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Review Article

A review of corncob-based building materials as a sustainable solution for the building and construction industry

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ABSTRACT

The building and construction industry faces mounting pressure to adopt sustainable practices and materials due to its significant environmental impacts. Corncob (CC), a by-product of the corn industry, has shown great potential as a sustainable and versatile building material as contained in literature. Although no study has categorised the different repurposing applications of CC in building and construction. This systematic review investigates the potential of corncob, an abundant agricultural by-product, as a sustainable building material. Through analysis of 33 peer-reviewed studies from 2000 to 2023, it examined the diverse applications and evolving research trends of corncob in the building and construction industry. Key findings highlight corncob's global availability, low carbon footprint, and favourable properties for building applications. The review reveals nine distinct uses, including thermal/acoustic insulation, soil stabilization, fillers, cement replacement, aggregates, composite materials, particleboard production, and alkali-activated binders. Emerging research focuses on corncob ash as a supplementary cementitious material, with optimal cement replacement levels of 5–30 % by weight identified. Corncob-based materials demonstrate enhanced fire resistance, chemical durability, thermal insulation, and long-term strength development, though compressive strength remains a limitation for structural applications. The study concludes that corncob shows significant promise for advancing environmental sustainability in construction, particularly for non-structural and insulation applications. However, further research is needed to optimize material properties, standardize production methods, and evaluate full lifecycle impacts to enable widespread commercial adoption. This review provides a foundation for future investigations into innovative, low-carbon building materials derived from agricultural residues.

1. Introduction

The quest for sustainable buildings has gained traction due to the escalating negative environmental impacts of conventional building materials. In recent times, many nations across the globe have made significant commitments towards achieving carbon neutrality [1]. This ambitious target entails a substantial reduction in greenhouse gas emissions resulting from anthropogenic activities, followed by the absorption and removal of the remaining greenhouse gases to achieve a net-zero carbon footprint. The adoption of such targets by major economies is a clear indication of the growing urgency to mitigate the impact of climate change by curtailing carbon emissions and transitioning to sustainable and low-carbon energy sources and materials [2]. According to Wu et al. [3], over hundred countries have pledged to undertake measures aimed at achieving carbon neutrality by 2050, and this trend is set to continue. From literature it is noteworthy that the building and construction industry is a substantial contributor to global greenhouse gas emissions and natural resource depletion responsible for a significant proportion of global final energy consumption, accounting for approximately 36 %, while CO_2 emissions from this sector amount to nearly 40 % [4]. Their CO_2 emission as shown in Fig. 1 cumulates to 14.6 gigatonnes and it is the greatest compared to any other sector [5]. These statistics underscore the critical role that the building and construction industry can play in mitigating climate change effects and transitioning to sustainable energy use.

Given that the sector consumes almost half of the world's total energy demand, it is imperative that stakeholders in this field prioritize the adoption of eco-friendly practices and embrace the use of renewable energy and materials to reduce carbon emissions and enhance environmental sustainability. Subsequently, as the demand for new buildings and infrastructure continues to grow due to skyrocketing human population, especially in developing nations [6,7], this could potentially

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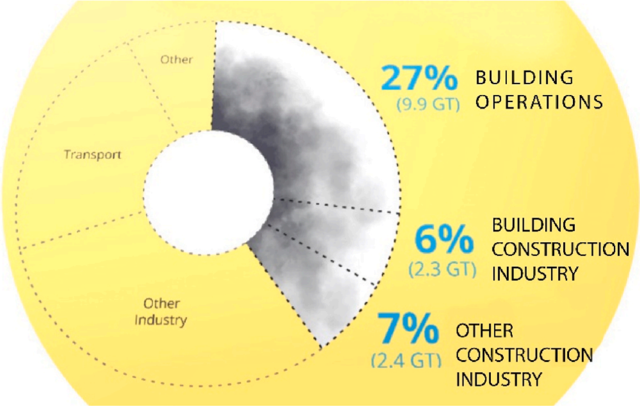

Fig. 1. Annual CO_2 emission of building and construction sector [5].

result in the emission of over 226 gigatonnes of CO_2 by 2050 [8]. This trend, if unchecked could be a challenge to achieving the carbon budget of 800 gigatonnes of total CO_2 emissions set by the Paris Climate Agreement after 2017 and their consideration was materials used in the design and construction process. Hence, there is an urgent call for more sustainable and environmentally friendly building materials [9]. Furthermore, using concrete as an example, it is the second most widely used material in the construction industry after water [10], with a great deal of carbon emissions from its production to consumption in the building industry. Research conducted by Lenzen and Treloar [11] showed that buildings framed with concrete have higher carbon emissions than those framed with wood. While cement production is a major contributor to the construction industry's carbon footprint, achieving sustainability in buildings requires a holistic approach that considers the entire lifecycle of materials and buildings. The use of bio waste products like corncob in building materials offers multiple pathways to reduce environmental impacts. These include lowering embodied energy [12], valorising waste [13], enhancing building energy performance [14], enabling partial cement replacement in some applications like binder [15], facilitating lightweight construction [16], and sequestering carbon [17]. By integrating such bio-based materials into construction practices, the industry can make progress towards carbon neutrality goals, even in applications where cement use continues. Thus, as noted by Annibaldi et al. [18], the correlation between building and construction activities with hazardous emissions and waste generation is now widely acknowledged, prompting numerous researchers to investigate potential solutions to mitigate this issue.

Considering the foregoing, researchers are now exploring other viable alternatives like industrial, agro and marine (aquacultural) waste products as potential sources of sustainable building materials. Furthermore, due to the large amount of waste generated by the various industries and agricultural sector; there is an opportunity to recycle, reuse and repurpose these materials, which are often considered to have low economic value. The growing emphasis on sustainability principles in building design and construction is also fuelling a heightened focus on the creation of building materials that are thermal, cost-effective, environmentally friendly, and low in carbon emissions. This involves utilizing natural or recycled materials and minimizing energy consumption during production. This trend is driving innovation in green building materials, with focus on developing eco-friendly solutions that support the transition to a low-carbon economy.

Heavy restrictions and regulations aimed at reducing air pollution have led to the production of considerable amounts of industrial by-product [19], which could be repurposed as pozzolanas or supplementary cementitious materials (SCMs) in building construction. Such industrial waste like fly ash, limestone powder waste, volcanic slag, reservoir sediments, silica fume, calcined kaolin, blast furnace slag etc. have received a considerable number of studies on its reuse and repurposing. The implementation of industrial waste materials in building applications has been proven successful, with examples including the utilization of fly ash, slag, and silica fume [20]. Moreso, the sustainability proponents and rating organizations in the construction industry award credits for utilizing industrial by-products such as fly ash, in concrete mixtures as reported by Hardin and McCool [21]. While studies on the use of most industrial waste demonstrate positive results, its readily availabilities [22] and proximity of supply [23] are yet an unanswered puzzle and hinder cost and reduced embodied energy of building materials. For instance, the current short supply of fly ash and furnace slag [24] presents a challenge to the building and construction industry and could lead to the creation of less resilient and environmentally friendly materials like concrete. This is gradually paving way for heavy dependence on the use of agricultural and aquacultural waste products for building and construction purpose since the transition from fossil-derived materials to bio-based alternatives is still a work in progress.

Global fisheries and aquacultural production have grown steadily over the last five decades with corresponding waste product generated [25]. Aquaculture by-products such as periwinkle shell [26], mussel shell [27], oyster shell [28], cockle shell [29] and scallop shell [30] have found useful application as aggregate replacement materials in concrete, and various studies in recent decades have been carried out to validate the claims of its green nature. However, their availability in non-coastal and arid regions raises concerns. This backdrop spurs more credit to the use and potency of agricultural by-products for widespread building and construction activities. As the world's natural resources are rapidly depleting resulting from the rising demand of the building and construction sector, agricultural waste such as bagasse, cereal straw, corn stalk, cotton stalks, kenaf, rice husks, rice straw, sunflower hulls and stalks [31], banana stalks, coconut coir, bamboo, durian peel, oil palm leaves [32,33], palm kernel shell, coconut shell, date seed, rubber shell, groundnut shell, sugarcane [34], corncob [35,36] among others are reported as possible raw organic building and construction materials. These by-products are essentially waste, and unfortunately several of them have a negative impact on the environment. Hence, incorporating these by-products is assumed to improve the characteristics of the resulting building material and simultaneously mitigate the need for their incineration or disposal in landfills.

Since literature has establish that the building and construction industry has an imperative to utilize agricultural by-products such as corncob, motivated by both environmental and economic considerations [37]. The industry through the production of green materials and preservation of natural resources can promote sustainability, while also protecting the environment, conserving energy, and promoting efficient waste management. Corncob a by-product of corn harvesting has received increasing attention as a potential source of sustainable building materials because of its global availability and peculiar physical/mechanical properties. Previous studies like Prusty and Patro [38]; González-Kunz et al. [39] and Aprianti et al. [13] have reviewed agricultural wastes including corncob as an alternative binding material for concrete production. While their reports offered valuable insights into the valorisation of agricultural by-products, it is important to note that they were broadly review papers on agro waste, lacking specific and in-depth emphasis on corncob alone. Based on this research gap and to the best of the authors knowledge, no study has comprehensively dealt with the diverse repurposing application of CC and it derivates ash for building and construction works. Consequently, this study aims to fill the gap by providing a systematic review of the utilization of corncob and their derivative ash in the field of building and construction.

The paper explores the potential of CC as a sustainable building material and discusses its various applications, with the trend of research in the evolving landscape of the building sector. Novel contributions include a comprehensive categorization of corncob applications, bibliometric analysis of research trends, and critical evaluation of sustainability impacts across environmental, economic and social dimensions. By investigating these aspects, the study will demonstrate the viability of corncob as a component for environmentally friendly building materials and is expected to ignite interest among stakeholders, researchers, and policymakers. This will propel further innovation and adoption of eco-friendly practices in the construction industry, fostering a circular economy and driving the transition to a low-carbon future.

1.1. Global Corn production

Corn has global availability, and it is one of the most widely cultivated cereal crop across the seven continents (see Fig. 2) with more than 170 regions actively involved in its production; having US, China, and Brazil as leading producing countries [40]. Although its production rate is not evenly distributed globally, corn holds great significance as a staple food in many countries of the world especially the developing nations [41].

In comparison with other food crop production rate, corn is the second most cultivated and produced food crop after sugarcane that has a global annual production rate of 1.85 billion metric tons (see Fig. 3). The global production of corn has witnessed a remarkable increase over the past decade, as indicated by the research conducted by Choi et al. [43], which reported a growth rate of 40 % in production. Presently, the annual global production of corn is 1.23 billion metric tons [44]. This increase in production can be attributed to the rising demand for corn, not only as staple food but also as feed for livestock, and raw material for various manufacturing and pharmaceutical industries. Hence, the global supply and accessibility of corncob for repurposing as a building material are significant, with potential for long-term sustainability to meet industry demand. This abundant supply is geographically diverse, with major corn-producing regions spread across continents, including North and South America, Asia, Africa and Europe [44]. Such widespread availability of corncob potentially reduces transportation costs and associated carbon emissions for local utilization in construction. This advantage likely drives current research efforts towards its integration into various industries, particularly the building and construction sector. The increased focus on corncob's potential in construction is reflected in the growing number of studies exploring its properties, applications, and benefits.

Corn is a C4 plant, therefore increasing its production rate to meet the future demands of the building and construction industry would have a relatively low environmental impact compared to other crops. This is because corn plant exhibits efficient photosynthesis and carbon fixation. This characteristic enables corn to capture and store a significant amount of carbon dioxide from the atmosphere, acting as a natural carbon sink. By absorbing carbon dioxide, corn helps mitigate the greenhouse effect and reduces the overall carbon footprint. It is a highly versatile crop that can adapt to diverse agro-climatic conditions and exhibits a wide range of genetic diversity, enabling farmers to select corn varieties that are suitable for their specific local environments [45]. The global production and yield of corn, as illustrated in Fig. 4, show that there has never been a significant decline in its production rate. In fact, compared to the latter years (20th century), the production rate in the millennium years has consistently exceeded the area harvested worldwide.

The graph demonstrates a steady increase in both production and yield over the six-decade period, with production rising more steeply than yield, particularly since the early 2000s. This trend underscores corn's substantial production levels and its prominent role in the global export market [40]. According to World Bank statistics [46], corn accounted for 42 % of all food export crops, making it the highest export crop. This significant share implies that regions which may show sign of lower production rate could be augmented by export commodities.

The corn stover which comprises of various components, including stalks, leaves, cobs, and husks is considered as waste. Approximately 90 % of corn stover goes unused, with the remaining 10 % being utilized as bedding materials and feed for livestock. While local household has found practical use for waste from corn plants like leaves and husks as animal feed; corncobs on the other hand, lack nutritional value with no financial worth and their effective utilization remains untapped [47]. The chemical composition of corncobs, as reported by Luana [48], consists of 10.9 % water, 36.48 % cellulose, 28.86 % hemicellulose, 3.16 % lignin, and 20.6 % silica. On burning it produces huge quantity of ash with 8 % loss on ignition [49]. Binici et al. [50] have drawn attention to the similarity in fiber components between corncob and wood, showing their slow decomposition rates and subsequently, are considered field waste with prolonged presence in the soil without contributing positively to sustainability.

Research indicates that approximately 40 % of corn plant waste is comprised of cobs [51,52], while about 20 % constitutes husks [53]. Although, studies by García-Condado et al. [54], Gottumukkala and Gorgens [55], Hassan et al. [56], and Quillope et al. [57] suggests that corncobs represent about 20 % of standing residue by weight, that are often buried or left in the field without being put to use. This constitutes 250 million tonnes to global waste accumulation. In the United States, corn waste accounts for one-third of the total generated solid waste [55, 58]. Therefore, repurposing corncob for building and construction application is a step towards the promotion of a global circular economy.

2. Research methods

The study research method is explicitly delineated with the flow chart in Fig. 5. The graphic representation indicates that the research process was conceptually divided into five primary stages, commencing with an exhaustive literature search, and culminating with the formulation of recommendations and conclusion.

The initiating step of the systematic review involved developing a research query that focused on identifying the trend and diverse applications with repurposing possibilities of CC and its derivative ash in the building and construction industry in response to global appetite for sustainability in this sector, and towards a transition to a low-carbon economy. Due to the uniqueness of the subject matter, "sustainability in building and construction" Engineering Village database was

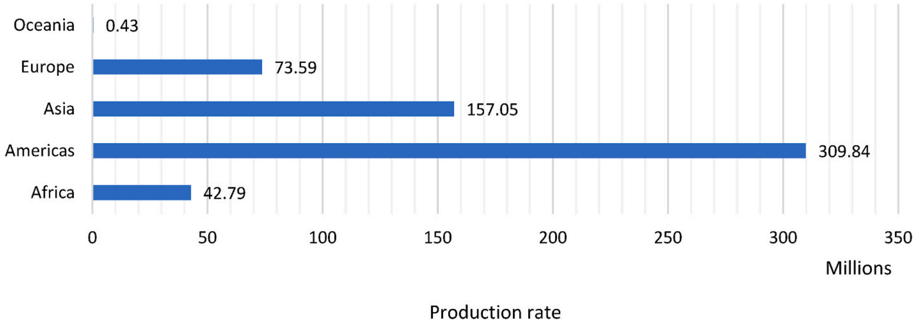

Fig. 2. Average production share of corn by region from 1961 to 2022 [42].

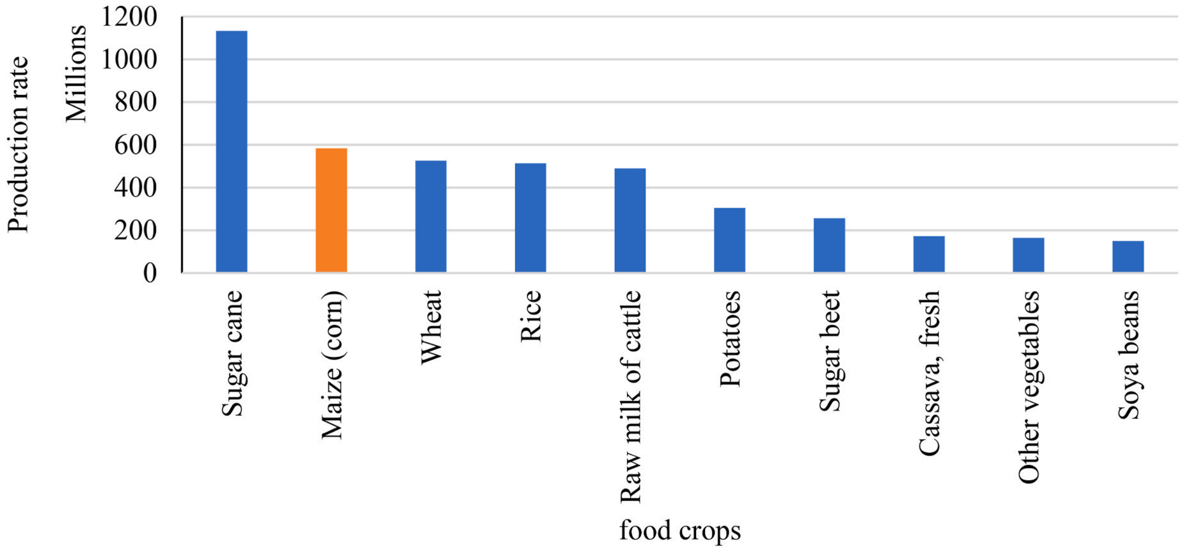

Fig. 3. Worldwide most produced food commodity from 1961 to 2022 [42].

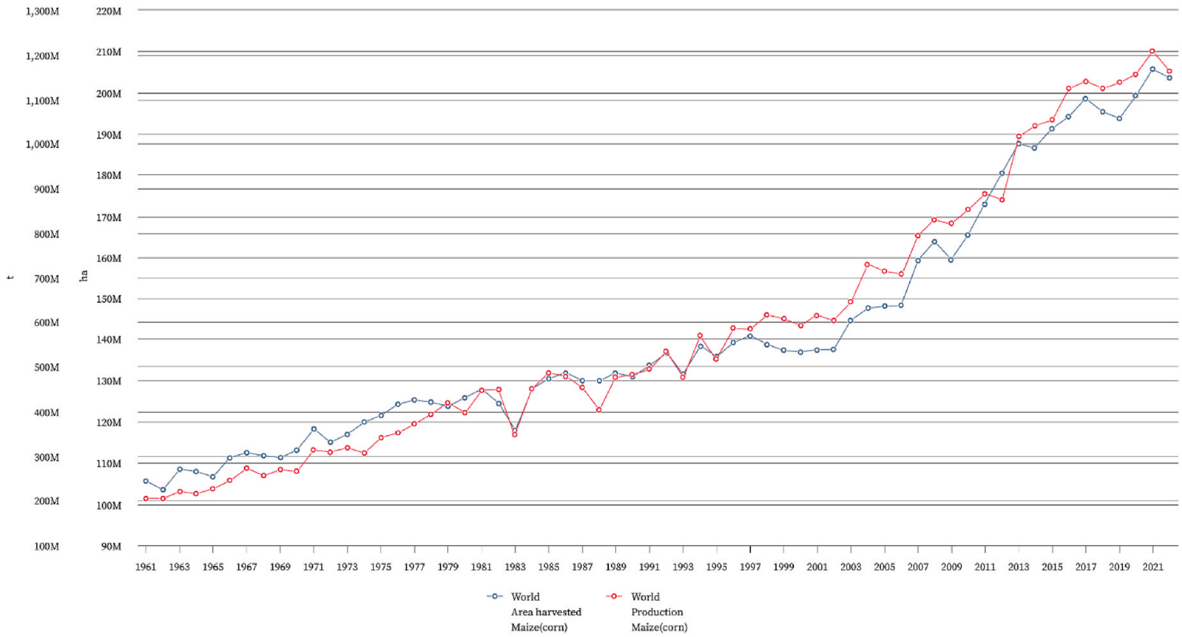

Fig. 4. Global corn production and yield trends (1961–2021) [42].

conveniently identified as a suitable search repository. This platform was deemed appropriate for this study as it contains important indexing databases, such as Knovel, Inspec, and Compendex. The search query utilized was '(corncob building) OR (corncob construction)' and it was purposefully chosen to maintain a focused scope with broad application capture, on the use of corncob in building and construction context.

In the second stage of the systematic review, the search results were screened and chosen according to specific selection measures.

Criterion 1: *Paper type:* conference proceedings and Journal article.

Criterion 2: *Publication year:* 2000–2023.

Criterion 3: *Publication language:* only studies in English.

Criterion 4: *Research Field:* corncob and sustainability in the building and construction industry.

Criterion 5: *Content:* studies addressing specific use of corncob and its derivative ash in the building and construction.

In this stage, Criteria 1, 2 and 3 were automatically applied to the records using the filter function available in Engineering Village. After that, duplicate records were eliminated. The remaining results were then manually screened against Criteria 4 and 5 of the selection criteria to ensure that adequate necessary information was gathered.

Furthermore, this was followed by a systematic review using the PRISMA method (preferred reporting items for systematic reviews and meta-analysis) as detailed in Fig. 6.

To determine the trend of research in this field, the data extracted underwent analysis in the VOSviewer software to create a map based on text data from the bibliographic dataset file obtained in Engineering Village (Scopus). The selected scientific papers considering diverse applications and repurposing of corncob waste and its derivative ash in the building and construction industry was used for the thematic analysis. The results are presented using descriptive statistics, maps, and charts.

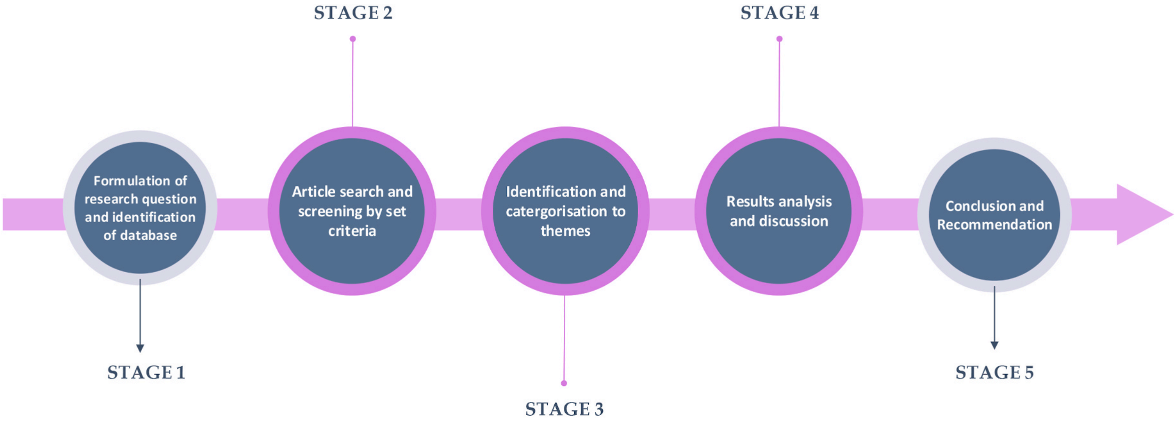

Fig. 5. Flow chart of research method.

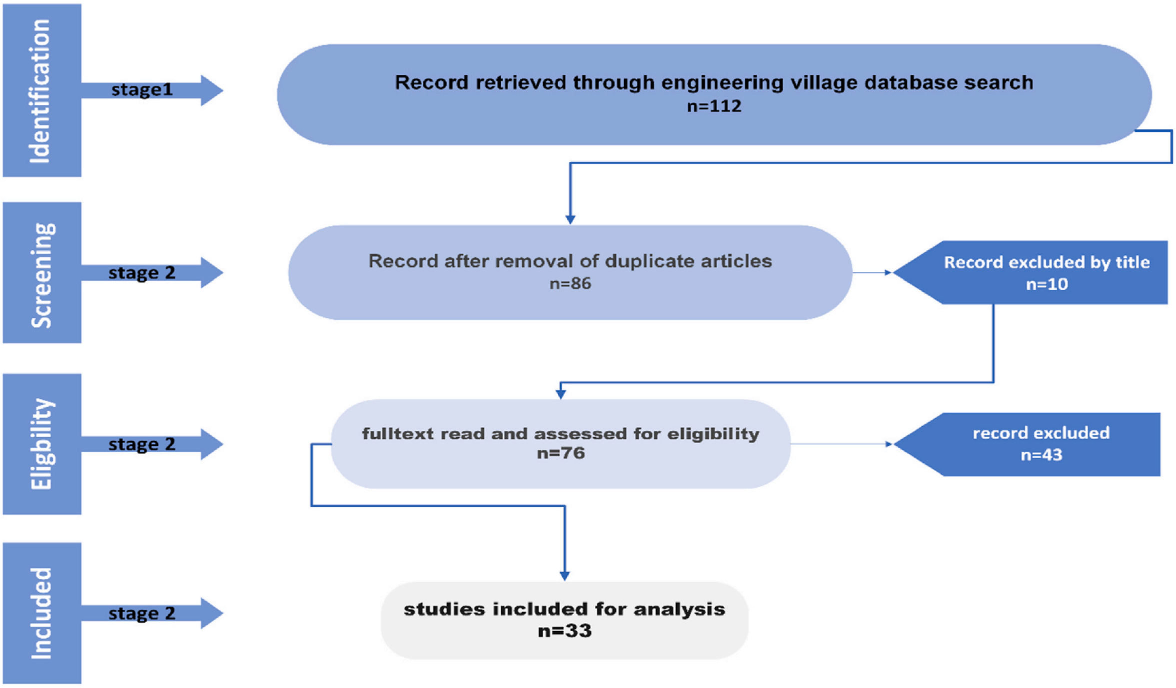

Fig. 6. Article screening procedure based on the PRISMA approach.

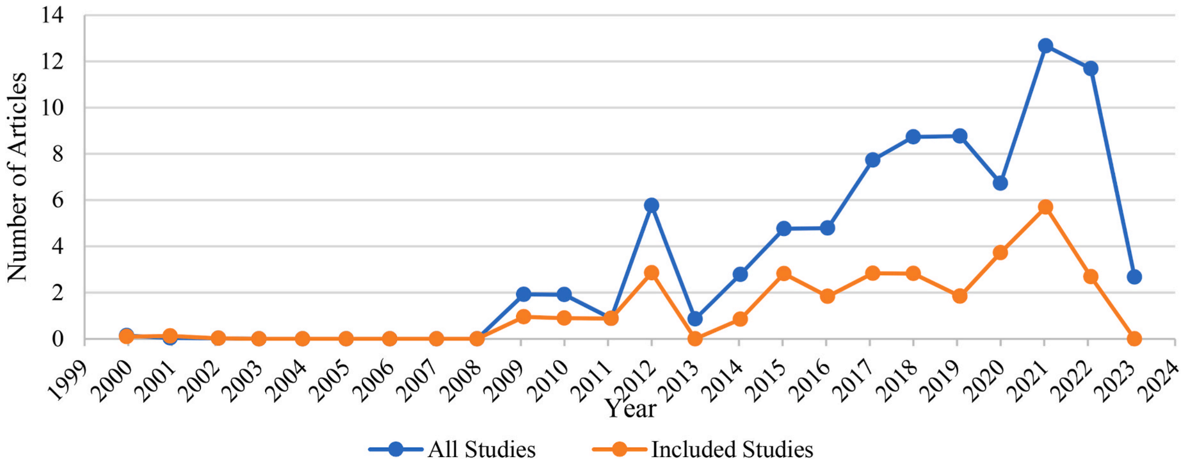

Fig. 7. Trend of scholarly publications output from 2000 to 2023.

3. Results and discussion

In stage one when Criteria 1, 2 and 3 were automatically applied before the search was initiated, 112 results were returned (see Fig. 6). However, when duplicate publications were eliminated, only 23.2 % of articles were removed. During stage 2 of the research process, articles were evaluated based on pre-established criteria, resulting in the exclusion of studies that did not meet the research criteria. Ultimately, 33 studies, comprising 29.46 % of the total results (n = 112), were selected for inclusion in the analysis. This confirms that the research field is beginning to gain global interest which can be attributed to its perceived economic, environmental, and social advantages.

3.1. Trend

The global literature on repurposing corncob waste in construction applications has witnessed an upward annual growth trend, as depicted quantitatively in Fig. 7. The gradually increasing output observed across both overall and domain-specific studies aligned to the current paper, confirms intensifying focus on corn waste valorisation. However, while the total number of articles on corncob continues to expand consistently, those included under the systematic review applying specificity filters witness a noticeable reduction. This implies that investigations directly concentrating on construction and building industry applications with relevance to the research question still have enormous scope for further enrichment. Furthermore, Fig. 7 shows that there has been a significant increase in the number of works on the topic researched in recent years. The growth trend of the included reviewed papers suggests driving factors such as escalating adoption of sustainability concepts in habitat design and life cycle approaches will spur greater research activity in future. However, it's important to note that like other new innovation, while research interest is growing, there remains a gap between academic studies and widespread commercial adoption. Future work should focus on bridging this gap by addressing practical implementation challenges and conducting comprehensive life cycle assessments to validate the long-term sustainability benefits of corncob-based materials in real-world construction scenarios.

The bibliometric map based on text data from the bibliographic dataset file obtained in Engineering Village (Scopus) is presented in Fig. 8. The map thus provides a visual representation of the evolution of CC research in building and construction over the last twenty-three years and demonstrates the progress made in this area of sustainable development. The map shows a notable shift in the focus of research, where initial efforts were concentrated on the examination of ordinary corncob waste. However, over time the scope of research broadened to encompass value-addition pathways for enhanced functionality. It expanded to include the utilization of derivate ash (biomass ash) and various other pre-treated and post-treated corncobs. The analysis indicates emerging focus areas spanning composite fabrication infused with phase change materials and geopolymer concrete mixtures incorporating corncob ash.

The bibliometric analysis was conducted using the VOSviewer software (version 1.6.19) a tool for visualizing and analysing bibliometric networks. The proximity of terms indicates their co-occurrence in the literature, with colours denoting distinct clusters of related concepts. The map revealed the presence of six different clusters, two of which were found to be the most prominent. These two major clusters were identified as "Cob" and "Corncob ash (CCA)". The "Cob" cluster refers to research that focuses on corncob waste as a potential resource, while the "Corncob ash" cluster pertains to the utilization of the ash derived from burning corncob. However, the analysis showed limited research has been conducted on the intersection between these two clusters; by implication, there have been relatively few studies that investigate the use of both corncob waste and its ash derivatives together. Nonetheless, the analysis did identify other emerging areas of research in the application and repurposing of the agro waste. For instance, the analysis

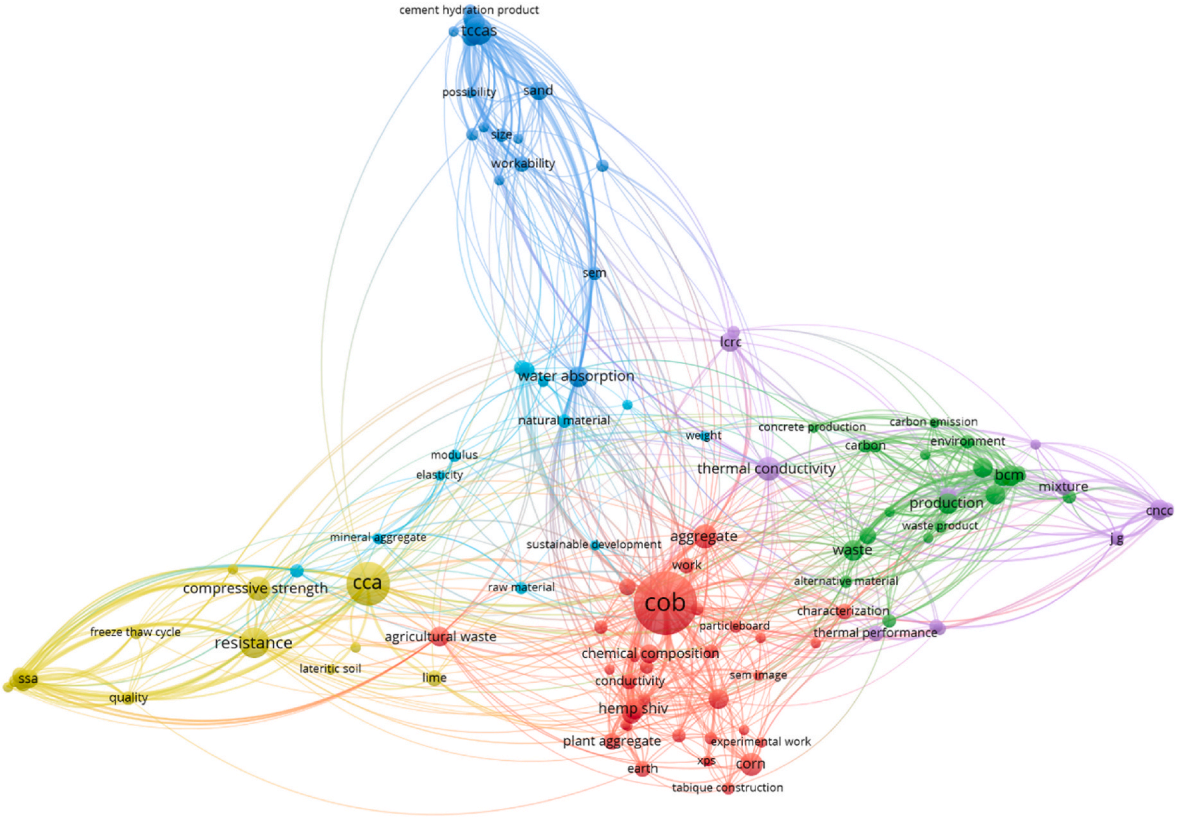

Fig. 8. Bibliometric analysis of bibliographic dataset.

revealed a growing interest in the use of corncob for the production of composite materials and geopolymer concrete [43,59]. These emerging areas of research suggest that there is a continued exploration of new and innovative ways to utilize this agro waste in the building and construction sector. This shift highlights an increasing recognition of the potential of corncob waste and its derivatives in the reduction of waste accumulation and promotion of environmentally friendly building and construction materials. Emerging studies on this agro waste suggests it possess very brilliant mechanical, chemical, thermal and physical property to qualify or substitute conventional building and construction material.

Notably, academic institutions in Nigeria have published the highest number of studies on corncob building materials, as depicted in Fig. 9. This research impetus likely stems from urgent sustainability challenges confronted in the country regarding exponential urbanization, affordable housing, and waste crises. With surging population growth [60] exacerbating shelter deficits, the predominant use of conventional construction materials burdens viability through excessive embodied emissions and expenditures [61]. Additionally, ineffective solid waste management has elicited concerns [62]. The progress from Nigerian research institutes thereby corresponds to an increasing prioritization of practical, locally resonant solutions, balancing environmental, social, and economic dimensions. A tropical climate focus dominates the published research, seeking solutions for improving building thermal performance in hot humid regions. However, the demographic distribution of research outputs reveals a significant and growing global interest in corncob waste recovery for construction applications, spanning both academic institutions and industry stakeholders. This rising global attention aligns closely with increasing urbanization trends and the urgent need for sustainable building practices in rapidly growing cities worldwide. The research landscape reflects a diverse range of focuses, from alternative corncob-based cement and concrete material in third world economies to developing high-performance insulation materials from corncob in developed climes. This diversity of approaches enriches the global knowledge base and accelerates innovation. While developed countries often contribute advanced analytical techniques and standardization approaches, developing nations bring crucial insights into local material availability, traditional building techniques, and context-specific sustainability challenges. This bidirectional flow of information is creating a more holistic and globally applicable body of knowledge on corncob utilization in construction.

3.2. Categorization of repurposing application based on screened records

Fig. 10 depicts the outcomes of the literature review involving 33 papers that examine the potential repurposing applications of corncob and its ash residue on combustion.

The present systematic review result indicates that corncob has been studied and found to have potential applications in various areas of the building and construction sector. However, the returned results demonstrated that the investigations into corncob's potential applications in building material are not only considering its technical aspects but also evaluating its broader sustainability impact on society, the economy, and the environment. Table 1, elucidate the sustainability focus of the studied papers.

The table 1 provides a categorization of reviewed manuscripts based on their sustainability focus across environmental, social, and economic dimensions. It is evident that 100 % of the papers addressed the environmental sustainability aspects, underscoring the urgent need to adopt alternative building materials to mitigate climate change impacts. Nearly half the studies (48 %) also incorporated economic sustainability considerations related to cost, affordability, and waste valorisation. This aligns with the emphasis on the potential for corncob utilization to foster circular economy principles. However, only 30 % of the works featured social sustainability factors. As established in literature, embracing sustainability in building and construction requires a holistic framework spanning environmental integrity, social equity, and economic prosperity. Thus, an area for further research is examining the societal implications of adopting corncob building materials from the lens of health, safety, and community development. Consequently, it was observed that majority of the selected studies were found to lack financial support. Therefore, it is imperative that funding alongside stronger industry-academia linkages be pursued and prioritize this research area. The next subsection explains in detail the thematic classification of the different repurposing applications.

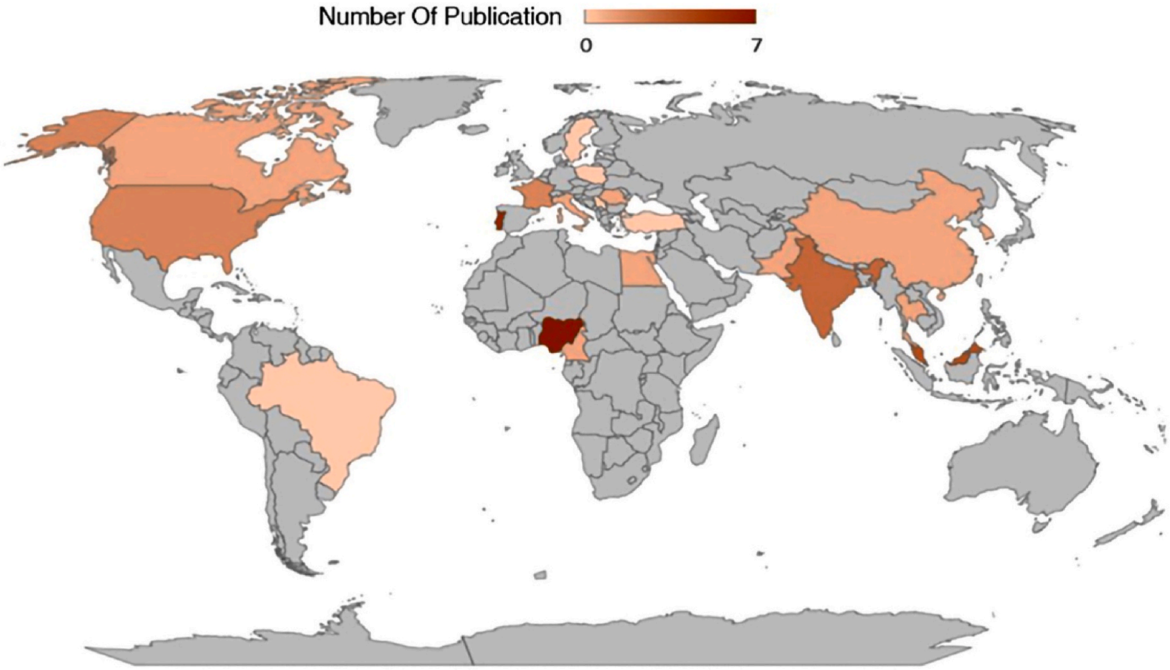

Fig. 9. Demographic analysis of reviewed papers in relation to publications output.

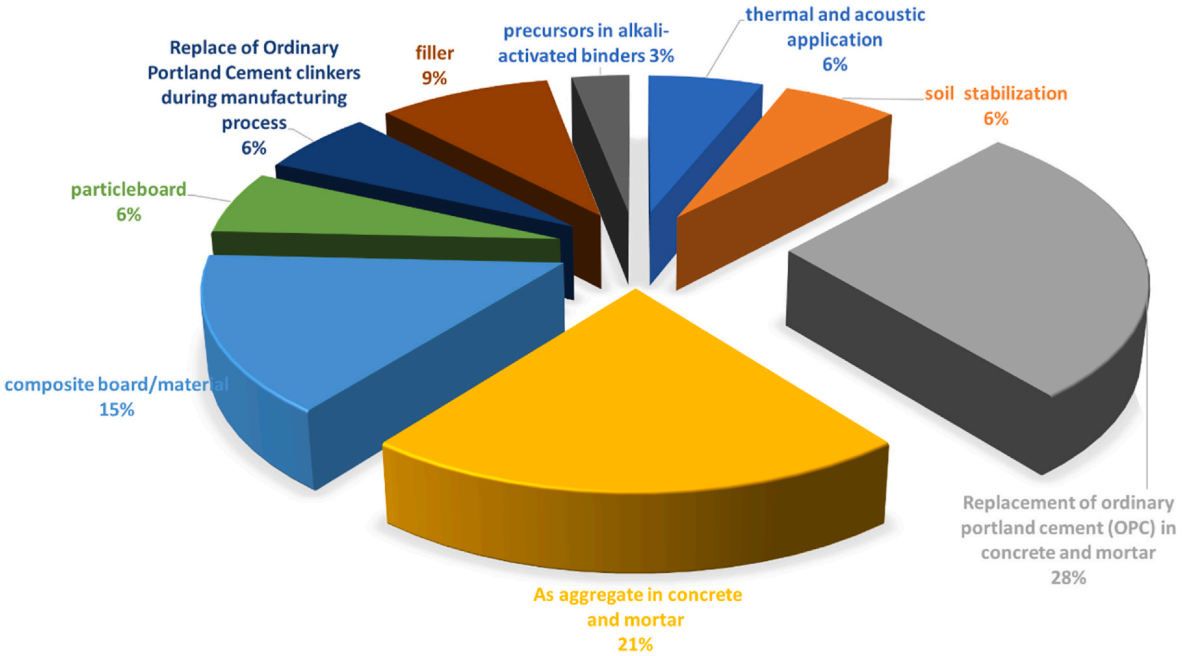

Fig. 10. Classification of review articles based on various repurposing applications.

3.2.1. *Thermal and acoustic applications*

The studies by Refs. [14,63] demonstrated the potential of corncob as an effective thermal and acoustic insulation material. In particular, Bovo et al. [63] provided a more in-depth characterization through their experimental analysis of factors like specific heat capacity, density, thermal conductivity, and sound absorption coefficients under different configurations. Their experiment showed that specific heat can vary from 1.4 to 1.9 J/(g·K), according to the given temperature and CC layers, while density is 200 kg/m^3 with the conductivity range of 0.14–0.26 W/(m·K) and thermal conductance value ranges from 0.62 to 1.13 W/(m^2·K). The observed values are comparable to those of other natural thermal insulation materials, such as cork. Additionally, the study highlights that CC possesses good acoustic absorption properties, exhibiting higher absorption coefficients at higher frequencies. This suggests that corncob has the potential to enhance the acoustic performance of building fabrics, potentially reducing noise transmission between rooms or from external sources.

Pinto et al. [14] evaluated the thermal conductivity and moisture content of corncob samples, comparing them with other insulation materials. They found corncob's thermal conductivity ranged from 0.058 to 0.081 W/(m·K), with apparent densities of 74.6–100.4 kg/m^3, comparable to expanded polystyrene (0.037 W/(m·K)) and glass wool (0.040 W/(m·K)). The average moisture content was 9.4 % under standard conditions. Results from Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS) analysis revealed similarities between corncob and extruded polystyrene (XPS) materials in physical properties, microstructure, and chemical composition, suggesting corncob's suitability for low-temperature environments. The study also referenced historical use of corncob as insulation in ancient tabique buildings in Portugal's *Trásos-Montes e Alto Douro* province, providing evidence of its long-term efficacy as an insulation material.

3.2.2. *Soil stabilization use*

Corncob ash (CCA) has proven effective in soil stabilization, offering a practical solution to enhance soil strength and mitigate erosion. Singh [64] conducted experiments using CCA and calcium carbide to stabilize silty clay. The introduction of CCA to weak soil resulted in a gradual increase in strength over time, attributed to an ongoing pozzolanic reaction. Notably, the M8 mix in Singh's study exhibited the highest strength values, reaching 215 kN/m^2, 301 kN/m^2, 342 kN/m^2, and 497 kN/m^2 at zero, seven, fourteen, and twenty-eight days of the curing period, respectively. These values represent a strength increase of 4.5, 3.9, 1.5, and 1.5 times the strength of the virgin soil. However, further treatment resulted in a decline in unconfined compressive strength [64]. Also, Nnochiri [74] showed that CCA enhances the performance of lime-stabilized lateritic soil. The optimal proportion of CCA was determined to be 4 % by weight of the soil. This specific blend displayed the highest California Bearing Ratio (CBR) and unconfined compressive strength (UCS) values, reaching 94 % and 1180 kN/m^2, respectively (refer to Fig. 11).

The increase in strength was attributed to the pozzolanic reaction occurring between the lime and CCA, leading to the formation of calcium silicate hydrate (C–S–H) gel. This shows that CCA could be developed further as a viable alternative to conventional pozzolanic materials for soil stabilization in civil works.

3.2.3. *As an aggregate in concrete and mortar*

Due to its predominantly lignocellulosic composition as highlighted by Ref. [48], corncob is a promising option for serving as partial replacement for traditional aggregates in the production of mortar and concrete. The inherent insulation properties of corncob suggest that incorporating it as an aggregate in concrete and mortar can yield materials with superior thermal insulation compared to conventional concrete and mortar [72]. This quality proves particularly beneficial in regions with extreme temperatures, potentially leading to reduced energy costs. Pinto et al. [78] and Faustino et al. [16] posit that it is an alternative organic aggregate of lightweight concrete and proposed its adequacy for both internal and external building applications. Laborel-Préneron et al. [67] reported that corncob aggregates have a bulk density ranging from 112 to 176 kg/m^3, significantly lower than conventional mineral aggregates. The moisture content of corncob aggregates typically ranges from 7 % to 15 % by mass, depending on environmental conditions and pre-treatment methods [66]. This high moisture absorption capacity, while beneficial for some applications, can affect the water-cement ratio in concrete mixes and must be carefully managed. When compared to concrete produced from other agricultural waste aggregates like coconut shells, date seeds, palm oil shells, and rubber seeds, Prusty and Patro [38] found that corncob concrete

Table 1
Sustainability emphasis of reviewed articles.

	Ref.	Paper Title	Authors	Funding	Sustainability focus of article		
					environment	social	economic
1	Bovo et al. [63]	Contribution to thermal and acoustic characterization of corncob for bio-based building insulation applications	Bovo, Marco; Giani, Niccolò; Barbaresi, Alberto; Mazzocchetti, Laura; Barbaresi, Luca; Giorgini, Loris; Torreggiani, Daniele; Tassinari, Patrizia	Not specified	✓		
2	Singh [64]	Experimental investigation of corncob ash on silty clay stabilized with calcium carbide	Sandeep Singh	Not specified	✓		✓
3	Bheel and Adesina [65]	Influence of binary blend of corncob ash and glass powder as partial replacement of cement in concrete	Naraindas, Bheel; Adeyemi, Adesina	Not specified	✓		
4	Shao et al. [66]	Feasibility of using treated corncob aggregates in cement mortars	Ke, Shao; Yunxing, Du; Fen Zhou	Yes	✓		
5	Laborel-Préneron et al. [67]	Characterization of barley straw, hemp shiv and corncob as resources for bio aggregate based building materials	Aurélie, Laborel-Préneron; Camille, Magniont; Jean-Emmanuel, Aubert	Yes	✓	✓	✓
6	Choi et al. [43]	Utilization of corncob, an essential agricultural residue difficult to disposal: composite board manufactured improved thermal performance using Microencapsulated PCM	Choi, Ji Yong; Nam, Jihee; Yun, Beom Yeol; Kim, Young Uk; Kim, Sumin	Yes	✓		✓
7	Ramos et al. [68]	Thermal performance and life cycle assessment of corncob particleboards	Ramos, Ana; Briga-Sá, Ana; Pereira, Sandra; Correia, Mariana; Pinto, Jorge; Bentes, Isabel; Teixeira, Carlos A.	Yes	✓	✓	✓
8	Serbanoiu et al. [69]	Corncob ash versus sunflower stalk ash, two sustainable raw materials in an analysis of their effects on the concrete Properties	Serbanoiu, A.A., Gradinaru, C.M.; Muntean, R.; Cimpoesu, N.; Serbanoiu, B. V.	Not specified	✓	✓	✓
9	Fouly et al. [70]	Evaluation of mechanical and tribological properties of corn Cob-reinforced epoxy-based composites—theoretical and experimental study	Fouly, Ahmed; Abdo, Hany; Seikh, Asiful; Alluhydan, Khalid; Alkhammash, Hend; Alnaser, Ibrahim; Abdo, Mohamed.	Yes	✓		✓
10	Pinto et al. [71]	Characterization of corncob as a possible raw building material	Pinto, Jorge; Cruz, Daniel; Paiva, Anabela; Pereira, Sandra; Tavares, Pedro; Fernandes, Lisete; Varum, Humberto	Not specified	✓	✓	
11	Bheel et al. [72]	Utilization of corncob ash as fine aggregate and ground granulated blast furnace slag as cementitious material in concrete	Bheel, N; Ali, M.O.A.; Yue Liu; Tafsirojjaman, T.; Awoyera, P.; Sor, N.H.; Bendezu Romero, L.M.	Yes	✓		✓
12	Shakouri et al. [73]	Hydration, strength, and durability of cementitious materials incorporating untreated corncob ash	Shakouri, M.; Exstrom, C.L.; Ramanathan, S.; Suraneni, P.	Yes	✓		✓
13	Pinto et al. [14]	Corn's cob as a potential ecological thermal insulation material	Jorge, Pinto; Anabela, Paiva; Humberto, Varum; Ana, Costaa; Daniel, Cruz; Sandra, Pereiraa; Lisete, Fernandes; Pedro, Tavares; Jitendra, Agarwal	Yes	✓	✓	✓
14	Nnochiri [74]	Effects of corncob ash on lime stabilized lateritic soil	Emeka Segun Nnochiri	Not specified	✓		
15	Oyebisi et al. [75]	Evaluation of reactivity indexes and durability properties of slag-based geopolymer concrete incorporating corncob ash	Oyebisi, S.; Ede, A.; Olutoge, F.; Ogbiye, S.	Yes	✓		✓
16	Adesanya and Raheem [15],	Development of corncob ash blended cement.	Adesanya, D.A. and Raheem, A.A.	Yes	✓		✓
17	Njeumen Nkayem et al. [76]	Preliminary study on the use of corncob as pore forming agent in lightweight clay bricks: physical and mechanical features	Njeumen Nkayem, D.E.; Mbey, J.A.; Kenne Diffo, B.B.; Njopwouo, D.	Yes	✓		✓
18	Akinyemi et al. [77]	Some properties of composite corncob and sawdust particle boards	Akinyemi, A.B.; Afolayan, J.O.; Oluwatobi, E.O.	Not specified	✓		
19	Pinto et al. [78]	Corncob lightweight concrete for non-structural applications	Pinto, J.; Vieira, B.; Pereira, H.; Jacinto, C.; Vilela, P.; Paiva, A.; Pereira, S.; Cunha, V. M.C.F.; Varum, H.	Not specified	✓		✓
20	Faustino et al. [79]	Impact sound insulation technique using corncob particleboard	Faustino, Jorge; Pereira, Luís; Soares, Salviano; Cruz, Daniel; Paiva, Anabela; Varum, Humberto; Ferreira, José; Pinto, Jorge	Yes	✓	✓	✓
21	Bagcal and Baccay [80]	Influence of agricultural waste ash as pozzolana on the physical properties and compressive strength of cement mortar	Bagcal, O and Baccay, M.	Not specified	✓		
22	Athira et al. [81]	Agro-waste ash-based alkali-activated binder: cleaner production of zero cement concrete for construction	Athira, V.S.; Charitha, V.; Athira, G.; Bahurudeen, A.	Not specified	✓		✓
23	Adesanya and Raheem [82],	A study of the permeability and acid attack of corncob ash blended cements	Adesanya, D.A. and Raheem, A.A.	Not specified	✓		
24	Aprianti [20],	A huge number of artificial waste material can be supplementary cementitious material (scm) for concrete production; a review part II	Evi Aprianti	Yes	✓		✓
25	Prusty and Patro [38],	Properties of fresh and hardened concrete using agro waste as partial Replacement of coarse aggregate – a review	Jnyanendra Kumar Prusty and Sanjaya Kumar Patro	Not specified	✓	✓	✓

(*continued on next page*)

Table 1 (*continued*)

	Ref.	Paper Title	Authors	Funding	Sustainability focus of article		
					environment	social	economic
26	LaborelPréneron et al. [83]	Effect of plant aggregates on mechanical properties of earth bricks	Laborel-Préneron; Aubert, J.E.; Magniont, C; Maillard, P.; Poirier, C.	Yes	✓		
27	Thomas et al. [84]	Biomass ashes from agricultural wastes as supplementary cementitious materials or aggregate replacement in cement/geopolymer concrete: a comprehensive review	Thomas, Blessen Skariah; Yang, Jian; Mo, Kim Hung; Abdalla, Jamal A.; Hawileh, Rami A.; Ariyachandra, Erandi	Not specified	✓		✓
28	Naganathan et al. [85]	Use of wastes in developing mortar- a review	Naganathan, S; Silvadanan, S; Tang Yew Chung; Nicolasselvam, M.F; Thiruchelvam, S	Not specified	✓	✓	
29	Aprianti et al. [13]	Supplementary cementitious materials origin from agricultural Wastes	Evi, Aprianti; Payam, Shafigh; Syamsul, Bahri; Javad, Nodeh Farahani	Yes	✓		
30	Uchechi [34],	Developments in utilization of agricultural and aquaculture by-products as aggregate in concrete – a review	Uchechi Eziefula	Not specified	✓	✓	✓
31	Hongthong et al. [86]	Determination of properties and heat transfer rate through building boundary of corncob cement material for applying to be construction material	Pakasit, Hongthong; Anan, Pongtornkulpanich; Kamonwan, Chawna	Yes	✓		✓
32	Faustino et al. [16]	Lightweight concrete masonry units based on processed granulate of corncob as aggregate	Jorge, Faustino; Elisabete, Silva; Jorge, Pinto; Edgar, Soares; Vitor, Cunha; Salviano Soares,	Yes	✓		
33	Oyebisi et al. [59]	Building a sustainable world: economy index of geopolymer concrete	Solomon, Oyebisi; Anthony, Ede; Festus, Olutoge; Olatokunbo, Ofuyatan; Tolulope Alayande	Yes	✓		✓

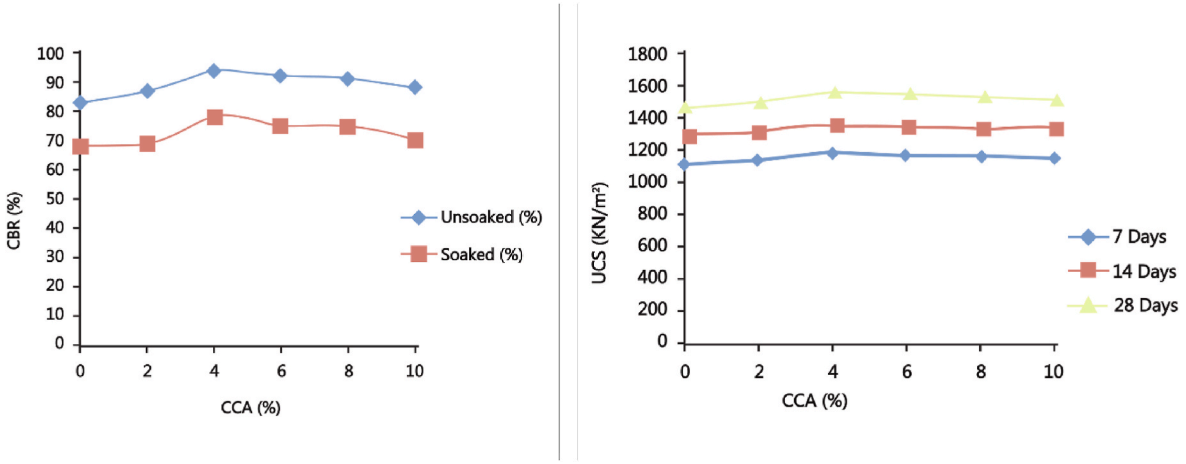

Fig. 11. Effects of CCA on CBR and UCS of lime-stabilized lateritic soil [74].

exhibited lower compressive strength, with values typically ranging from 5 to 20 MPa depending on the replacement ratio and mix design. Shao et al. [66] utilized treated corncob as an aggregate in cement mortar and observed increased porosity and water absorption, alongside decreased workability and mechanical properties. The reduced mechanical properties and workability supports the findings of [38]. The limitations of employing CC as an aggregate in concrete and mortar production are summarized below in these findings.

Moisture content: CC has a high moisture content, which can affect the quality of concrete and mortar if it is not properly dried before use. Moisture can also lead to the growth of mold and bacteria, which can compromise the strength and durability of the concrete or mortar.

Density: CC has a lower density than conventional aggregates, which means that it may not provide the same level of strength as traditional concrete and mortar. This can be addressed by using a higher percentage of corncob in the mix or by adding other materials to the mix to increase its strength.

Compatibility: The compatibility of CC with various cement and mortar mixtures varies. It is therefore important to test the compatibility of corncob with different types of cement and mortar mixtures to ensure that it does not compromise the strength and durability of the final product.

3.2.4. *As a precursor in alkali-activated binders*

The study of Athira et al. [81] investigated the use of agro waste ash-based alkali-activated binder to produce zero cement concrete. Corncob ash was one of the agro-waste ashes that were tested as a potential source of silica and alumina for the alkali-activated binder. The analysis of corncob ash showed that it contained a high percentage of silica and alumina, which are essential components for the formation of the alkali-activated binder. The X-ray fluorescence analysis showed that CCA have 64.1 % silica content and an alumina content of 13.7 %. The X-ray diffraction (XRD) analysis also confirmed the presence of amorphous silica and alumina in the corncob ash [81]. The study found that the use of corncob ash as a partial replacement for cement in the alkali-activated binder improved the compressive strength of the resulting zero cement concrete. The highest compressive strength was obtained with a 20 % replacement of cement with corncob ash, which realized a compressive strength of 25.68 MPa at a curing period of 28 days. Efflorescence was also reported for higher molarity in CCA-based specimens [81]. The compressive strength of corncob ash alkali-activated binders (AAB) specimens decreased more quickly than that of control specimens as the immersion time in acid and sulphate solutions increased. However, it performs better than slag-based AAB at higher temperatures. Yet, compared to slag-based AAB, it demonstrated improved performance at elevated temperatures. With CCA high specific gravity it can be conclude that it is a valuable source of silica and alumina for the production of alkali-activated binder and zero cement concrete.

3.2.5. *Production of composite material/board*

The use of natural fibers and fillers as reinforcements for polymer-based composites has shown growing interest in recent years. Oyebisi et al. [59] carried out a study on the use of CC to produce composite materials and geopolymer concrete, while [43] explored the use of CC powders with microencapsulated phase-change material to develop composite boards. The study revealed that the porous sponge structure of CC can be infused with microencapsulated phase-change material. The thermal performance of the resulting CC composite board with MPCM was improved, as validated by the Differential scanning calorimetry analysis which revealed a latent heat of 20.11 J/g at a melting point of 27.8 °C. Also, through a series of mechanical and tribological experiments [70] demonstrated that the addition of corncob to the epoxy matrix resulted in significant improvements in the mechanical and tribological properties of the resulting composites. Specifically, the Young's modulus and compressive yield strength of the epoxy composites were shown to increase by 21.26 % and 22.22 %, respectively, with the addition of up to 8 wt% corncob. Moreover, the tribological tests revealed that the coefficient of friction was reduced by 35 % and the wear resistance was increased by 4.8 % in the epoxy composites reinforced with 8 wt% corncob [70]. These results suggest that corncob has the potential to serve as a natural reinforcement for polymer-based composites, offering improvements in both mechanical and tribological properties. Pinto et al. [78] opined that composites boards manufactured from CC had a low fire spread rate and produced relatively low smoke emissions, indicating their potential suitability for use as fire-resistant insulation materials. Composite corncob and sawdust were used to make board using urea formaldehyde as binder in the study of Akinyemi et al. [77]. The results indicated that panels containing 50 % corncob replacement were the most desirable due to their positive physical characteristics suitable for indoor use in buildings. Notwithstanding, these panels are not recommendable for load-bearing purposes due to their poor mechanical properties. However, it was observed that the mechanical properties tended to improve with an increase in the CC composition from 25 % to 75 %.

Subsequently, Geopolymer concrete (GPC) has gained traction as a cheaper and more viable alternative to conventional Portland cement concrete. The adoption of GPC can significantly mitigate both the environmental impacts from cement production and issues of structural deterioration globally [75]. Similar to ordinary concrete, studies of Oyebisi et al. [59] have found that partially replacing cement content with CCA in geopolymer concrete causes the compressive strength to improve up to an optimal level due to the pozzolanic reaction. However, excessive ash content beyond this point decreases strength. Notably though, durability indicators like resistance to chloride penetration and carbonation will be enhanced with higher CCA addition. This results from the refined pore structure, yielding an eco-friendly concrete with superior long-term performance.

3.2.6. *Replacement of Ordinary Portland Cement clinkers during manufacturing process*

Since there are evidence of corncob partially or totally replacing cement, Adesanya and Raheem [15] went on to investigate the replacement for Ordinary Portland Cement clinkers during the manufacturing process of cement. They developed a blended cement by incorporating corncob ash with ordinary Portland cement at varying ratios from 0 % to 30 % by weight. Characterization encompassed dimensional stability and strength indicators including setting time, water absorption and compressive strength, alongside durability properties pertaining to chloride ion ingress and acid resistance. Outcomes evidenced enhanced performance for a 20 % replacement level of OPC with CCA - reduced water absorption and heightened compressive strength values were attained, concurrently with improved resistance to aggressive chemical conditions with higher ash content. The significant findings highlight the promise of corncob ash as a supplementary cementitious material to develop greener cements. This represents a prospective materials chemistry strategy toward transitioning construction practices from traditional to sustainable low-carbon binder technologies with restorative life cycle implications.

3.2.7. *Corncob to particleboards*

Development of particleboards using CC was documented by Abetie [87] and Oliveira et al. [88]. Ramos et al. [68] also investigated the thermal performance and life cycle assessment of corncob particleboards. The study revealed that corncob particleboards, bonded with polyvinyl acetate adhesive, exhibited average coefficients of thermal transmission and conductivity of 1.33 W/(m^2·°C) and 0.052 W/(m·°C), respectively. Particleboards bound with Fabricol AG222 glue showed slightly higher values at 1.92 W/(m^2·°C) and 0.087 W/(m·°C). These results suggest that the particleboards possess commendable thermal insulation properties, making them suitable for applications in building insulation. Furthermore, a life cycle assessment (LCA) was conducted by Ref. [68] to evaluate and compare the environmental impacts of corncob-based and traditional wood-based particleboards. The LCA results indicated that corncob particleboards have a lower life cycle environmental impact compared to wood-based particleboards across most impact categories. Specifically, the production of corncob particleboards was found to emit fewer greenhouse gases, with global warming potential impact approximately 18 % lower than that of wood-based particleboards. In a study by Faustino et al. [79], particleboard was manufactured from corncob, and subsequent tests compared its impact sound insulation to other conventional and traditional building materials. The impact sound insulation gain (ΔL_w) for corncob was estimated at 30 dB, with comparisons to other materials as follows: Kenaf (without slab) 37; Coco fiber 23; Sheep wool 18; Wood wool 21; Cork 17; Cellulose 22; Glass wool 31; and Expanded polystyrene 30. These findings suggest that corncob particleboard could serve as a feasible alternative to conventional building materials, as its insulation properties fall within a comparable range.

3.2.8. *Replacement for ordinary Portland cement (OPC) in concrete and mortar production*

The most promising application is the use of CCA as a supplementary cementitious material (SCM), with majority of reviewed studies highlighting its viability as a partial replacement for OPC in concrete and mortar production. This aligns with the construction industry's efforts to transition from traditional binders with substantial carbon footprints to more sustainable alternatives. Characterized as a Class F pozzolan, corncob ash contains high amorphous silica content that reacts with cement hydration products, enhancing strength and durability [89]. Investigations across replacement levels of 5–30 % by weight validate quality lightweight concrete manufacturing without compromising structural performance [90]. Although no study supports complete OPC substitution at present, the inherent Calcium Oxide deficiency can likely be offset using activators and mineral admixtures to increase reactivity. Overall, the pozzolanic properties substantiate the potential for corncob ash integration as an eco-friendly supplementary cementitious material, driving gains in mechanical properties, lifecycle impacts, and waste valorisation.

Experimental studies of Bagcal and Baccay [80] and Thomas et al. [84] have shown that partially replacing cement with corncob ash, which has high silica content, can enhance the compressive strength and durability properties of concrete and mortar. The pozzolanic reaction of amorphous silica in the ash with cement hydration products contributes to this improvement. Using corncob ash reduces the cement requirement in mixes, resulting in decreased carbon dioxide emissions and cost savings [20]. However, most investigations indicate a decline in workability and post-curing compressive strength with replacement levels exceeding 10 %, presenting a key limitation for high strength structural applications. This deficiency likely owes to factors like particle size distribution, calcium content (see Table 2), and lack of standardization in blending procedures. While higher CCA substitutions diminish mechanical strength, some durability indicators like fire and chemical attack resistance improve with greater percentages [69,82]. This trade-off between strength and durability is a key research area, with studies like Bheel and Adesina [65] demonstrating that adding compensatory admixtures such as glass powder can potentially balance these conflicting trends. However, the CaO and SO_3 deficiency in CCA (refer to Table 2) relative to cement remains an unresolved concern. Addressing the chemical composition divergence alongside particle size and reactivity factors can enable extensive utilization for sustainable concrete production. With refinements to augmentation procedures, the high silica content and pozzolanic nature offers climate mitigation potential, warranting further investigation into optimal hybrid cement replacements.

Studies analysing the embodied energy and emissions associated with CCA production demonstrate its sustainability benefits over conventional cement. Jimoh and Apampa [91] examined the energy consumption and CO_2 emissions associated with the production of cement clinker and CCA. Their findings revealed that the CO_2 emissions from Ordinary Portland Cement were 0.70 kg higher than those from CCA. Additionally, the energy consumption per unit (MJ/kg) for OPC and CCA was 5.16 and 4.33, respectively. Furthermore, Abubakar et al. [92] compared the embodied energy coefficient (MJ/kg) and CO_2 emission factor (kg CO_2/kg) for OPC and CCA. They found that cement required 4.60 MJ/kg and emitted 0.830 kg CO_2/kg, whereas CCA only needed 1.35 MJ/kg and emitted just 0.008 kg CO_2/kg. These results align with the findings of Sinka et al. [12], indicating that corncobs are a bio-based material that demands less processing energy and releases fewer CO_2 emissions into the atmosphere, hence supporting cleaner manufacturing.

While CCA shows promise as a supplementary cementitious material, some limitations exist in its application. Variability in chemical and physical characteristics depending on agricultural source, production methods and combustion conditions poses standardization challenges that can impact concrete/mortar quality. Its highly porous and hygroscopic nature demands careful measures during handling, storage, and transportation to prevent moisture ingress or dust accumulation through atmospheric exposure.

3.2.9. *Used as fillers*

The lightweight and porous structure of corncob lends well to its application as a filler in developing sustainable construction solutions. As a renewable resource with favourable insulation properties, incorporating corncob fillers can enhance the performance of materials like concrete blocks, bricks, and wall panels. Experimental studies have explored its efficacy in improving ductility and thermal resistivity in earthen construction components and biodegradable packaging [86]. As a pore-forming agent in earthen lightweight bricks, Njeumen Nkayem et al. [76] showed increased bulk density and high-temperature strength alongside declining mechanical properties with greater filler percentages. However, water absorption and porosity improved, concluding thermal/acoustic insulation viability. Laborel-Préneron et al. [83] evidenced similar strength reductions but improved ductility in cob-filled bricks. While higher filler quantities challenge mechanical performance, the lightweight and high porosity benefits seem potential for insulation components. Developing appropriate mixtures balancing pore distribution and particle packing can better leverage these contrasting morphological influences. Integrating cob fillers into earth masonry and bricks offers a renewable processing approach towards energy efficiency, especially in buildings.

Table 2
Analysis of chemical composition between CCA and OPC.

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Na_2O
PC	18.11	4.31	2.38	60.22	2.87	0.18
CCA	67.23	6.34	5.33	10.75	1.04	0.37

Source: Bheel and Adesina [65].

3.3. *Gap analysis*

While the preceding subsections summarized the nine different applications found for corncob in building and construction, there remain avenues for additional research to address gaps in understanding its optimal utilization. One major trend identified is the prevalent focus on incorporating corncob and its ash into concrete and cementitious materials, representing a major fraction of the reviewed papers. This clearly highlights the building and construction industry's imperative to pursue alternatives to conventional concrete in order to mitigate the substantial climate impacts from existing practices. However, variability exists in the ideal replacement rates found across studies, ranging from 5 % to 30 % substitution with CCA [15,90]. There is a lack of consistency in determining the optimum balance to enhance properties like strength while retaining workability. More work is thus required on elucidating the particle size distribution, mixing procedure standardization, role of activators, and hybrid additions that enable superior performance. Furthermore, a promising area that has received limited attention is the potential use of corncob-derived compounds as chemical additives in concrete and mortars [93] and use of corncob as a source of lignocellulosic fibers for reinforcing cementitious materials [94]. Some studies have suggested that certain extracts from corncob may have a retarding effect on cement hydration, which could be beneficial in hot weather concreting or for extending workability time [95]. Further research is needed to identify and isolate specific compounds from corncob that influence cement hydration and investigate the mechanisms of interaction between corncob-derived additives and cementitious materials. The second most common application is using corncob for insulation and acoustic panels. While existing research focused on demonstrating the efficacy of these composite boards, future efforts can undertake comparative LCAs (Life cycle assessment) against traditional insulation materials made from glass wool, expanded polystyrene, etc. Also, as observed from the revealed studies, the current manufacturing processes for these materials often involve labour-intensive steps such as manual sorting, cleaning, and shaping of corncob particles. Optimizing fabrication methods and automating processes can significantly aid mass adoption of corncob-based insulation and acoustic panels. There is also potential in leveraging the hollow tubular structure of corncob itself as a lost-formwork material in insulating concrete forms. This application takes advantage of corncob's inherent geometry and insulative properties. The concept involves using whole or partially processed corncobs as a sacrificial form within concrete structures, where they serve dual purposes: (a) as a temporary formwork during concrete pouring and curing. (b) as a permanent insulation layer within the concrete structure. This approach is similar to other bio-based lost formwork systems, such as those using bamboo [96]. The hollow structure of corncob provides natural insulation due to trapped air, potentially enhancing the overall thermal performance of the concrete structure. Additionally, the organic nature of corncob allows for gradual biodegradation over time, which could contribute to the creation of a network of micropores within the concrete, further improving its insulative properties.

Beyond direct use in buildings, another promising area garnering interest is chemically extracting and precipitating silica from corncob and ash to serve as a precursor in geopolymers [43]. More research on refining these biogenic sources can provide sustainable alternatives to mined materials. Investigating other biorefinery approaches to obtain cellulosic sugars, biofuels, and bioplastics can also spur innovation at the intersection of agricultural residues and construction. Overall, while the current studies demonstrate the versatility of corncob waste for various building materials, addressing the identified gaps through multi-disciplinary efforts combining agricultural science, biotechnology, and construction engineering can facilitate their scaled implementation and commercial adoption into construction practices.

3.4. Limitations of using corncob as a building and construction material

Corncobs, as a natural and sustainable material, offer several environmental benefits and economic advantages for use in building and construction. However, their application is limited by several significant disadvantages.

3.4.1. Heterogeneity

Corncobs exhibit significant variability in their physical and chemical properties due to factors such as growing conditions, species, and harvesting methods. This heterogeneity leads to inconsistent performance in construction applications, where uniformity and predictability are essential. Quality control is challenging, as ensuring consistent mechanical properties and performance can be difficult. Additionally, the irregular size and shape of corncobs complicate processing and manufacturing, requiring additional steps to standardize the material.

3.4.2. Mechanical strength limitations

The mechanical strength of corncobs is relatively low compared to traditional construction materials such as concrete and steel. This limitation restricts their use in load bearing structures and reduces their overall utility. Corncob based materials are unsuitable for applications requiring high load-bearing capacity, such as beams, columns, and structural supports. Furthermore, their mechanical properties can degrade over time, especially when exposed to environmental factors like moisture and temperature fluctuations.

3.4.3. Biodegradability

While biodegradability is often viewed as an environmental advantage, it poses a significant drawback in construction applications. Corncobs can degrade over time, particularly when exposed to biological agents such as fungi, bacteria, and insects. This biodegradability compromises the longevity and durability of construction materials, necessitating more frequent maintenance and replacement. Additionally, corncob materials are susceptible to pest infestation, which can lead to further degradation and potential health hazards.

3.4.4. Durability concerns

The hygroscopic nature of corncob poses challenges for long-term durability and mechanical properties. Moisture absorption can cause corncob materials to swell and weaken, making them more susceptible to biological degradation. This leads to dimensional instability and potential structural issues in construction applications [67]. Prolonged exposure to moisture can reduce the load-bearing capacity of corncob-based materials, increasing the likelihood of failure.

3.4.5. Chemical compatibility

In cementitious applications, the high alkalinity of cement can degrade cellulose fibers in corncob over time, potentially compromising the long-term performance of the composite material. The interaction between corncob and various construction chemicals (e.g., plasticizers, water reducers) is not well understood, which can lead to unexpected effects on material properties.

3.4.6. Environmental and economic considerations

While corncob utilization in construction aligns with circular economy principles, it may compete with other potential uses such as biofuel production in developed countries. This raises questions about the most sustainable allocation of this resource. Additionally, while corncob is generally inexpensive as a raw material, the additional processing requirements may impact the cost-competitiveness of corncob-based materials compared to conventional options.

3.4.7. Limited technical knowledge and industry experience

As a relatively new material in construction, there is a lack of long-term performance data for corncob-based building materials. This knowledge gap can make engineers and architects hesitant to specify its use. The construction industry's limited familiarity with corncob-based materials may also lead to resistance in adoption and potential issues in proper installation and maintenance.

3.4.8. Presence of organic impurities

Corncobs contain organic impurities, including starch, proteins, and other extractives, which can interfere with the hydration process of cement. Starch, in particular, act as retarders, delaying the setting time and affecting the early strength development of cementitious materials. This delay complicates construction schedules and can lead to project delays. Organic impurities can also impair early strength development, which is crucial for the timely removal of formwork and subsequent construction phases. Additionally, these impurities may promote degradation processes such as microbial attack, affecting long-term durability. Various pre-treatment methods, such as washing, chemical treatment, and thermal processing, can reduce the content of organic impurities in corncobs. However, despite these mitigation strategies, the inherent limitations of corncob materials necessitate careful consideration and ongoing research to optimize their performance and ensure their viability as sustainable construction materials.

4. Conclusion

This systematic review has investigated the potential of corncob as a sustainable building material, exploring its various applications and research trends in the building and construction industry. It highlights that global corn availability and accessibility supports its scaled repurposing, while the low nutrient content and prolonged field presence pose waste management concerns that are addressed. Based on the research findings and analysis, the following conclusions are made:

Diverse applications and growing research interest.

- The review identified nine distinct applications for corncob in building and construction, ranging from thermal insulation, soil stabilization, particle board production to aggregate and partial cement replacement.
- There is a clear upward trend in research output, particularly in recent years, indicating growing recognition of corncob's potential in sustainable construction.
- Also, emerging research focuses on corncob ash as a supplementary cementitious material and the use of corncob as a source of lignocellulosic fibers for composite materials. This highlights the trend of development in this field as elaborated in the bibliometric analysis.

Environmental and performance benefits

- Corncob-based materials demonstrate several advantageous properties, including enhanced fire resistance, improved thermal insulation, and potential for long-term strength development in cementitious applications.
- The use of corncob in construction aligns with circular economy principles, offering a pathway to valorise agricultural waste and reduce the carbon footprint of building materials.
- Life cycle assessments, although limited, suggest that corncob-based materials can have lower environmental impacts compared to conventional alternatives.

Challenges and limitations

- While promising for many applications, corncob-based materials face limitations in structural applications due to concerns about compressive strength.
- Variability in chemical composition and physical characteristics of corncob, depending on agricultural source and processing methods, poses challenges for standardization and quality control.
- There remains a significant gap between laboratory-scale studies and commercial implementation, highlighting the need for research on scalability and real-world performance.

Implications for sustainable construction

- The versatility and abundance of corncob make it a promising candidate for advancing sustainability in the construction sector, particularly in regions with significant corn production.
- Integration of corncob-based materials into building practices could contribute to reducing the industry's environmental impact, aligning with global efforts towards carbon neutrality.
- Continued research and development in this field have the potential to drive innovation in eco-friendly building materials and support the transition to more sustainable construction practices.

Suggestion of further studies

- Further investigation is needed into the use of corncob-derived compounds as chemical additives in concrete and mortars, particularly their potential retarding effects on cement hydration.
- Optimization of corncob fiber extraction, treatment, and integration into cementitious matrices presents a promising area for developing high-performance, sustainable composites.
- Comprehensive life cycle assessments and economic viability studies are crucial to validate the long-term sustainability benefits and commercial potential of corncob-based building materials.

By addressing these research areas, future studies can significantly advance the field of sustainable construction materials and potentially unlock new applications for corncob in the building industry. This could lead to more efficient use of agricultural waste, reduced environmental impacts, and the development of novel, high-performance building materials.

Ethics

The study adhered to the ethics guidelines of the canterbury christ church university and followed the Declaration of Helsinki—principles of informed consent, voluntary participation and withdrawal, confidentiality, and privacy of the participants.

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Availability of data and materials

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials, available at the behest of the first author.

CRediT authorship contribution statement

Francis O. Okeke: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abdullahi Ahmed:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Adil Imam:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software. **Hany Hassanin:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition.

Declaration of competing interest

Author declare no conflict of interest.

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