Date Palm Fiber Reinforced Composites

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Contributor: Musa Adamu , Yasser Ibrahim , Hani Alanazi , Fayez Alanazi ,

The use of natural fibers in cementitious composites continue gaining acceptability and applicability due to the shortcomings and disadvantages of synthetic fiber; this is because natural fibers have advantages of sustainability, eco-friendliness, and economy. Biodegradable natural fibers, being low density and lightweight, with typical values of strength-to-weight ratio, aspect ratio, elastic modulus, and strength, may be competitive for substituting synthetic fibers such as glass and carbon. Indeed, natural fibers are mostly non-irritating for the skin and typically pose no troubles or issues for breathing, which is not the case with many synthetic fibers. Date palm fiber (DPF) is a natural fiber obtained as waste material from a date palm tree. In many countries, with large date production, DPF is easily available as a process by-product, with a low processing cost. Being sustainable and environmentally friendly, DPF is continuously gaining acceptability as fiber material in different composites such as concrete, mortar, gypsum composites, clay composites, and bricks.

Natural Fiber | Date Palm Tree | Date Palm Fiber | Cementitious Composites | Mortar | Concrete

1. Date Palm Tree

Date palm tree followed the botanical classification as: Kingdom of Plantae; Subkingdom of Tracheobionta; Superdivision of Spermatophyta; Division of Magnoliophyta; Class of Liliopsida; Subclass of Arecidae; Order of Arecales; Family of Arecaceae; Genus of Phoenix L.; Species of Phoenix dactylifera L [1]. Date palm tree belongs to the Angiosperms/monocotyledon (Aracaceae family) consisting of more than 200 genera and 200 species. The date palm tree falls into the phoenix (Coryphoideae phoeniceae) genera with approximately 14 species, with only the Phoenix dactylifera which means “finger bearing” cultivated for its fruit [2][3]. Date palm (phoenix dactylifera L) is one of the oldest trees grown mainly for fruit and is mostly cultivated in arid regions of North Africa, Middle East including the Persian Gulf Nations dated back to more than 3,500 years ago [4][5][6][7]. According to another findings, the history of date palm tree cultivation was dated back to more than 7000 years back [2]. Based on archaeological findings and data, the cultivation of date palm tree dated back to 5000–3000 BC near the Gulf of Persia and spread throughout the Middle East [8][9][10][11]. The date palm is one of the few trees that can tolerate high temperature, long period without rain (drought), and salinity; this is why the desert regions consider it as a symbol of life [11]. Date palm trees can withstand and grow in any climatic zone as it has a good resistance to bad climatic conditions. It can grow in regions with temperature ranging between –6 and 50 °C [2]. The average productive lifespan of a date palm tree is 40 to 50 years, with few reaching more than 100 years [12].

The date palm tree is generally dioecious, i.e., have different trees categorize as male (staminate) and female (pistillate). The pollen is produced by the male tree while the fruit is produced by the female palm tree, and the date fruit is produced through pollination which occurs naturally by wind action; however, for commercial production purposes, artificial pollination is normally introduced [3][13]. The main advantage of date palm tree is the fruit production. The date fruit is very sweet and is consumed in fresh, hardened, or processed state. It is a good source of energy to humans and animals when consumed. The average energy for a kilogram of fresh and dry dates are 1570 calories and 3000 calories, respectively. About two-third of date fruit weights is sugar and one-fifth is made of water. The remaining weight comprises minerals, protein, fat, vitamins, tannis and other components, which is why date fruit is beneficial for the human diet [2]. Other beneficial use of date palm to humans includes the production of baskets, mats, and ropes using the leaves. Some parts of the date palm trees are utilized for making paper, production of energy, toxic and heavy metals absorption [6][14].

There are more than 120 million date palm trees globally, out of which about 67% of it are cultivated in the Middle East and North Africa [15]. Date palm is also found in countries such as India, Pakistan USA (California), Canary Islands, Mexico, southern Africa, South America [12][14].

2. Date Palm Fiber

Date palm fiber (DPF) is one of the most readily available, cost effective, sustainable, and environmentally friendly natural fiber in many countries. The DPF are obtained from the large quantities of the waste generated from the date palm tree which are mostly disposed without proper utilization. DPF has a specific advantage of higher strength-to-cost ratio in comparison to other natural and synthetic fibers [16]. A typical date palm tree is normally trimmed annually to cut down the tree branches and fibers. For a single tree about 10 to 15 branches are removed and more than 20 kg of dry fiber and leaves are generated, which are mostly not properly recycled or utilized, despite the DPF having high content of cellulose, lignin, hemicellulose, and other compounds. [16][17][18][19][20][21][22]. In Saudi Arabia, more than 500,000 tons of date palm waste including the fiber are generated annually, and are mostly not properly utilized [22]. Out of these amounts, about 100,000 tons are waste generated from the date palm leaves and 15,000 tons from the DPF [20][23][24]. The DPF is obtained from the palm tree stem which is covered with a mesh of single fiber. A natural woven mat of intersected fibers of different diameters are formed by the fiber all-round the tree stems/trunk. The woven mat is conventionally used for making baskets and ropes in several countries after it has been removed from the tress and cleaned; however, only a small percentage of the fiber is used for these applications considering the global generation of the DPF [25][26].

DPF contains high amount of cellulose within the lignin matrix. The cellulose and lignin contents of DPF are similar to that of hemp, sisal and coir fibers, buts its water absorption is less than that of the other fibers mentioned. The lower water absorption of the DPF in addition to its lower density compared to other plant based natural fibers, makes it suitable for use in automotive and polymeric composite applications [27][28].

3. Date Palm Fiber Utilization in Cementitious Composites

Date palm fiber (DPF) has been used in different cementitious composites, such as concrete and mortar as reported by several studies. Other DPF reinforced composites are gypsum and clay bricks composites.

3.1. DPF Reinforced Mortar

Benmansour et al. [29] studied the effect of DPF as an insulating building material in cement mortar; they prepared different cementitious composites using three different fiber sizes based on diameter. The DPF sizes were 3mm, 6mm and a combination of the 3mm and 6 mm diameters; they prepared different mortar mixes using DPF concentrations of 5%, 10%, 15%, 20%, 25% and 30% of the total weight of the composites. The findings showed that the density and thermal conductivity of the mortar decreases with increases in DPF contents; this decrement is more pronounced on the lower sized DPF. Similarly, the compressive strength of the mortar decreased with increase in DPF. At 5% DPF content, there was a decrease by 92%, 91.9% and 95% for 3 mm DPF, 6 mm DPF and their combinations, respectively; however, they achieved acceptable strengths at lower concentrations of DPF less or equal 15% which can be used for structural applications and improved thermal insulation. Boukhattem et al. [30] produced binder less board using DPF, and in another mix produced cement composite (mortar) using DPF with varying percentages from 0 to 51%; they washed the DPF with high pressure water to remove impurities and then oven dried it at 70 °C until it was completely dried. Their findings showed that DPF reduced the unit weight of the cement composite, where for 51% DPF addition, a reduction of 30% and 39% in fresh and hardened densities, respectively, were reported. Furthermore, DPF increased the water absorption and porosity of the mortar, where for 51% DPF addition an increment in porosity by 71% was recorded. Thermal conductivity of the mortar was also reported to decrease with addition of DPF, where a decrease by 42% and 70% at saturated and dry state, respectively, were reported. In a similar study, Boumhaout et al. [31] investigated the effect of DPF addition on the mechanical properties and thermal insulation of mortar; they varied the DPF from 0% to 51% by volume of the material, and washed the DPF using high pressure water and then sun-dried it for 48 h and then oven-dried it at 70 °C to remove impurities. The findings showed the ductility of the mortar increased with increment in DPF content; however, the flexural and mechanical strengths of the mortar decrease with increment in DPF addition. A reduction of up to 63% and 81.5% were recorded for flexural and compressive strengths, respectively, at 51% DPF. Additionally, the thermal conductivity and diffusivity of the mortar decreases with increase in DPF addition. For 51% DPF addition, a reduction by 70% and 52% were reported for thermal and diffusivity conductivities, respectively. In a similar work, Haba et al. [32] studied the thermal and hygric properties of cement mortar reinforced using 15% DPF by weight as a new insulation building material; they also reported increased porosity and water absorption by up to 58% and 62%, respectively, with addition of 15% DPF. The thermal conductivity of the mortar was reported to decrease with the addition of the DPF. Their conclusions revealed that DPF concrete is highly permeable to water vapor due to its high porosity. Additionally, the DPF mortar was classified as type II based on its sorption isotherm curve which was characterized as a macro-porous adsorbent material. Lastly, they concluded that DPF mortar can be used as a thermal insulation material. Khelifa et al. [33] studied the effect of DPF volume, length, and treatment (NaOH concentration and immersion time) on the mechanical properties of mortar; they designed the experiments using response surface methodology (RSM), where they used the following variables: fiber content (1%, 3% and 5% volume), fiber length (5mm, 10mm and 15 mm), NaOH concentration (1%, 3% and 5%) and immersion time (2, 8 and 14 h). The concentrations of NaOH and immersion time were used for treating the fibers before applying into the mortar. After treating with NaOH, the DPF were immersed into 0.5% sulfuric acid and then washed with deionized water to achieve a neutral pH. Their findings showed that the bending stress and modulus, compressive strength and modulus increases or decreases depending on the combinations of the variables; they achieved the highest flexural strengths using 1% fiber with 5 mm length, when treated using 3% NaOH for 8 h; this showed increase in flexural stress and modulus of 27.5% and 18.9%, respectively, compared to the control mortar. The highest compressive strength was achieved using 1% fiber with 10 mm length treated using 5% NaOH for 8 h; this gave an increase by 46.6% and 36.3% for compressive stress and modulus, respectively, compared to the control mortar. On the contrary, the lowest flexural properties were obtained using 5% DPF of 15 mm length treated using 3% NaOH for 8 h, giving a reduction by 35% and 82.1% for bending stress and modulus, respectively. In terms of compressive properties, the lowest values were obtained using 5% DPF with 10 mm length treated using 3% NaOH solution for 2 h, achieving a reduction by 37.5% and 62.5% for compressive stress and modulus, respectively.

Vantadori et al. [34] and Benaimeche et al. [35] studied the effect of DPF on the flexural performance mortar; they added 0%, 2%, 4%, 6%, 8% and 10% by volume. The findings showed that DPF decreased the density, flexural strength, and fracture toughness of the mortar. Flexural strength decreased by 9%, 17% and 52% with the addition of 2%, 4% and 10% DPF, respectively; they attributed the decrease in flexural strength to high porosity resulting from fiber addition and lower modulus of elasticity of the fiber compared to the mortar. The fracture toughness decreased by 7%, 32% and 66% with the addition of 2%, 6% and 10% DPF, respectively; they attributed this decrease to the poor bonding between the fiber and cement matrix. On the contrary, they reported enhancement in ductility with the addition of fiber. There was an increase from 27% to 162% with the addition of 2% to 10% DPF. In similar research, Benaniba et al. [36] also investigated the effect of DPF on the mechanical properties of bio-composite mortar; they added concentrations of 6%, 12%, 18%, 24%, and 30% of DPF weight, and reported increase in water absorption with increased DPF content, where this increment to the hygroscopic nature of the fiber. The thermal conductivity of the mortar decreased with increment in fiber content, where addition of 24% DPF reduced the thermal conductivity by 92%. There was improvement in flexural strength with the addition of up to 12% DPF, where the optimum DPF content was 6%, and this improvement to the crack bridging effect of the fiber; however, the addition of DPF above 12% resulted to significant reduction in flexural strength. Additionally, the compressive strength of the mortar decreased with increment in addition of DPF; they attributed the decrease in strength to increase in porosity and poor fiber distribution in the cement matrix. Ali-Boucetta et al. [37] examined the effect of different treatment methods of DPF on the fresh and hardened properties of mortar; they applied three treatment methods namely NaOH, boiling water and linseed oil treatments to the DPF before adding 2% DPF by volume of sand. For the NaOH treatment, they used different concentrations of NaOH (1%, 3%, 6% and 9%). For boiling water treatment, they boiled the DPF at different boiling times (5 min, 1 h, 2 h and 3 h). For linseed oil treatment, they used different ratios of linseed oil/DPF (0.25, 0.50, 1 and 1.5) for the treatment. The water absorption of the DPF and the setting time of the DPF mortar were all reduced for all kind of treatment, with the linseed oil treatment method giving the most significant reductions. For water treatment, boiling for 1 h or more led to reduction in water absorption of the fiber, which was due to partial depolymerization and dissolution of lignin. For NaOH treatment below 9% concentration also reduced the water absorption of the fibers, where the lowest absorption was reported using 3% NaOH. For linseed oil treatment, the reduction in water absorption was proportional to the amount of oil added to the DPF. The tensile strength of the DPF was improved with boiling for 3 h and treatment using 3% NaOH; however, linseed treatment does not contribute to tensile strength improvement of DPF. Furthermore, the flexural strength and compressive strength of the mortar improved with fiber addition, and further improved with the fiber treatments. The flexural strength was enhanced at 28 days by 60.1% and 9% and compressive strength by 19.9% and 11% for NaOH and boiling water treatments, respectively, compared to mortar containing untreated DPF; however, linseed oil treatment decreased the flexural and compressive strengths strength of the DPF mortar; they attributed the improvement in flexural strength to the change in morphology, increased roughness, and fineness of the fiber due to treatment, which resulted to improved bonding between the cement matrix and fiber, hence improved strengths.

3.2. DPF Reinforced Concrete

Kriker et al. [38] investigated the effect of different DPF types on the physical and mechanical properties of concrete; they selected the best DPF from male palm, Deglette-Nour, Degla-Bida and Elguers palms for use in concrete, and prepared mixes using of the best DPF, where they added the fiber at 2% and 3% by volume. The fiber length used were 15 mm and 60 mm; they found that the male palm DPF has the highest tensile strength and elongation compared to the other fibers and hence was selected for producing the DPF reinforced concrete. From their result findings, the compressive strength at all age decreased with increase in fiber addition and length; however, increase in fiber length and percentage enhanced the ductile behavior of the concrete. The flexural strength which was measured in terms of load-deflection also decreased with increase in fiber volume. At 28 days, the first crack load for 3–60% mm DPF concrete was lower than that of control concrete by about 65%; they attributed this decrease to mediocre mechanical properties of the DPF and the fiber–cement paste interface strength adhesion, and recommended DPF to be treated before use in concrete.

Djoudi et al. [39] studied the effect of DPF on the thermal properties of gypsum (plaster concrete); they added DPF at dosages of 1%, 1.5% and 2% by volume using different fiber lengths of 2cm, 3cm and 4cm. The thermal conductivity increased with increase in the fiber length and decreased with increment in fiber volume due to escalation of void content in the cement matrix. The best insulating concrete material was achieved using 2% DPF with 2 cm length with reduction in thermal conductivity by about 40%. Additionally, the specific heat capacity increased while the thermal diffusivity of the concrete decreased with increment in fiber content and decrease in fiber length, which was attributed to the alveolar structural behavior of the DPF which was opposite to heat flow. Lastly, they reported based on microstructural evaluation that a good bonding existed between the hydrated gypsum crystals, calcite layers and the DPF cells. Alatshan et al. [40] investigated the effect of DPF as alternative to conventional fibers on the mechanical properties of concrete; they added the fibers at dosages of 0.5, 1, 1.5, 2 and 2.5% by mass. The fiber length added were 5cm, 6cm and 7cm; they reported a decrease in workability and compressive strength with increment in fiber dosage and length; however, they observed increase in compressive strength with addition of 0.5%-5cm DPF which was higher than that of the plain concrete. Additionally, they reported increase in flexural strength with addition of DPF and length; they attributed the increase in flexural strength to the tensile and ductile behavior of the fiber.

3.3. DPF Reinforced Gypsum Composites

Al-Rifaie and Al-Niami [41] reported the influence of DPF on the performance of gypsum as a low-cost construction material. The composites were produced using gypsum and DPF; they first premixed the gypsum with water then added DPF to the plastic slurry and mixed. After which they fabricated panels of sizes 500 × 500 × 20/25 mm using the composites for testing. The variables considered were water-to-gypsum ratio (w/g) and fiber content. The proportions for w/g were 40%, 60% and 80% while for DPF were 0%, 2%, 4%, 6%, 8% and 10%; they reported decreased workability with increment in DPF content in the composite. The maximum compressive strength was achieved with the composite containing 4% DPF, after which the strength reduces with increment in fiber content which they attributed to the lower density and strength of the fiber. DPF increases the plastic modulus of rupture and impact resistance of the composite. The highest improved property of the gypsum composite with addition of DPF is its impact strength with about 50% improvement. Braiek et al. [42] developed a gypsum/plaster composite with DPF for reduction in energy consumptions in buildings, where the DPF-gypsum boards can be used as substitute to plaster boards as building insulation materials; they studied the effect of the DPF on the thermal properties of the gypsum composites where they added different proportions of DPF of 5%, 10%, 15% and 20% by weight. Their findings showed that the density of the composite decreased with increment in DPF content, where a reduction of up to 44% was reported with the addition of 20% DPF, this gives the composite advantage of seismic resistance and lower handling cost. Additionally, the thermal conductivity, thermal diffusivity, thermal effusivity and capacity of the composites all decreases with increment in DPF content. With the addition of 20% DPF to the composites, there was a reduction by 61.5%, 39.58%, 50.5% and 36.22% for thermal conductivity, diffusivity, effusivity and capacity, respectively. Therefore, the recommended the addition of up to 20% DPF in gypsum composites for improved and better thermal properties for a sustainable building

Chikhi et al. [43] investigated the effect of DPF on the mechanical properties, thermal conductivity and water absorption of gypsum based composite material; they utilized hemihydrate gypsum (HG) for producing the composite using two different DPF sizes of 3 mm and 6 mm diameters added at proportions of 0%, 1.2%, 3%, 5%, 7%, 8% and 10% by weight. Their results showed the water absorption and saturation time of the composite at any time increased with increment in DPF content. Furthermore, Gypsum composites containing smaller sized DPF had higher water absorption compared to the larger sized DPF composite. In terms of mechanical properties, the compressive and flexural strengths of the composite decrease with increase in fiber content., with the 3mm-DPF composites having higher strengths compared to the 6mm-DPF composites. The addition of 1.2% DPF decreases the compressive strengths of the 3mm-DPF and 6mm-DPF composites by 58% and 45%, respectively, at 14 days, and 15% and 4% at 28 days, respectively. While with 1.2% DPF addition, the flexural strength decreased by 45% and 31% for the 3mm-DPF and 6mm-DPF composites, respectively, at 14 days, and by 33% and 26%, respectively, at 28 days. With regards to thermal properties, the addition of DPF to the gypsum composites decreases the thermal conductivity of the composites, where with the addition of 10% DPF, there was a reduction in thermal conductivity by 62% and 66% for 3mm-DPF and 6mm-DPF composites, respectively. Finally, they recommended that a good gypsum composites with high mechanical and thermal properties and for use for thermal insulation in building can be produced using 5% DPF [43]. In a similar study by Chikhi [44], he studied the effect of DPF addition on the elasticity and thermophysical properties of gypsum composites. He added two sizes of DPF (3mm and 6 mm diameter) in proportions of 0%, 1.2%, 3%, 5%, 7%, 8% and 10% by weight. The porosity of the gypsum composites was affected negatively with the addition of both sizes of DPF. with regards to the effect of DPF sizes on the porosity of the gypsum composite, there was no trend.

3.4. DPF Reinforced Clay Brick Composites

DPF have been used in the production of clay mortars for improved thermal conductivity and heat resistance due to its better thermal properties. Mekhermeche et al. [45] produced a brick using a combination of clay, sand and DPF; they varied the percentage of DPF between 0% to 3% and sand dune between 0 to 40% by weight of the materials. Their results revealed that the thermal properties of the clay brick improved with increase in the fiber and sand dune content; this was measured through reduction in specific heat capacity, thermal diffusivity and effusivity, and thermal conductivity. For 3% DPF addition, they reported a decrease by 6%, 57% and 6% for specific heat capacity, thermal conductivity, and density, respectively. In a study, Hakkoum et al. [46], also produced clay brick using clay, sand dune and DPF, where they kept the sand dune at 30% and varied DPF between 0% to 3% by weight of material; they reported similar results i.e., improvement in thermal properties, however, they observe reduction in compressive and flexural strengths in the composites with increase in DPF addition. [47] also developed clay bricks using clay, sand and DPF; they varied the sand at 20% and 30% by weight of materials, and DPF at 0%, 1%, 2% and 3% by weight of Material, and reported a decrease in thermal conductivity and specific heat capacity with increment in DPF and sand content in the composite. In terms of thermal conductivity, for the clay composite containing 30% sand, they found a reduction by 7.04%, 18.3% and 32.4% for 1%, 2% and 3% DPF contents, respectively. While for the composite with 20% sand, they reported a decrease by 1.6%, 11% and 28.13% for 1%, 2% and 3% DPF contents, respectively. Furthermore, they reported increased thermal resistance of the composite with increment in DPF content. For the composite containing 20% sand, they reported increase by 2.9%, 5.9% and 16% for 1%, 2% and 3% DPF contents, respectively. While for the composite with 30% sand, they recorded an increment by 2.3%, 8.1% and 9.2% for 1%, 2% and 3% DPF contents, respectively.

References

1. Mohamed, H.I.; El-Beltagi, H.S.; Jain, S.M.; Al-Khayri, J.M. Date palm (Phoenix dactylifera L.) secondary metabolites: Bioactivity and pharmaceutical potential. In Phytomedicine; Elsevier: Amsterdam, The Netherlands, 2021; pp. 483–531.
2. Ashraf, Z.; Hamidi-Esfahani, Z. Date and Date Processing: A Review. Food Rev. Int. 2011, 27, 101–133.
3. Salomón-Torres, R.; Krueger, R.; García-Vázquez, J.; Villa-Angulo, R.; Villa-Angulo, C.; Ortiz-Uribe, N.; Sol-Uribe, J.; Samaniego-Sandoval, L. Date Palm Pollen: Features, Production, Extraction and Pollination Methods. Agronomy 2021, 11, 504.

4. Nixon, R.W. The date palm—“Tree of Life” in the subtropical deserts. Econ. Bot. 1951, 5, 274–301.
5. Al-Alawi, R.A.; Al-Mashiqri, J.H.; Al-Nadabi, J.S.M.; Al-Shihi, B.I.; Baqi, Y. Date Palm Tree (Phoenix dactylifera L.): Natural Products and Therapeutic Options. Front. Plant Sci. 2017, 8, 845.
6. Jonoobi, M.; Shafie, M.; Shirmohammadli, Y.; Ashori, A.; Hosseinabadi, H.Z.; Mekonnen, T. A review on date palm tree: Properties, characterization and its potential applications. J. Renew. Mater. 2019, 7, 1055–1075.
7. Karasawa, K.; Uzuhashi, Y.; Hirota, M.; Otani, H. A Matured Fruit Extract of Date Palm Tree (Phoenix dactylifera L.) Stimulates the Cellular Immune System in Mice. J. Agric. Food Chem. 2011, 59, 11287–11293.
8. Abbo, S.; Gopher, A.; Lev-Yadun, S. Fruit domestication in the Near East. Plant Breed. Rev. 2015, 39, 325–377.
9. Tengberg, M. Beginnings and early history of date palm garden cultivation in the Middle East. J. Arid Environ. 2012, 86, 139–147.
10. Chaluvadi, S.R.; Young, P.; Thompson, K.; Bahri, B.A.; Gajera, B.; Narayanan, S.; Krueger, R.; Bennetzen, J.L. Phoenix phylogeny, and analysis of genetic variation in a diverse collection of date palm (Phoenix dactylifera) and related species. Plant Divers. 2019, 41, 330–339.
11. El-Juhany, L.I. Degradation of date palm trees and date production in Arab countries: Causes and potential rehabilitation. Australian. J. Basic Appl. Sci. 2010, 4, 3998–4010.
12. Chao, C.T.; Krueger, R.R. The date palm (Phoenix dactylifera L.): Overview of biology, uses, and cultivation. HortScience 2007, 42, 1077–1082.
13. Mostaan, A. 9 Mechanization in Date. In Dates: Production, Processing, Food, and Medicinal Values; CRC Press: Boca Raton, FL, USA, 2012.
14. Alawar, A.; Hamed, A.M.; Al-Kaabi, K. Characterization of treated date palm tree fiber as composite reinforcement. Compos. Part B Eng. 2009, 40, 601–606.
15. Awad, S.; Zhou, Y.; Katsou, E.; Li, Y.; Fan, M. A Critical Review on Date Palm Tree (Phoenix dactylifera L.) Fibres and Their Uses in Bio-composites. Waste Biomass-Valorization 2021, 12, 2853–2887.
16. AL-Oqla, F.M.; Alothman, O.Y.; Jawaid, M.; Sapuan, S.; Es-Saheb, M. Processing and properties of date palm fibers and its composites. In Biomass and Bioenergy; Springer: Berlin/Heidelberg, Germany, 2014; pp. 1–25.
17. FAOSTAT. Production of Dates: Top 10 Producers; Food and Agriculture Organization (FAO) of the United Nations: Rome, Italy, 2019.

18. Al-Oqla, F.M.; Sapuan, S. Natural fiber reinforced polymer composites in industrial applications: Feasibility of date palm fibers for sustainable automotive industry. J. Clean. Prod. 2014, 66, 347–354.
19. Barreveld, W. Date Palm Products; Food and Agriculture Organization: Rome, Italy, 1993.
20. Alotaibi, M.D.; Alshammari, B.A.; Saba, N.; Alothman, O.Y.; Sanjay, M.; Almutairi, Z.; Jawaid, M. Characterization of natural fiber obtained from different parts of date palm tree (Phoenix dactylifera L.). Int. J. Biol. Macromol. 2019, 135, 69–76.
21. Dhakal, H.; Bourmaud, A.; Berzin, F.; Almansour, F.; Zhang, Z.; Shah, D.; Beaugrand, J. Mechanical properties of leaf sheath date palm fibre waste biomass reinforced polycaprolactone (PCL) biocomposites. Ind. Crop. Prod. 2018, 126, 394–402.
22. Wazzan, A.A. The Effect of Surface Treatment on the Strength and Adhesion Characteristics of Phoenix dactylifera-L(Date Palm) Fibers. Int. J. Polym. Mater. Polym. Biomater. 2006, 55, 485–499.
23. Wazzan, A. Effect of fiber orientation on the mechanical properties and fracture characteristics of date palm fiber reinforced composites. Int. J. Polym. Mater. Polym. Biomater. 2005, 54, 213–225.
24. Al-Sulaiman, F.A. Mechanical Properties of Date Palm Fiber Reinforced Composites. Appl. Compos. Mater. 2002, 9, 369–377.
25. Al-Kaabi, K.; Al-Khanbashi, A.; Hammami, A. Date palm fibers as polymeric matrix reinforcement: DPF/polyester composite properties. Polym. Compos. 2005, 26, 604–613.
26. Eslami-Farsani, R. Effect of fiber treatment on the mechanical properties of date palm fiber reinforced PP/EPDM composites. Adv. Compos. Mater. 2014, 24, 27–40.
27. Dhakal, H.N.; Ismail, S.O. Sustainable natural fibre reinforcements and their morphological structures. In Sustainable Composites for Lightweight Applications; Woodhead Publishing Series in Composites Science and Engineering; Elsevier: Kidlington, UK, 2021; pp. 17–51.
28. Chand, N.; Fahim, M. Natural fibers and their composites. In Tribology of Natural Fiber Polymer Composites, 2nd ed.; Woodhead Publishing Series in Composites Science and Engineering/Elsevier Science Publishing Co Inc.: Amsterdam, The Netherlands, 2021; pp. 1–59.
29. Benmansour, N.; Agoudjil, B.; Gherabli, A.; Kareche, A.; Boudenne, A. Thermal and mechanical performance of natural mortar reinforced with date palm fibers for use as insulating materials in building. Energy Build. 2014, 81, 98–104.
30. Boukhattem, L.; Boumhaout, M.; Hamdi, H.; Benhamou, B.; Nouh, F.A. Moisture content influence on the thermal conductivity of insulating building materials made from date palm fibers mesh. Constr. Build. Mater. 2017, 148, 811–823.

31. Boumhaout, M.; Boukhattem, L.; Hamdi, H.; Benhamou, B.; Nouh, F.A. Thermomechanical characterization of a bio-composite building material: Mortar reinforced with date palm fibers mesh. Constr. Build. Mater. 2017, 135, 241–250.

32. Haba, B.; Agoudjil, B.; Boudenne, A.; Benzarti, K. Hygric properties and thermal conductivity of a new insulation material for building based on date palm concrete. Constr. Build. Mater. 2017, 154, 963–971.

33. Khelifa, H.; Bezazi, A.; Boumediri, H.; del Pino, G.G.; Reis, P.N.; Scarpa, F.; Dufresne, A. Mechanical characterization of mortar reinforced by date palm mesh fibers: Experimental and statistical analysis. Constr. Build. Mater. 2021, 300, 124067.

34. Vantadori, S.; Carpinteri, A.; Zanichelli, A. Lightweight construction materials: Mortar reinforced with date-palm mesh fibres. Theor. Appl. Fract. Mech. 2019, 100, 39–45.

35. Benaimeche, O.; Carpinteri, A.; Mellas, M.; Ronchei, C.; Scorza, D.; Vantadori, S. The influence of date palm mesh fibre reinforcement on flexural and fracture behaviour of a cement-based mortar. Compos. Part B Eng. 2018, 152, 292–299.

36. Benaniba, S.; Driss, Z.; Djendel, M.; Raouache, E.; Boubaaya, R. Thermo-mechanical characterization of a bio-composite mortar reinforced with date palm fiber. J. Eng. Fibers Fabr. 2020, 15, 1–9.

37. Ali-Boucetta, T.; Ayat, A.; Laifa, W.; Behim, M. Treatment of date palm fibres mesh: Influence on the rheological and mechanical properties of fibre-cement composites. Constr. Build. Mater. 2021, 273, 121056.

38. Kriker, A.; Debicki, G.; Bali, A.; Khenfer, M.; Chabannet, M. Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate. Cem. Concr. Compos. 2005, 27, 554–564.

39. Djoudi, A.; Khenfer, M.M.; Bali, A.; Bouziani, T. Effect of the addition of date palm fibers on thermal properties of plaster concrete: Experimental study and modeling. J. Adhes. Sci. Technol. 2014, 28, 2100–2111.

40. Alatshan, F.; Altlomate, A.M.; Mashiri, F.; Alamin, W. Effect of date palm fibers on the mechanical properties of concrete. Int. J. Sustain. Build. Technol. Urban Dev. 2017, 68–80.

41. Al-Rifaie, W.N.; Al-Niami, M. Mechanical performance of date palm fibre-reinforced gypsums. Innov. Infrastruct. Solutions 2016, 1, 18.

42. Braiek, A.; Karkri, M.; Adili, A.; Ibos, L.; Ben Nasrallah, S. Estimation of the thermophysical properties of date palm fibers/gypsum composite for use as insulating materials in building. Energy Build. 2017, 140, 268–279.

43. Chikhi, M.; Agoudjil, B.; Boudenne, A.; Gherabli, A. Experimental investigation of new biocomposite with low cost for thermal insulation. Energy Build. 2013, 66, 267–273.
44. Chikhi, M. Young's modulus and thermophysical performances of bio-sourced materials based on date palm fibers. Energy Build. 2016, 129, 589–597.
45. Mekhermeche, A.; Kriker, A.; Dahmani, S. Contribution to the study of thermal properties of clay bricks reinforced by date palm fiber. AIP Conf. Proc. 2016, 1758, 030004.
46. Hakkoum, S.; Kriker, A.; Mekhermeche, A. Thermal characteristics of Model houses Manufactured by date palm fiber reinforced earth bricks in desert regions of Ouargla Algeria. Energy Procedia 2017, 119, 662–669.
47. Chaib, H.; Kriker, A.; Mekhermeche, A. Thermal Study of Earth Bricks Reinforced by Date palm Fibers. Energy Procedia 2015, 74, 919–925.