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Impact of Date-Palm Fibers on Fine Soil's Compaction and Strength Properties

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ABSTRACT

This paper investigates the influence of date-palm fibers on the compaction and strength properties of fine soil. The laboratory tests, including specific gravity, compaction tests, and unconfined compression strength tests, were conducted, integrating different proportions (ranging from 0 to 2%) of date-palm fibers into the soil mixture. The palm fibers were divided into two distinct lengths (30 mm and 60 mm) to be mixed with the soil. Nine samples were prepared with varying proportions of date-palm fibers for the experimental investigation, aiming to specifically examine the influences exerted by both palm-fiber length and palm-fiber content on the soil's compaction and strength characteristics when mixed with date-palm fibers. The compaction test results demonstrate a decrease in the dry unit weight and an increase in the optimum moisture content by approximately 10%. Additionally, the length of the date-palm fibers impacts the optimum moisture content and the maximum dry unit weight of the soil mixture. In contrast, the unconfined compressive stress increased by about 30% with higher date-palm fiber contents. This increase in unconfined compressive stress due to increased date-palm fiber content is a significant finding, indicating improved soil strength. This finding holds the enhancing construction performance, sustainability, and cost-efficiency. In conclusion, this soil-fiber mixture shows suitable hydraulic applications. The utilization of natural materials in civil engineering demands the exploration of available natural fibers.

Keywords: Date-Palm fiber, Optimum moisture content, Dry unit weight, Unconfined compressive strength.

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تأثير ألياف نخيل التمر على رص التربة الناعمة ومقاومتها

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الخلاصة

يوضح هذا البحث تأثير ألياف نخيل التمر على خصائص رص ومقاومة التربة الناعمة. لمعالجة هذه المشكلة، تم إجراء الاختبارات المعملية، بما في ذلك الجاذبية النوعية، واختبارات الرص، واختبارات قوة الضغط غير المحصورة، ودمج نسب مختلفة (تتراوح من 0 إلى 2٪) من ألياف نخيل التمر في خليط التربة. ألياف النخيل هي مادة ذات أهمية خاصة، وقد تم تقسيمها إلى طولين متميزين (30 مم و60 مم) ليتم خلطها مع التربة. تم تحضير تسع عينات بنسب متفاوتة من ألياف نخيل التمر للتحقيق التجريبي، بهدف فحص التأثيرات التي يمارسها كل من طول ألياف النخيل ومحتوى ألياف النخيل على خصائص ضغط التربة وقوتها عند مزجها بألياف نخيل التمر. تظهر نتائج اختبار الرص انخفاضا في الكثافه الجافه وزيادة في محتوى الرطوبة الأمثل بنسبة 10٪ تقريبا. بالإضافة إلى ذلك فإن طول ألياف نخيل التمر له تأثير على محتوى الرطوبة الأمثل والحد الأقصى للكثافه الجافه لخليط التربة. في المقابل، زاد إجهاد الضغط غير المحصور بنحو 30٪ مع ارتفاع محتويات ألياف نخيل التمر. هذه الزيادة في إجهاد الانضغاط غير المحصور بسبب زيادة محتوى ألياف نخيل التمر هي نتيجة مهمة، مما يشير إلى تحسن قوة التربة. هذه النتيجة تبشر بتعزيز أداء البناء والاستدامة وفعالية التكلفة. في الختام، يظهر خليط ألياف التربة هذا ملاءمة واعدة للتطبيقات الهيدروليكية. يتطلب الاستخدام المتزايد للمواد الطبيعية في الهندسة المدنية استكشاف الألياف الطبيعية المناسبة المتوفرة بسهولة.

الكلمات المفتاحية: ألياف النخيل، محتوى الرطوبة الأمثل، الحد الأقصى الكثافة الجافة، مقاومة الانضغاط غير المحصورة.

1. INTRODUCTION

The progress in the economy experienced generally has caused a substantial rise in the generation of both solid and liquid wastes **(Ramachandra et al., 2018; Shah et al., 2023)**. Particularly, the waste has led to severe environmental problems, including groundwater contamination and soil degradation through indiscriminate land disposal. Despite efforts to reduce and recover wastes, the data obtained from the study on the chemical composition of Iraqi date cultivars can be used to assess their nutritional adequacy, aid in dietary planning, support the development of value-added products, and promote their utilization in the food industry **(Siddiqua et al., 2022; Al-Farsi and Lee, 2008)**. Landfilling remains the dominant method of waste disposal worldwide, albeit with its drawbacks, such as the production of contaminated liquid known as leachate once rainwater penetrates the waste. (**Arunbabu et al., 2017; Djoudi et al., 2021; Wijekoon et al., 2022)** studied the development of pollution from landfill leachate contributing to understanding the risks, pollution potential, treatment methods, and challenges associated with landfill leachate management. Also, there is an increase in utilizing non-industrial (i.e. natural) building resources. These materials are characterized by their simple, energy-efficient manufacturing processes, often employing raw materials available on-site or in the vicinity **(Daud et al., 2016; Nik Daud et al., 2017)**.

Fibers have assured the in-enhancing properties of soils, like tensile, compression, and shear strength. Incorporating fibers in the soil can prevent erosion in slopes and canals and reinforce embankments, especially in clay soils, thereby offering a prospective solution to environmental interests **(Syed et al., 2020).** Through an exploration of mechanical properties including strength, stiffness, and deformation characteristics of reinforced soil by glass-fiber, the research offers valuable perspectives regarding this reinforcement technique in improving the engineering properties of subgrade soils. **(Chegenizadeh and Nikraz, 2011; Mekkiyah, 2013; Ali and Yousuf, 2016; Sujatha et al., 2021; Alqaissi et al., 2022; Gul and Mir, 2022; Shakir et al., 2022; Aksu Alcan and Çelik, 2023)**.

Reinforced soil encompasses a range of theories and application approaches, forming a subdivision within geotechnical science that focuses on enhancing and stabilizing soil engineering characteristics like strength, durability, and deformability **(Santoni et al., 2001; Ghiassian et al., 2004)**. **(Santoni et al., 2001)** examined the impact of various factors on the performance of fiber-stabilized sand specimens. Five main findings were obtained through laboratory tests on sand samples reinforced with randomly oriented discrete fibers: 1) The inclusion of fibers significantly improved the sand's compressive strength. 2) An optimal fiber length of 51 mm was identified. 3) The best performance occurred with a fiber dosage rate between 0.5% and 1.0% of the dry weight. 4) Specimen performance was enhanced under wet and dry conditions, particularly near the optimum range. 5) Including up to 8% of silt did not significantly affect the fiber reinforcement's performance. (**Ghiassian et al., 2004)** focused on the behavior of fiber-reinforced soil, which acts as a composite material with high-tensile-strength fibers embedded in a plastic soil matrix. This was to understand how synthetic fibrous materials can improve the strength of fine sandy soil, with a particular interest in repurposing discarded fibrous carpet waste for soil reinforcement. Drained triaxial tests were conducted on cylindrical specimens. The results demonstrate that including fibrous materials from carpet waste enhances the shear strength of silty sands.

Reinforced soils can be created using two approaches: one involves including continuous strengthening presences (such as sheets, bars, or strips) in a specific arrangement within a soil mass, whereas the other method involves mixing detached fibers arbitrarily with a soil fill. The fibers are introduced and mixed into the soil **(Yetimoglu et al., 2005; Bawadi et al., 2020; Arfin et al., 2023)**. For example, (**Arifin and Normelani, 2019)** used natural fiber derived from oil palm empty fruit bunches (EFB), to reinforce soft soil and enhance its shear strength and load-bearing capacity. Their study investigates various fiber-to-soil compositions (5%, 6%, 7%, and 8%) through multiple tests, including compaction, unconfined compression, laboratory vane, and California Bearing Ratio tests. The results reveal that soft soil can be effectively compacted with a fiber content exceeding 5%, reaching a maximum density of 0.92 g/cm^3 at 7% fiber content. The soil-EFB mixtures significantly improve shear strength and load-bearing capacity, transitioning the soil's consistency from soft to medium. The optimal fiber content shows the highest unconfined compressive strength (q_u), undrained shear strength (S_u), and California Bearing ratio (CBR) values (0.8 kg/cm^2, 0.65 kg/cm^2, and 6%), respectively, which is found to be between 6% and 7%. This research demonstrates the potential of EFB-derived natural fiber to enhance the engineering properties of soft soil for construction applications.

On the other hand, laboratory tests were conducted by **(Yetimoglu et al., 2005)** using the California Bearing Ratio (CBR) method to examine the behavior of sand reinforced with randomly distributed fibers for soft clay. The study aimed to assess how varying fiber content affected bearing capacity, stiffness, and ductility in this system. The results indicated that adding fibers to the sand fill significantly increased the peak piston load, with greater reinforcement benefits seen at higher fiber content levels. However, initial stiffness remained relatively unaffected. Additionally, the penetration depth at which the maximum piston load occurred increased with higher fiber content. Importantly, increasing fiber content also led to increased brittleness, resulting in a greater loss of peak strength in the reinforced soil.

Therefore, employing date-palm fibers becomes an achievable choice for the reinforcement of clayey soil using a natural material. Additionally, palm trees are located in many areas throughout the world, particularly in the Middle East. Iraq may be considered the date-palm fiber country. Its growth extends through Tikrit on the Tigris and Ana on the Euphrates, down to Al-Faw on the Arabian Gulf. It is estimated that the number of palm trees in Iraq exceeds 22 million trees, which covers an area of over 120,000 hectares **(Alotaibi et al., 2023)**. Date-palm fiber ranks among the plentiful natural resources that are easily obtainable and there are many types of palm trees that mostly not only benefited from date fruits, but they benefited from all parts of that tree, including leaves, trunk, and fibers **(Nnochiri and Aderinlewo, 2016; Ramu and DayakarBabu, 2022)**. Natural fibers exhibit many advantages and properties. The main benefit of employing natural fibers lies in substantial cost reduction and the creation of lightweight products. This is driving significant interest in their replacement for other types of fibers.

(Morel et al., 2007) used compacted remaining granite soil treated with Palm Oil Fuel Ash (POFA) in concentrations ranging from 0% to 15%. The purpose was to assess its hydraulic conductivity for potential use in landfill scenarios. The samples were subjected to water permeation, focusing on how water content (%) and POFA content influenced the results. Samples were established threshold of 1.9 x 10^{-9} m/s which were used to establish criteria zones for different POFA mixtures. The findings indicated that hydraulic conductivity values decreased as compaction efforts, water content, and Fuel ash content increased, particularly up to around 10%. This specific soil-POFA combination was identified as the most suitable for hydraulic applications.

A sequence of swelling and compression soil tests was completed by (**Al-Taie et al., 2021)** to evaluate the effectiveness of subjectively distributed date-palm fibers in addressing the behavior of swelling of expansive soils. From the outcomes of this study, the swelling potential of expansive soils has been reported as a decreasing function of fiber content reaching 61% of reduction at 2% of date-palm fiber content. The outcomes of the date-palm on swelling were noticed more significantly for samples subjected to low initial consolidation pressure before sample wetting. Moreover, from the consolidation test, the compression index in fiber-reinforced soils decreased linearly with the increase in fiber content. Then, it should be noted that the coefficient of permeability has shown an optimal value of around 1% of fiber content which suggests an optimal value for fiber content of around 1%. The results obtained from the tests go by findings of other research utilizing other natural fibers. It is suggested that the effectiveness of the fibers in limiting the swelling of expansive soil goes through the interfacial resistance developed in the soil-fiber contact zone, by the fibers stretching throughout the soil matrix during swelling. Those suggestions may be confirmed through shear strength evaluation of unreinforced and palm leaf fibers reinforced expansive soils. (**Raghab et al., 2013)** investigate the utilization of natural fibers, specifically those derived from oil palm bunches (EFB), to improve the strength and the bearing capacity of the soft soil. Different mixtures of EFB fibers, ranging from 5% to 8%, were incorporated into the soft soil. Various tests were conducted, including compaction, California Bearing Ratio (CBR), and unconfined compression tests. The results highlight that the soil was compacted with more than 5% fiber content, with the best density achieved at

7%. The addition of EFB fibers enhances the shear strength, and ultimate bearing capacity of the soft soil, resulting in a transition from soft to medium consistency. The optimal fiber content for maximum values of q_u, Su, and CBR was found to be around 6% to 7%.
Therefore, this study aims to assess the effects of Date-palm fiber on the compaction, and strength properties of soil, considering different palm contents and fiber lengths. The experimental results presented in this paper offer valuable understanding regarding the implementation of mixing the soil with the date-palm fiber.

2. MATERIALS

2.1 Date-Palm Fiber

Across the Middle East and North Africa, there exist more than 140 million date palms. Leading the production of dates are countries like Egypt, Iran, Saudi Arabia, UAE, Pakistan, and Sudan. Each year, the act of pruning this date-palm fiber for agricultural needs generates a waste volume exceeding 48.8 million tons. As a result, the manufacture of date-palm fiber has become a significant achievement. These countries utilize sustainable textile fibers derived from various date-palm fiber byproducts such as branches, leaves, flyers, and fruit twigs. Within the scope of this study, the date-palm fibers are mixed with the soil at percentages of 0.5%, 1%, 1.5%, and 2% of total weight and different lengths (the fibers are cut in 30 mm and 60 mm long pieces, as shown in **Fig.1**. Some specific properties of the date-palm fiber proposed by (**Elseify et al., 2020)** as shown below:

1. Length: 25-240 mm
2. Diameter: 100-1000 μm
3. Density: 9-12 kN/m^3
4. Tensile Strength: 54-187 MPa
5. Elongation at Break: 4-12%

Table 1 shows the properties of the date-palm fiber. The date-palm fiber exhibited an average density of 8.2 kN/m^3, which is markedly less than frequently used synthetic fibers like E-glass fiber (25.6 kN/m^3) and carbon fiber (14–188 kN/m^3) but higher than other natural fibers. The finding is within the specifications of (**Elseify et al., 2020)** and agrees with **(Syed et al., 2016)**.

Figure 1. Date-palm fibers at two different lengths; 30 mm (right) and 60 mm (left)

Table 1. Properties of used date-palm fiber

Property	value
Average diameter (mm)	0.47
Average length (mm)	253
Average density (KN/m^3)	8.2
Natural moisture content (%)	7.2

2.2 Soil

The soil used is fine, and it can be considered as high plasticity clay (CH) soil according to the USCS System. **Table 2** shows the properties of the soil.

Table 2. Soil properties

Property	value
USCS	CH
Specific gravity	2.62
Natural Water Content (%)	17.4
Liquid Limit (%)	41
Plastic Limit (%)	24
Optimum water content %	15.5
Maximum dry unit weight (KN/m^3)	18.0

The water content is calculated according to **(ASTM D2216-10, 2010).** The Classification according to USCS-CH (**ASTM D2487-17, 2020)**. The liquid and plastic limits are calculated according to **(ASTM D4318-10, 2012)**. The specific gravity test is carried out according to **(ASTM D854-14, 2002)**. The compaction test is calculated according to **(ASTM D698-12, 2021).** The strength test is carried out according to (**ASTM D2435-04, 2011).**

3. EXPERIMENTAL WORK

Laboratory tests including specific gravity, compaction tests, and unconfined compression strength tests are aimed to judge the influence of date-palm fiber on the geotechnical characteristics based on the soil-fiber mixture at percentages (0.5%, 1%, 1.5%, and 2%) by weight of date-palm fiber. Initially, the soils were subjected to drying in a heating oven at around 105°C before their incorporation into the mixtures. The total dry weight, denoted as w, necessary for specimen preparation can be determined from **Eq. (1)**.

$$w = w_s + w_{dp} \tag{1}$$

Where w_s and w_{dp} signify the weights of the fine and date-palm fiber, respectively. To create the soil-palm mixture, the essential quantities of soil and date-palm fiber were initially measured to achieve the total weight, w, of the sample. These components were then combined in their dry states. Subsequently, the dry mixture of soil and date-palm fiber was blended with the appropriate quantity of water, as defined by the optimal water content. All mixing procedures were conducted physically, ensuring meticulous attention to ensure consistent mixtures at every mixing stage. The materials used and the corresponding tests are described as follows:

3.1 Compaction Tests

The Standard proctor tests **(ASTM D698-12, 2021)** were accomplished to examine the compaction features of the soil-date-palm fiber mixtures **(Darby et al., 1993)**. The necessary compaction effort was employed to achieve uniform compaction of the moist clay-date-palm fiber mixtures. To guarantee consistent compaction, the required amount of the wet mixture was placed within the mold collars get-together and then compressed in three stages, alternating from both ends until the specimen attained the dimensions of the mold.

3.2 Unconfined Compression Strength

The compressive strength of the soil-date-palm fiber compacted samples was examined through unconfined compression strength tests **(ASTM D2166-16, 2016).** The test is commonly employed because it is a cost-effective method for approximating the compressive strength of fine soils. Cylindrical samples of a length-to-diameter ratio of 2; the length L is 70 mm, and the diameter D is 35 mm; were prepared for the strength tests. The samples were equipped at the maximum dry unit weight and optimum water content for both the soil and date-palm fiber mixtures. To extrude the compacted samples out of the mold, a hydraulic jack was used. A minimum of three samples were prepared for each grouping of variables to ensure reliable compressive strength results. The samples that were prepared were placed within a humid container to avoid drying as they awaited their turn in the compression machine. For every combination of variables, a minimum of three models were exposed to testing, with a deformation rate of 0.16 mm/min, following the previously described specimen preparation method.

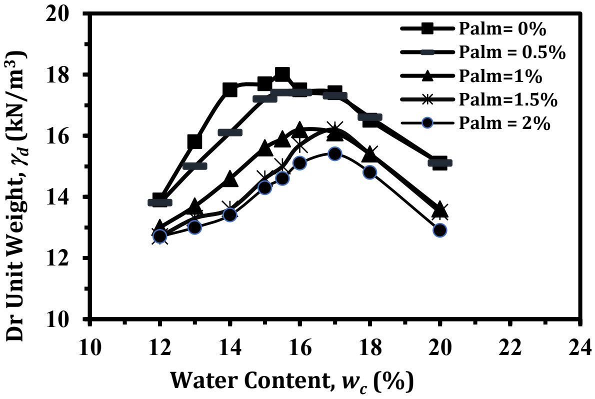
4. RESULTS AND DISCUSSION

4.1 Impacts of Date-palm Fiber on Compaction Behavior

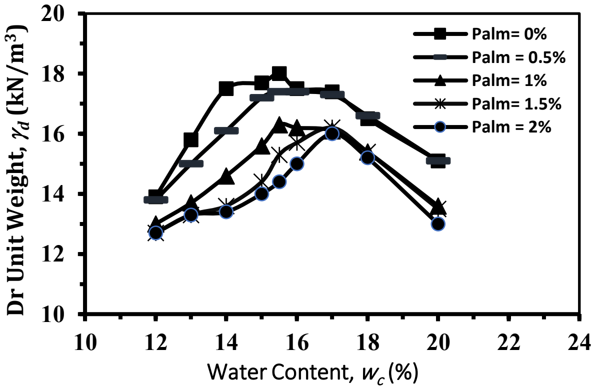
A series of compaction tests were applied on the date-palm fiber-soil mixture at different proportions of (0.5%, 1%, 1.5%, and 2%) by weight of palm fiber. The optimum water contents (OMC) and the maximum dry unit weight (MDD) values of the soil specimens are shown in **Fig. 2**; for different contents and lengths of palm, The results show that the MDD has an opposite relation with the date-palm fiber which appears in decreasing the MDD of the stabilized soil with increasing palm content. The replacement of soil by the palm of low density tends to decrease the unit weight of the stabilized clay within a certain volume. Mixing the clay with the palm of 0.5% decreases the MDD by 3% less than the pure clay, then MDD continues its reduction to 12% at the palm content of 2%. The Optimum Moisture Content (OMC) values for Date-Palm fiber-reinforced soil results show that as the percentage of Date-Palm fiber content increases, the OMC also increases. Specifically, the OMC rises from 15.5% at 0% fiber content to 16.9% at 1.0% fiber content. Beyond 1.0% fiber content, the OMC remains constant at 17.0%. This suggests that Date-Palm fibers initially act as absorbent materials, necessitating more moisture for proper compaction, but beyond a certain threshold, additional fibers have no substantial impact on the OMC. These findings provide valuable insights for optimizing construction practices when working with

PL=30mm Date-Palm fiber-reinforced soil, ensuring proper moisture content for effective compaction and soil stability. While, for Pl=60 mm, The OMC starts at 15.5% with 0% fiber content, increases slightly to 16.2% at 0.5% fiber content, decreases to 16.0% at 1.0% fiber content, and remains constant at 17.0% for 1.5% and 2.0% fiber content. This suggests that the influence of Date-Palm fibers on moisture requirements for compaction may be less pronounced in the PL=60mm situation compared to PL=30mm.

As a result, the optimum moisture content (OMC) shows a direct relation with palm content—the ability of palm fiber to absorb water which tends to increase the OMC. The above results are well compared with (**Arifin et al., 2023)**. Although palm of 1.5% and 2% seem to have a low and similar value of MDD for the fiber contents used in this study this content shows the greatest value of OMC compared to other palm contents as is shown in **Fig. 2.** The MDD and OMM results are illustrated in **Table 3** in which it shows the compaction tests results for the fine soil specimen (without date-palm fibers) and soil specimen with 0.5%, 1%, 1.5% and 2.0% of date-palm fibers at lengths of 30 mm and 60 mm.



(a) Date-palm fiber Length is 30 mm



(b) Date-palm fiber Length is 60 mm.

Figure 2. Dry unit weight versus water content relations for lengths of 30mm and 60 mm

Table 3. Compaction test parameters for palm lengths (PL) of 30mm and 60mm.

Date-palm fiber content %	Maximum Dry unit weight (MDD)		Optimum Moisture Content (OMC)	
	PL=30mm	PL=60mm	PL=30mm	PL=60mm
0	18.0	18.0	15.5	15.5
0.5	17.4	17.4	16.0	16.2
1.0	16.2	16.3	16.9	16.0
1.5	15.7	16.2	17.0	17.0
2.0	15.4	16	17.0	17.0

The optimum water percentage of the tested soil without fibers is (15.5%) and its maximum dry unit weight is (18.0 KN/m^3). As the fiber content increases, it leads to a rise in the optimum water content and a drop in the dry unit weight; agreeing with findings from other studies **(Salih, 2022; Shaker and Dafalla, 2017; Nik Daud et al., 2017)**. The rise in the OMC can be ascribed to the significant water absorption capacity of date-palm fibers, which surpasses that of the soil. Conversely, the decline in MDD is due to the replacement of dense soil particles with lighter palm fibers. The length of palm fibers has little consequence on the OMC and the MDD of the soil-mixture. **Fig. 3** shows that the mixing of the palm fiber caused a rise in the average optimum moisture content and a reduction in the average MDD (for the two cases of lengths) at rates of (9.7 % and 10 %). To compare MDD between the palm lengths of 30mm and 60 mm, **Fig. 3** shows that MDD records similar unit weight for the palm content of 0% to 2%. Later, an improved MDD from 1% of palm to 2 % for the length of 60 mm. The variation in OMC, as indicated in **Fig. 4**, lacks a clear and scientifically explainable trend, indicating the necessity for more in-depth research in this area. The decrease in MDD beyond the 18% fiber content threshold might be attributed to the decrease in the specific gravity *Gs* of the soil samples resulting from the addition of more date-palm fiber. The finding agrees with **(Nnochiri and Aderinlewo, 2016).**

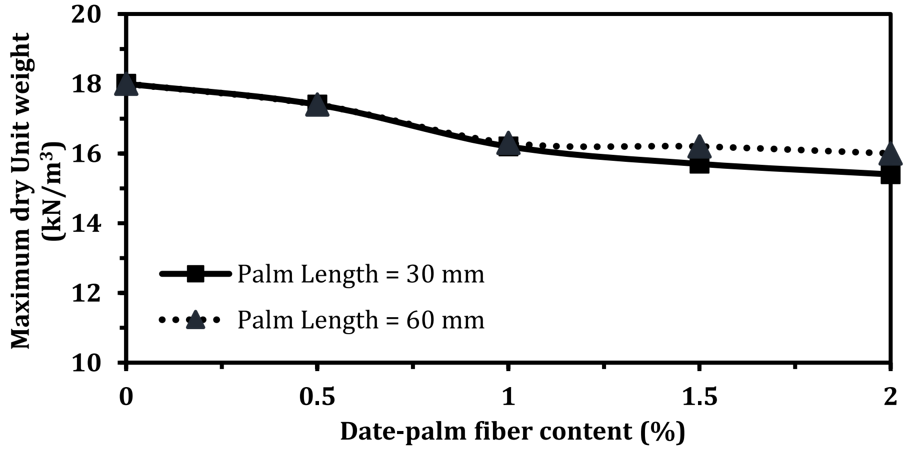


Figure 3. Date-palm fibers versus maximum dry unit weight relations.

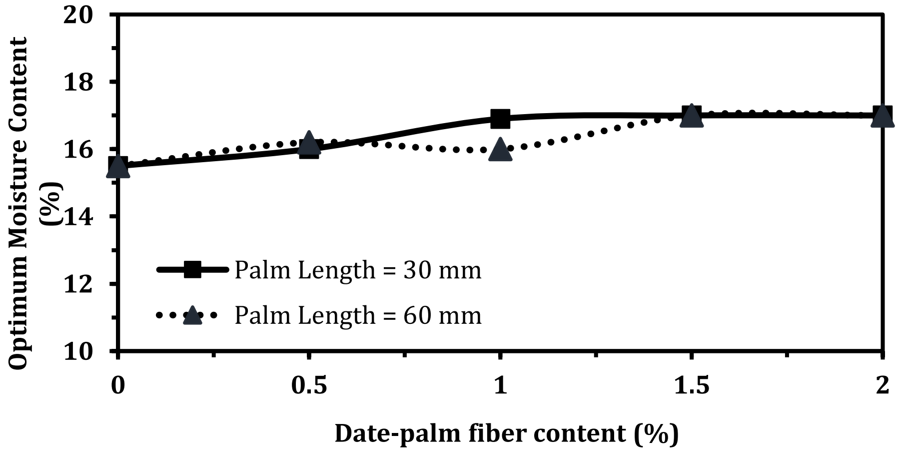


Figure 4. Relation between date-palm fiber content and optimum moisture content

4.2 Effects of Date-Palm Fibers on the Unconfined Compressive Strength

Unconfined compression tests were done on cylindrical compacted specimens of maximum dry unit weight MDD and optimum moisture content OMC. The prepared samples were then tested in unconfined compression test equipment. The specimens' contents of date palm fibers were 0.5%, 1.0%, 1.5%, and 2.0% by the dry weight and the fiber lengths were 30mm and 60mm. The results of the compression tests are given in **Table 4.** The results demonstrate that the unconfined compressive stress increases with increasing the palm fiber content as reported by (**Nik Daud et al., 2017)**.

Fig. 5 shows the unconfined results conducted on unstabilized and stabilized soil with varying percentages of date-palm fiber, from 0.5% fiber content to 2% fiber content. This curve indicates that the presence of arbitrarily distributed palm fiber improved load resisting capacity of the soil suggestively. The date-palm fiber length of 30 mm is more effective in providing high compressive strength and hence improving the soil strength. Shorter fibers tend to distribute more evenly throughout the soil matrix and create a stronger bond with the soil particles. This improved distribution allows for better load transfer between the soil and fibers and enhanced compressive strength. Also, shorter fibers are more likely to align in a preferred orientation within the soil matrix during compaction. So, it can be seen that the effectiveness of fiber length can vary depending on factors such as soil type, compaction method, and specific engineering requirements. Therefore, conducting inclusive testing and analysis to determine the ideal fiber length for a given situation is necessary. In this case, the compressive test results of 86 kPa suggest that a fiber length of 30 mm is the most effective choice for improving soil strength.

Compared to non-fibrous specimens, compressive stress increased by about 30%. This happens since manually molded samples are not homogenous; hence, preventing a homogenous distribution of the load to the fibers, which causes lower compressive stress. Whereas shorter fibers give better mixing and more uniform distribution. There is an unimportant change in the strength of initially adding 0.5% of the palm fiber to the soil which was observed in comparison to higher addition levels than 0.5% which improved with the increased inclusion of the palm fibers. This will lead to a different result, and it can be qualified to the aspect that additional frictional resistance is mobilized between the soil particles and the fibers.

Table 4. Max. stress for different date-palm fiber content at palm fiber lengths (PL) of 30mm and 60 mm.

Date-palm fiber contents %	Unconfined compressive strength (kPa)	
	PL=30mm	PL=60mm
0.0	66	66
0.5	70	68
1.0	83	73
1.5	85	76
2.0	86	76

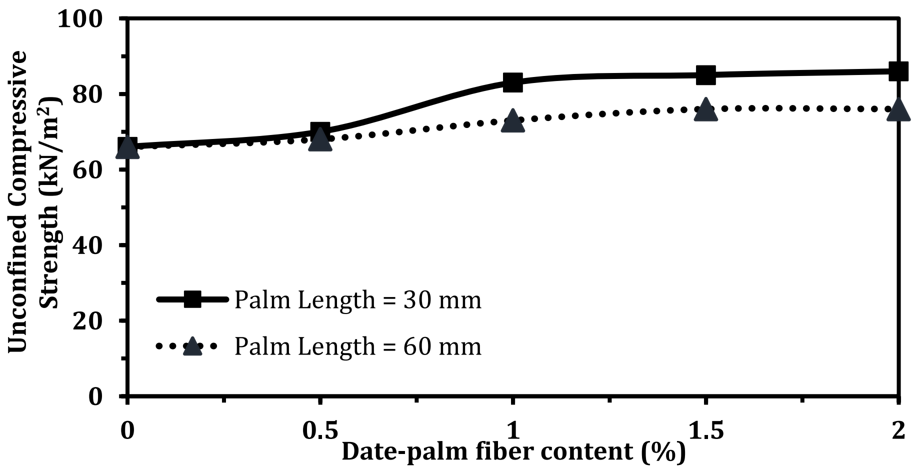


Figure 5. Relation between unconfined compression strength and date-palm fiber content

The relation between the shear strength and palm content is shown in **Fig. 6**. Although the 0% date-palm fiber content specimens have the lowest unconfined compressive strength results, it is shown that the shear strength of soil rises when mixed with palm fibers having a ratio 0.5% to 2%. The shear strength of the mixture is developed when adding fibers. It is similarly shown that the shear strength results of soil mixed with a fiber length of (60mm) were lower than those of fiber with a length of (30mm) as shown in **Fig. 6**. At a fiber length of 30 mm, the shear strength exhibits a significant increase, rising from 66 kN/m^2 for the untreated soil to 86 kN/m^2 at a 2% fiber content, marking an approximately 30% enhancement. Similarly, with a fiber length of 60 mm, the shear strength increases from 66 kN/m^2 for the natural soil to 76 kN/m^2 at a 2% fiber content, representing an approximate 15% increase. The soil samples' pattern is shown in **Fig.7**. These above findings agree with similar outcomes documented in the literature using various stabilizing agents **(Nnochiri and Aderinlewo, 2016; Nik Daud et al., 2017)**. Therefore, the shear strength is developed when using the fiber length of 30 mm compared with the 60 mm, which concludes that both the length of the date-palm fiber and the content of date-palm fiber controlled the shear strength performance. Also, the increase in unconfined compressive stress with higher Date-Palm fiber content is a significant and promising observation. It signifies the potential for enhanced soil strength, offering numerous benefits in-terms of construction performance, sustainability, and cost-effectiveness.

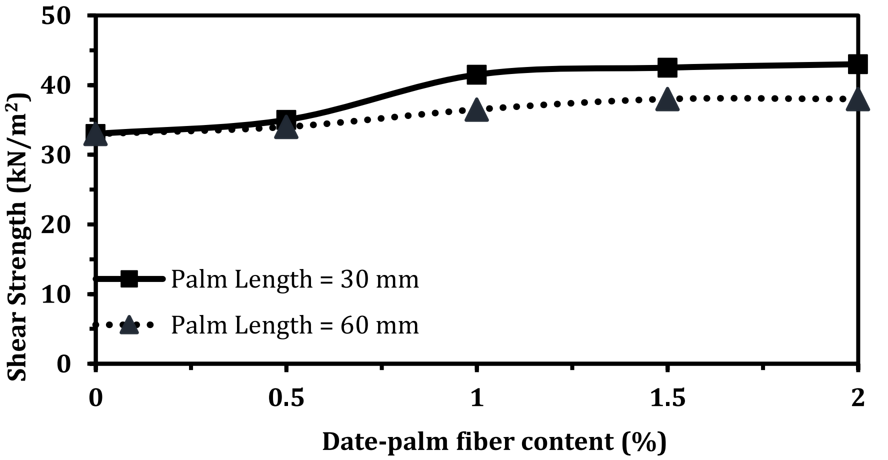


Figure 6. Relation between shear strength and date palm fiber content

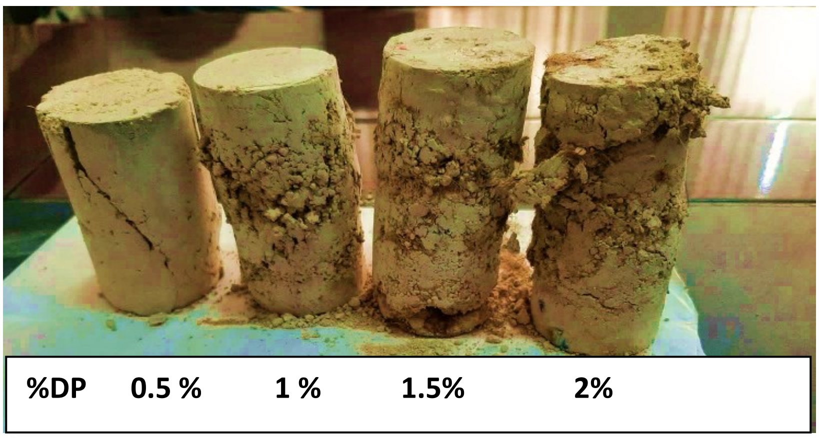


Figure 7. Soil samples' pattern

However, further research and practical applications are necessary to fully harness the advantages of Date-Palm fiber-reinforced soil in construction projects. The findings indicate that the mixing of the date-palm fiber affects both the compaction and strength characteristics of the soil. The compaction test results revealed that increasing the palm content caused a decrease in the MDD and an increase in the OMC. Specifically, the least MDD of 16 kN/m^3 was achieved, while the highest optimum moisture content of 17 kN/m^3 was obtained.
Regarding the effect of fiber length, it was revealed that the length of date-palm fiber did not significantly improve both OMC and MDD. However, when assessing the unconfined compressive strength, the results showed that higher date-palm fiber contents led to increased compressive stress. The best performance regarding the compressive strength was achieved through a fiber length of 30 mm, recording a 30% increase in comparison with non-fibrous specimens. Additionally, it was observed that the distribution and uniform mixing of Date-palm fiber became more challenging with longer fiber lengths, leading to an uneven fiber distribution and lower compressive stress.
The effect of the palm fiber on soil compaction and strength characteristics is addressed, emphasizing the importance of considering fiber content and length for optimal results. The outcomes contribute to the understanding of utilizing date-palm fiber as a reinforcement material in soil engineering applications. Further research is recommended to explore aspects such as long-term durability and the performance of palm fiber in different soil types, to evaluate its suitability and potential in various geotechnical projects. The results underline the likelihood of using date-palm fiber as an operative reinforcement material for enhancing soil compaction and strength properties, providing detailed knowledge for engineers and researchers to outline the optimum fiber content and length.

5. CONCLUSIONS

An experimental study was conducted to examine the significant influence of adding date-palm fibers on the compaction behavior and unconfined compressive strength of fine soil. Different proportions (ranging from 0 to 2%) of date-palm fibers were mixed with fine soil and divided into two distinct lengths (30 mm and 60 mm). Nine samples were prepared with varying proportions of date-palm fibers for the experimental investigation, with the specific aim of examining the influences exerted by both palm-fiber length and palm-fiber content on the soil's compaction and strength characteristics when mixed with date-palm fibers.
The compaction test results showed that higher date-palm fiber content led to lower MDD and higher OMC, with the least MDD recorded at 16 kN/m^3 and the highest OMC reaching 17 kN/m^3. While the unconfined compressive stress increased with higher date-palm fiber contents. The best compressive test results were achieved with a fiber length of 30 mm, resulting in a compressive stress of 86 kPa, representing a 30% increase compared to non-fibrous specimens. In contrast, the 60 mm fiber length posed challenges in achieving uniform mixing, resulting in uneven fiber distribution and lower compressive stress. Furthermore, both fiber length and content had a noticeable impact on the shear strength performance of the soil. These findings suggest that date-palm fibers can effectively reinforce fine soil, particularly in various automotive industries. Successful utilization requires comprehensive research, testing, and adherence to engineering best practices to ensure both short-term and long-term sustainability benefits.

NOMENCLATURE

Symbol	Description	Symbol	Description
CBR	California Bearing Ratio	S_u	undrained shear strength
MDD	Maximum Dry Unit Weight	w	total dry weight
OMC	Optimum Water Contents	w_{dp}	weight of date-palm fiber
POFA	Palm Oil Fuel Ash	w_s	weight of the fine soil
q_u	Unconfined Compressive Strength		

Credit Authorship Contribution Statement

Zina Mikhael: Writing, review, and editing. Writing of original draft, and methodology.
Zena Hadi: writing, review, and editing.

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.

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