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Improving strength and hydraulic characteristics of regional clayey soils using biopolymers

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ABSTRACT

This paper portrays a unique demonstration of sustainable low-cost ground improvement for regional soil deposits, by comparing locally sourced biopolymer soil stabilisation soil with imported biopolymer stabilisation. The conventional materials often utilized for soil and ground improvement come with major challenges of large carbon footprints and some negative environmental impacts. As a result, suitable eco-friendly and sustainable materials are necessary. In this study, the potential use of Rice Husk Powder (RHP), Cassava Peel Powder (CPP) and Carboxymethyl Cellulose (CMC), as biopolymer-based materials to improve the engineering properties of a regional clay was investigated using a gamut of geotechnical compaction, strength and hydraulic conductivity tests according to BS 1377, 1990. The results revealed that locally sourced CPP performed better than both imported CMC and local RHP in improving the engineering properties of the regional clay. The shear strength value of the natural clayey soil (43.5 kPa) increased twenty and ten times respectively when treated with CPP (893 kPa) and CMC (450 kPa). One percent content of CPP and CMC performed optimally among the (0.5, 1.0, 1.5, 2 and 2.5) percent studied in improving the engineering properties of the case study regional clay.

1. Introduction

The increasing preference for eco-friendly and sustainable materials and procedures utilized in soil/ground improvement for engineering applications has revealed the need to explore appropriate regional and local materials and specifications for tropical developing countries. Previously, the demand for greater performance in all fields of engineering took precedence above environmental concerns, particularly environmental sustainability. Soil stabilization as one of the ground/soil improvement techniques refers to a variety of methods (mechanical and chemical) for modifying soil parameters in order to improve its engineering properties and performance [1-3]. The employment of chemical methods to improve the engineering properties of soil for geotechnical applications is inevitable since it is not feasible to confine soil improvement to mechanical methods alone [4]. Chemical treatment involves chemical

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reactions such as hydration or pozzolanic reactions inside the soil to create artificial binding [5]. While considering the negative environmental impacts of materials that are generally used for chemical stabilization, Ordinary Portland Cement (OPC) tops the list. The widespread use of OPC in various engineering soil/ground improvement applications, such as concrete structures and highway pavements is associated with its high strength, durability, workability and relatively low cost [6]. However, there are a number of environmental concerns attached. The most significant of these are carbon dioxide (CO_2) and nitrogen oxide (NO_X) gases emissions and particulate air suspension [7,8]. Others include an increase in soil pH, an increase in the effect of desertification, groundwater/soil contamination, increased runoff etc. [9,4,10]. As a result of these shortcomings, there is a need for eco-friendly and sustainable alternative materials.

Recently, a novel biogrouting technique has shown promise in soil cementation via microbially induced carbonate precipitation (MICP). This approach mimics natural processes by depositing calcite ($CaCO_3$) on the soil grains, thereby increasing the material's stiffness/strength and reducing its erodibility [11,12]. Another recent emergence in the field of geotechnical engineering is the use of alternative eco-friendly materials as a replacement for OPC-soil treatment [13]. These include geosynthetics (e.g., geogrids, geotextiles, geonets, geomembranes, geosynthetic clay liners etc.), chemical polymers, geopolymer and bio-mineralization. The demand for eco-environmental geosynthetics means that there is a growing need to expand biodegradable geosynthetics to civil/environmental fields [14]. Before the development of green geosynthetic technology in developing countries, innovative binders such as biopolymers would be the eco-friendly/sustainable alternative to conventional binders like cement and lime for geotechnical and structural purposes [15], such as microbial-derived biopolymers [16]. Also, chemically synthesized polymers such as anionic polyacrylamide which are majorly incorporated into the soil to mitigate soil erosion are associated with toxicity and water pollution problems [17]. Limitations to broad utilisation of geopolymer for soil stabilisation are related to the cost limitations, caused by the need for high activator contents to allow for curing at ambient temperature. It is also due to the uncertainty of treating all soil types, and the absence of practical design procedures compared to those existing for traditional binders [18].

Biopolymers are polymeric compounds produced by a living organism. Biopolymers are known to be environmentally friendly with a wide range of applications: in agriculture, biomedical engineering, food processing, chemical industry as well as in environmental protection and remediation [4]. Depending on their functional groups, biopolymers can bind metals [19], soil particles, bind and isolate soils' organic contaminants [20], and form interpenetrating cross-linking networks with other polymers [21]. The three main types of biopolymers are polypeptides, polynucleotides, and polysaccharides, with polysaccharides being the most commonly used [22]. Polysaccharides group biopolymers such as starch can be found in a variety of plants, including cassava, maize, rice, and wheat, and have a wide range of applications outside of food and agriculture [23] while other Polysaccharides such as xanthan gum, guar gum, gellan gum etc. are of microbial origin produced industrially [10]. While it has been proven [2,20] that mixing biopolymer with soil increases soil strength, resistance to erosion, and reduces hydraulic conductivity by acting as a binder, its application in geotechnical and geoenvironmental engineering is relatively unexplored when compared to other areas [9,24].

[25], reported improvement in the performance of sand treated with agar and modified starch. The performance was found to be directly dependent on the concentration of agar as the main component and starch as the additive. Experimental results demonstrated the compatibility of microbiological-grade agar and commercial modified starches and improvement in the strength characteristics of sand without causing environmental toxicity, using this biopolymer combination. Biopolymers (diutan gum, xanthan gum, CMC and guar gum) have also been found to effectively stabilize particulate grout suspensions at very low dosages (0.25–1.0%) [26]. A study on the undrained shear strength (Su) of various size/shape sands treated with xanthan gum (XG) biopolymer by employing an extensive series of laboratory fall-cone penetration tests, revealed that XG biopolymer addition was concluded to have a greater efficacy on finer and more angular grains than coarser and more rounded grains [27].

When XG biopolymer was used to stabilize the low-plasticity clay, it was observed that low percentages of about 1–3% of the xanthan gum can be adopted to improve the properties of such clays [28]. The strength of the clay amended with xanthan gum biopolymer changed significantly both with xanthan gum content and the curing time. [29], carried out an experimental study on the strength and deformation characteristics of two different biopolymers (xanthum gum and guar gum) treated kaolin clay. The specimens were cured for 1 d, 7 d, 28 d, 90 d and some of the specimens were kept in the curing room for 3 years to observe the long-term performance of the biopolymer treated soil. The results revealed that the strength of the 3-year cured specimens was 2 or 3 times greater than that of 90-day cured specimens and greater strength values were obtained for specimens containing 2% xanthan gum.

The above-mentioned biopolymer applications in the geotechnical engineering field are mostly explored using industrially produced biopolymers that are of microbial origin. For example, the major area of starch application has been adhesives for drilling [30]. In developing nations such as Nigeria, cassava is a key source of starch. Cassava peel (CP) accounts for 20–35 per cent of the tuber's weight, particularly when peeling by hand [31]. About 11 million tonnes of cassava peel are produced each year [32]. Cassava peels are discarded indiscriminately due to gross underutilization and a lack of proper recycling equipment, posing a serious challenge and resulting in an environmental crisis. As a result, the necessity to find new ways to use cassava peels has arisen. Another biopolymer with success in the food industry is Carboxymethyl Cellulose (CMC), a cellulose derivative [33]. It has also been shown to have the ability to reduce soil erosion [34]. The largest source of CMC, cellulose, is abundant in nature and is the fundamental component of plant cell walls. Owji et al., [34] further revealed that several tons of wheat straw are produced annually as agricultural waste around the world, which is deposited in fields, causing pollution. Wheat straw has a cellulose content of 48 per cent and can be used to manufacture CMC in large quantities.

Fine-grained soils of high compressibility and low shear strength are found in many regions of the world. Bearing capacity problems, differential settlement issues, and unacceptable lateral movements on loading are the common challenges associated with such soils. When replacement with suitable soils will not be economical, soil improvement techniques are commonly recommended for these soils [35]. Macroscale tests conducted to investigate the shear strength and hydraulic behaviour of the disturbed Isan clayey soil include compaction tests, unconfined compressive strength (UCS) tests, and the compressibility/hydraulic conductivity (oedometer) tests. These experiments were carried out on treated specimens at various curing time intervals to investigate the related changes in engineering properties and microstructural traits over time. Therefore, it becomes important to perform research such as this to provide objective scientific support for the use of novel biopolymers as a product to stabilize weak soils.

The recent trend of developing novel soil improvement products from biological processes, provided the impetus to compare the performance of a commercially available biopolymer (CMC) with low-cost plant/agriculture waste biopolymers. Such products modify the structural properties of the subsurface soil, in terms of strength, volume stability, durability, and permeability through novel biochemical techniques. This paper evaluates the potential of Rice Husk Powder (RHP), Cassava Peel Powder (CPP), and Carboxymethyl Cellulose (CMC) as biopolymer materials to improve the strength and hydraulic characteristics of a regional clayey deposit,

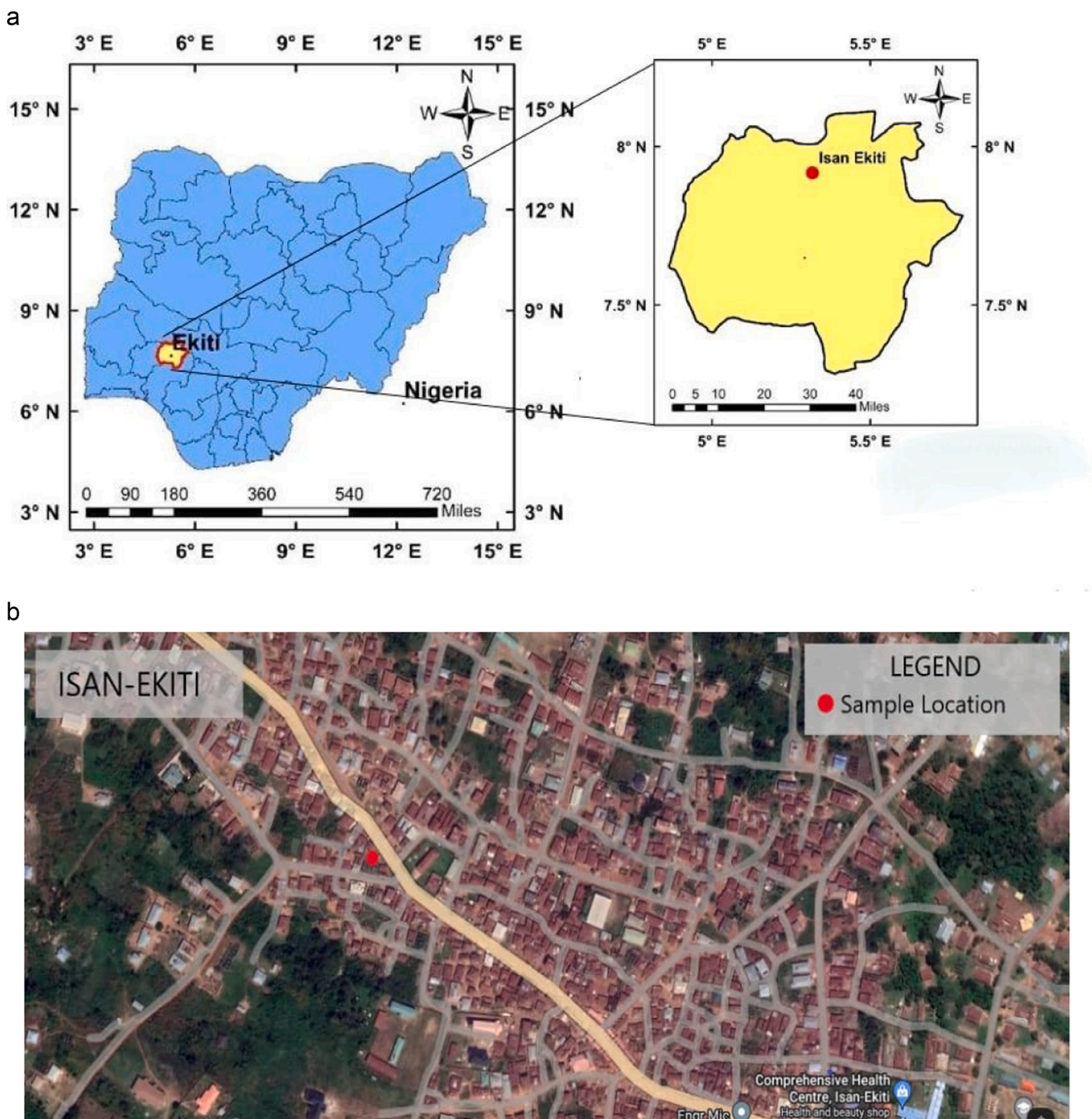


Fig. 1. a. Political map of Nigeria showing (inset) location of Isan-Ekiti in Ekiti State. Fig. 1**b**. Ariel view of the Site Location for soil sample collection in Isan-Ekiti (Source, Google Earth).

the Isan clayey soil. This study is an original demonstration of sustainable low-cost ground improvement for regional soil deposits, by comparing locally sourced biopolymer soil stabilization soil with imported biopolymer stabilization.

2. Materials and methods

2.1. Materials

Isan Clayey Soil (ICS) was sampled from Isan (Latitude: 7.9214° N, Longitude: 5.3168° E) in Ekiti State, Nigeria (Fig. 1a & 1b). The clayey silty soil is predominantly used in pottery moulding by the locals. Mining Corporation and the Raw Materials Research Development Council (RMRDC), deposits of local clays in Nigeria have been modestly projected to be above 700 million metric tons [36]. The collected soil sample was transported in an airtight bag to the laboratory for pulverization because it was in lump form. The chemical composition was carried out at the Research Institute of Obafemi Awolowo University. The remaining pulverized sample was transported to the FUTA/KURE Geotechnical Engineering laboratory of the Federal University of Technology, Akure for further tests. Fig. 2 shows the particle size distribution of the soil from the sieve and hydrometer analysis, while Table 1 summarizes the physical properties, and Fig. 8a the chemical compositions as determined by Energy Dispersive X-Ray Analysis (EDX) 3600B X-ray Fluorescence Spectrometer. ICS was classified as clayey soil (A-7–5), since it has fines (<0.075 mm) greater than 35% and a plasticity index greater than 11, according to the American Association of State Highway and Transportation Officials (AASHTO) classification system [37]. It is also classified as silt of high plasticity (MH) according to the Unified Soil Classification System (USCS) (Table 1). The case study soil is the regionally abundant clayey silty soil in most parts of Nigeria.

Carboxymethyl Cellulose (CMC) is one of the most important products derived from cellulose, its great importance to the industry and also in everyday life cannot be overemphasized. CMC is an anionic polysaccharide with a linear, long-chain structure. Its water-soluble property overcomes the limitations of conventional cellulose polymers [39]. Purified cellulose, in addition, is a white to cream-coloured powder that is tasteless, odourless, and free-flowing [40]. The CMC utilized in this study is gotten from the major supplier in Abuja, the Federal Capital Territory, Nigeria.

Rice Husk (RH) and Cassava Peels (CP) are non-traditional additives used in the stabilization of regional clay soil in this study. RH is a by-product of rice production during milling and CP is a by-product of cassava processing. The RH and CP were pulverized into powder form (RHP & CPP) for research purposes.

2.2. Test specimen and procedure

The disturbed clay soil collected was air-dried and pulverized. The testing specimens were prepared with varying contents of the biopolymers by weight of the dry soil to obtain the mix designs as shown in Table 2. According to the standard procedure in clause 3.3.4.2 of BS 1377: Part 4, [41], optimum moisture content (OMC) and maximum dry density (MDD) were determined for the natural soil and for the treated soil mixes. The microstructural features of the RHP and CPP treated soil specimens were investigated using Field Emission Scanning Electron Microscopy (FESEM). EDX was used to identify the elemental composition of materials and mineralogical characteristics of the treated soil sample were investigated using X-ray diffraction (XRD) analysis. The untreated (natural soil) and treated soil specimens were prepared at their OMC for the engineering tests necessary (i.e., strength and hydraulic conductivity tests).

Standard Proctor compaction test was carried out in accordance with BS 1377–4:1990, Section 3.3.4.2 to obtain the MDD and OMC of the natural soil and soil specimens treated with biopolymers at different contents. At different OMC and MDD obtained for soil specimens as described above, Unconfined Compressive Strength (UCS) cylindrical samples were prepared for the untreated and treated specimens. UCS test was performed following the procedure stated in BS 1924–2:1990 [42]. A minimum number of three (3) specimens were tested for each biopolymer content level at curing time intervals (0, 14, and 28days), with the average strength value recorded. Specimens were left to cure at ambient laboratory temperature (26 °C ± 1 C) and humidity.

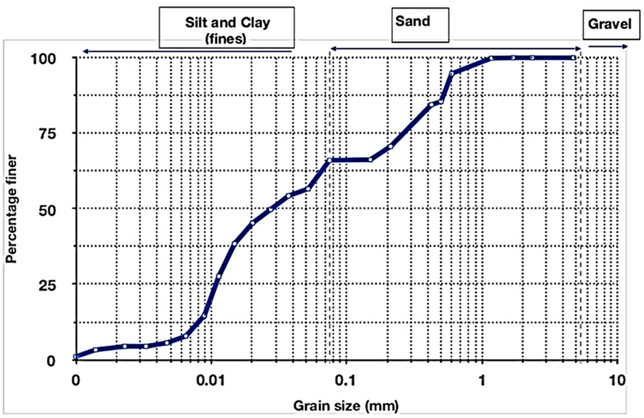
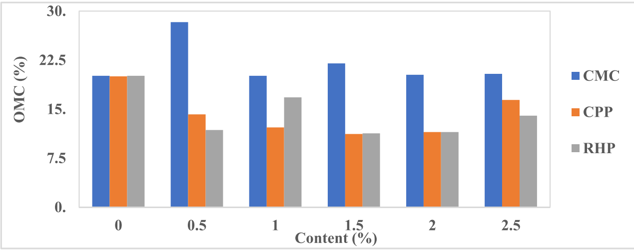


Fig. 2. Particle size Distribution Curve for Isan clayey soil.

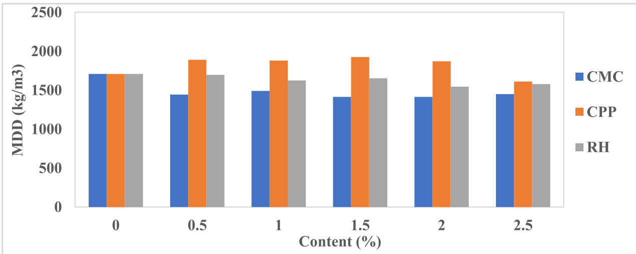
Table 1
Physical Properties of the Isan clayey soil.

Property	Value
Specific Gravity	2.67
Liquid Limit, LL (%)	70.00
Plastic Limit, PL (%)	46.67
Plasticity Index, PI (%)	23.33
Linear Shrinkage (%)	5.71
Maximum dry density (kN/m^3)	17.08
Optimum Moisture Content (%)	20.10
AASHTO Classification	A-7–5
USCS Classification	MH

Key: USCS –Unified Soil Classification System; AASHTO –American Association of State Highway and Transportation Official



(a)



(b)

Fig. 3. Compaction characteristics for soil biopolymer mixtures **(a)** OMC **(b)** MDD.

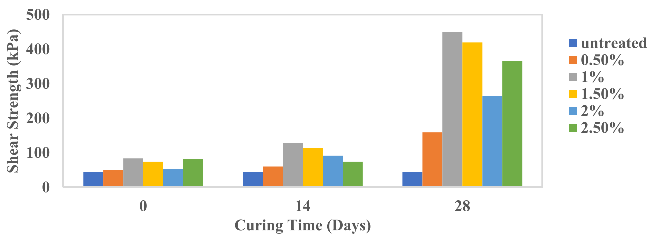


Fig. 4. Undrained shear strength for CMC-treated clay soil at different additive contents and curing times.

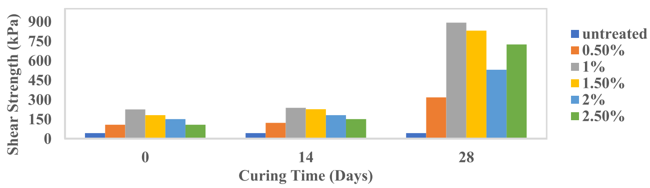


Fig. 5. Undrained shear strength for CPP-treated clay soil at different additive contents and curing times.

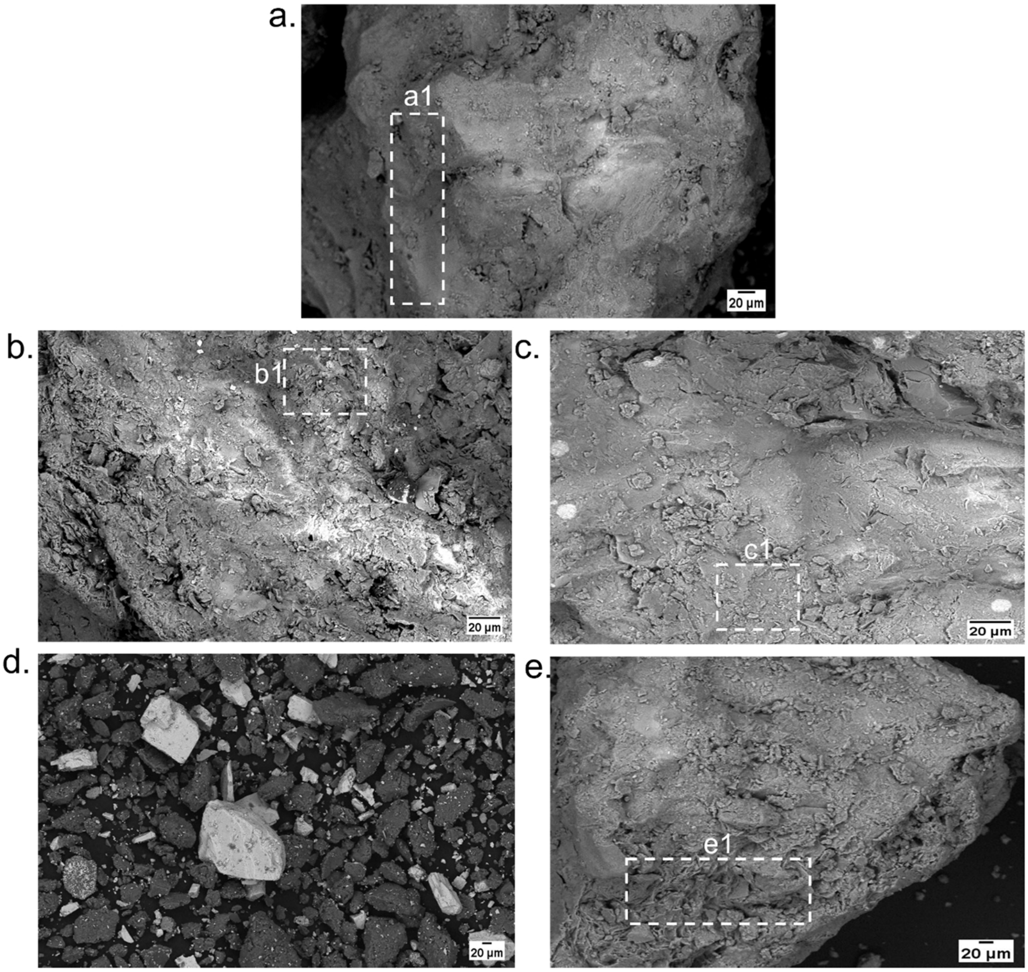


Fig. 6. SEM micrographs showing (a-b) 1% content of CPP-treated clay at 28-days, (c) 1% content of CMC-treated clay soil at 28-days, (d) untreated local soil (e) 1% content of rice husk treated clay soil at 28-days. Key: b1 – interparticle stacking; b1 and c1 – aggregated soil particles and stacking, treatment-based bio-coating; e1 – aggregated local soil [38].

Based on BS 1377–5:1990 [43], one-dimensional consolidation tests were performed on soil specimens. The selected soil specimens for consolidation tests are those with the highest compressive strength determined from the UCS tests to earn time. The corresponding hydraulic conductivity is then calculated using the relevant mathematical equation.

3. Result and discussion

3.1. Compaction characteristics

Soil compaction is the densification of soil grains by reducing or removing the air in the pore spaces (voids) of the soil matrix. As a result, the engineering properties of the soil are improved. CMC increased the stabilized soil OMC to a maximum of 28% at 0.5% content. A general trend of increase in OMC was observed for all the various CMC contents for soil stabilisation compared to the control sample (Fig. 3a). This is in agreement with the trend observed by [44], who also obtained higher OMC and lower MDD in loess specimens stabilized with CMC. It can also be observed that the CMC-treated clay mixtures had higher OMC when compared with CPP and RHP - treated clay mixtures. This is because CMC has better water-absorbent properties than CPP and RHP. The optimum moisture content (OMC) is generally reduced with increasing content of biopolymer for cassava peel powder (CPP) and Rice Husk Powder (RHP) with the lowest value of 11.2% at 1.5% CPP (Fig. 3a).

From Fig. 3b, the maximum dry density (MDD) increased with increasing CPP contents and achieved the highest value (1925 kg/ m^3) at 1.5% content (which corresponded to the lowest OMC recorded) as shown in Fig. 3a. [29], observed a similar trend of increasing MDD and decreasing OMC with biopolymer content for xanthan gum and guar gum biopolymer stabilized kaolin clay, with 0.5%, 1%, 1.5% and 2% biopolymer inclusions. For RHP and CMC, the MDD reduced from 1708 kg/m^3 at zero percent content to 1696 kg/m^3 and 1444 kg/m^3 respectively at 0.5% content with no further significant increment or reduction in MDD as the RHP and CMC content

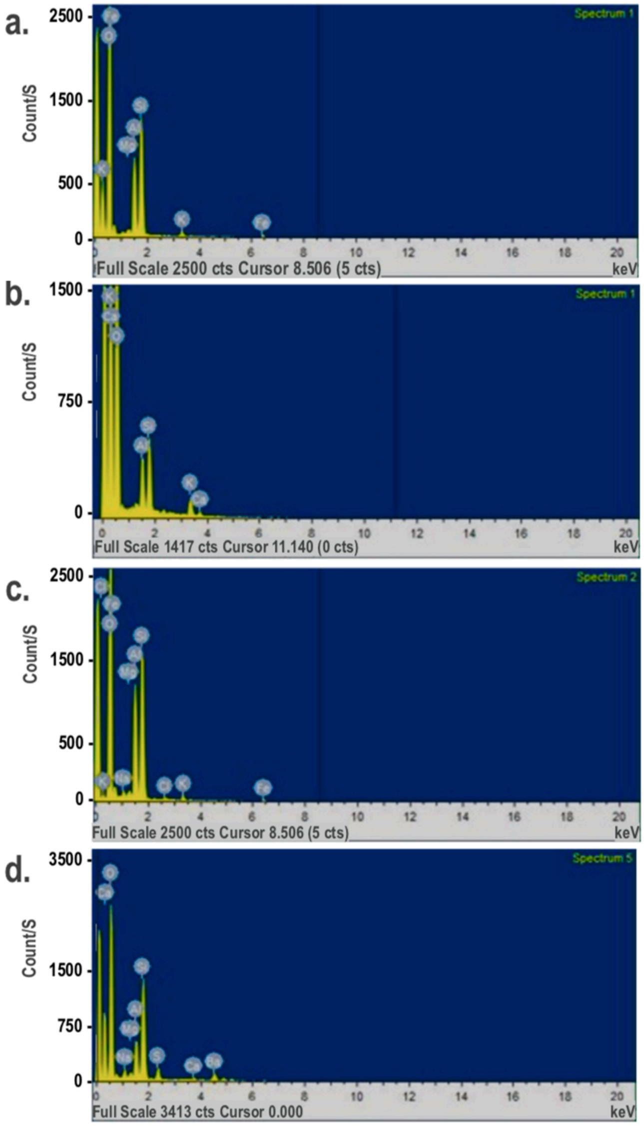


Fig. 7. **:** EDX analysis of untreated and biostimulated local soils: (a) EDX of untreated soils; (b) CPP treated soils; (c) EDX of CMC treated soils and (d) EDX of clayey soil-rice husk treated soil.

increased. Soil treated with CPP recorded a higher MDD value in comparison with RHP and CMC treated soil (Fig. 3b). These could be attributed to the fibrous nature of cassava peels (the source for CPP). Since higher MDD values were obtained for all the local CPP additive biopolymer contents during compaction, than that of local RHP biopolymer (Fig. 3b), CPP was selected as the optimum local biopolymer for strength characteristics testing in the unconfined compressive strength (UCS) test.

3.2. Shear strength

The unconfined compressive strength tests (UCS) were used as the indicator of shear strength for the imported CMC and local CPP biopolymer stabilised clay. Figs. 4 and 5 show the UCS test results for clay soil treated with the two biopolymer materials under consideration. From these figures, the UCS values of the treated soil are higher than the untreated soil as expected. In addition, the UCS value increases with increasing biopolymers content and has its highest values (900 kPa and 1786 kPa for CMC-treated clay and CPP-treated clay respectively) at 1% content beyond which the values reduced with increasing additives content. Therefore, the highest undrained shear strength mobilised at 1% content by the CMC-treated clay and CPP-treated clay are 450KPa and 893KPa respectively. This is because undrained shear strength is one half of unconfined compressive strength and it is a major indicator of geotechnical engineering behaviour [45].

The maximum compressive strength attained was 4110 kPa when CMC content was 1.0% in Loess Stabilized with Sodium

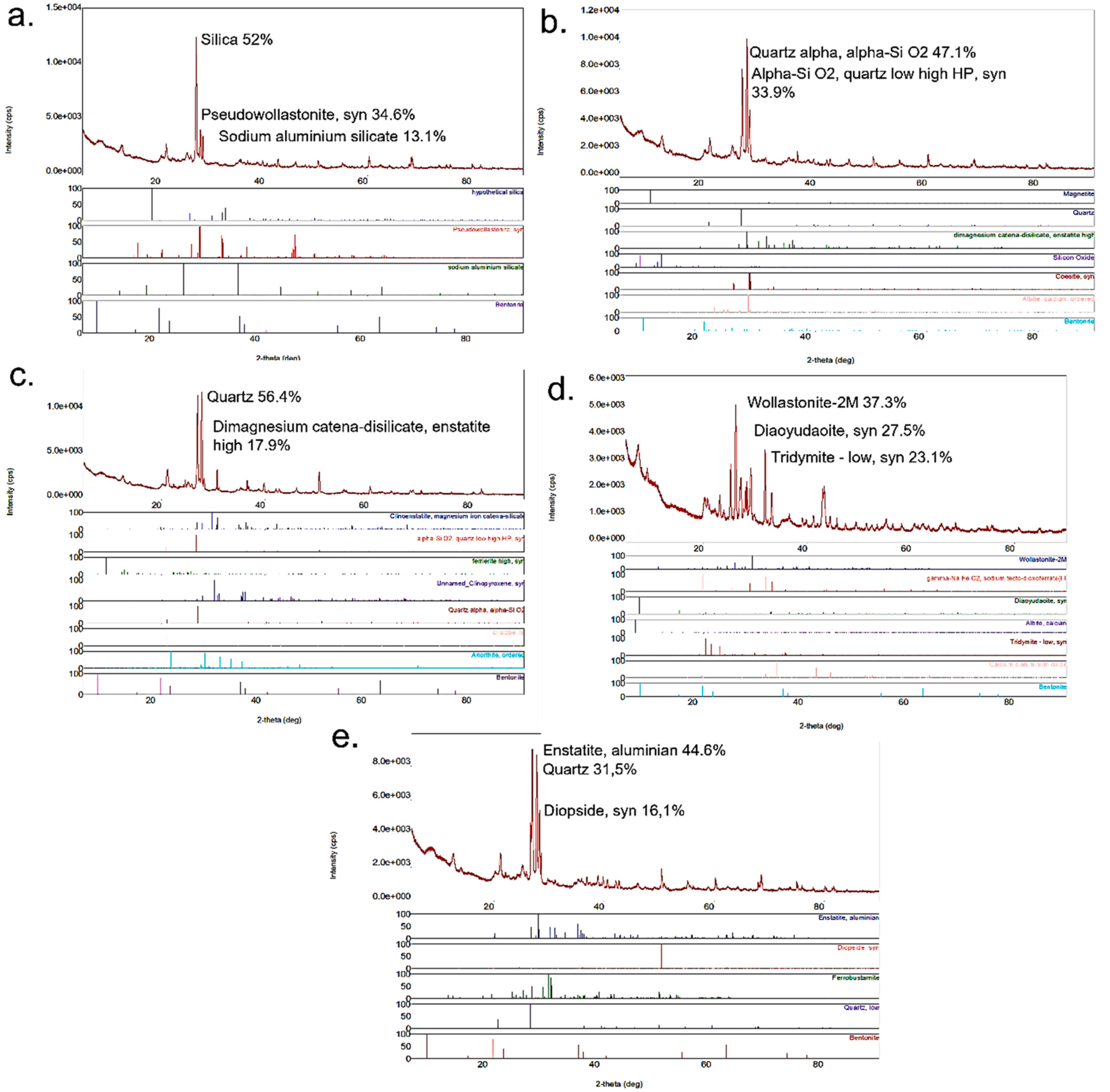


Fig. 8. **:** X-ray patterns for (a) untreated clayey soil, (b) soil samples treated with CPP, (c) soil samples treated with CMC, (d) untreated clayey soil, and (e) clayey soil samples treated with rice husk.

Table 2
The experimental design of the test samples.

S/N	Isan soil %	Biopolymers' content (%)					
		CPP (%)	Specimen code	CMC (%)	Specimen code	RH (%)	Specimen code
1	100	0	C-CP_0	0	C-CM_0	0	C-RH_0
2	99.5	0.5	C-CP_1	0.5	C-CM_1	0.5	C-RH_1
3	99.0	1.0	C-CP_2	1.0	C-CM_2	1.0	C-RH_2
4	98.5	1.5	C-CP_3	1.5	C-CM_3	1.5	C-RH_3
5	98.0	2.0	C-CP_4	2.0	C-CM_4	2.0	C-RH_4
6	97.5	2.5	C-CP_5	2.5	C-CM_5	2.5	C-RH_5

Carboxymethyl Cellulose [44]. Also, upon the addition of 0.2 M (~1%, Mass biopolymer/Mass sand) biopolymer additive to silica soil (100%), there was a significant increase in strength relative to the negligible UCS exhibited by control silica soil alone, for most biopolymers the strength exceeded the UCS achieved by a 10% cement mixture. A UCS (after 7 days of curing at 20 °C) of CMC stabilisation (2475 kPa), Xanthum Gum [XG] (2975 kPa), Guar Gum [GG] (2878 kPa), and locust bean gum [LB] (1979 kPa) was achieved. This confirms that biopolymers exhibit not only desirable environmental characteristics but also improved stabilization properties, at much lower concentrations, when compared to cement stabilization/solidification of soils [46].

It was also discovered that the undrained shear strength increased with curing time, with the greatest impact occurring at 28 days. This could imply that significant soil-biopolymer reactions occurred within 28 days. Furthermore, clayey soil treated with local cassava peel powder (CPP) showed higher shear strength values than the corresponding content of imported Carboxymethyl Cellulose treated clay at the same curing time. [47] observed that biopolymers enhanced the shear strength of biopolymer treated soils, demonstrating an optimal biopolymer content beyond which shear strength values plateaued.

Based on the above results, the optimum biopolymers (CPP and CMC) content recommended for the regional clay considered in this study is 1%. Clay treated with 1% CMC has a 28-day shear strength value that is ten (10) times that of untreated clay (43.5 kPa), while clay treated with 1% local CPP has a 28-day shear strength value that is twenty (20) times that of untreated clay (43.5 kPa).

3.3. Microscopic soil-structure analysis using FESEM, EDX and XRD

The strength increase recorded was studied at the microstructural level using Scanning Electron Microscopy (SEM) analysis as shown in Fig. 6(a-d). The cementitious material that was established (areas of compacted particles) welded the soil particles and filled the pore space for both the cassava peel powder CPP–clay and the CMC-clay soil matrices. This direct interaction between the clay particles and the established CPP and CMC fibres occurs due to the electrical charge on the clay particles, hence, the shear strength was improved. The surfaces are covered with a pellicle of fine material also showing traces of much smaller particles on the surfaces of the particle grains and a polymeric coat, indicating a bio-coating stabilization mode of action (see Fig. 6c-d) [38]. A recent study show "gum strands" aiding the biopolymeric stabilisation of weak clay-based soils [48]. The regional clayey soil treated with rice husk indicated a compact and agglomerated soil structure after 28-days of curing, indicating a relatively fast chemical reaction [38] as shown in Fig. 6f (cf Fig. 6e). The effect was similar to previous studies showing the addition of rice husk reduced the swelling pressure of bentonite soils, therefore, resulting in improved compaction [49].

The EDX analysis as shown in Fig. 7a-d shows typical silica peaks, an important feature of the pozzolanic reaction to form cementitious material whereas, Fig. 7(b and d) soil treated with CPP and rice husk, respectively shows strong peaks of calcium and oxygen. Supporting evidence is clear from Fig. 6(b and d) that this may be calcite precipitated after the treatment and is bridging the soil grains. This is similar to a study by Islam et al. [50] and [49] which shows a calcium carbonate precipitate stabilising clayey and bentonite soils, respectively.

In this study, the XRD powder was prepared to determine the presence of crystalline minerals in natural soil and to monitor mineralogical changes caused by bio-based treatments. Samples for XRD testing were prepared by crushing and oven-dried at 100 ^oC, after which approximately 10 g was used to make the pellet. Fig. 8a shows the XRD pattern of the untreated clay. The main mineralogical constituents of the untreated local clayey soil are hypothetical silica SiO_2, Pseudowollastonite, syn $Ca_3(SiO_3)_3$, sodium aluminium silicate, $Na_8Al_4Si_4O_{18}$ and Bentonite Na-Al-Si-O-OH-H_2O. The treated specimens show variation in the mineral contents as shown in Fig. 8(b,c and e), a previous study by Saeed et al. [51] which shows this behaviour may be indicative of the physiochemical interaction which binds soil particles. Further investigation is necessary to understand the breakdown of clay minerals after bio-based treatments and the formation of other predominant compounds such as enstatite aluminian shown in Fig. 8e.

3.4. Hydraulic conductivity

The hydraulic conductivity was obtained for untreated clay and for specimens C-CP_2 and C-CM_2 (Table 3) at 28 days of curing time. This content for each biopolymer was selected being the optimum content that produced the highest compressive strength determined from the UCS test. The tests were carried out at their respective optimum moisture content obtained (Fig. 3a) using the oedometer test apparatus. Hydraulic conductivity was, therefore, calculated from the parameters obtained from the oedometer test using equation 1.0 [52]:

$$k = c_v m_v \gamma_w \tag{1.0}$$

Where: c_v is coefficient of consolidationm_v is coefficient of volume compressibilityγ_w is unit weight of water$k$ is hydraulic conductivity.

Table 3
Calculated hydraulic conductivity at 28 days curing time.

Soil Specimen	Hydraulic conductivity, k (m/s)
Untreated clay	9.88E-08
C-CP_2	4.6E-13
C-CM_2	8.4E-11

The calculated hydraulic conductivity is shown in Table 3 below. From this Table, a decrease in hydraulic conductivity was achieved for both CPP-treated clayey soil and CMC-treated clayey soil. CPP-treated clayey soil had the lowest hydraulic conductivity at the curing time considered. [53] also observed a similar trend of a considerable decrease in hydraulic conductivity for CMC stabilized mineral clay (bentonite).

4. Conclusions

The potential of cassava peel powder (CPP), rice husk powder (RHP), and Carboxymethyl Cellulose (CMC) as biopolymer-based materials to improve the engineering properties of Isan regional clayey soil was investigated. In summary, the maximum dry density (MDD) increased with increasing CPP contents and achieved the highest value (1925 kg/m^3) at 1.5% content (which corresponded to the lowest optimum moisture content [OMC] recorded). For RHP and CMC, the MDD reduced from 1708 kg/m^3 at zero percent content to 1696 kg/m^3 and 1444 kg/m^3 respectively at 0.5% content with no further significant increment or reduction in MDD as the RHP and CMC content increased. In comparison to CMC-treated soil, CPP-treated soil had greater MDD values. The results revealed that locally sourced CPP performed much better than both imported CMC and local RHP in improving the engineering properties of the regional clay. The shear strength of the soil treated with each of the two biopolymer materials increased with curing time up to 28 days. The microstructural results revealed that the chemical reactions between the CPP/CMC and clay particles result in the formation of new cementitious products that fused the soil particles and filled the pore space. CPP performed better than CMC in enhancing the regional clayey soil shear strength. CPP-treated soil had an undrained shear strength that is 20 times that of untreated soil; and 10 times that of CMC-treated clay. Therefore, the optimum local biopolymer, cassava peel powder (CPP) content of 1% is recommended for the regional clayey soil improvement, based on the high UCS value, 1786 kPa, and undrained shear strength value of 893 kPa. The waste containment potential is also enhanced with a significant reduction in Hydraulic conductivity value for possible waste containment applications.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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