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SUSTAINABILITY APPLICATIONS OF CORNCOB ASH FOR COMPOSITE APPLICATIONS: A REVIEW

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Abstract
Environmental awareness about possible adverse effects has substantially expanded, and, consequently, recycling or utilizing agricultural and industrial waste by-products has become an increasingly desirable option for waste disposal. Corncob ash, a byproduct of agricultural processing, has gained attention in recent years for its potential as a sustainable material in composite applications. This review article provides an overview of the utilization of corncob ash in composite materials, focusing on its properties, influence on mechanical properties of composites, and environmental benefits. Additionally, challenges and future directions for the sustainable application of corncob ash in composite materials are addressed. Overall, this study underscores the increasing critical role of corn cob ash in advancing sustainability in composite production.

1. Introduction

Recently, there has been an increased focus on sustainability materials, including bio-sourced, recycled materials, waste resources, and their combinations with respect to composite production (Andrew & Dhakal, 2022; Mohanty et al., 2018). The increasing demand for sustainable materials has prompted researchers to explore alternative resources for composite applications (Maiti et al., 2022). Composites, referred to as engineered materials produced from two or more other materials, are known to have a wide range of physical, chemical, and mechanical characteristics (Bhong et al., 2023). Composite applications cut across a vast spectrum of human discoveries, including aerospace, automobile, construction, medical, marine, defence, energy, infrastructure, sports, and recreation, which highlights their importance (Sadhu et al., 2023; Bhong et al., 2023; Zhou et al., 2023; Egbo, 2021). Their vast spectrum of applications is made possible owing to their tailorable properties suitable for many service demands and requirements.

The shift towards sustainability of materials has been enhanced immensely with the use of agricultural wastes (Rahman et al., 2023). Agricultural wastes are now used for value-added purposes instead of being disposed of in a hazardous way to society to aggravate environmental issues (Bala et al., 2023). Agricultural wastes being polymeric materials possess unique polymeric properties such as low density, low melting point, and low frictional and mechanical properties (Phiri et al., 2023; Maraveas, 2020). Commonly used agricultural waste for composite production includes bagasse, rice husk, bamboo, hemp, jute and oil palm, coconut shell, corn cob, groundnut shell and so on (Kurien et al., 2023). Fibre-reinforced polymer composites (FRP) are the most widely used polymer-based composites owing to their lightweight and easy variation in mechanical properties (Bhong et al., 2023). Agricultural waste used in composites has been reported to improve certain properties of such composites but is still far from the high-performance conventional glass or carbon FRP composites (Maiti et al., 2022). This, therefore, necessitates a balance between composite performance and biodegradability, with approaches that result in an eco-friendly composite.

One of the most abundantly produced grains globally is corn, with more than 1.23 billion metric tons produced in the 2023/2024 trade year, making it take the lead among the most important crops (Shahbandeh, 2025). Corncob ash, a waste product generated from the agricultural processes of corn, has emerged as a promising candidate for sustainable composite production due to its abundance, low cost, and environmental friendliness (Arpitha et al., 2022). Corn cob ash is produced by burning corn cob, the hub or core of corn which holds the kernels (Mestry et al., 2022). Corn cob itself is traditionally used as biomass, livestock fodder, or regarded as agricultural waste. Corn cob ash can be produced for value-added materials through four basic steps: collection, burning conditioning and sieving. The corn cobs are usually collected and cleaned to remove unwanted materials. They are subsequently burnt at a high temperature to ashes using a muffle furnace, and the atmospheric conditions are controlled (conditioning) for optimising properties. The resulting ash is then sieved to have corn cob ash with uniform sizes. This can also be milled to nanoscale depending on the desired size.

Figure 1: Corn cob after removing the kernels (Murthi et al., 2020)

Figure 2: Corn Cob Ash Preparation Sequence. Source: Swami et al., (2022)

Most of the time, the ash generated from corn cobs is dumped in low-level arrears or landfills, which causes environmental problems, especially in developing countries (Murthi et al., 2020). Sustainability efforts in recent years have seen it utilised as an aggregate in the production of lightweight concrete masonry units, an alternative aggregate to produce lightweight concrete for non-structural application purposes, a plant waste in the treatment of industrial wastewater, and a thermal insulation material (Oyewole et al., 2023). Sustainability efforts have also seen corn cob ash investigated for a few of its properties, for instance, its pozzolanic properties (Ahmad et al., 2023), energy production application (Anukam et al., 2017), derivative production such as silica (Okoronkwo et al., 2013), corn cob ash (CCA) as an alternative material for ceramic hollow fiber membrane for beer and extract application (Kamarudin et al., 2018).

While various reviews have been carried out on the use of corn cob ash as a cementitious material, very few reviews have been carried out on the studies of corn cob ash as a reinforcement for high-performance, low-cost metal and polymer-based composites. Therefore, with the increasing interest in corncob ash, this article reviews the recent advancements in utilising corncob ash as a sustainable filler in composite materials, highlighting its potential to contribute to the circular economy and reduce the environmental impact of industrial processes.

2. Physical Properties of Corncob Ash

The physical properties of CCA, such as colour, size, moisture content, specific gravity, etc, depend on the burning method, time, and temperature (Oyewole et al., 2023). The colour of corn cob ash ranges from amorphous white to black, with the latter indicating a high proportion of carbon. Olafusi et al. (2018) obtained a greyish purple corn cob ash at a temperature of 625^{o}C - 650^{o}C for 4 to 5 hours. Bheel et al. (2021), while investigating the utilisation of corn cob ash as a cementitious material in concrete, burnt corn cob under an uncontrolled temperature arrangement for five hours to convert it into corn cob ash and obtained a greyish colour corn cob ash. In another study carried out by Oyebisi et al. (2017), corn cob was subjected to an uncontrolled burning temperature of 200°C to 350°C, resulting in ash with black colour and high carbon content. Further burning of the ash under controlled conditions for 3hrs 15 minutes until the temperature reached 650°C and was kept constant for one hour, resulting in a reduction in the carbon content. Several works seen in the literature have limited the particle sizes to microns. Olafusi et al. (2018) reported milling the ashes to 75 microns, while Sam et al. (2021) obtained a particle size of 35µm. Sam et al. (2021) also reported open-air burning of corn cob until complete combustion and a subsequent air quenching at room temperature followed by conditioning at 650⁰C for 180 min using an electric furnace to reduce the carbonaceous volatile constituent present in the ash effectively. This is consistent with another study by Fatile et al. (2014), where after burning corn cob in the open air, carbonaceous and volatile contents were reduced through conditioning of the corn cob ash in a furnace at the temperature of 650⁰C for 180 minutes. Other properties such as specific surface area, density, and specific gravity of corn cob ash were measured to be 272 m2/kg, 1.96 g/cm3, and 2.54, respectively (Adesanya, 1996; Bheel et al., 2021; Fatile et al., 2014).

Figure 3. Corn Cob Ash, Source (Bheel et al., 2021)

The chemical properties of Corn cob ash are also influenced by the burning method, time, and temperature (Oyewole et al., 2023). Corncob ash is primarily composed of silica, potassium, calcium, and other minerals, which impart desirable properties such as high surface area, low density, and thermal stability. These inherent characteristics make corncob ash an attractive filler for enhancing the mechanical and thermal properties of composites while simultaneously reducing the reliance on conventional materials derived from non-renewable sources. The chemical constituents of corn cob ash primarily consist of oxides, which determine the pozzolanic characteristics of the corn cob ash. A study by Suwanmaneechot et al. (2015) shows that heating temperatures of 200⁰C to 600⁰C for 4 hrs improved the pozzolanic properties of corn cob ash. A chemical analysis of corn cob ash carried out by Tumba et al. (2018) shows it's a pozzolanic material. Also, the chemical composition of corn cob ash was reported to consist mainly of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), which are more than 70% of the percentage composition. Others include CaO, MgO, Na_2O, and K_2O (Fatile et al., 2014). in a review carried out by silica content ranges from 56.29 to 79.39%, alumina content ranges from 0.98 to 17.57%, while iron oxide ranges from 0.67 to 9.07% (Murthi et al., 2020). This composition makes it particularly useful as reinforcement in composites where wear resistance is required. Silica and alumina phases have been well-reported to improve the wear properties of composite materials.

Table 1: Chemical Composition of Corn Cob Ash

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O	P_2O_3	MnO
77.05	5.64	2.97	2.45	1.71	0.25	0.49	3.81	0.71	0.23

Source: Fatile et al., 2014.

3. Microstructural properties

The microstructural properties of corn cob ash influence its mechanical properties. The ash usually contains uneven particles in shapes and sizes that aid internal strength and are influential to the properties of the matrix of the composites. The microstructure, as presented in studies, reveals the presence of particles that will enhance the barrier to dislocation flow when used as reinforcement in composite, thereby increasing the strength of the alloy matrix (Pharm et al., 2021). Studies have also been inconsistent in reporting the uniform distribution of corn cob ash particles and their adhesion to the matrices of composites (Nzelu et al., 2025; Mestry et al., 2022; Oladele et al., 2022; Fatale et al., 2014). However, more studies have reported agglomeration of corn cob ash in matrixes, especially at higher weight fractions. This is evident in the decreased mechanical properties with increasing weight fractions reported in many studies. This might also suggest how important the production method is in ensuring good matrix-reinforcement bonding and distribution. One of the limitations reported in the literature on the use of corn cob ash is the marginal decrease in strength, which is attributed to its microstructure (Nzelu et al., 2025; Fatile et al., 2014). The EDS analysis carried out on epoxy reinforced with corn cob ash shows high silicon and oxygen content, suggesting the presence of silica (Mestry et al., 2022). An EDS carried out on corn cob ash particles also shows a high content of silicon calcium and oxygen (Oladele et al., 2022). Also, Nzelu et al. (2025) carried out an FTIR on corn cob ash particles and identified peaks attributed to hydroxyl groups' O–H stretching vibration and silica phase, which signifies the presence of adsorbed water and silica. Several studies have focused more on examining the microstructure of composites reinforced with corn cob ash to analyse its influence on the matrix than examining its natural microstructure.

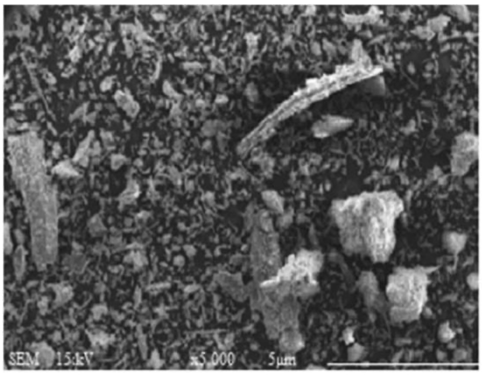


Figure 4: Microstructure of Corn Cob Ash, Source: Pharm et al., 2021.

3.1. Effect of Corn Cob on Mechanical Properties of Composites.

Corn cob ash has been investigated extensively for its influence on metallic and polymeric matrices both as a single and hybrid reinforcement. Reddy et al. (2021) investigated the hardness of aluminium-reinforced corn cob ash with 1wt.% to 4wt.% in step 1. It was observed that hardness increased with increasing weight fraction of corn cob ash. Ikubanni et al. (2020) reported an increasing ductility of aluminium composite with corn cob ash reinforcement with a further increase in weight fraction resulting in a decline. In the study by Fatile et al. (2014), the influence of corn cob ash in a hybrid composite (Al-Si-Mg/SiC/Corncob) was evaluated. The hardness, ultimate tensile strength, and per cent elongation of the hybrid composites decreased gradually in the corn cob ash content of the composites. However, the fracture toughness increases with increasing corn cob ash content. Nzelu et al. (2025) reported a decrease in the tensile strength of epoxy with increasing corn cob ash content.

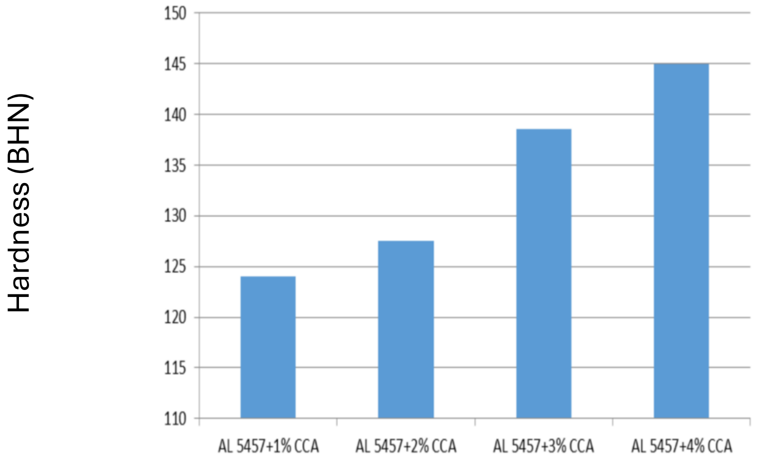
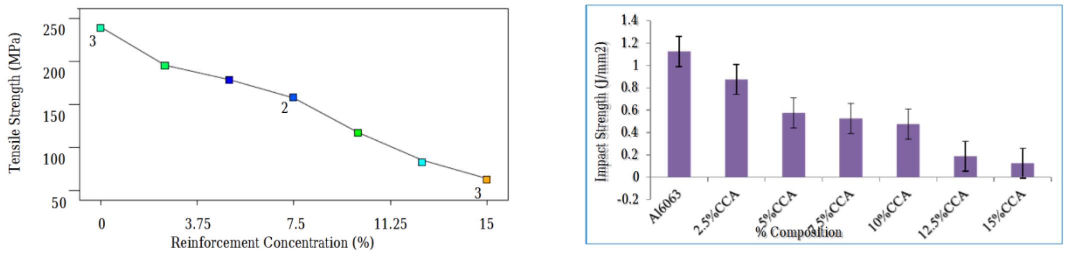


Figure 5: Hardness of Aluminum reinforced with Corn Cob Ash Composite Source: Reddy et al., (2021).

One common limitation to the use of corn cob ash for metal composites is the marginal decrease in the mechanical properties that are being observed when used as a filler (Fatile et al., 2014).

Fatile et al. (2014) studied the mechanical properties of aluminium reinforced with silicon carbide and corn cob ash using two-step stir casting. In the study, the hardness, ultimate tensile strength, and yield strength of the composites are observed to decrease gradually in the value of corn cob ash content in the composites. The study observed 2.15%, 3.23%, 7.53% and 12.90% reduction in hardness and 2.16%, 5.95%, 8.11% and 12.43% reduction in ultimate tensile strength for hybrid composite containing 1, 2, 3, and 4 wt% CCA respectively in comparison to composite without CCA. However, the fracture toughness of the hybrid composites containing CCA increased when compared with the single-reinforced composites that do not contain CCA. Nzelu et al. (2025) also studied the mechanical properties of epoxy reinforced with corn cob ash using cold stir casting. The tensile strength was reported to reduce while the hardness marginally increased with increasing weight fraction of corn cob ash. Also, an increase was reported in the impact and flexural strength of epoxy at a low weight fraction of 3wt.% before a decline at a reducing weight fraction. Odoni et al. (2020) studied the mechanical properties of aluminium 6063 reinforced with corn cob ash in weight fractions 2.5 to 15wt.% in steps of 2.5 produced using the stir casting method. The hardness and wear index reportedly increase while the tensile strength and impact are reduced with increasing weight fraction of corn cob ash. The optimisation solution carried out by the authors shows that 7.919 wt.% of corn cob ash will yield optimal composite response properties. Oladele et al. (2022) investigated the mechanical properties of PVC/coconut fibre/corn cob ash composite produced by the hot compression technique. The study shows that single reinforced PVC composites with coconut fibre gave overall better mechanical properties (tensile strength, flexural strength, impact strength, hardness, and wear index) compared to when corn cob ash was added. A high percentage of corn cob ash in the PVC hybrid composites resulted in a general decrease in mechanical properties. However, corn cob ash at a lower weight fraction (5wt.%) in the hybrid composites shows the best impact and flexural strength.

Furthermore, Mestry et al. (2022) focused on the utilisation of corn cob ash particle reinforcement in the matrix of epoxy resin to develop low-friction and wear-resistant epoxy composites. Composites with corn cob ash weight percentages of 2, 6 and 10% were fabricated and subsequently tested for their tribological performance using a Pin-on-Disc tribometer. Using response surface methodology, mathematical models for friction and wear responses of the composites were generated in terms of corn cob ash content, normal load and sliding speed. The study showed improved wear and frictional properties with increasing weight fraction of corn cob ash. It was also reported that particle size in the range of microns highlighted the suitability of CCA to be used as a hard reinforcement that can improve the wear and frictional properties of epoxy. In the bid to further improve the wear resistance of epoxy reinforced with corn cob ash, Swami et al. (2023) studied the effect of using graphite particles as secondary reinforcement to epoxy reinforced with corn cob ash to produce epoxy composites with low-friction and wear-resistant. The CCA weight percentage was set at 6%, graphite weight percentages were 3, 5, and 7%, and composites were tested for tribological performance using a pin-on-disc tribometer. The study shows that employing graphite as a secondary reinforcement had a favourable effect on wear and friction, with friction and wear being decreased when compared to the CCA-reinforced epoxy composite. Sam et al. (2021) investigated the mechanical properties of an aluminium hybrid with boron nitride, boron carbide, and corn cob ash as reinforcements. To determine the influence of CCA on the hybrid composite, percentages of CCA varied (2, 4 and 6 wt.%) along with constant percentages of BN (3 wt.%) and B4C (4wt.%), resulting in 21.8%, 28.7% and 26.4% improvement in hardness compared to alloy respectively. The maximum hardness (70.7 BHN) was observed with 4 wt.% CCA, which suggests that the presence of CCA beyond 4 wt.% causes a clustering phenomenon and reduction of hardness. Also, the addition of CCA increased the impact strength of the composites by reducing the crack initiation sites and increasing the amount of energy required for crack propagation. Impact strength of composites obtained with varying percentages of CCA (2, 4 and 6 wt.%) along with constant percentages of BN (3 wt.%) and B4C (4wt.%) are 33.3%, 77.8% and 66.7%, respectively compared to alloy.



a. b.

Figure 6: a. Tensile Strength b. Impact Strength of Corn Cob reinforced composites and the unreinforced aluminium AA6063 alloy. Source: Odoni et al. (2020)

3.2. Environmental Benefits Cob Ash Applications

Phiri et al. (2023) identified issues such as the limited availability of landfills, the lasting impact of plastic, the exhaustion of petroleum resources, the harmful emissions that result from incineration, and the risks posed to living organisms as critical towards raising awareness about the necessity to protect the environment. Additionally, population increase and the demand for lighter, affordable, and readily available materials have increased the production of plastic products. Furthermore, the authors highlighted that the production and usage of plastic have a significant environmental impact, particularly regarding climate change and greenhouse gas emissions. However, utilising corncob ash (like other agricultural wastes that have been reported) in composite materials offers significant environmental benefits by reducing the volume of agricultural waste disposal and mitigating the carbon footprint associated with traditional manufacturing processes. The broad spectrum of real-world uses for agricultural wastes in composites includes packaging, construction, automobile parts, biofuels, soil amendments, and medical uses, making it important to consider its environmental benefits (Gowda et al., 2023). A review of studies on utilising corn cob ash, especially in construction applications, shows it improves workability and resistance to aggressive environmental conditions, making it a promising material for sustainable construction (Sathiparan, 2025). This is because the incorporation of corncob ash into construction materials contributes to the sequestration of carbon dioxide through mineral carbonation, thereby offsetting greenhouse gas emissions and promoting climate resilience. This is the same for composite production, where corn cob ash is used as a sustainable reinforcement option. The use of corn cob ash in composites will generally reduce the use of raw materials that are increasingly becoming depleted, thereby preserving nature.

Ali et al. (2022) studied the role of agricultural waste in recycled plastic biocomposites and reported that the environment benefits from the use of agricultural waste as reinforcements in polymer composites. The study highlights that using agricultural waste is a more environmentally responsive option to take care of plastic waste and save costs, along with land area. In a review by Vigneswari et al. (2024), an analysis of the emerging trends in the production of various bioplastics using agro-waste as an approach to carbon neutrality and adopting a sustainable economy was carried out. The authors reported that exploitation and maximum usage of agricultural residues as a source of useful products will reduce the burden on the environment. They also emphasised that an alternative way to reduce the cost of production is by using renewable substrates, such as agricultural waste, as feedstock for biodegradable plastic production, which are environmentally safe and have been widely researched to minimise environmental pollution, potentially substituting fossil-based plastics in the future. Generally, the production of composites with agricultural wastes as reinforcements promotes resource efficiency by making use of renewable and abundant natural resources, reducing the reliance on non-renewable materials. Therefore, using corn cob ash in polymer production while adding value to corn will further increase the interest of researchers in investigating more materials that also benefit the environment and reduce pollution. The presence of derivatives of agro wastes in composites controls overall inventory cost, improves machinability, lowers density, and limits environmental pollution. (Sam et al., 2021).

4. Challenges and Future Directions

Despite the promising potential of corncob ash in composite applications, several challenges remain to be addressed, including optimising filler dispersion, maximising compatibility with matrix materials, and ensuring long-term durability. Future research efforts should focus on developing sustainable processing techniques, exploring novel applications, and investigating the life cycle environmental impacts of corncob ash-based composites to advance their widespread adoption in various industries.

Sathipayan (2025) proposed future research directions in the use of corn cob ash to include optimisation of processing techniques, life cycle assessments, and real-world applications to fully leverage the potential of CCA in promoting environmentally friendly construction practices.

Despite the promising potential of corncob ash in composite applications, several challenges must be addressed to optimise its performance, scalability, and sustainability. These challenges include filler dispersion, compatibility with matrix materials, long-term durability, processing conditions, and environmental considerations. Overcoming these obstacles will require innovative research and development efforts. One of the key challenges in incorporating corncob ash into composite materials is achieving uniform dispersion within the matrix, as reported earlier. Poor dispersion can lead to the agglomeration of ash particles, resulting in stress concentration points and reduced mechanical performance (Kim and Jun, 2020). Effective surface modification techniques, such as silane coupling agents or functionalised polymers, have been explored to improve the interfacial bonding between reinforcements and various matrices (Chen et al., 2025). However, further research is needed to identify cost-effective and eco-friendly surface treatments that can enhance compatibility without compromising the sustainability of the composite. Also, the fabrication of corncob ash-based composites requires optimisation of processing parameters such as curing time, temperature, and mixing techniques to achieve the desired mechanical and thermal properties. Studies have shown that excessive heat treatment can lead to the degradation of organic residues in corncob ash, potentially affecting the structural integrity of the composite (Suwanmaneechot et al., 2015). Innovative processing techniques, such as microwave-assisted curing and controlled pyrolysis, may offer solutions for maintaining the beneficial properties of corncob ash while improving composite performance.

Furthermore, the long-term durability of corncob ash-based composites is another area that requires thorough investigation. Factors such as moisture absorption, thermal degradation, and resistance to chemical exposure influence the performance of these materials over time (Ighalo et al., 2021; Memon et al., 2018). Incorporating hybrid fillers, such as combining corncob ash with nanomaterials like graphene or silica nanoparticles, has shown potential in improving durability and resistance to environmental degradation (Paduvilian et al., 2021). However, further studies are needed to assess the impact of these modifications on large-scale applications.

While laboratory-scale studies have demonstrated the benefits of corncob ash in composite applications, scaling up production remains a significant challenge. The availability of consistent-quality corncob ash, processing infrastructure, and supply chain logistics must be addressed to enable commercial adoption. Additionally, the economic feasibility of corncob ash-based composites compared to conventional fillers needs further evaluation to ensure competitive market entry. Additionally, one of the primary motivations for using corncob ash in composites is its sustainability; however, comprehensive life cycle assessments (LCA) are necessary to quantify its true environmental impact. Factors such as energy consumption in ash processing, emissions from pyrolysis, and end-of-life disposal must be evaluated to confirm the ecological benefits of these materials (Fonts et al., 2023).

Future research should focus on developing circular economy models where corncob ash-based composites can be efficiently recycled or repurposed after their service life. Researchers can also investigate eco-friendly surface treatments to enhance compatibility between corncob ash and polymer/cement matrices. Synergies between corncob ash and other bio-based or nanomaterials can be explored to enhance mechanical and thermal properties. Energy-efficient processing methods such as microwave-assisted curing, 3D printing, and controlled pyrolysis can be developed to save energy and produce quality composites. Durability assessments under real-world environmental conditions can also be conducted to ensure structural integrity over extended service periods. Standardised LCA (Life Cycle Assessment) methodologies can also be established to validate the environmental benefits of corncob ash-based composites. Gaps can be bridged between research and industry by fostering collaborations between academia, manufacturers, and policymakers to promote sustainable material adoption. Research, when carried out towards these directions on corncob ash-based composites, can become a viable and eco-friendly alternative in multiple industries, contributing to sustainable material innovation.

5. Conclusion

The sustainability application of corncob ash in composite materials presents a promising avenue for the development of eco-friendly, cost-effective, and high-performance materials. As a renewable agricultural byproduct, corncob ash serves as an alternative reinforcement in composite applications, reducing dependence on non-renewable reinforcements and contributing to waste valorisation. This review highlights the potential of corncob ash in various composite systems, including polymer and metal-based materials, demonstrating improvements in mechanical properties. The utilisation of corncob ash in composite production aligns with circular economy principles by repurposing agricultural waste into high-value products, thereby reducing landfill accumulation and minimising environmental impact. However, several challenges must be addressed before large-scale adoption can be realised. Issues related to particle dispersion, interfacial bonding, long-term durability, processing techniques, and standardisation require further research and development. Advances in surface modification, hybrid reinforcement strategies, and innovative processing methods such as 3D printing and microwave curing can enhance the overall performance of corncob ash-based composites. Moreover, comprehensive life cycle assessments (LCA) and economic feasibility studies are essential to validate the sustainability benefits and commercial viability of these materials. Future research should focus on optimising material formulations, exploring novel applications, and bridging the gap between academia and industry to facilitate the large-scale production and commercialisation of corncob ash-based composites. With continued advancements, corncob ash has the potential to revolutionise composite manufacturing by providing a greener alternative to conventional reinforcements while addressing global sustainability challenges.

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