recycling

Type of the Paper (Article)

Supplementary file of the article titled "Recycling of Egyptian Shammi Corn Stalks for Maintaining Sustainable Cement Industry: Scoring on Sustainable Development Goals"

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Darkening of the mortar color

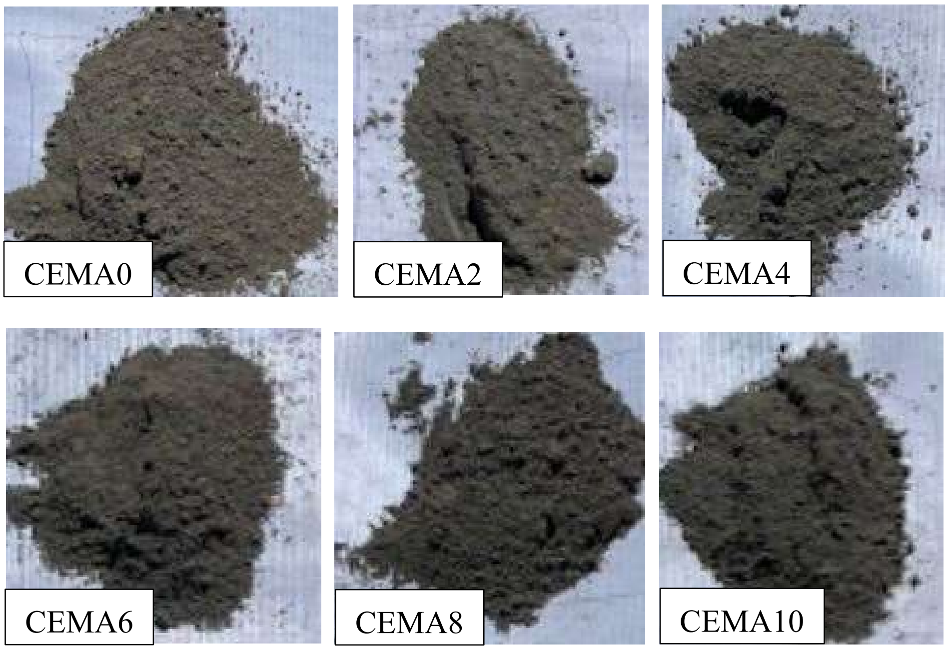
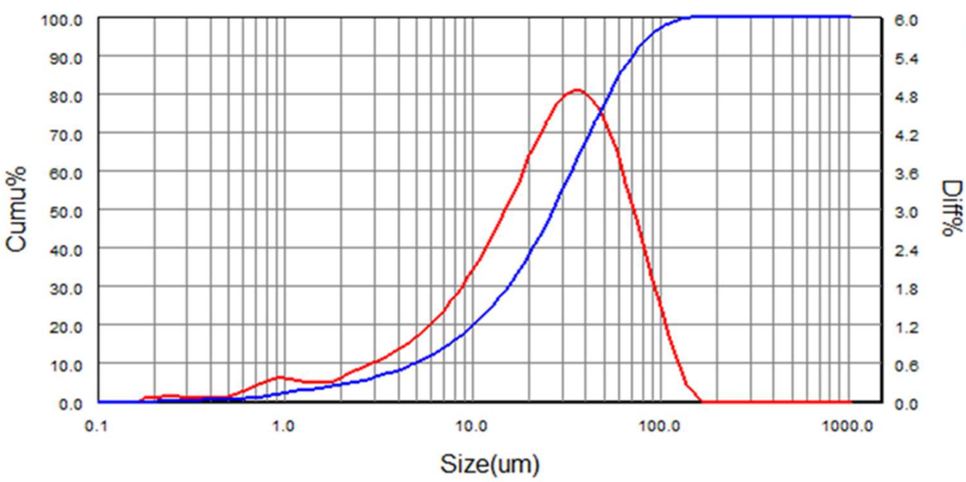


Figure S1. Color variations among the cement mixtures, used to estimate the darkness coefficient (ΔE) values.

Egyptian Shammi corn

Maize (*Zea mays* L.), commonly known as corn, is an essential cereal crop in Egypt and its residual biomass can be involved in the manufacturing of several materials (e.g., oil, ethanol, glucose syrup, bioplastic, and composites). The conversion of this crop stalk into ashes, which are then used as a supplementary cementitious material (SCM) in cement has also been reported [1]; [2]. Shammi corn is one of these agronomic and food crops, containing higher silica levels in leaf blades, tassels, stems, leaf sheaths, and roots. Large quantities of the stalk parts of Shammi corn (e.g., stem, cob, leaf, husk; Supplementary Figure S2) are disposed of in landfills or incinerators, suggesting their potential recycling as a SCM in cement manufacturing. However, understanding the recyclability performance of Shammi corn stalk ash (SCSA) should be evaluated, regarding material strength and durability and environmental implications, further opening new avenues for sustainable construction practices.

Figure S2. Egyptian Shammi corn residue.



Size	Percent
0.176	0.00
0.375	0.54
0.799	1.58
1.702	3.98
3.627	7.65
7.729	15.43
16.47	32.08
35.09	61.98
74.78	91.42
159.7	100.00

Figure S3. Estimation of Shammi corn stalk ash (SCSA) particle size.

Primary selection of the optimum replacement ratio of Egyptian Shammi corn stalk ash (SCSA)

A preliminary test was conducted to determine cement mixture properties over a wide range of cement replacement ratios, observing a failure of cube cement specimens at a substitutional level of over 10% (Supplementary Figure S4). This step was conducted based on the results of previous studies [1]; [2]. Increasing the substitutional level of cement by over 10% caused considerable cracking to the sample and a reduction in the cement's compressive strengths.

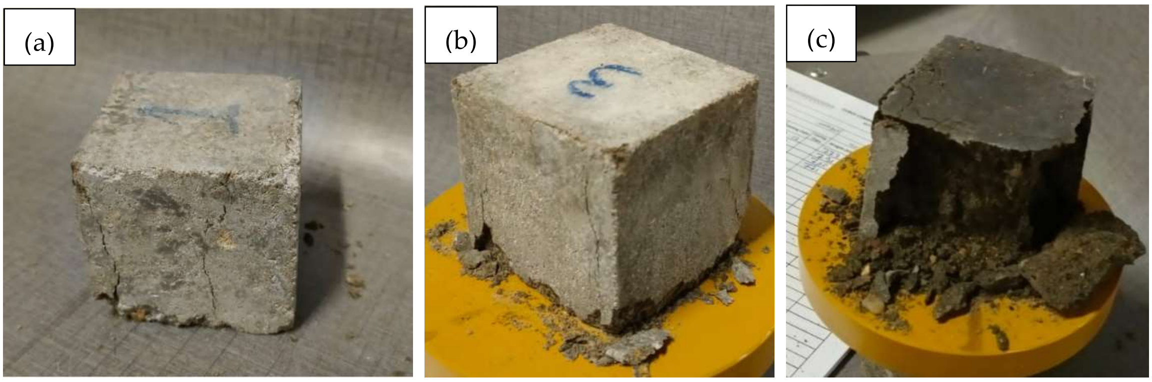


Figure S4. Failure of cement samples at substitutional levels of (a) 5%, (b) 10%, and (c) 25%.

Figure S5. Cement moulds used for determining the strength criteria.

Categories and Sub-categories for Decision of Alternatives Using AHP-TOPSIS

The normalized values were multiplied by (−1) if larger raw values reduce sustainability achievements [3].

Table S1. Normalized values of each indicator for the two alternatives.

Indicator	CEMA0	CEMA4
Strength (I1)	0.668	0.744
Setting time (I2)	–0.733	–0.680
Fineness (I3)	0.636	0.772
Workability (I4)	0.750	0.661
Initial cost (I5)	–0.832	–0.555
Maintenance cost (I6)	–0.914	–0.406
Health and safety (I7)	–0.832	–0.555
Employment opportunities (I8)	0.316	0.949
CO_2 gas emissions (I9)	–0.721	–0.693
Energy consumption (I10)	–0.721	–0.693

Table S2. Mechanical strength for CEMA4 compared with other agricultural ashes used in cement preparation.

Replacement material	Replacement ratio (w/w)	Compressive strength -28 days (N/mm^2)	Flexural strength -28 days (N/mm^2)	Ref.
Corn cob ash	2.5%	26.83	3.75	[4]
Sunflower stalk ash	2.5%	26.72	2.67	[4]
Cornstalk ash	10%	23	5.6	[1]
Corn cob ash	10%	34	3.8*	[5]

Fly ash	50%	6.35	2.3	[6]
Corn cob ash	50%	7.55	2.2	[6]
SCSA	4%	60	8.2	This study

* Split tensile strength

Table S3. Separation measures; Ideal separation (Si^{+}). Negative-ideal separation (Si^{-}).

Indicator	CEMA0	CEMA4
Si^{+}	0.0796	0.0082
Si^{-}	0.0106	0.0033

Test procedures for estimating setting time (initial and final) of cement mixtures

This test method is used to determine the setting time of hydraulic cement by Vicat needle apparatus [7]; [8]. According to ASTM specification, the initial setting time shall not be less than 45 min but in the field, an initial setting of cement is preferred to be not less than 90 min.

Table S4. Procedures used to estimate setting time (initial and final) of cement mixtures.

Step	Action
1	Place the dry paddle and the dry bowl in the mixing position in the mixer. Place all the mixing water in the bowl
2	Add the cement to the water and allow 30 seconds for the absorption of the water. Start the mixer at low speed for 30 seconds. Stop for (15 seconds) and make sure no materials have collected on the sides of the bowel
3	Start mixing at medium speed for 1 min. Quickly, form the cement paste into the approximate shape of a ball with gloved hands. Putting hand at (15 cm) distance, throw the cement paste ball from hand to hand six times.
4	Press the ball into the larger end of the conical ring to completely fill the ring with paste. Remove the excess at the larger end by a single movement of the palm of the hand. Place the ring on its larger end on the base of the plate of the Vicat apparatus.
5	Slice off the excess paste at the smaller end at the top of the ring by a single sharp-ended trowel and smooth the top. (Take care not to compress the paste). Center the paste under the plunger end which shall be brought in contact with the surface of the paste, and tighten the set-screw.
6	Set the movable indicator to the upper zero mark of the scale or take an initial reading, and release the rod immediately. This must not exceed 30 second after the completion of mixing. The paste shall be of normal consistency when the rod settles to a point 10±1 mm below the original surface in 30 second after being released.
7	Make trial paste with varying percentages of water until the normal. Consistency is obtained. Make each trial with fresh cement.

Test procedures for estimating normal consistency of cement mixtures

The normal consistency of cement is the quantity of water that needs to be added to cement for the Vicat Apparatus plunger to penetrate the cement paste up to a depth of 33 – 35 mm from the top (or 5 – 7 mm from the bottom). The step-by-step procedure for carrying out a standard consistency test of cement using the Vicat Apparatus is as follows [7]; [9]:

Table S5. Procedures used to estimate normal consistency of cement mixtures.

Step	Action
1	Take 400 grams of cement sample, and put it in a mixing tray

2	Start by assuming a consistency of 28%. So, add 28% of water (by the weight of cement) to the cement. That is, add 112 grams of water.
3	Mix the cement and water gently but thoroughly for 3 to 5 min to get a cement paste.
4	Place the mold on a non-porous glass plate. Use the cement paste to fill the mold. Use a trowel to trim off excess cement paste from the mold's surface, making the paste level with the mold's top.
5	Place the glass plate and Vicat mold under the moving rod of the Vicat apparatus. Lower the Vicat apparatus plunger gently until its tip just touches the surface of the cement paste.
6	Quickly release the plunger, allowing it to penetrate the cement paste freely. Use the Vicat apparatus scale to record the plunger's depth of penetration

Table S6. Procedures of flow table test used to measure the workability of cement mortar.

Step	Action
1	The mixed mortar was placed on the flow table in truncated mould in two layers.
2	the flow table was mechanically raised by 10 mm and dropped at a rate of once per second for about 15 second.
3	flow diameter of the mortar flow was measured in orthogonal directions to determine the average flow value for each mortar mix.

Table S7. Definitions of AHP-TOPSIS main categories and sub-categories used to assess the implementation of Shammi corn stalk ash (SCSA) in preparing cementitious mixtures.

Main category	Sub-category	Definition
Physical properties	Strength	The compressive strength is defined as the maximum compressive load divided by the cross-sectional area of the sample.
	Setting time	When the cement paste is set, it becomes a solid and no longer behaves as a liquid that can exert lateral hydrostatic pressure. Therefore, the first time corresponding to the total side pressure becoming null after the initial hydrostatic pressure is proposed as a definition of the setting time of cementitious materials.
	Fineness	The fineness of the cement depends on the surface area that the cement particles occupy. The higher the surface area, the higher the fineness.
	Workability	Workability is an assembly of several properties, such as consistency, plasticity, and cohesion. Given that plasticity and cohesion are difficult to measure, consistency is frequently used as the measure of workability.
Cost	Initial cost	It includes costs of crusher, mill, kiln, and accessory equipment (e.g., dryer, grate cooler, conveyor, and cement silo). Additional infrastructure and equipment prices are used to estimate the cost of building an incinerator for ash production.
	Maintenance cost	It includes transportation of agricultural waste and raw material, energy consumption, chemical utilization, and salary.
Social impact	Health and Safety	In the cement-manufacturing industries, quarrying causes dust emissions and noise. Dust is also released by raw material preparation, clinker burning, and packaging. The raw material collection and transportation procedures are accompanied by releasing various toxic gas emissions, such as CO, CO_2, NO_x, and SO_2. The clinker burning/cooling and cement milling have the potential to cause cancer and lung diseases (e.g., lung function impairment). Because of these adverse impacts, ensuring healthy and safe working conditions for employees is one of the most

		significant issues for the cement industry. SCSA preparation is a promising strategy to reduce emissions of smoke, particulates, breakdown products, dioxins, and associated odour accompanied by crop residue burning.
	Employment Opportunities	The cement industry plays a major role in improving the living standard by creating a lot of employment, and job vacancies. Using agricultural residues to partially replace cement creates job opportunities due to cement capacity expansion, further enhancing the welfare level. Increasing the number and rate of employed labor in the cement industry has a direct correlation with manufacturer profit and investment.
Environmental impact	CO_2 emissions	Cement production is one of the principal anthropogenic sources of CO_2 emissions. The three stages responsible for this air pollution source are raw material quarrying and preparation, clinker calcination, and cement grinding, as previously reported. CO_2 can be released from the decarbonation of $CaCO_3$ and $MgCO_3$ to give CaO and MgO, respectively. SCSA utilization is beneficial to reduce the generation of climate-relevant emissions, mainly emissions of CO_2, accompanied by the incineration of agricultural waste.
	Energy Consumption	Clinker substitution, alternative fuel use, and waste heat recovery are responsible for consuming large amounts of energy in the cement-producing industries. For instance, about 100 kWh of electrical energy is consumed for each ton of cement production. Most of this amount is utilized for the grinding of coal, raw materials, and clinker.

Table S8. A questionnaire sheet used in the multi-criteria decision making (MCDM) model for Shammi corn stalk ash (SCSA) utilization in cement production.

	CEMA0	**9**	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	**CEMA4**
Economic category											
Initial cost											
Maintenance cost											
Social impact											
Health and Safety											
Employment opportunities											
Environmental impact											
CO_2 emissions											
Energy consumption											

Table S9. Saaty's Fundamental Scale used in the multi-criteria decision making (MCDM) model for Shammi corn stalk ash (SCSA) utilization in cement production. The scores were assigned using interconnected decision elements from experimental work, a comprehensive review of previous studies, and comments from experts, professionals, and practitioners.

Score	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another

5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments	When compromise is needed

Table S10. Random consistency index (RI).

Order of matrix (n)	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0.00	0.00	0.58	0.89	1.12	1.24	1.33	1.40	1.45	1.49

In this matrix (Table S11), the number of targets achieved per goal was identified and then divided by the total number of targets for the same goal [10].

Table S11. Scoring on the fulfilment of each goal by its associated indicators (Matrix$_{(8\times10)}$). Correlation between 10 criteria (I1-I10) with 8 SDGs. The indicators are Strength (I1); Setting time (I2); Fineness (I3); Workability (I4); Initial cost (I5); Maintenance cost (I6); Health and safety (I7); Employment opportunities (I8); CO_2 gas emissions (I9); Energy consumption (I10). The goals are Goal 1: No poverty; Goal 2: zero hunger; Goal 3: Good health and well-being; Goal 8: Decent work and economic growth; Goal 9: Industry innovation and infrastructure; Goal 11: Sustainable cities and communities; Goa12: Responsible consumption and production; Goal 13: Climate action.

	I1	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**	**I9**	**I10**
Goal 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.143	0.000	0.000
Goal 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000
Goal 3	0.000	0.000	0.000	0.000	0.000	0.000	0.231	0.000	0.231	0.077
Goal 8	0.000	0.000	0.000	0.000	0.167	0.167	0.083	0.167	0.000	0.000
Goal 9	0.375	0.375	0.375	0.375	0.000	0.000	0.000	0.000	0.000	0.000
Goal 11	0.300	0.300	0.300	0.300	0.000	0.000	0.000	0.000	0.000	0.000
Goa12	0.091	0.091	0.091	0.091	0.273	0.273	0.091	0.273	0.000	0.000
Goal 13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.600	0.000

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