagasse
SCBA	Sugarcane bagasse ash
SiO_2	Silicon dioxide
SLWA	Sugarcane leaf waste ashes
SO_3	Sulfur trioxide
SUHPC	Developing sustainable Ultra High-Performance Concrete
TiO_2	Titanium dioxide
TIS	Thailand Industrial Standards
VOCs	volatile organic compounds
UHSC	Ultra-high-strength concrete

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Oluwatoyin Joseph Gbadeyan http://orcid.org/0000-0002-7906-3965

Data availability statement

The data that support the findings of this study are openly available in [repository name] at [URL], as reference in the manuscript.

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