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Review

Advances in Applications of Cereal Crop Residues in Green Concrete Technology for Environmental Sustainability: A Review

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Abstract: Concrete is mainly employed as a construction material. Due to the manufacturing of cement and the extent of concrete usage, numerous environmental issues and water suction have presented challenges. There is an immediate need to overcome these problematic issues by substituting natural resources with wastes and by-products of different biological processes in the production of concrete in order to make green concrete. Green concrete provides a relatively low-impact material to satisfy potential concrete demand and offers a cheaper, robust and highly reliable alternative that could fulfil future construction requirements in an environmentally safer way. The present review highlights the possible use of waste residues of agricultural origin from cereal farming in concrete as alternative materials to cement, fine aggregate and fiber reinforcement. The review also considers appropriate methods of treatment, the selection of residual resources and the blending ratios that may allow the development of next-generation green concrete with better physicochemical and mechanical properties. It also explores in-depth studies and the wider range of innovations in cereal farming residues for appropriate use in green construction for environmental sustainability. Green concrete could be an alternative material that could replace those used in conventional methods of construction and help make a further step towards environmental sustainability and a circular bioeconomy.

Keywords: green concrete; wheat straw; corn cob; rice husk; barley; crop residues

1. Introduction

Due to the rapid rate of urbanization, the demand for construction and infrastructure development is increasing around the world. To fulfill this demand, large amounts of concrete are being employed; however, there are numerous demerits to this usage, such as higher water utilization and CO_2 emissions. Continuous urban development and negative environmental issues have led researchers to look for a better eco-friendly option of green concrete for construction purpose to reduce the environmental burden on nature due to current practices. One of the main motives is the mitigation of the undesirable environmental impact of the use of building materials, such as sand, aggregates and cement. Furthermore, the production of cement is totally dependent upon natural resources, the exhaustion of which harms flora and fauna and leads to negative environmental impacts in the long run. In addition, excessive and illegal mining, as well as processing in the extraction of these resources, have led to the mutilation of eco-systems and to air, water and soil pollution, with consequences for human health [1–3].

The conventional methods of cement production are energy-intensive processes and have the drawbacks of emitting particulate matter and greenhouse gases (GHGs), mainly CO_2. Cement manufacturing is a key contributor, which is reported to contribute around 1.8 gigatons (GT) of CO_2 per annum, accounting for roughly 5–7% of the CO_2 generated all across the world [4]. Life cycle reports indicate that approximately 0.8 tons of CO_2 is released in the manufacture of 1 ton of cement [5]. Presently, eco-friendly initiatives are being implemented all over the world to bring forward the sustainable and efficient reuse of waste in order to reduce overall energy consumption in the conventional brick industry. Recent research and development efforts have supported the concept of green concrete and taken a pragmatic approach in addressing the effective and efficient use of industrial waste, agricultural waste and municipal waste resources [6–8]. Massive quantities of industrial waste, such as residual ash, have been predominantly used globally [9–12], while the use of industrial waste in concrete making can easily be approved and developed. However, the assimilation of waste residues in concrete manufacture is still under-developed and in the investigation phase. In this regard, there has been specific interest in utilizing waste residues from the cereal farming industries.

India is an agricultural country and has larger farms devoted to agriculture where farming and cultivation are the prime sources of occupation in rural areas; however, no effort has been made to dispose of the bio-degradable waste generated by agricultural processes [13]. The major proportion of such waste is either fed to livestock as food or is dried and burnt. These harmful processes create environmental issues, such as smog, air pollution and contamination, which is evident from the pollution levels during winter in the northern states of India, including Haryana, Punjab, Delhi and Rajasthan. Therefore, waste utilization is an issue of high priority that needs to be addressed in the wake of alarming environmental conditions. Several studies have been undertaken over the past few years regarding the utilization of agricultural waste residues in concrete [2,3,6–8]. Cereal-farming waste residues may represent the best alternatives to cement, sand, aggregate, fiber reinforcement and supplementary cementitious material (SCM) as binding elements. Nowadays, there is an emerging trend of utilization of farming waste residues as substitutes in concrete making, such as the straw of wheat, rice, corn and barley [13,14]. Agriculture residues from cultivation have widely been used by researchers as partial cement substitutes in concrete. Vegetation growing in soil receives certain amounts of inorganic compounds, including silica (SiO_2) and minerals, and silica, specifically, is obtained at high levels per annum in full-grown vegetation [15]. Farming residues can be a good potential source of cement replacement materials with good binding properties as well as pozzolanic reactivity [15]. Another benefit is that they can also be used for fiber reinforcement, which may strengthen the eventual concrete structures. The reasons for the employment of natural fibers in cement making are due to various beneficial factors, such as the ones mentioned below [16]:

(i) Low cost and ease of availability;
(ii) Does not require high degrees of industrialization;
(iii) Eco-friendly waste utilization;
(iv) Few natural fibers have greater strength than synthetic fibers.

Some cereal waste resources have already been utilized as partial sand and aggregate substitutes in building materials to help the environment as well as minimize reliance on traditional aggregates (i.e., natural sand, gravel and granite) [17–19].

Whether a substance such as cereal waste is pozzolanic or not depends on the reactive quality of silicon and alumina, as well as the percentage of amorphous structure. Other common parameters, such as fineness modulus, maximum grain size and reaction between pozzolana and calcium hydroxide, are considered [20–22]. Danchenko et al. (2020)

has observed that a blend of buckwheat and oat husk forms a uniform filled-composite structure with minimum internal stresses [23]. Mixtures of sorghum husk ash and recycled concrete aggregate were used in a concrete mixture which showed better strength and other mechanical properties. A similar kind of research was performed with kenaf fiber and sorghum husk ash in concrete by Ogunbode et al. (2021); the resultant material was found to be technically and environmentally sustainable [24,25].

Bheel et al. [26,27] utilized millet ash with other materials in concrete, and it was noted that the compressive and split tensile strength were significantly enhanced, which shows the importance of blending the agricultural residual materials with conventional concrete to produce green concrete.

There has been research on the compressive strength of different Portland cement combinations, which may constitute a step towards the future development of an environmentally friendly concrete that integrates and optimizes cereal-farming residues [28]. This review brings forward the holistic approach of utilizing cereal waste by effective and efficient methods for the production of green concrete. The research and development in this domain have to be examined with regard to the common behavior of different waste resources, including their advantages and disadvantages, in concrete making, as well as their characterization, such as physical and chemical composition.

2. Manufacturing of Green Concrete

The production procedure for green concrete varies and mainly depends on the ingredients used and the projected applications. The required properties of concrete and cement quality must be described in the first phase. The properties of the raw materials must be experimentally analyzed, characterized and calculated [29]. There are five steps to be followed, as listed below [29,30]:

I. Estimation of optimal relevant properties of chosen concrete ingredients;
II. Obtainment of a suitable water–cement ratio on the basis of the strength of the concrete and cement contents;
III. Determination of the close interconnections within the particle grain distribution;
IV. Determination of the packing density appropriate to the decreased water content;
V. Production of fresh concrete and estimation of its properties related to compactness and predicted compressive strength.

The methods of optimization that can be used in green concrete production require the development of atom packaging by granular optimization of all concrete ingredients [30,31]. After microanalysis data have been obtained, mathematical modeling and calcium silicate hydrate (CSH) gel evaluation are to be conducted [32–34]; other forms of optimization require the micro-optimization of ranking fine gradient arrangements [35]. The allocation of grain size for all granular elements by the mixture of grain size templates should be optimized. The packing density of grain structures is closely intertwined with grain size distribution. Therefore, it is necessary to choose the percentages of materials available according to an optimal distribution for grain size compaction [30]. The benefit of optimization in green concrete lies in the relation of air pressure to maximum strength and optimizing the properties of end-product materials. It was suggested to separately grind each supplementary cementitious material (SCM) to obtain higher compressive strengths for ternary mixed cement concrete [36]. Few properties, such as physical, thermochemical, mechanical, workmanship and fire resistance properties, of concrete are altered in the manufacturing of green concrete, as is shown in Figure 1. These properties define the capability and life of the concrete in all aspects. Mechanical properties of materials include strength (tensile and compressive), stiffness, elasticity, plasticity, hardness, brittleness and resilience, which describes the behavior under the action of external loads. Thermal and fire resistance are also considered as important parameters in the manufacture of green concrete of high quality.

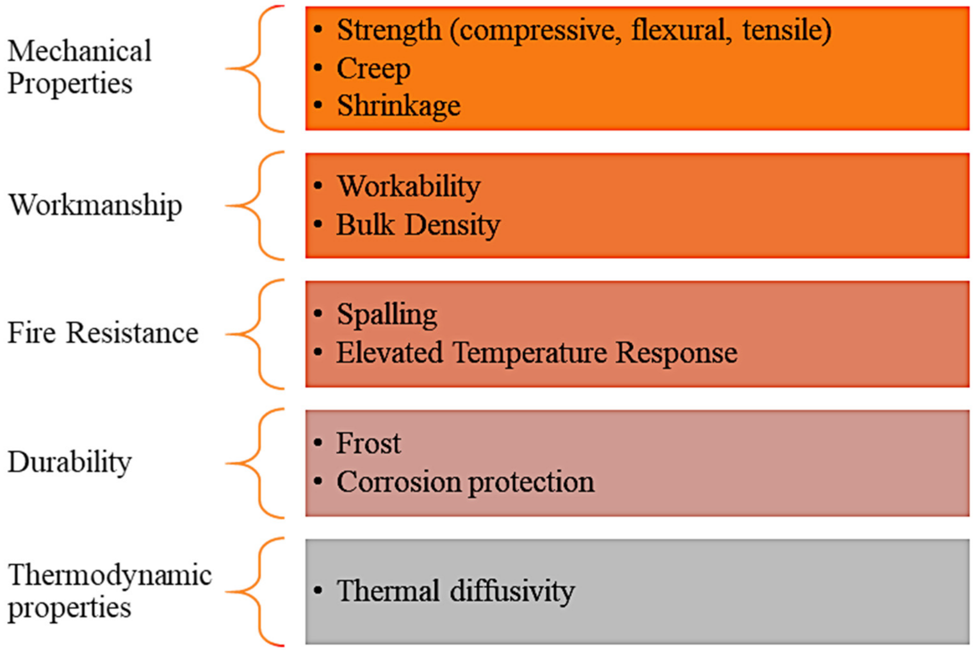

Figure 1. Properties of concrete.

2.1. *Cereal-Farming Residues*

Cereal farming is highly prevalent in India, with most of the cereal crops harvested being used as sources of food grains for Indian people. States such as Haryana, Punjab, Uttar Pradesh, Bihar and West Bengal are India's largest producers of cereal-based agricultural products. However, after the crops are reaped and gathered in the fields and they are effectively and efficiently segregated, there is a lot of waste left over, such as straw, husks, stalks and leaves, depending on the cereals in question. These residues also reduce the fertility and biodiversity of agricultural soil. Therefore, efforts to promote efficient collection and transportation must be prioritized to increase soil fertility and the amounts of valuable products that can be obtained from it [30]. Scientists have recently started to use the aforementioned waste materials as partial substitutes for traditional concrete products and have come up with interesting results [3]. The following section reviews the major crop residues used in concrete production and their characterization.

2.1.1. Waste from Wheat Cereal Harvesting

Wheat is one of the main cereal sources of food production and consumption in India. According to the Ministry of Agriculture (Government of India), wheat production increased to a record 101.20 million tons for the 2018–2019 (July–June) crop year and by 1.3 percent year-on-year in the third annual crop output survey. Wheat straw (WS) residue is one of the primary by-products of wheat production and is usually burnt by farmers in open areas, with a major impact on environmental pollution and human health [37]. Wheat straw ash (WSA) is obtained when it is burnt at a high temperature. Ash has an excess silica content and higher fineness compared to cement [17]. Therefore, wheat straw ash may be a source of alternative material that can be used in concrete production processes [38]. However, depending on the process of ignition, WSA has different chemical properties. The burning temperature of WS was found to be in the range of 570–670 °C for 5 h (Figure 2); hence, the color of white and grey ash denoted the absolute burning of ash [15].

(**a**) (**b**)

Figure 2. Wheat straw (**a**). Wheat straw ash (WSA) (**b**).

Further, it has been observed that if WS is burnt at 900 °C for 6 h it gives a black-colored ash [15,18,38,39]. It has also been reported that cement hydration was accelerated when WSA was pretreated in a comparison with untreated WSA, which retards cement hydration. Results also demonstrated a significant (32%) surge in compressive strength when WSA was treated and compared with normal concrete mortar made with untreated WSA [39]. The positive outcomes for WSA as an accompanying concrete material in mortar were reflected in a superior compressive strength of around 25% [39]. Moreover, when 8% of WSA was mixed in cement, the achieved compressive strength was quite satisfactory as compared to concrete made without WSA after the 180th day [40]. The primary reason was a slow chemical reaction between pozzolana and calcium hydroxide. When WSA was mixed in cement up to 16%, the flexural strength of the concrete was enhanced on the 28th day [40].

The most important criterion of concrete quality is its durability, and many researchers have been conducting studies on the durability of concrete material combined with WSA as a partial cement substitute. It was found that when WSA was mixed in concrete with magnesium sulfate solution, the concrete showed up to 8% higher performance [40]. A further positive result for the freezing and thawing resistance of WSA mixed concrete as compared to normal concrete was also shown [41]. The WSA replacement level was increased from 5–15%, which helped to increase the freezing and thawing resistance of the concrete. Furthermore, the resistance of WSA mixed concrete to deterioration by alkali and silica was a bit higher compared to equivalent normal concrete made without WSA. If the WSA content is increased to 15%, it has a higher resistance to the reactions that occur between alkali and silica [42].

Most important is the influence of WSA on the oxidation of alkali and silica in concrete mixed with a lower water–cement ratio [42]. In due course, some researchers have also explored the prospect of the efficient usage of WSA as a partial substitute for sand in concrete. Promising results were achieved when WSA was partly mixed with cement up to 10.9%, due to the higher fineness of WSA as compared to cement, which has reduced workability, though water demand was found to be increased [17]. Along with this, another important factor, namely, setting time of new concrete, was enhanced by up to 92% given the presence of WSA as 10.9% of a sand substitute, the effect on setting time being one of the major reasons for the particular binding characteristics of WSA [17]. In terms of strength features or properties, up to 10.9% mixing of WSA with fine aggregate showed increments in tensile, flexural and compressive strengths of concrete of up to 67, 71 and 87%, respectively [17]. Similarly, as reported by Binici et al. [18], with partial replacement with WSA up to 6%, WSA concrete's compressive strength was enhanced in comparison with normal concrete after the 28th day, and it was observed that the compressive strength on the 7th day was similar [17]. It was found that mixing of WSA as a partial fine aggregate replacement (6%) resulted in the concrete with the best durability. According to reports in the literature, sulphate resistance is the main area of concern in concrete production and in which WSA has shown promising results, with water penetration and abrasion resistance having been found to be increased in concrete made with WSA due to denser pore formation [18]. Concrete exposed to a thermal cycling process shows a decrease in compressive strength and it was found that this decrease was less sharp for WSA concrete in comparison with normal concrete. It has been well reflected that WSA concrete has better resistance when exposed to thermal cycling, even when WSA as a fine aggregate partial substitute was used up to 15% [43]. Moreover, the cracks in WSA concrete were observed to develop at a much later stage due to the presence of fibers in WSA, which helps in binding the other ingredients of concrete as well. Electrical resistivity further enhances the resistance of WSA concrete at higher temperatures [42]. With regard to the use of WS for fiber reinforcement in concrete, it was concluded that the tensile strength of wheat straw fiber (WSF) was around 40 megapascals (MPa) (Table 1) [44]. This was ascribed to the irregular surface attributes of WSF promoting bond formation in the cement and fiber matrix, which was composed of a mix of low-strength fibers, and the breakdown of the concrete was considered to involve the pulling out of fibers rather than their rupture [44].

Table 1. Natural fiber properties of WS [44–46].

Physical Properties	Bulk Density (kg/m^3)	Moisture Content (%)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)
Wheat straw	160.75	6.4	40	3.1–3.7

MPa: Megapascal, GPa: Gigapascal.

Effect of the mixing ratio of WSA with Cement, Sand and Fiber

The mixing of WSA with cement and sand may alter the chemical and physical as well as the mechanical composition of cement because WSA has its own oxide composition and physical, chemical and natural fiber properties. Varying the percentage of WSA mixed in cement affects the final properties of concrete to different extents. Hence, the study of the different ratios is essential to establish the appropriate proportions of WSA and adequate cement mixing is required to achieve desired properties in concrete. Previous studies have revealed the blending ratios for the desirable properties of concrete, which are mentioned below.

Effect of partial replacement of WSA with Cement

When cement was replaced with 8, 16 and 24% WSA [40], the compressive strength was reduced on 28th day; the equivalent strength at 180 days confirmed the superiority of the replacement level of 8%. This provides higher flexural strength and also enhanced the sulfate tolerance along with the compressive strength. When cement was replaced with 5, 10 and 15% WSA [42], the reliability of alkali–silica reactions was improved, and when cement was replaced with 20% pretreated WSA [39], the compressive strength was raised.

Effect of partial replacement of WSA with Sand

When sand was replaced with 3.6, 7.3 and 11% WSA [17], the flow properties were reduced, initial setting time improved and the compressive, flexural and splitting tensile strengths increased. When sand was replaced with 5, 10 and 15% WSA [43], resistance to thermal cycling was strengthened. When sand was replaced with 2, 4 and 6% WSA [18], compressive strength, sulfate resistance and abrasion resistance were improved and the rate of water penetration was reduced.

Effect of partial replacement of WSF addition in Cement

When wheat straw fiber was added to cement (0.19%) [44], a nominal rise in fracture strength was observed.

The oxide composition and physical and chemical properties of wheat straw materials are detailed in Tables 1–4.

Table 2. Oxide composition of WSA [15–18,40–42].

Oxide Composition	SiO_2	CaO	Al_2O_3	Fe_2O_3	Na_2O	MgO	K_2O	LOI
WSA (%)	4.9–7.8	9.4–24.4	0.1–4.6	0.1–1.3	0.1–5.4	0.6–4.6	0.7–24.7	1.1–29

Table 3. Physical properties of WSA [17,18,39,41,42].

Physical Properties	Specific Gravity	Blaine's Specific Surface Area (m^2/Kg)	BET Specific Surface Area (m^2/g)
WSA	1.97–2.89	430–552	8.3–168

Table 4. Natural fiber chemical and morphological characteristics of WS [44,47–55].

Chemical Properties	Lignin (%)	Cellulose (%)	Hemicellulose (%)	Length (mm)	Width (%)
Wheat straw	6.5–22	30.1–49.1	22.2–34	40	-

2.1.2. Waste from Rice Cereal Harvesting

As per the Ministry of Agriculture, India, rice production was projected at 115.6 million tons in 2018–2019, which was higher than in 2017–2018. There is a lot of waste generated in rice production, such as the straw and husks left after harvesting. Rice husks (RH)—a cereal waste obtained from the crushing of rice—constitute another good substitute material for cement manufacturing [56]. They are considered one of the major globally accessible waste residues. RH from rice fields is one of the best alternative materials that can be used as a partial replacement for ash to enhance the properties of concrete in terms of strength, workability and durability and can also reduce the quantity of cement by weight.

RH is an exterior paddy grain cover and accounts for 20–30% of the weight of paddy rice collected [56]. RH is usually used as a fuel in boilers due to heat generation during combustion (13–16 MJ/kg) [57]. Rice husk ash (RHA) is obtained after the burning of RH, which accounts for 18–25% of RH's preliminary weight. RHA presents a land-filling problem, as it is not utilized. Generated by rice mills, it is a source of environmental contamination and there has been debate over the issue of dumping [58]. If this accessible waste is not treated or handled properly, it may contribute to pollution. The color of RHA depends on the raw material resources and can vary from black to white gray depending on the incineration process, the duration of burning and burning temperature. RH is exposed to a self-controlled high temperature between 600–800 °C for 1 h in a closed environment in a furnace/incinerator. The ash produced is cooled after the firing process, either slowly or quickly. The quick cooling process is carried out by continuously spreading the ash in dishes at an ambient lab temperature of 21°C after achieving the appropriate temperature of 800 °C for 1 h. In this way, RHA is obtained when the furnace/incinerator is cooled down at a lower rate [59–61].

In RHA, silica content is a major factor in producing C-S-H gel through reaction with calcium hydroxide and lime. C-S-H is mostly essential for the strength and other micro-structural properties of concrete [62]. RHA has a similar character to WSA in that it has excess silica content. It consists of 80–95% silica, which is an important factor in concrete; however, when compared to conventional concrete, ordinary Portland cement only contains 21% silica [63–65]. Due to the higher silica content of RHA, it can be used to enhance the transition zone and surface area between the cement paste and the microscopic framework [39]. Thermo-chemicals, such as dilute acid, increase the rate of pozzolanic reactions by increasing the surface area and volume of amorphous silica and reducing RHA carbon content [66]. Researchers are committed to finding economic routes to extract nano-silica from RHA due to an increasingly extensive market for amorphous silica.

Alkali extraction is a cheap method that can be used to prepare high-purity silica sol or nano-silica powder for various mullite ceramics [67–69]. When RHA is treated well, a C-S-H gel is formed which can fill the gaps between cracks in concrete and protect it from leaching degradation and corrosion. The silica present in RHA reacts with $Ca(OH)_2$ to form a resistive layer that acts as a protective layer for the materials when subjected to acidic conditions. When RHA was used as a partial replacement concrete-making material, it was found that it enhanced the tensile strength, compressive strength and modulus of elasticity of the mixed concrete as compared to normal concrete [70]. RHA consists of minerals that are used as SCMs in mortar and concrete making. The water absorption and porosity of the two samples decreased with an improvement of up to 15% in the RHA content and then began to increase. For the normal concrete, water absorption was 6.4, 4.8 and 4.3% at the 7th, 28th and 91st day and declined to 5.5, 3.7 and 3.5%, respectively, after mixing with 15% RHA. On the other hand, the porosity analysis revealed a decrease of 26, 17 and 14% for concrete mixed with 15% RHA as compared to the control combination at the 7th, 28th and 91st day. Such changes are due to the creation of additional C-S-H gel by the pozzolanic reaction between calcium hydroxide and silica found in RHA, with decreased pores and improved concrete capacity [71,72]. When RHA was at a partial replacement level of 15%, water demand was increased because of the lower fineness modulus and higher surface area of RHA particles. Nonetheless, decreased concrete workability likely resulted in pores and voids being created, which in effect improved the concrete's susceptibility to water absorption [71]. In fact, there is a lack of $Ca(OH)_2$ to react with the higher amount of SiO_2 present at such high doses. Consequently, a significant amount of silica remains unreacted, which, through growing porosity, breaks down the consistency of the concrete's micro-structure. The maximum water permeability of concrete mixed with 15% RHA was 72, 64.7 and 87.5% lower than that of normal concrete at the 7th, 28th and 91st day. Concrete water permeability is a feature of porosity and mixing of RHA up to 15% as partial cement replacement decreased the voids in concrete due to pozzolanic action and micro-filling, thereby decreasing water permeability [72].

The amount of nano-silica present in RHA changes the character of concrete made with RHA and is responsible for the development of the rough surface texture as well as the layered polymerized structure which enhances the cohesion between cement mortar and aggregates. Using RHA to make green concrete would help to reduce global carbon emissions from the manufacturing of concrete. RHA-modified concrete is currently in the development stage at laboratory scale. RHA-mixed strong castable concrete has led to economic and ecological advantages in the refractory industries [66]. However, the manufacture of green concrete needs to be promoted to the upper level and be adopted in mass manufacturing at commercial scale [29].

Effect of partial replacement of RHA in Cement

When partial replacement of cement with RHA is performed, the chemical and physical properties of the cement will be changed, different proportions of RHA influencing to different degrees the final properties of the concrete. Previous reports in the literature have revealed the outcomes of different blending percentages on the properties of concrete, as described below. When cement replacement at 25% was performed [73]:

- ➢ The lowest water absorption rates on the 7th day were about 4.8% and on the 28th day of curing about 3%;
  - There was a change of 6.9% in compressive strength at the 7th day and 6.8% at the 28th day;
  - The most improved tensile strength was achieved with up to 6.8% RHA, then it tended to fall;
  - This contributed to a dramatic improvement in the permeability of the mixed concrete relative to normal concrete;
  - Water permeability was reduced to 26%;
  - This led to a reduction in chloride permeation of 78%.

➢ When cement replacement at 15% was performed [74–76]:

- The compressive strength rose by 15%; at the 7th, 28th, 56th and 91st day, by 9, 12, 13 and 16% above that of the control combination, respectively;
- The average elasticity element was 14% higher than the 0% combination;
- The 28th-day flexural strength of the maximum flexural strength was 21% higher than that of the 0% combination.

The oxide composition and physical and chemical properties of RHA have been summarized in Tables 5–7.

Table 5. Oxide composition of RHA [62–65,77].

Oxide Compo-sition	SiO_2	CaO	Al_2O_3	Fe_2O_3	Na_2O	MgO	K_2O	LOI
RHA (%)	85–95	0.31–1.5	0.05–0.3	0.06–0.2	0.06–1.36	0.35–0.6	1.4–2.3	0.8–1.4

Table 6. Physical properties of RHA [3,78–80].

Physical Properties	Specific gravity	Blaine's Specific Surface Area (m^2/Kg)	BET Specific Surface Area (m^2/g)
RHA	2.14	350–376.8	117.6

Table 7. Natural fiber chemical and morphological characteristics of RHA [41,81–85].

Chemical Properties	Lignin (%)	Cellulose (%)	Hemicellulose (%)	Length (mm)	Width (%)
Rice husk	6.8–20.4	33.4–50.1	3.8–21.7	-	-

2.1.3. Waste from Corn Cereal Harvesting

Corn is produced as a major cereal product in India, along with rice and wheat [86]. Corn cob is a cereal waste that is obtained from corn or maize. It is another substitute for utilization in concrete making in place of cement, sand and coarse aggregate to reduce the quantity of raw materials required for concrete production. Corn cob ash (CCA) is obtained by burning maize cob waste at a temperature of 600 °C for 3 h and 650 °C for a period of 8 h [18,87]. It is pozzolanic in nature and has a significant quantity of loss on ignition (LOI) and reactive amorphous silica content [18]. According to previous studies, the percentage of silica contained in CCA is around 37–66% [18,86] (Table 8). When CCA was mixed with cement up to a level of 25%, as the percentage of CCA increased, the LOI of the mixed cement was enhanced due to an increase in the organic percentage present in CCA [88]. This has an undesirable effect on cement properties because cement works as a binding material in concrete, providing strength [88]. Due to this phenomenon, the reliability of the mixed cement will be compromised, while the soundness as well as the setting times of the mixed cement will be enhanced [88]. The increase in the setting time and soundness of cement was attributed to the CCA, which decreased the surface area of the cement. Since CCA is very light-weight in comparison to cement, it delayed the hydration process [88]. Similarly, the workability decreased as the CCA percentage increased due to this. Water demand also increased.

Table 8. Oxide composition of CCA [18,87,88].

Oxide Composition	SiO_2	CaO	Al_2O_3	Fe_2O_3	Na_2O	MgO	K_2O	LOI
CCA (%)	37–66.4	11.6–13	2.4–7.5	1.2–4.4	0.3–0.4	2.1–7.4	4.9–15	22.5

Regarding compressive strength, the production of mixed concrete with CCA worked equally in comparison to normal cementitious materials. It was found that the early strength of CCA concrete was lower, but after some time it exhibited higher strength due to the effective pozzolanic reactions between SiO_2 and $Ca(OH)_2$ in the CCA [87]. When CCA and WSA were used up to 6% as partial fine aggregate replacements, it was found that the compressive strength of CCA mixed concrete was enhanced by up to 40% in comparison with WSA mixed concrete at the age of 365 days [33]. If we look CCA used as a partial fine aggregate replacement, then the overall development factors and performance of CCA concrete show it to be superior to WSA concrete. Similarly, it was also observed that the durability performance, e.g., abrasion resistance, sulphate resistance, and water penetration resistance, of CCA concrete was enhanced in comparison to WSA concrete [33]. It was found that when CCA was used as a coarse aggregate replacement, better light-weight concrete resulted as compared with other light-weight concretes made with long-drawn-out clay aggregates [89]. Finally, it was observed that CCA concrete has a compressive strength (0.12 MPa) that is lower in comparison with that of long-drawn-out clay concrete (1.36 MPa). The overall thermal performance and density were consistent, suggesting that CCA concrete might be used in light-weight structures or single-storey buildings.

Effect of Mixing of CCA with Cement, Sand and Aggregate

When partial replacement of CCA with cement, sand, and aggregate is performed, then the chemical composition and physical properties of cement change because CCA and cement have different chemical and physical properties. It is therefore important to find different ratios to establish the idol composition of CCA and cement mixing necessary to achieve appropriate concrete properties. These properties were shown above, in Tables 8–10.

Table 9. Physical properties of CCA [18,88].

Physical Properties	Specific Gravity	Blaine's Specific Surface Area (m^2/Kg)	BET Specific Surface Area (m^2/g)
CCA	2.97	270–385	-

Table 10. Natural fiber chemical and morphological characteristics of Cornstalk [85,90–95].

Chemical Properties	Lignin (%)	Cellulose (%)	Hemicellulose (%)	Length (mm)	Width (%)
Cornstalk	3.8–21.7	37.5–49.3	22.5–30	0.7–0.9	0.023–0.029

Effect of partial replacement of Cement with CCA

➢ Cement replaced with 2 to 25% CCA [87,88]:
- Reduced workability;
- Decreased early strength;
- Improved strength gain;
- Enhanced initial and final setting time.

Effect of partial replacement of Sand with CCA

➢ Sand replaced with 2, 4 and 6% CCA [18,88]:
- Enhanced compressive strength;
- Improved sulfate resistance;
- Higher aberration resistance;
- Reduced rate of water penetration.

Effect of replacement of coarse aggregate with 100% CCA

➢ Coarse aggregate replaced with 100% CCA [89]:
- Similar thermal properties to lightweight concrete.

2.1.4. Waste from Barley Cereal Harvesting

Barley is also produced in India as a key cereal crop, along with rice, corn and wheat. Consequently, straw of barley is also accumulated excessively and burnt due to a lack of efficient utilization methods [95]. Similar to wheat straw ash, barley straw could also be utilized for ash generation and barley straw ash (BSA) may be used as a pozzolanic substance for concrete production, though there has been insufficient investigative work carried out on using BSA as SCM. In general, BSA has a high amount of potassium and a slightly lower amount of silica (21.2%) in comparison to WSA, as shown in Table 11 [96]. Furthermore, BSA structure and crystallography can rely on pozzolanic reactivity. Similar molecules undergo different reactions during the solution process in interaction with saturated $Ca(OH)_2$, impacting the speed and length of the reaction. Owing to the occurrence of KCl, the pozzolanic action of BSA may be lesser in comparison to traditional pozzolans, viz., fly ash, and it led to low divergence in compressive strength at the 7th day and the 28th day [96]. Barley straw with a tensile strength of approximately 115 MPa and a modulus of elasticity of 9.92 GPa was used as an alternative to wood shavings to produce sand concrete of lower weight [97]. The findings of the study described that the addition of barley straw fiber led to a 35% increase in thermal diffusivity, along with an improvement in the compressive strength and toughness of the produced concrete. In this study, since the pozzolanic substance had the same particle size and fineness, there was improved pozzolanic reactivity throughout the BSA and fiber addition as compared to the other samples [96].

Table 11. Oxide composition of BSA [96].

Oxide Composition	SiO_2	CaO	Al_2O_3	Fe_2O_3	Na_2O	MgO	K_2O	LOI
BSA (%)	21.2	10.0	2.8	3.5	4.1	-	38.0	-

Effect of Fiber addition in Concrete

When partial replacement of fiber addition in cement concrete is performed, the chemical composition and physical properties of cement would be changed because BSA and cement have different chemical and physical properties (Tables 11–13).

Table 12. Natural fiber chemical and morphological characteristics of WSA [97,98].

Chemical Properties	Lignin (%)	Cellulose (%)	Hemicellulose (%)	Length (mm)	Width (%)
Barley straw	13.72–15.8	37.6	34.9	35	-

Table 13. Natural fiber properties of barley straw [97,99].

Physical Properties	Bulk Density (kg/m^3)	Moisture Content (%)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)
Barley straw	30–130	-	115	9.92

Fiber addition in concrete [97] leads to:

- Lower shrinkage;
- Increased porosity;
- Reduced thermal diffusivity;
- Improved ductility;
- Higher compressive strength.

3. Inferences from the Literature Related to the Usage of Agricultural Waste Residue Ash in Concrete

From the data reported in the literature, it can be inferred that natural agricultural wastes obtained from cereals, such as wheat, rice, barley and corn, can serve as alternative materials in the production of green concrete. The addition of residual ash to concrete affects the mechanical and physicochemical properties of the end product. The compressive strength of green concrete is reduced at first but becomes equivalent to conventional concrete after 180 days due to the stability of the residue ash. Nevertheless, with appropriate pretreatment of residues (mainly thermal treatment) the durability of concrete may be improved. Similarly, the higher content of silica in waste residue ash promotes pozzolanic reactivity, which leads to the higher strength of the final concrete. The foremost significance of the utilization of waste residues lies in the mitigation of CO_2, CH_4 and NO_x emissions, reduced dependence on fossil fuels and increase in the recycling of materials, which indirectly reduces the degradation of the environment. Additionally, it is reported that the water absorption of green concrete (made with waste residue ash) is lower after the 7th, 15th and 28th days of curing as compared to conventional concrete. Moreover, the early strength of green concrete is reduced, though it increases later on due to effective pozzolanic reactions between SiO_2 and $Ca(OH)_2$.

4. Conclusions

Cereal waste handling and environmental degradation are major concerns for all nations, especially agriculturally rich and developing countries, such as India. Cereal waste residues have potential applications as partial substitutes for cement, sand, coarse aggregate and fiber reinforcement as they have significant mechanical properties. Residues from agriculture can be used to make green concrete, increasing the strength and properties of the final concrete depending on the type and amount of residue used in its production. In addition, if appropriate pretreatment of waste materials is carried out, the waste may be incorporated into concrete to enhance its mechanical and durability properties. In addition, optimization of the packing density of grain, the grain size distribution of blends, and water–cement ratios may further improve the performance of cereal residue-based concrete. Green concrete consisting of one-quarter customary cement may show adequate robustness with respect to composition and conditions during corrosive exposures. Consequently, a more productive design for green concrete made with cereal residues may be a promising area to explore further in the future that will result in the recycling of waste and the reduction of undesirable effects on the environment. Eventually, it will contribute to innovation in the sustainable building sector and the construction industry and at the same time promote a cleaner environment.

Green concrete with desirable properties and high sustainability may increase the possibilities and the feasibility of using cereal crop residues in future applications. The limitations include starting up, the economics of the process and the sustainable supply of agricultural residues due to seasonal variations, geographical factors and climatic conditions.

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