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Use of Biopolymers in the Stabilization of Clay Soils

Idoui Imane[1], Rehab Bekkouche Souhila[2], Benzaid Riad[3], Berdi Inas[4]

[1, 3, 4] Geological Engineering Laboratory (LGG), Jijel University, Algeria.
[2] Civil Engineering Department, LMGHU Laboratory, Skikda University, Algeria.
e-mail: solrehab@yahoo.fr

Abstract

The treatment and stabilization of soils make it possible to recycle materials on construction sites in preparation for the installation of a final covering or the construction of a road network. In road geotechnics, various materials such as lime, cement, and pozzolans were used as additions to stabilize clay soils. In recent years, bio-polymers and bacteria are of increasing interest to researchers in the field of stabilization and improvement of the physico-mechanical and chemical characteristics of clay soils. Currently, in place of traditional clay treatment techniques and to minimize environmental problems, natural fibrous waste is being used increasingly and spectacularly. Several studies on biotechnological engineering applications already exist, such as the use of vegetation, algae, bacteria, enzymes, and biopolymers. The northern Algerian region where the urban tissue does not stop expanding contains significant potential in terms of wheat straw, which represents a very present agricultural waste. So, there is a local interest in the sustainable development of several regions known to produce wheat. This study is interested in investigating the effect of wheat straw on the stabilization of swelling clay soil. In order to improve the physico-mechanical characteristics of clay soils, a series of laboratory tests (Atterberg limit, Proctor test, direct shear test, Oedometer test, and unconfident compressive strength test) were carried out on reconstituted clay soil with defined initial properties through numerous analyses (e.g., XRD and XRF) and then treated with different vegetable fiber content. The results indicate that there is an improvement in the compressibility characteristics of the treated soil, a remarkable decrease in the swelling index and the compressibility index respectively with increasing percentages of wheat straw.

Keywords: biopolymer, soil improvement, treatment, clay, wheat straw.

1 Introduction

Jijel province in northern Algeria knows a significant expansion of urban fabric due to the demographic growth in the last years (103.6 habitants per km²) [1]. This expansion stretches and extends over virgin terrains in the vicinity of the major cities. As the geology of Jijel and its climatology know a serious complexity, the targeted terrains are mainly argillaceous terrains that often show lower geotechnical characteristics like consistency limits, particle size, compaction, consolidation, permeability, and shear strength and their interactions [2]. These characteristics differ over the different regions of the province. Subsequently, the

construction sites and urban infrastructures face numerous engineering and geotechnical problems (settlement, collapse, and land-sliding). Soil stabilization is the ultimate solution to improve the geotechnical properties of these soils, where numerous technics are being employed like using lime and cement to the soils [3, 4] which offer practical and economical solutions, other researchers have studied the influence of the addition of polymers on the improvement of the geotechnical properties of clays, they have confirmed the favorable effect of these materials [5- 8].
Even though these traditional technics are efficient in strengthening the soils and bettering their technical properties, serious environmental problems are encountered, especially ecological ones like greenhouse gases emission, pollutant leakage to groundwaters, recycling of concrete and cements wastes, plus their expansive costs [9]. [10] Have studied the immediate and long-term effects of lime and wheat straw on consistency characteristics of clayey soil, the study has shown that the shrinkage and swelling of clayey soils may adequately be managed through mixing an appropriate amount of lime and wheat straw as soil stabilizing agents for both immediate and long-term effects.The current study deals with soil stabilization using eco-friendly biopolymer “Wheat Straw”. The use of this biopolymer in soil stabilization is not brand new, where it has been used in the last years in different countries China [11], India [12, 13], and Algeria [14]. In conjunction with plentiful biopolymers, mainly extracted from vegetable fibers such as rice husk [15, 16], fiber jute [17], bagasse fiber [18], coconut fiber [19], sisal fiber [20], and wheat husk [21]. These materials showed decent improvement on the characteristics of the treated soil [22], principally in shear resistance, dry density, and plasticity parameters. Yet, the use of these materials in the Jijel area is still limited or not even used. Also, the actual knowledge about their efficiency and the exact impact of using them on these soils’ characterization is not well constrained. Hence, we offer in the actual work a detailed study on the impact of using Wheat Straw in enhancing geotechnical properties of a reconstituted soil from the Herraten region, in Jijel province. The idea of using a reconstituted soil in this study is to obtain a swelling soil with well-defined properties that can be used further as a reference, then to see the effect of wheat straw on its geotechnical properties.

2 Data and Methodology

Cost The studied soil was extracted from a potential construction site in the new city of Herraten, nearby Jijel town in northern Algeria Figure 1A). The studied area and generally Jjjel region are characterized by a humid climate, significant precipitation, and an important hydrographic network.The geological studies indicate that the studied area is located in the Jijel basin. This basin is mainly filled by Neogene and quaternary sedimentary deposits. Herraten is situated on the Hill of Herraten where the outcrops are basically post-nappes deposits Figure 1.B). These deposits are identified as blue grayish clays with mediocre geotechnical properties. The technics used so far in the studied area to enhance these parameters are the aforementioned classic techniques (lime and cement).

2.1. Soil

The soil samples were taken from approximately 3.5 to 4m of depth. The initial properties and

measurements of the raw soil were taken in the first place, then, it was mixed with the Bentonite powder, a commercial product with clayey characteristics that will boost the swelling properties in order to fit with study purposes. The resulting reconstituted soil will be the initial sample of the work that will receive additives, or as referred to soil 0% in all further analysis, tests, and experiences in this study. Using reconstituted soil is also crucial in eliminating the inconsistency of specimens during the tests and ensuring the repeatability and sufficient samples with exact known parameters [23]. These factors are imperative for any comparative studies with additive content [24].
The bentonite used comes from the M'sila Sidi-Ali region, Mostaganem province. It was provided by BENTAL Company. The detailed geotechnical properties of the raw soil, bentonite powder, and the resulting reconstituted soil are described below.

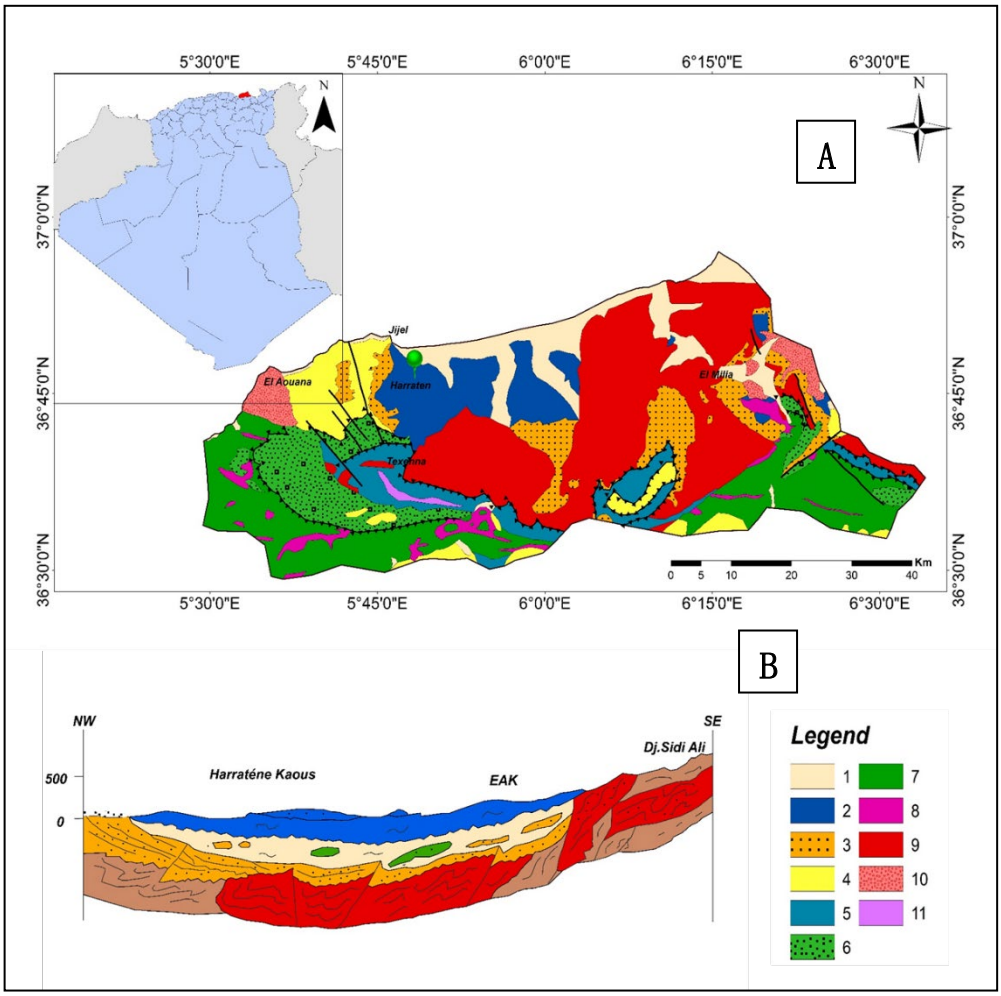


Figure 1: Simplified geological map of the Jijel region and the localization of the study area.

Legend: 1. Quaternary 2. Postnappe 3. Oligo Miocéne Kabyle 4. Numidian series 5. Tellian 6. Massylien flysch 7. Mauritanien Flysch 8. Triassic Rocks 9. kabyle basement 10. Magmatic rocks 11. Volcano sedimentary unit [25]

2.1.1. Natural Soil characterization

Even there were previous studies that dealt with soil samples from the region of Herraten, different chemical, mechanical and physical measurements, and analyses were carried out on the natural soil samples to define its exact characteristics. The most important parameters of the soil are resumed below. Table 1 displays the physical properties of the soil where the dry density, optimum moisture content, Atterberg limits, and the blue methylene value were calculated. These measurements indicate that the soil has low plasticity and low swelling properties. The results of the chemical analysis (XRF) are shown in Table 4.

Table1: Physical Properties of the natural soil

Maximum dry density(t/m^3)	Water content (%)	Liquid limit (%)	Plastic limit (%)	Plastic index (%)	Methylene Blue
1.75	16.14	45.63	20.36	20.27	3.8

Figure 2 shows the grain size distribution of the studied soil. 98% of the soil grains have less than 100µm in diameter and 65% of the grain are smaller than 10µm.
After the GTR classification, the soil is considered as clay soil Class A2.

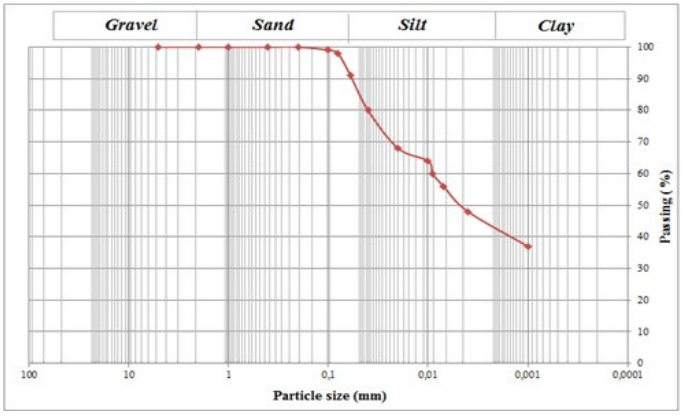


Figure 2: Grain size distribution of base soil

2.1.2. Bentonite

The Bentonite powder is a commercial product derived from a sedimentary rock that has the same name and is mainly used in the ceramic industry. It is characterized by high adsorption properties and ionic exchange. As mentioned before, it is employed in the ongoing study to augment the swelling properties of the soil. Table 4 shows the results of the chemical analysis (XRF) of bentonite which are related to its mineralogical origin. These chemical properties show that bentonite is composed of a high percentage of SiO_2 Al_2O_3 and CaO. the value of the SiO_2 / Al_2O_3 ratio is 4.53. This value is the index of a montmorillonite [26]. The bentonite is classified in the calcic type given the preponderance of the percentage of calcium over sodium [27]. Table 2 shows the initial physical properties of the bentonite which are critical in constraining the reconstituted soil parameters in further steps of this study.

Table 2: Physical properties of the bentonite

Maximum dry density(t/m^3)	Water content (%)	Liquid limit (%)	Plastic limit (%)	Plastic index (%)	Methylene Blue
1.75	16.14	175	30	145	25.21

2.1.3. Reconstituted soil

The soil 0% adopted in our study is a mixture of 60% natural soil and 40% bentonite (Figure 3) [6, 27]. Enhance mineralogical analyzes on the reconstructed soil were carried out by X-ray diffraction (XRD). The obtained detailed mineralogical composition of the reference soil and which has a direct influence on the geotechnical characteristics of the soil mainly the porosity, permeability, and swelling is displayed in Figure 4. As this soil is continued by the mixture of the two given components, it's mainly constituted by tectosilicates, phyllosilicates, inosilicates, and carbonates.

The diffractogram (XRD) presented in Figure 4, presents characteristic peaks that correspond to crystalline phases formed mainly by Quartz, calcite, and Montmorillonite. Other minerals also are present but minor. The chemical analysis on the reconstituted soil was performed by an X-ray fluorescence spectrometer (XRF).

The results of this analysis are shown also in Table 4. And reveal the abundance of silica SiO_2, aluminum oxide Al_2O_3 and calcium oxide CaO with almost 55%, 14,3%, and 17,4% respectively; The K_2O, MgO, Na_2, and TiO are present in form of traces. The geotechnical characteristics of the reference soil are resumed in Table 3.



Figure 3: a) Natural soil; b) Bentonite; c) Reconstituted soil (60% natural soil +40% bentonite); d) Wheat straw

Table 3: Geotechnical properties of reconstituted soil (60 % Natural soil + 40% Bentonite)

Physical and chemical characteristics	Values
Liquid limit *LL* (%)	68.72
Plastic limit *PL* (%)	25.3
Plasticity Index *IP* (%)	43.42
Optimum water content W_{opt} (%)	23.12
Maximum dry density γ_{dmax}(t/m^3)	1.64
Cohesion *C* (kPa)	0.28
Internal friction angle φ (°)	4
Methylene blue value	8.33

Table 4: Chemical composition of Bentonite, Natural soil, Reconstituted soil, and Wheat straw. X-Ray Fluorescence results

	SiO_2	CaO	Al_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	TiO	Cl	SO_3	P_2O_5
Natural Soil	47.2	25.4	14.1	6.8	2.37	1.95	0.339	0.59	/	0.119	0.276
Reconstituted soil	55	17.4	14.3	5.44	2.54	2.36	1.43	1.06	/	0.215	0.225
wheat straw	34.8	19.8	8.15	8.42	10.4	1.46	4.08	0.92	5.66	3.99	1.74
Bentonite	65.8	6.36	14.5	3.5	2.65	2.87	3.04	0.34	0.14	0.47	/

2.2. Wheat straw (WS)

Wheat straw is a natural biopolymer with the ion-exchange property. Wheat straw, a by-product obtained after harvesting wheat grains, with an annual world global production of 529 million tons [28]. The composition of these residues contains about 32.7% of cellulose and 24.5% of hemicelluloses [29]. Cellulose fibrils and lignin confer mechanical strength properties [30]. WS is an abundant and eco-friendly material.

In the current study, the wheat straw used for soil treatment is obtained from agricultural wheat fields from Mila province in Algeria. Before using it in further steps, the wheat straw was subjected to initial pretreatment: first, it was air-dried to remove moisture, then was carefully sieved using a 5mm caliber sieve. The diameter of the resulting straws ranges from (0.5 to 5 mm) and have a length of (10 mm to 50 mm), Figure 3. Properties of wheat straw of the reference soil are resumed in Table 5.

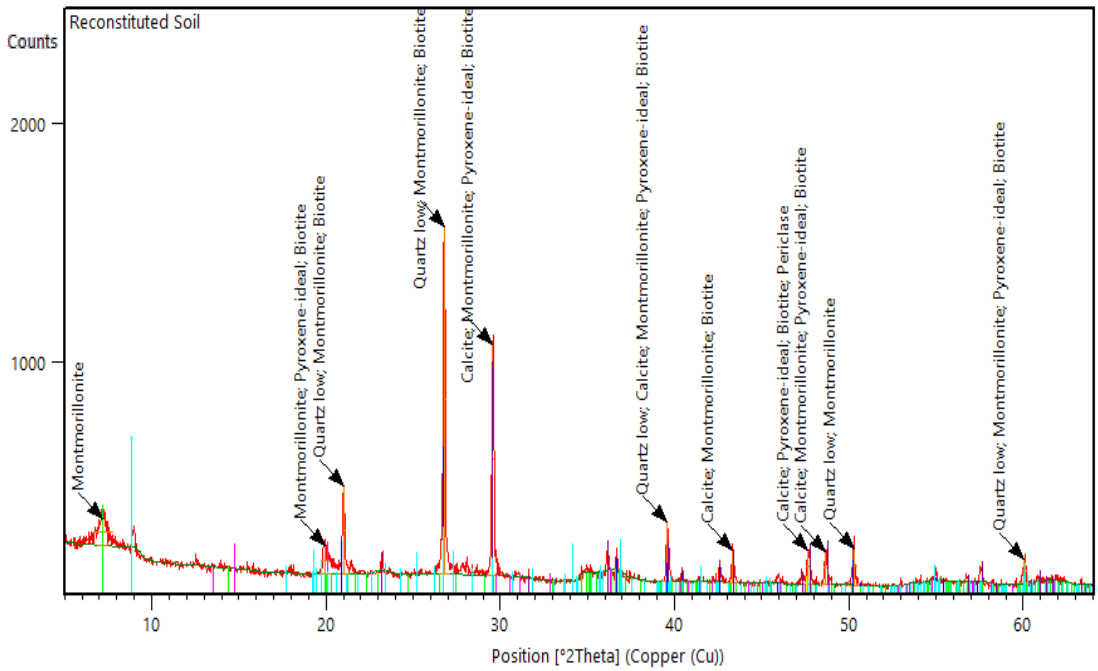


Figure 4: X-ray diffraction pattern of reconstituted soil for mineralogical composition

Table 5: Properties of wheat straw

Color	pH	Specific gravity *Gs*
Straw yellow	7.7	0.19

Once we have reconstituted the soil with the desirable geotechnical characteristics, four pretreated WS proportions were added. These proportions are 1%, 3%, 6%, and 9% relative to the weight of the used soil.

2.3. Test procedure

To evaluate and determine the influence of wheat straw on the physic mechanical properties of the mixture (Reconstituted soil - wheat straw), we performed an experimental program on both untreated and wheat straw treated samples. This program includes the determination of the specific gravity (*Gs*), the effect of WS on the pH, plasticity tests to evaluate the Atterberg limits, Proctor analysis, direct shear test, the unconfined compression strength analysis to determine resistance (UCS). Finally, two different types of tests to determine the swelling: the odometer test and free swelling index.

Table 6: Engineering test with standard code

Name of the test	Description of the test	Test code
specific gravity (*Gs*)	ratio of the weight of a given volume of the material to the weight of an equal volume of distilled water, using water pycnometer method determine the specific gravity of a soil composed of particles.	BS 1377-2 (1990)
pH analysis	Evaluate the impact of wheat straw on the pH of the soil.	NF ISO 10390-1994
Atterberg limits	determine soil liquid limit, plastic limit and plasticity index in compliance with the conditions stipulated in the standard test methods	NF P94-052-1
Proctor standard compaction test	Determine the maximum dry density (MDD) and the optimum moisture content (OMC).	NF P94-093
Direct shear strength	Study the influence of the treatment of wheat straw on the resistance parameters using the casagrande box using the wet mix method(under consolidated drained conditions).	NF P94-071-1
Free swelling index test (FSI)	Determine the free-soil swelling index. Free swell is the raise in the volume of a soil when immersed or soaked in water or other solvent, without any external constraint.	with IS 2720 (Part-40)-1977
Unconfined compressive strength	A compression test is carried out to determine the compressive strength of treated and untreated soil. The test pieces were assayed in varying proportions wheat straw and crushed	NF P94 -077

3 Results and discussion

3.1 Effect of wheat straw on the specific gravity

Table 7 presents the measured specific gravity of solid grains (*Gs*) of the used materials. The first *Gs* value (WS) represents the specific gravity of the wheat straw only, whereas the second value (0%) represents the specific gravity of the untreated soil. The remaining values represent the value of the specific gravity of each treated soil sample.

Table 7: Variations of the specific gravity of soil with the addition of the WS

WS content (%)	WS	0%	1%	3%	6%	9%
Specific gravity (*Gs*)	0.19	2.31	2.14	1.64	2.29	2.31

The behavior of the specific gravity of the soil can be described as follow; first, with adding 1% of WS the *Gs* decreased significantly compared to its initial value of 2.31 (untreated soil). This behavior was also observed when adding 3% of WS. A gentle decrease of the *Gs* is observed on the soil treated with 6% of WS. The value of the *Gs* remains unchangeable with the addition of 9% of WS.

Note that 3% marks the decreasing threshold of *Gs* that may be due to the fact that WS replaces a large part of the voids in the soil, thus making the soil much denser. Previous studies have reported a decrease in the specific gravity of the soil depending on the addition of wheat straw [10].

3.2 Effect of wheat straw on soil pH meters

The variation of the pH value in function of the proportions of added wheat straw is illustrated in Table 8. An additional proportion of WS 12% was used to confirm the obtained threshold in this test.

Table 8: The effect of wheat straw content on pH value of soil

pH value	0%	1%	3%	6%	9%	12%
Additive content (%)	10.33	10.22	9.98	9.60	9.59	9.59

The value from the table shows that when Wheat Straw is applied to the soil with a 1, 3, and 6%, ratio, the pH reached 10.22, 9.98, and 9.60 respectively while no change in the pH value was observed when using 9% or more of the WS.

The slight decrease in the pH value of the treated soil is probably due to the mineralogical composition of the soil used. The optimum wheat straw content corresponds to a pH value of 9.59 at which the amount of WS added is sufficient for chemical reactions to take place.

3.3 Effect of adding Wheat straw on Atterberg limits

We performed Atterberg limit tests on soil treated with different percentages of wheat straw (WS). The obtained results are summarized in the following Table:

Table 9: Atterberg limits test results

WS content (%)	Atterberg limits		
	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)
0%	76.86	22.66	54.2
1%	89.58	40.48	49.10
3%	91.36	42.71	48.65
6%	89.42	43.96	45.46
9%	87.09	49.2	37.89

In the beginning, we observed an increase in the liquidity limits until the addition of 3% of wheat straw, followed by a decrease beyond this percentage (Table 9).
Table 7 shows a decrease in the plasticity index value has decreased from 54.2% to 37.89% with 9% WS additive.

Adding the powder to the clay soil causes the Atterberg limit values to change slightly. The results indicate that as the percentage of wheat straw increases, the liquidity limit (*LL*) and plasticity limit (*PL*) also increase, however, the plasticity index (*PI*) decreases.

The increase in the liquidity limits is due to the reaction of the wheat straw with clay particles. The decrease in the plasticity index indicates an improvement in the workability of the soil, these results are similar to those found in the literature [12, 13].

3.4 Effect of wheat straw on Compaction Characteristics

The results of the compaction test of the treated soils in comparison with reference soil are shown in Figure 5, They show an increase in the optimal moisture content (OMD) of the soil from 16% to 20% parallelly to the decrease of the maximum dry density (MDD) from 1.65 to 1.32 g/cm^3, depending on the increasing proportions of the added wheat straw (0% to 6%). The behavior of the soils treated with 9% is different from the other treated soils, where the OMD remains stable compared to the non-treated soil, the dry density goes down to 1.29 g/cm^3.

These results indicate that the optimum of the proctor curve of the treated soils shifts right and downward compared to the optimum of the reference soil (Figure 5) for the soils treated with 1% to 6%. Whereas the optimum of the soil treated with 9% shifts only downward compared to the curve of reference.

The rise in moisture content is explained as the amount of water required to moisten the added WS's that is characterized by a wide surface area and its ability to absorb water. On the other hand, the use of wheat straw leads to a reduction in dry density progressively. This reduction indicates that the soil is less compacted, in other words, it contains more voids. This variation is of course due to the low density of the wheat straw compared to the soil.

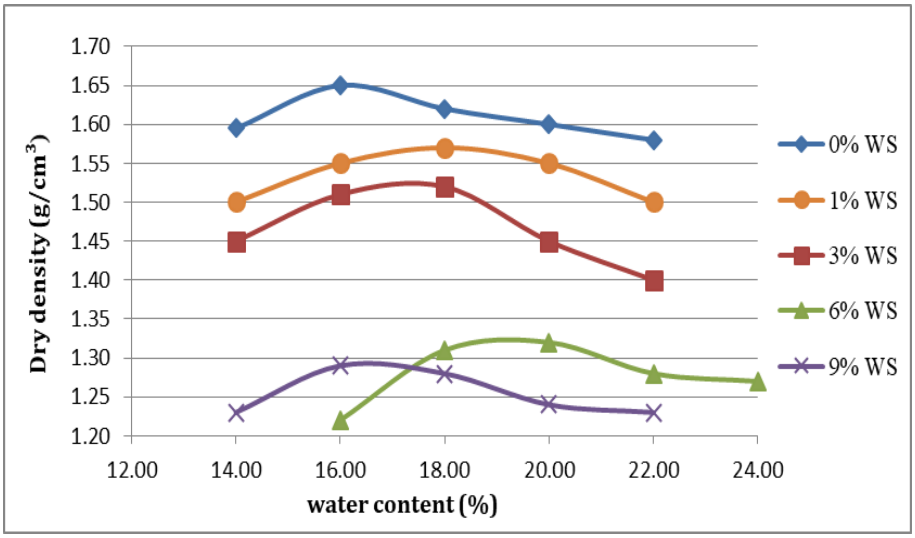


Figure 5: Compaction curves of soil with different percentages of wheat straw

These effects on the maximum dry unit weight are similar to that on the specific gravity of the wheat straw stabilized soil and could have resulted from the variation of the specific gravity of the stabilized soil with the wheat straw content, these results are confirmed by those found in previous studies [12].

3.5 Effect of wheat straw on Shear Strength Parameters (Direct Shear Test)

The shear strength tests of the untreated soil and treated soil with different percentages of wheat straw were performed as per NF P 94-071-1. The results of the influence of the different percentages of wheat straw on the cohesion and the friction angle are shown in Table 10.
In general words, we note that the increase in the concentration of wheat straw leads to a higher friction angle (φ) and a decrease in cohesion (C). According to Table 10 below, the friction angle varied from 6° to 16.17° for an addition ranging from 1% to 9% meanwhile the initial friction angle of the untreated soils was 4°. A higher value of the cohesion was observed on the results of the soil treated with 1% in comparison to the untreated soil. This increase was followed by a progressive decrease from 0.36 bar to 0.04 bar upon the percentages of the added wheat straw.

Table 10: Friction angles and cohesion of wheat straw-treated clay

Wheat straw concentration (%)	Cohesion C (bars)	Friction angle φ (°)
0	0.3	4
1	0.36	6
3	0.2	8
6	0.17	10.75
9	0.04	16.17

From the results of the tests, it can be concluded that the shear characteristics after the addition of different proportions of straw were improved considerably compared to the untreated soil. The improvement is explained by the resulting composition of the granular matrix of the treated soil which gives it a solid character.

3.6 Effect of wheat straw on soil compressibility

The compressibility tests of the untreated soil and treated soil with different percentages of wheat straw were performed as per NF P94- 068.
Figure 6, Figure 7, and Figure 8 show the results of the effect of wheat straw on the variation of the soil compressibility for different percentages of wheat straw fiber. The results include the consolidation pressure index, the coefficient of compressibility, and swelling.

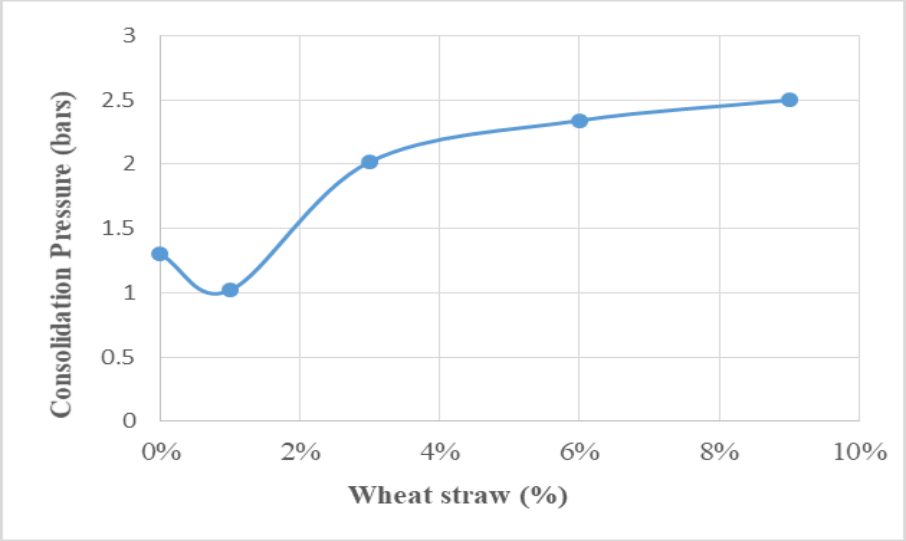


Figure 6: Consolidation Pressure Variation as a function of % wheat straw

The compressibility index as a function of the percentage of wheat straw presents a disproportional behavior where it decreases in response to the increase of the WS. It is worthy to mention that the decreasing was more important with the adding of 1% till 3%, after that, only a gentle decrease is observed.

The swelling index curve displays a different behavior from the previous one. When adding 1% almost no change is observed. Then it is followed by a significant decrease of the SC from 12 to almost 6% with the adding of 3%. The addition of 6% of WS seems doesn't have a significant effect where no change of the SC is observed, however, the addition of 9% is marked by another significant decrease of the SC down to 4%.

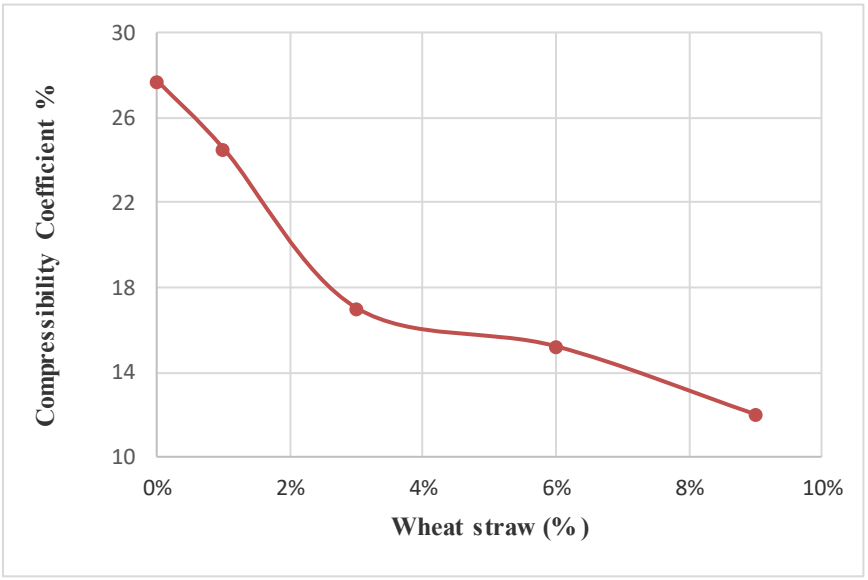


Figure 7: Compressibility Coefficient Variation as a function of % wheat straw

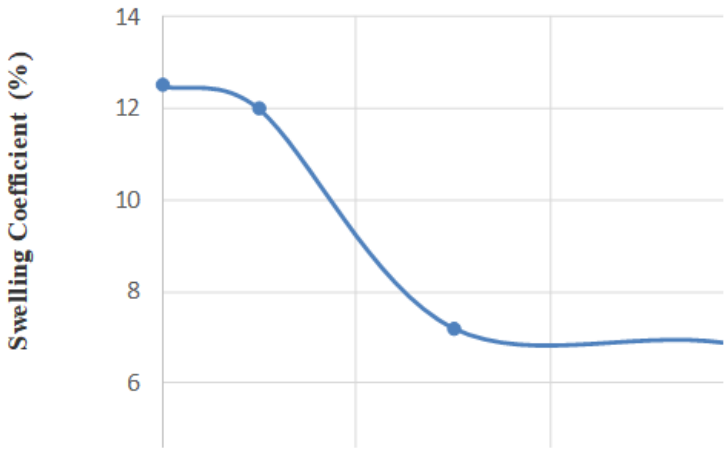


Figure 8: Swelling Coefficient Variation as a function of % wheat straw

We note that the consolidation pressure decreases until the addition of 1% wheat straw, once exceeding this proportion, the consolidation pressure increases in function of the adding proportions where the soil seems to reach the threshold of 9%.

We found that there is an improvement in the compressibility characteristics of the treated soil, a remarkable decrease in the swelling, and the compressibility indexes respectively with increasing percentages of wheat straw.
The decrease in the compressibility index is probably due to the decrease in porosity of the soil and subsequently the decrease in permeability. The reduction in permeability prevents water from flowing inside the soil, thus reducing the efficiency of the dissolution of biopolymer particles (wheat straw) inside the treated samples. This effect was described in numerous studies [31].

3.7 Effect of wheat straw on the free swelling index test (FSI)

The free swelling index (FSI) of the clay treated with the addition of 1, 3, 6, and 9% are shown in Table 11.

Table 11: Effect of WS on Free Swell Index behavior of soil

Additive content (%)	0%	1%	3%	6%	9%
Value FSI (%)	86	33.33	27.27	23.07	15.78

From Table 11, it can be concluded that increasing the percentage of WS in soil from 0% to 9%, led to a significant reduction of FSI. When the WS content reached 9%, the value of the Free Swell Index was reduced from 86% to 15.78%. The decrease in the FSI values can be reached even with small percentages of WS as is proved in the results of the test using 1%.

It can be concluded that even with a very low rate of wheat straw, the value of FSI can considerably reduce this reduction indicates that the addition of WSB reduces the swelling of the clay soil.

3.8 Effect of wheat straw on the unconfident compressive strength (UCS) test

The test pieces were assayed in varying proportions wheat straw and crushed after 24 hours (Figure 9).
Figure 10 shows the variation in stress-strain of the samples of the untreated reconstituted soil and the reconstituted soil treated with different content of wheat straw after 24 hours of curing.

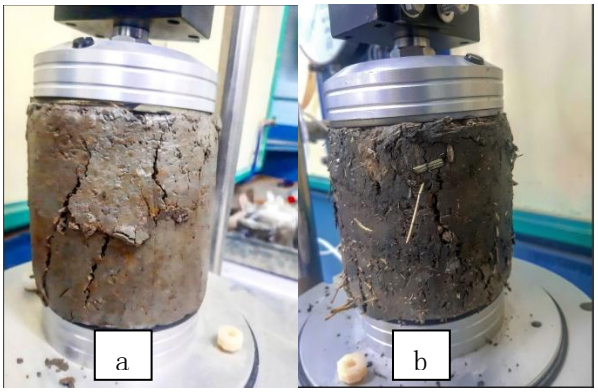


Figure 9: Specimen deformation: (a) untreated soils, and (b) Soil stabilized with 6 % WS

The plot displays the results of the axial stress and the rupture threshold in the function of the axial strain (deformation). A clear differential behavior is observed on the curves of the different proportions with almost a linear proportional aspect. Both the duration and resistance to the compression are expanded parallelly to the adding of the WS. The untreated soil needed only 200 kPa to reach the rupture point whereas the 9% of soil required almost 500 kPa to reach the rupture threshold.

Figure 11 shows the variation of wheat straw on the unconfined compressive strength (UCS) of soil reconstituted alone and treated with different proportions of WS. The value of the unconfined compressive strength increased significantly from 197.95 kN/m^2 at 0% addition to 494.51 kN/m^2 at 9% wheat straw. It is clear that if we increase the wheat straw content the peak of the value of the UCS increases.

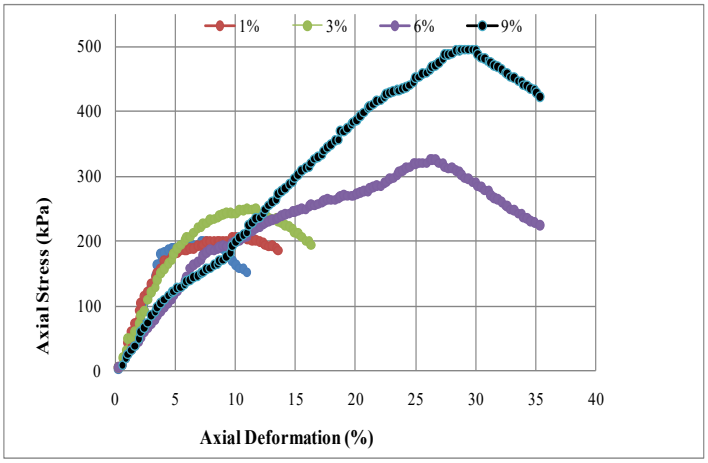


Figure 10: Stress–strain curves for Stress–strain curves for specimens containing different amounts of wheat straw

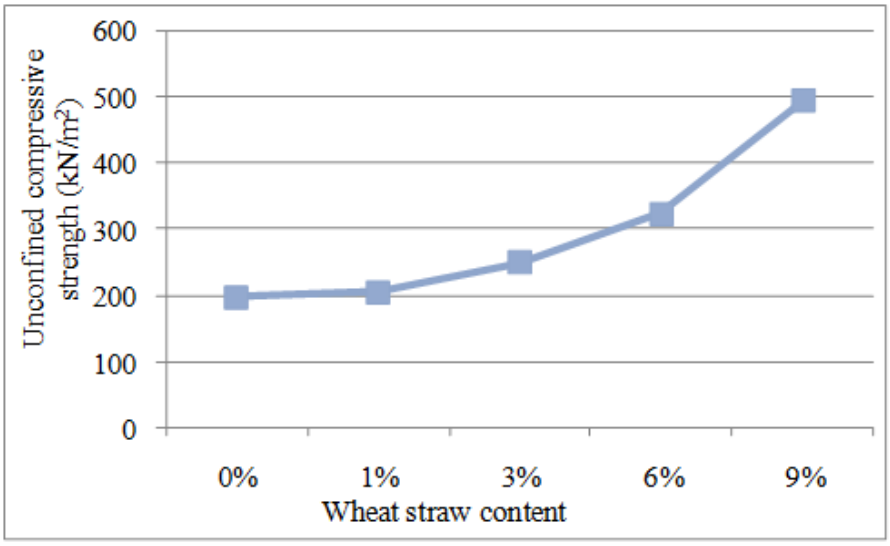


Figure 11: Influence of wheat straw on the unconfined compressive strength

This increase in compressive strength is attributed to the reaction of wheat straw with clay soil particles which results in the formation of a straw binder that enhances the cohesivity of the soil particles, these results are confirmed by those found in previous studies [12, 22].

4 Conclusions

Clay soil changes volume depending on its humidity. It swells with moisture and tightens with drought, causing vertical and horizontal piles and cracking of the soil. The present work was carried out in order to improve the geotechnical characteristics of a reconstituted soil (Soil-bentonite) from the Harraten region in the Jijel province using eco-friendly biopolymer "wheat straw". Different proportions of wheat straw; 1%, 3%, 6%, and 9% were used to depict the behavior of the soil in the function of these added materials. In the light of this study, numerous tests were performed (specific gravity, Atterberg Limits, Proctor standard compaction, Unconfident compressive strength, free swelling index, Direct Shear Test, and odometer test). According to the obtained results, significant changes in the physico-mechanical parameters were observed by the addition of wheat straw, these changes are related to the quantity of the WS. The information that can be derived from these results can be resumed as follow:

- In function, if its specific gravity, the soil became much denser by the adding of WS where it replaces a large part of the voids in the soil. Where the 3% marks the decreasing threshold of *Gs*.
- The optimum wheat straw content corresponds to a pH value of 9.59 at which the amount of WS added is sufficient for chemical reactions to take place.
- Adding the powder to the clayey soil caused alight change in the Atterberg limit values. The results indicate that as the percentage of wheat straw increases, the liquidity limit (*LL*) and plasticity limit (*PL*) also increase, meanwhile the plasticity

index (*PI*) decreases.

- The results of the compaction test of the treated soils in comparison with reference soil show an increase in the optimal moisture content (OMD) of the soil from 16% to 20% parallelly to the decrease of the maximum dry density (MDD) from 1.65 to 1.32 g/cm^3.
- In general words, we note that the increase in the concentration of wheat straw leads to a higher friction angle (φ) and a decrease in cohesion (C) From the results, it can be concluded that the shear characteristics after the addition of different proportions of straw were improved considerably compared to the untreated soil.
- We found that there is an improvement in the compressibility characteristics of the treated soil, a remarkable decrease in the swelling index and the compressibility index respectively with increasing percentages of wheat straw.
- From the results, it can be concluded that increasing the percentage of Wheat Straw in soil from 0% to 9%, led to a significant reduction of FSI, and adding WS to the soil improved the values of unconfined compressive strength.

The study of the effect of wheat straw on the mechanical behavior of swelling clays has shown that the shrinkage and swelling of clay soils which can cause several problems in civil engineering infrastructure can be adequately managed and solved by mixing an appropriate amount of wheat straw as a soil stabilizer.

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