JENER Journal of Empirical and Non-Empirical Research
Volume 2, Issue 3, Page 101-106 | Article No. 13
DOI: 10.4898/jener.v2i3.a13
ISSN: 7895-9216
Journal homepage: https://jenerjournal.com
Journal email: editor@jenerjournal.com

JENER Journal
JENER Journal of Empirical and Non-Empirical Research

The Use of Plant Extracts as Alternative Binders in Laterite Buildings

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ARTICLE INFORMATION

Article history:
Published: March 2026

Keywords:
Laterite
Plant Extract
Binders
Buildings

ABSTRACT

The researchers studied Locust Bean Pod Extract and Coconut Husk Extract as environmentally friendly yet inexpensive binding materials which they tested to determine their ability to strengthen laterite soil found in Barkin Ladi Plateau State Nigeria. The construction industry needs to find eco-friendly solutions which use local materials because Ordinary Portland Cement (OPC) has high costs and produces major carbon emissions. Scientists treated Clayey Laterite soil samples with various LBPE and CHE concentrations at 2% to 8% while using 5% cement as their control. The research results show that both plant extracts improve the geotechnical properties of the soil. The Maximum Dry Density (MDD) increased to 1.78 (Mg/m)3 and Unconfined Compressive Strength (UCS) reached 520 (kN/m)2 after 8% LBPE treatment. The California Bearing Ratio (CBR) showed a twofold increase when compared to untreated soil while erosion resistance displayed a more than 60% improvement. The 8% LBPE treatment achieved nearly acceptable structural strength limits for affordable housing construction even though cement produced the strongest overall performance. The study demonstrates that plant extracts serve as sustainable alternatives to conventional stabilizers because they contain agricultural waste materials that help reduce environmental impacts of construction work in rural tropical areas.

1. Introduction

Construction remains one of the largest consumers of natural resources worldwide, with conventional binders such as Ordinary Portland Cement (OPC) dominating building practice. Although OPC provides structural strength and durability, its production contributes significantly to global carbon dioxide (CO_2) emissions and energy use (United Nations Environment Programme, 2021). In many developing countries, especially across tropical regions, building materials are often derived from locally available soils such as laterite, a naturally occurring soil rich in iron and aluminium oxides formed under hot and wet climatic conditions (Banne et al., 2024).

Lateritic soils are widely used for low-cost housing and rural structures because they are abundant, inexpensive, and have acceptable engineering properties when suitably stabilized.

Traditionally, laterite stabilization involves binders like cement or lime to improve strength, shrinkage resistance, and water durability. However, the high cost and significant environmental impact of cement drive interest in sustainable and cost-effective alternatives. Consequently, the use of plant-based binders—such as extracts from agricultural residues and natural fibres—has gained research attention as environmentally friendly, locally accessible stabilizers.

Among such alternatives, locust bean pod extract (LBPE)—derived from the pods of Parkia biglobosa—has been used historically in parts of West Africa to strengthen earthen materials and mortar. Traditional use includes reinforcing sun-dried bricks and protecting walls against rainfall erosion, representing indigenous knowledge of soil binding (Ibrahim, 2021). Recent geotechnical studies also show that LBPE can improve compaction properties and mechanical performance when incorporated into soil stabilisation applications (Sunyani Technical University Research, 2024). Concurrently, coconut husk ash (CHA)—a by-product from coconut processing—contains silica, potassium oxides, and other oxides with potential pozzolanic activity, which can contribute to increased dry density and California Bearing Ratio (CBR) of lateritic soils (Oluremi et al., 2014). While many stabilization studies focus on ash or fibre phases, there is limited research specifically addressing coconut husk extracts or husk-derived binders as alternatives in laterite building contexts.

Given these potentials, plant extracts and agro-waste derivatives present sustainable, low-cost, and locally obtainable alternatives to conventional stabilisers. Investigating their application in laterite building materials has the potential to promote environmental sustainability, reduce construction costs, and enhance the utilisation of agricultural by-products in rural communities, such as those in Barkin Ladi Local Government Area of Plateau State, Nigeria.

1.2 Statement of the Problem

In Barkin Ladi Local Government Area and similar rural regions, the high cost and limited availability of conventional stabilisers such as cement constrain affordable building material production. Cement production also poses notable environmental concerns due to high energy demand and CO_2 emissions. Indigenous building practices often rely on locally available materials without formal scientific validation, which limits adoption of traditional stabilisers by modern practitioners.

Although plant extracts such as locust bean pod extract are used informally for binding soil in some construction contexts, research on their efficacy and mechanisms as engineered stabilizers is sparse. Likewise, while coconut husk ash has been studied as an additive, evidence remains limited on coconut husk extracts and their potential as binders in lateritic soils. This research addresses this gap by systematically evaluating the use of locust bean pod extract and coconut husk extract as alternative stabilising agents for laterite building materials in the study area.

1.3 Research Objectives

1.3.1 General Objective

To assess the potential of locust bean pod extract (LBPE) and coconut husk extract (CHE) as alternative binders to conventional stabilisers in laterite building materials in Barkin Ladi Local Government Area, Plateau State, Nigeria.

1.3.2 Specific Objectives

The specific objectives of the study are to:

- Determine the effects of locust bean pod extract on the mechanical and durability properties of laterite building materials.
- Evaluate the influence of coconut husk extract on the engineering performance of laterite stabilization.
- Compare the performance of laterite materials treated with LBPE and CHE against those treated with conventional binders such as cement.
- Identify optimal concentrations and practical application methods for using plant extract binders in building material production.

1.4 Significance of the Study

This research contributes to sustainable construction practice by validating low-cost and eco-friendly materials suitable for rural housing and infrastructure. Findings will inform artisans, local builders, and policymakers on the viability of integrating plant extracts as stabilisers in lateritic building materials. The documented evidence could reduce dependence on energy-intensive binders, promote the use of agricultural by-products, and support broader sustainability goals in rural construction. The outcomes may also stimulate further research into other biobased stabilisers across tropical regions.

1.5 Scope of the Study

The study focuses on laboratory evaluation of lateritic soil samples from Barkin Ladi Local Government Area stabilized with locust bean pod extract and coconut husk extract. Performance indicators such as compressive strength, compaction behaviour, and durability metrics will be assessed and compared to conventional stabilizers. The scope does not include full-scale field testing or long-term weathering evaluation of constructed walls.

1.6 Definition of Key Terms

Laterite: A soil rich in iron and aluminium formed in hot, humid tropical regions, widely used in earth-based construction.

Binder: A substance that improves cohesion and mechanical properties in a composite material.

Plant Extract: A solution derived from plant material containing bioactive compounds that can bind or influence material properties.

Locust Bean Pod Extract (LBPE): A solution obtained from Parkia biglobosa pods, traditionally used in local building practices.

Coconut Husk Extract (CHE): A liquid or concentration derived from coconut husk material, evaluated here for its potential binding activity.

2. Review of Literature

2.1 Laterite Soil in Construction

Laterite soil is widely used in traditional and modern earth construction due to its high iron content, plasticity, and availability in tropical regions (Banne et al., 2024). Laterite's engineering suitability depends on its particle size distribution, moisture content, and stabilization method (Adesanya et al., 2021). Strength and durability of lateritic building materials are drastically improved when chemically or biologically stabilized due to reduced swelling/shrinkage and enhanced cohesion (Olorunnisola et al., 2021).

2.2 Conventional Stabilization Techniques

Traditional stabilizers include ordinary Portland cement (OPC), lime, fly ash, and bituminous materials. OPC is the most common, providing high compressive strength and durability. However, cement production is energy-intensive and contributes up to 7% of global CO_2 emissions — an environmental concern in sustainable construction (UNEP, 2021). In addition, the high cost and limited availability of cement in rural areas constrain its widespread use in local building industries (Okunlola et al., 2021).

2.3 Plant Extracts and Biopolymers as Sustainable Binders

2.3.1 Overview of Biopolymer Soil Stabilizers

Biopolymers and plant derived extracts have emerged as sustainable soil stabilizers. They are biodegradable, locally available, and reduce dependence on industrial chemical binders (Ghosh, 2021). Common biopolymers include guar gum, xanthan gum, and aloe vera extract, which have been shown to improve strength and reduce permeability in various soils (Banne et al., 2024).

2.3.2 Locust Bean Pod Extract as Soil Stabilizer

Locust bean (Parkia biglobosa) pods are rich in polysaccharides and natural gums which have adhesive properties. Traditional building practices in some parts of West Africa include the use of locust bean pods to enhance cohesion of earth wall materials (Ibrahim, 2021). While limited, experimental work has shown that locust bean pod extract can improve compaction characteristics and California Bearing Ratio (CBR) in lateritic soils, indicating an increase in load-bearing performance (Sunyani Technical University Research, 2024).

2.3.3 Coconut Husk Extract and Derivatives

Coconut husk, a common agro-waste in coastal and sub-tropical regions, contains significant organic compounds and silica content. Most research has focused on coconut husk ash (CHA) for soil stabilization due to its pozzolanic characteristics when combined with lime or cement (Oluremi et al., 2014). CHA has been shown to increase dry density, reduce plasticity index, and enhance CBR — all desirable for lateritic building materials. However, comparatively fewer studies examine the direct application of coconut husk extract as a binder, representing a gap this study addresses.

2.4 Comparison Between Plant Extracts and Conventional Binders

Research comparing biobased stabilizers to conventional ones shows that plant extracts can achieve comparable strength gains under optimized conditions, especially in light structural applications (Ghosh, 2021). Biopolymers often improve cohesion and reduce permeability, enhancing durability against weathering (Olorunnisola et al., 2021). However, performance depends heavily on the extract type, concentration, and soil mineralogy.

2.5 Theoretical and Conceptual Perspectives

This study draws on eco-sustainability theory and appropriate technology frameworks, emphasizing the use of locally available materials that reduce environmental impact while meeting engineering requirements. Integrating indigenous knowledge about plant material use with modern geotechnical evaluation supports sustainable innovation in rural construction.

2.6 Research Gaps

Current literature highlights several research gaps:

Limited empirical evidence on coconut husk extract as a soil binder.

Sparse comparative analyses between plant extract binders and conventional cement stabilizers.

Few region-specific studies addressing rural construction challenges in African contexts such as Barkin Ladi Local Government Area.

3. Methods

3.1 Research Design

The study employed an experimental laboratory design, where lateritic soil samples were stabilized with locust bean pod extract (LBPE), coconut husk extract (CHE), and a control stabilizer (cement). This allows controlled evaluation of engineering performance changes.

3.2 Study Area

The research was conducted in Barkin Ladi Local Government Area, Plateau State, Nigeria. Barkin Ladi lies within the tropical savannah climate, with distinct wet and dry seasons, and abundant lateritic soil formations typical of central Nigeria's geology. Primary materials were sourced from designated soil deposit sites mapped with GPS coordinates during fieldwork.

3.3 Population and Sampling

3.3.1 Soil Sample Collection

A total of 15 laterite soil samples were collected from five different locations within Barkin Ladi using a stratified random sampling approach. Each sampling point provided approximately 20 kg of lateritic soil from a depth of 0.5–1.0 m to ensure uniformity.

3.3.2 Plant Extract Preparation

Locust Bean Pod Extract (LBPE): Mature Parkia biglobosa pods were collected, sun-dried, milled, and processed to obtain aqueous extracts using standardized solvent extraction techniques (Ibrahim, 2021).

Coconut Husk Extract (CHE): Coconut husks were collected, oven-dried, grated, and processed using hot water extraction and filtration to obtain the extract concentrate.

3.4 Experimental Procedures

3.4.1 Soil Characterization

Standard geotechnical tests conducted on raw laterite soil included:

Particle size distribution (sieve analysis)

Atterberg limits (liquid and plastic limits)

Natural moisture content

Specific gravity

Tests were conducted in accordance with ASTM standards (ASTM D4318, ASTM D698).

3.4.2 Stabilization and Mix Design
Soil was stabilized with:
Locust Bean Pod Extract (LBPE): 2%, 4%, 6%, 8% by weight
Coconut Husk Extract (CHE): 2%, 4%, 6%, 8% by weight
Control: Conventional cement at 5% and 10% by weight
Each mix was compacted at optimum moisture content and cured for 7, 14, and 28 days.

3.4.3 Strength and Durability Tests
The cured soil specimens were tested for:
Unconfined Compressive Strength (UCS): Determines peak strength (ASTM D2166).
California Bearing Ratio (CBR): Evaluates load-bearing capacity.
Water Absorption and Durability: Assessed through wetting-drying cycles.

3.5 Data Analysis
Data were statistically analysed using Analysis of Variance (ANOVA) to determine significant differences between means of treated and control groups. Trends in strength gain and durability were analyzed graphically using SPSS (Version 26).

3.6 Ethical Considerations
Ethical protocols were observed in field sample collection, local community engagement, and reporting. No human subjects were involved; therefore, informed consent was limited to verbal permission for soil collection on private lands.

3.7 Limitations of the Study
Laboratory conditions may differ from field environments. Long-term performance under climatic exposure was not evaluated.

4. Results and Discussion
The laterite samples were collected from Barkin Ladi Local Government Area, Plateau State, Nigeria, characterized by tropical savannah climatic conditions and iron-rich soil deposits.

Table 4.1: Physical Properties of Natural Lateritic Soil

Property	Value Obtained	Standard Requirement (Building Laterite)
Natural Moisture Content	12.80%	—
Specific Gravity	2.62	2.60–2.75
Liquid Limit (LL)	42%	< 50%
Plastic Limit (PL)	24%	—
Plasticity Index (PI)	18%	< 20%
Soil Classification	CL (Clayey laterite)	Suitable with stabilization

The Plasticity Index (18%) indicates moderate plasticity, suggesting suitability for stabilization. Similar values were reported in lateritic soils used for compressed earth blocks (Olorunnisola et al., 2021).

Table 4.2: Compaction Results

Binder Type	% Binder	OMC (%)	MDD (Mg/m³)
Natural Soil	0%	14.2	1.68
LBPE	4%	15.1	1.74
LBPE	8%	16.3	1.78
CHE	4%	14.8	1.72
CHE	8%	15.6	1.76
Cement	5%	13.5	1.82

Both LBPE and CHE increased Maximum Dry Density (MDD), indicating improved particle bonding. Cement showed slightly higher densification, but plant extracts demonstrated comparable enhancement. Biopolymer-based soil stabilization similarly increased density in studies by Ghosh (2021).

Table 4.3: UCS Results (28 Days Curing)

Binder	% Binder	UCS (kN/m²)
Natural Soil	0%	210
LBPE	4%	390
LBPE	8%	520
CHE	4%	360
CHE	8%	480
Cement	5%	650

LBPE at 8% achieved 520 kN/m², representing a 148% increase over untreated soil. CHE at 8% achieved 480 kN/m². Although cement produced the highest strength, LBPE performance approached acceptable structural thresholds for low-cost housing. These findings align with reports of improved cohesion using plant-based stabilizers (Ibrahim, 2021).

4.5 California Bearing Ratio (CBR)

Table 4.4: CBR Results

Binder	% Binder	CBR (%)
Natural Soil	0%	12
LBPE	8%	26
CHE	8%	24
Cement	5%	35

LBPE doubled the load-bearing capacity compared to untreated soil. The results confirm improved inter-particle bonding and resistance to deformation.

4.6 Durability Test (Wetting-Drying Cycles)
After 5 wet-dry cycles:
Natural soil showed 32% mass loss.
LBPE (8%) showed 12% mass loss.
CHE (8%) showed 15% mass loss.
Cement (5%) showed 8% mass loss.
Plant extracts significantly improved erosion resistance, though cement remained superior.

4.7 Discussion of Results
The engineering characteristics of natural lateritic soil are fully demonstrated through the experimental results which appear in Tables 4.1 through 4.4 together with the results from three different stabilizing materials which include Locust Bean Pod Extract (LBPE) and Cactus Height Extract (CHE) and Cement.
The natural lateritic soil (Table 4.1) exhibits a Specific Gravity of 2.62, falling within the standard range of 2.60–2.75 for building laterite. The soil meets the classification requirements for Clayey Laterite (CL) because it has a Liquid Limit of 42% and a Plasticity Index (PI) of 18%. These values indicate moderate plasticity and suggest that while the soil is relatively stable, it requires modification to meet more stringent structural requirements. The PI specifically remains below the 20% threshold which is often cited for compressed earth blocks and this finding matches the results of Olorunnisola et al. (2021).
The compaction results (Table 4.2) demonstrate a clear trend: the addition of bio-binders (LBPE and CHE) increases both the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD). The MDD of the natural soil increased to 1.78 Mg/m3 after adding 8% LBPE. The density increase indicates that plant extracts function as lubricants during compaction and they also act as adhesives which enhance particle bonding. The MDD of 5% Cement produced the highest result at 1.82 Mg/m3, but 8% LBPE performed at 1.78 Mg/m3 which shows that plant-based stabilizers provide similar densification results according to Ghosh (2021) biopolymer research.
The Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests results shown in Tables 4.3 and 4.4 demonstrate how effective bio-binders work. The natural soil UCS value of 210 kN/m2 reached 520 kN/m2 after researchers added 8% LBPE to the soil. The soil reached 148% of its original state because of this change which brought it closer to structural thresholds needed for low-cost housing construction. The CBR values which serve as a main measure for subgrade strength showed improvement from 12% to 26% for LBPE and 24% for CHE.
The 8% LBPE concentration which shows strong potential to function as a sustainable low-cost binder solution demonstrates its ability to deliver sufficient strength and cohesion required for community-based construction work.

5. Conclusion and Recommendations
5.1 Conclusion
This study assessed the potential of Locust Bean Pod Extract (LBPE) and Coconut Husk Extract (CHE) as alternative binders in laterite building materials in Barkin Ladi LGA.
Both LBPE and CHE improved mechanical and durability properties of lateritic soil.
LBPE at 8% concentration produced the best performance among plant extracts.
Strength gains were substantial, though slightly lower than cement stabilization.
Plant extracts significantly reduced erosion and improved cohesion.
Therefore, LBPE and CHE are viable eco-friendly alternatives for low-cost laterite construction in rural Plateau State.

5.2 Recommendations
LBPE at 6–8% is recommended for compressed earth block production.
Further long-term weathering studies are recommended.
Field-scale pilot housing projects should be conducted.
Government and NGOs should promote agro-waste utilization in rural construction.
Future studies should investigate hybrid stabilization (plant extract + small % cement).

Acknowledgements
The authors acknowledges The Tertiary Education Trust Funds (TETFund) for sponsoring the research.

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