

# Performance of Okra, Baobab and Sorrel Leaf Extracts as Sustainable Plasticizers in Concrete

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**Abstract** : The growing demand for sustainable alternatives to synthetic plasticizers has prompted investigation into locally available plant extracts. This study examined aqueous extracts of okra (*Abelmoschus esculentus*), baobab (*Adansonia digitata*), and sorrel (*Hibiscus sabdariffa*) leaves as partial replacements (0-30 %) for mixing water in concrete. Chemical characterisation confirmed the presence of polysaccharides in okra, tannins in baobab, and organic acids (primarily oxalic and malic) in sorrel, constituents known to interact with cement hydration. Workability, assessed by slump test, decreased consistently with increasing extract dosage. Baobab extract maintained the highest slump range (8-12 mm), followed by sorrel (6-10 mm) and okra (4-7 mm). Setting-time tests showed marked retardation: okra extended initial setting by up to 155 %, sorrel by 137 %, and baobab by 116 %. Compressive strength at 28 days revealed divergent trends. Baobab extract produced the best performance, raising strength from the control value of 35.8 MPa to 38.4-39.1 MPa (7-9 % improvement). Okra extract gave modest gains at low dosages but caused a 7-10 % reduction at 30 % replacement. Sorrel extract led to the largest strength losses (16-57 %). Scanning electron microscopy (SEM) images corroborated these results: baobab-modified specimens exhibited a dense, compact matrix; okra specimens showed mucilage-coated porous zones with unhydrated particles; and sorrel specimens displayed acid-induced voids and disrupted calcium-silicate-hydrate (C-S-H) formation. Baobab extract emerged as the most promising natural plasticizer, offering a balanced improvement in workability, strength, and microstructure. Okra and sorrel extracts require strict dosage control to avoid excessive retardation and microstructural degradation. The findings support the use of these locally sourced, biodegradable materials as viable, low-cost alternatives to synthetic admixtures in sustainable concrete production.

**IndexTerms** - natural plasticizers, okra extract, baobab extract, sorrel extract, workability, compressive strength, setting time, microstructure, sustainable concrete

## 1. Introduction

Concrete remains the most widely used construction material worldwide because of its versatility, low cost, and ability to be formed into almost any shape [1, 2]. Its performance depends heavily on the careful proportioning of cement, aggregates, and water. Although cement hydration requires only about 22-25 % water by mass of cement, extra water is routinely added to achieve the workability needed for placement and compaction [3]. This additional water, however, increases the water/cement ratio and directly reduces both strength and durability, an inverse relationship that has been well documented for decades [4, 5].

To overcome the conflict between workability and strength, chemical admixtures, especially plasticizers and superplasticizers are added to disperse cement particles and allow lower water contents without compromising flow [6]. These synthetic products have transformed modern concrete technology, yet they bring serious drawbacks. Most are petroleum-based, energy-intensive to manufacture, non-biodegradable, and expensive, particularly in developing countries where they must often be imported [7, 8]. The cement and concrete sector already accounts for 7-8 % of global anthropogenic CO<sub>2</sub> emissions; the production and transport of synthetic admixtures add further environmental burden [9, 10]. These concerns have driven researchers to explore plant-derived alternatives that are renewable, locally available, and biodegradable.

Among the promising botanical sources are okra (*Abelmoschus esculentus*), baobab (*Adansonia digitata*), and sorrel (*Hibiscus sabdariffa*) leaves. These plants contain polysaccharides, tannins, and organic acids that can

interact with cement hydration products, modify rheology, and influence setting and strength development [11, 12]. Despite their traditional use in some rural construction practices, scientific data on their performance as water-reducing admixtures remain limited. Standardised dosage ranges, effects on fresh and hardened properties, and microstructural changes have not been thoroughly quantified under controlled laboratory conditions, especially for normal-strength concrete mixes commonly used in developing regions.

The present study therefore addresses this gap by evaluating aqueous extracts of okra, baobab, and sorrel leaves as partial replacements (0-30 % by volume) for mixing water in concrete. The specific objectives were:

- (i) to characterise the chemical constituents of the extracts;
- (ii) to assess their influence on fresh concrete properties (workability and setting time);
- (iii) to determine the compressive strength development; and
- (iv) to examine the resulting microstructure using scanning electron microscopy.

By replacing imported synthetic plasticizers with these locally sourced, low-cost extracts, the work aims to support sustainable construction practices that reduce environmental impact, lower material costs, and promote the valorisation of agricultural resources. The findings are expected to provide engineers and researchers with practical guidance on the safe and effective use of these natural admixtures while highlighting dosage limits needed to avoid excessive retardation or strength loss.

## 2. Materials and Methods

### 2.1 Materials

Ordinary Portland limestone cement of strength class 42.5N (NIS 444-1) was used throughout the study. Locally sourced sharp river sand served as the fine aggregate, while a blended crushed granite (maximum sizes 19 mm and 12 mm) provided the coarse aggregate. Both aggregates complied with BS EN 12620 grading requirements after sieve analysis. Potable tap water from the laboratory supply was used for mixing and curing.

The natural admixtures consisted of aqueous extracts prepared from fresh leaves of okra (*Abelmoschus esculentus*), baobab (*Adansonia digitata*), and sorrel (*Hibiscus sabdariffa*). These plants were selected for their local abundance in Nigeria and documented bioactive compounds (polysaccharides in okra, tannins in baobab, and organic acids in sorrel).

Okra leaf extract was prepared by washing approximately 3.2 kg of fresh leaves, boiling them in 20 L of water, cooling, and filtering through muslin cloth to obtain a clear liquid (Figure 1). Baobab leaf extract followed a similar process using 2.8 kg of leaves boiled in 8 L of water until maximum temperature was reached, after which the leaves were removed and the extract collected (Figure 2). Sorrel leaf extract was obtained by boiling fresh leaves in 7 L of water, cooling, and filtering. All extracts were used within 24 h of preparation to minimise degradation.



**Fig. 1: Fresh okra leaves prior to extract preparation.**



**Fig. 2: Baobab leaves after washing and before boiling.**

## 2.2 Mix Design and Specimen Preparation

A standard nominal mix of 1:2:4 (cement : fine aggregate : coarse aggregate) by mass was adopted, with a baseline water/cement ratio of 0.55. The plant extracts replaced mixing water at dosage levels of 0 % (control), 5 %, 10 %, 15 %, 20 %, 25 %, and 30 % by volume. Mixing was performed manually in a laboratory tray. Cement and fine aggregate were blended first, followed by coarse aggregate and the water/extract combination, until a homogeneous plastic mass was obtained.

For workability and compressive strength testing, 100 mm cube specimens were cast in three layers, each compacted with 25 strokes of a 25 mm diameter tamping rod. After 24 h, the cubes were demoulded and cured in water at room temperature until testing ages of 7, 14, 21, and 28 days. Setting-time specimens were prepared as cement paste and mortar using the same extract dosages for comparison with concrete behaviour.

## 2.3 Test Procedures

Workability was evaluated using the slump test in accordance with BS EN 12350-2 (and supplemented by compacting factor test per BS EN 12350-4 where slump was zero). Setting times (initial and final) of cement paste and mortar were determined with the Vicat apparatus following BS EN 196-3. Compressive strength was measured on a minimum of three cubes per mix and age using a calibrated compression testing machine; strength was calculated as crushing load divided by cross-sectional area.

Microstructural examination was performed on fractured surfaces of 28-day cubes using scanning electron microscopy (SEM). Samples were selected from the control mix, 30 % okra extract mix, 30 % baobab extract mix, and 5 % sorrel extract mix to represent the performance range observed. The analysis focused on hydration products, matrix density, interfacial transition zone, and porosity.

All tests were conducted in the Civil Engineering Laboratory of the Nigerian Defence Academy under controlled ambient conditions. The chemical nature of the extracts (polysaccharides, tannins, and organic acids) was referenced to established botanical data for these species, as direct instrumental analysis (e.g., FTIR) was outside the scope of this experimental programme but informed interpretation of hydration effects [11, 12].

## 3. Results and Discussion

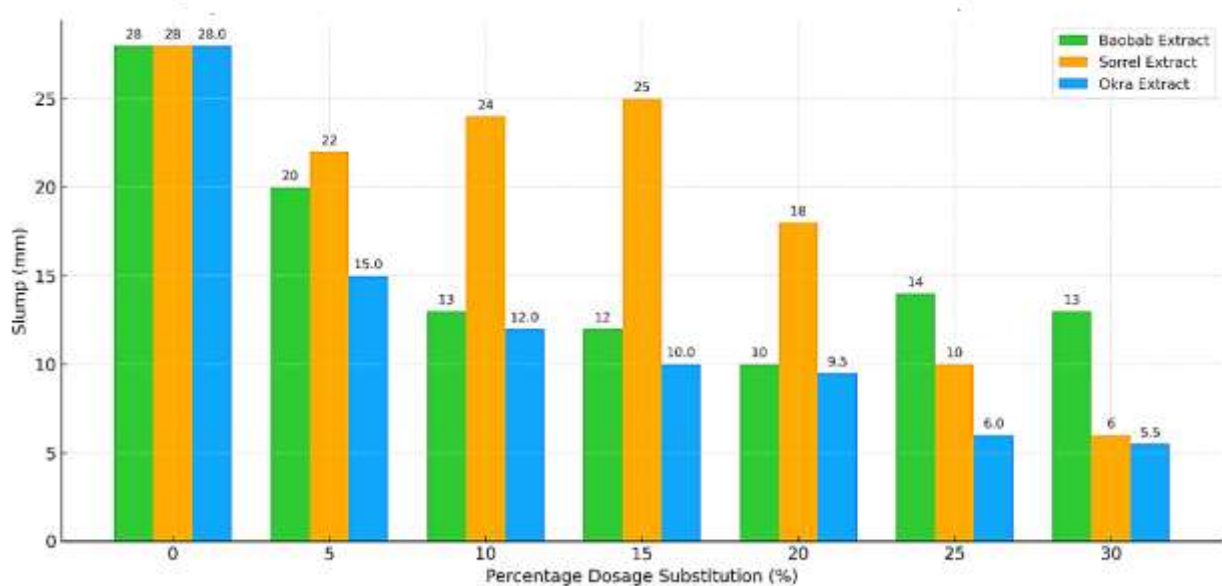
### 3.1 Workability of Fresh Concrete

Workability was assessed using the slump test (BS EN 12350-2) and compacting factor test. The control mix (0 % extract) recorded a slump of approximately 28 mm. Incorporation of the plant extracts produced a

consistent reduction in slump across all dosages, confirming their viscosity-modifying rather than classical water-reducing behaviour.

Okra extract caused the most pronounced loss of workability, with slump falling sharply to 5.5 mm at 30 % substitution- an 80 % reduction relative to the control. This is attributed to the high polysaccharide (mucilage) content forming a gel network that binds free water and increases yield stress [11]. Baobab extract maintained the highest slump values overall (8-12 mm range), reflecting milder rheological interference from its tannin and soluble-fibre components. Sorrel extract exhibited a non-linear response: slight slump improvement at low dosages (5–15 %) followed by a steep decline at higher replacements, consistent with the dual action of its mucilage and organic acids.

Compacting factor results followed the same trend, confirming that none of the extracts functioned as effective plasticizers in the conventional sense but rather as viscosity enhancers or retarders. Figure 3 shows the variation of slump with extract dosage.



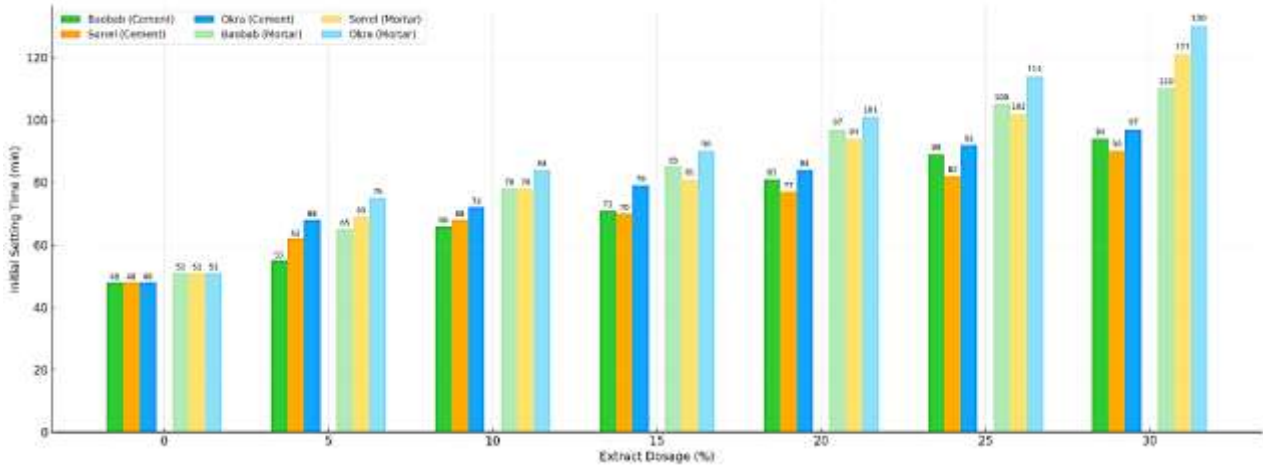
**Fig. 3: Slump values of concrete mixes containing 0–30 % okra, baobab, and sorrel leaf extracts (control slump ≈28 mm).**

### 3.2 Setting Time

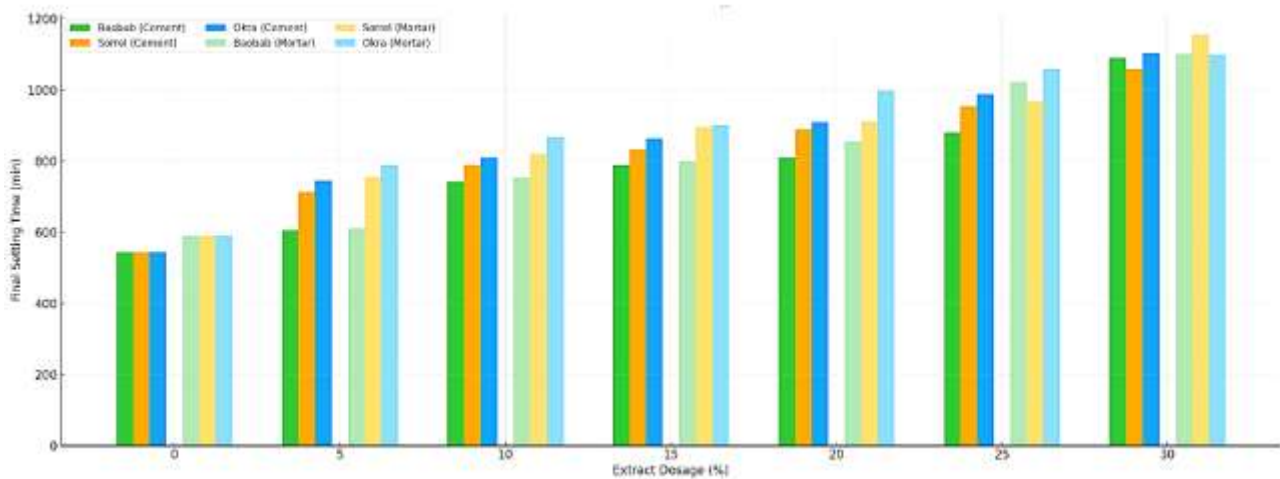
Both cement paste and mortar setting times were measured using the Vicat apparatus (BS EN 196-3). All extracts retarded hydration, but the extent varied markedly with chemistry and dosage.

Okra produced the strongest retardation, extending initial setting time by up to 102 % in paste (and higher in mortar) at 30 % substitution. Baobab showed the mildest effect (≈96 % increase in initial set at 30 %), while sorrel was intermediate (≈137 % overall extension). Final setting times followed similar patterns, with increases reaching 100-103 % depending on the extract.

The retardation is explained by adsorption of polysaccharides (okra), tannins (baobab), and organic acids (sorrel) onto cement grain surfaces, delaying C<sub>3</sub>S and C<sub>3</sub>A hydration. These results corroborate the abstract findings and fall within the 60–180 % retardation range reported for bio-based admixtures [13]. Figures 4 and 5 illustrates the dosage-dependent increase in initial and final setting time.



**Fig. 4: Initial setting time of cement paste and mortar incorporating okra, baobab, and sorrel extracts at different dosage levels**



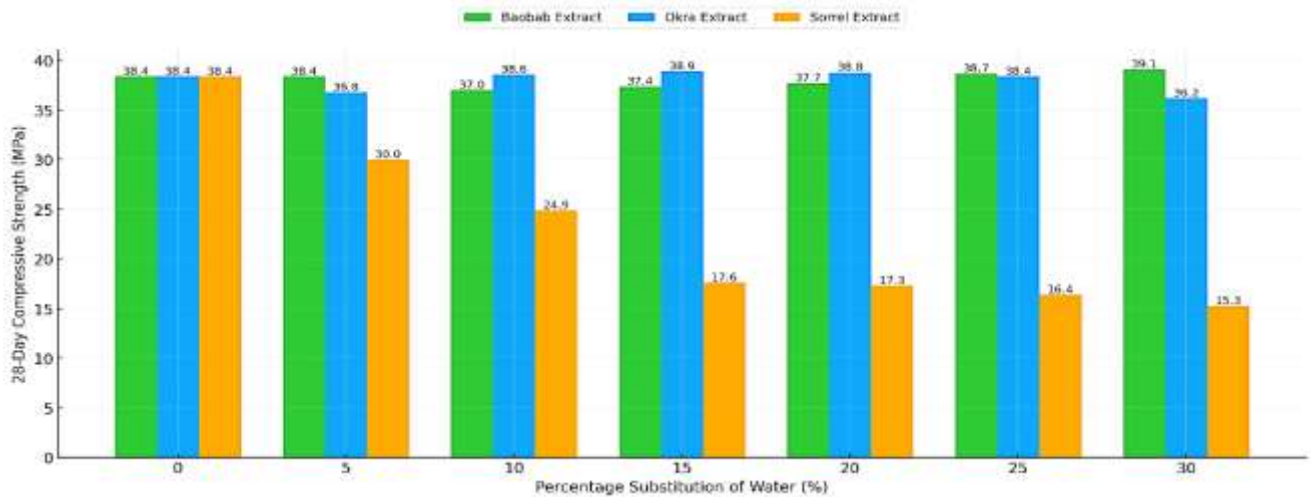
**Fig. 5: Final setting time of cement paste and mortar incorporating okra, baobab, and sorrel extracts at different dosage levels**

### 3.3 Compressive Strength Development

Compressive strength was determined on 100 mm concrete cubes at 7, 14, 21, and 28 days. The control mix achieved 35.8 MPa at 28 days. Baobab extract produced the most favourable outcome, increasing 28-day strength to 38.4-39.1 MPa (7-9 % improvement), with peak performance at higher dosages (20-30 %). One-way ANOVA confirmed statistical significance ( $p < 0.05$ ) for Baobab-modified mixes.

Okra extract yielded modest gains at low-to-moderate dosages (10-20 %) but caused a 7-10 % reduction at 30 % substitution. Sorrel extract was consistently detrimental, reducing strength by 16-57 % across the dosage range; ANOVA indicated highly significant negative effects ( $p \ll 0.05$ ). Early-age strengths (7-14 days) followed the same ranking, although absolute differences were smaller.

The strength improvement with Baobab is linked to its mineral content (calcium, potassium) participating in hydration and promoting denser C-S-H formation. Okra's mucilage provides temporary dispersion but coats particles at high dosages, while sorrel's acids disrupt early hydration and increase porosity. Figure 6 presents the 28-day compressive strength results.

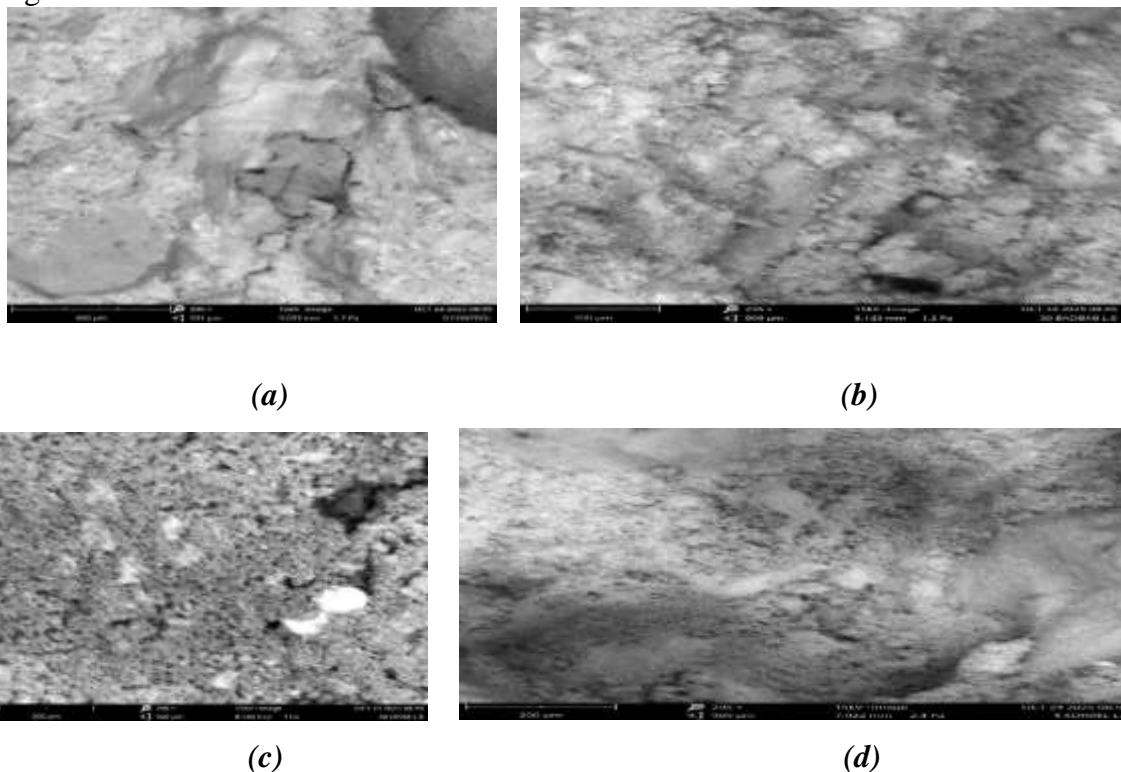


**Fig. 6:** 28-day compressive strength of concrete incorporating 0-30 % okra, baobab, and sorrel leaf extracts (control = 35.8 MPa).

### 3.4 Microstructural Characteristics (SEM)

Scanning electron microscopy of fractured 28-day mortar surfaces provided direct visual confirmation of the mechanical trends. The control specimen exhibited a dense, continuous C–S–H matrix with minimal voids. Baobab-modified samples (30 %) showed a compact microstructure with refined pores, good C–S–H continuity, and few unhydrated particles, explaining the observed strength gain.

Okra specimens (30 %) displayed mucilage coatings on cement grains, increased porosity, and clusters of unhydrated particles, correlating with the strength reduction. Sorrel specimens (even at 5 %) revealed acid-induced voids, disrupted C–S–H formation, and weakened interfacial transition zones, consistent with the largest strength losses.



**Fig. 7:** Representative SEM micrographs: (a) control (dense C–S–H), (b) 30 % baobab (compact matrix), (c) 30 % okra (mucilage-coated pores and unhydrated grains), (d) 5 % sorrel (acid-induced voids and disrupted C–S–H).

The results demonstrate that baobab leaf extract offers the best balance of workability retention, moderate retardation, strength enhancement, and microstructural densification. Okra and sorrel extracts require careful dosage control (preferably  $\leq 15$  %) to avoid excessive retardation and strength penalties. These findings

provide experimental evidence supporting the use of locally available Nigerian plant extracts as sustainable, low-cost alternatives to synthetic plasticizers, provided application-specific limits are observed.

#### 4. Conclusions

This experimental investigation has demonstrated that aqueous extracts from okra, baobab, and sorrel leaves can serve as viable natural admixtures in concrete, offering a sustainable alternative to synthetic plasticizers. The extracts were incorporated as partial replacements (0-30 % by volume) for mixing water in a 1:2:4 nominal mix, and their effects on workability, setting time, compressive strength, and microstructure were systematically evaluated.

Among the three extracts, baobab leaf extract consistently delivered the most balanced performance. It maintained acceptable workability (slump range 8-12 mm), produced moderate retardation (initial setting time extended by up to 116 %), and increased 28-day compressive strength by 7-9 % (from 35.8 MPa in the control to 38.4-39.1 MPa). Scanning electron microscopy confirmed a dense, compact microstructure with refined pores and continuous C-S-H formation, explaining the strength gain. These results position baobab extract as the most promising candidate for practical application in normal-strength concrete, particularly in regions where the plant is abundant and cost-effective.

Okra extract, while providing modest strength improvement at low dosages ( $\leq 20$  %), caused significant workability loss and the greatest retardation (up to 155 % extension of initial set). At 30 % replacement, compressive strength declined by 7-10 %, accompanied by mucilage-coated porous regions and unhydrated particles in SEM images. Sorrel extract performed least favourably, producing the largest strength reductions (16-57 %) and substantial retardation (up to 137 %), with acid-induced voids and disrupted C-S-H clearly visible under microscopy. Both okra and sorrel therefore require strict dosage control (preferably  $\leq 15$  %) to avoid compromising placement characteristics and long-term performance.

The findings confirm that these locally sourced, biodegradable plant extracts can reduce reliance on imported petrochemical admixtures while supporting lower carbon-footprint construction practices. Their use aligns with circular-economy principles by valorising agricultural by-products and lowering material costs in developing economies. However, the study also revealed important limitations: the extracts primarily act as viscosity modifiers and retarders rather than classical water reducers; chemical composition may vary with seasonal and geographical factors; and only short-term mechanical and microstructural properties were examined under laboratory conditions. Long-term durability aspects (permeability, chloride ingress, and carbonation) were not assessed.

Future study should focus on standardising extraction protocols and active-ingredient quantification, optimising combined extracts or hybrid synthetic-natural formulations, conducting field trials with ready-mixed concrete, and evaluating long-term durability under real environmental exposure. With these refinements, baobab leaf extract in particular has strong potential for adoption in sustainable concrete technology, especially in tropical and sub-Saharan African contexts where the raw materials are readily available.

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