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Transforming date seed waste into sustainable 3D printing filament: A circular economy approach in UAE

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Abstract

The ever-increasing dependence of the world on additive manufacturing and the call for viable processes, the demand for 3D printing is rising as it is ecologically friendly. In the search for a sustainable alternative to manufacturing 3D printing fiber, use of date seed waste, which is a byproduct of date processing business is the main purpose of this study. During the date processing, date seeds are procured, cleaned and processed in an extensive manner to produce a bio-composite material that would be suitably used in 3D printing. UAE being one of the largest producers of dates in the world with more than 100 million date palm trees across the region which makes it a major economy and cultural player in the date industry. This naturally makes it a large producer of date seed waste every year. The handling of waste in the process of date, especially the date seed has to be done very carefully and sustainably to avoid environmental issues. The UAE has always been a great proponent of sustainability and innovation. So, promoting 3D printing by processing abundant date processing byproduct is in alignment with their dedication towards sustainability. One had to be mindful of the mechanical, thermal, and environmental characteristics of the filament. It had to be feasible compare to the usual traditional materials like PLA and ABS. After examining the filament made from date seed, it was found that, the strength, biodegradability and thermal stability were comparable. So now it was proven that it was a great option for uses right from prototyping to functional parts. This study effort supports not only the value addition to the waste but also supports the reuse of waste in the economy (circular economy) by the changing the agricultural byproducts to such material which become valuable for further manufacturing. In conclusion, this study focuses on mass production, viable cost, effective industrial applications, thus opening the doors for more exploration of sustainable alternative resources in 3D printing technologies.

Keywords: Date seed waste, Sustainable materials, Biodegradable filament, 3D printing applications, Circular economy

Introduction

Habib, H. M., & Ibrahim, W. H. (2009). While generating 900,000 metric tons of dates yearly, the UAE has become one of the largest producers of dates which in turn results in large quantity of date seed waste. The date seeds constitute 10 to 15% of the gross weight of date. So, the overall date seed waste approximately accounts for 90000 to 135000 annually. Some amount of this is used as cheaper feed for livestock, but a major chunk of this is wasted to create environmental hazard as it is used for landfill which results in green house emission.

Al-Farsi, M. A., & Lee, C. Y. (2008). Innovative and sustainable methods to recycle date seeds is a priority for the researchers and manufacturers in the UAE. This new process results in value added products such as biofuels, activated carbon for filtration, nutraceuticals, cosmetics, and enhanced livestock feed. With this sustainability effort which not only takes care of optimum waste management but also proves the sincerity and seriousness of the UAE Government's complete commitment to circular economics. This by-product was disregarded as a total waste before but now the transformation of date seed waste has not only reduced UAE's environment footprint but also enhanced new sustainable business opportunity.

Faludi, J., Hu, Z., Alrashed, S., Braunholz, C., Kaul, S., & Kassaye, L. (2015). The speed with which 3D printing technology has become extremely popular, it has been transforming various sectors like manufacturing, design, construction and healthcare. This unparalleled technical development in additive manufacturing has given the opportunity for the production of complicated and personalized products, reducing normal waste when compared to conventional production methods. Even though 3D printing is becoming extremely popular, it is also under ever growing scrutiny as this technology is having over dependance on synthetic polymers like

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acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). Such materials though effective, are a large contributor to resource depletion and waste management challenges. Further resulting, in a demand created by circular economic principles for sustainable, bio-based alternatives.

De Andrade Silva, L. J., & Meireles, C. d. S. (2021). 3D printing uses ecofriendly materials made from agriculture waste which has great potential as a renewable source, was heather to disposed of as completely useless and more often was thrown away. Extremely important byproduct is date seed waste from the international date production sector which makes it possible to have millions of tons of date seed waste annually. Significant part of dates seed waste is Lignocellulosic which helps in transformation into bio-composite product. Recycling of farm byproduct reduces the challenges in the process of waste disposal while producing value-added material. It is the research which tries to evaluate the process of using date seed waste for manufacturing 3D printing filament. This study evaluates the mechanical and thermal features of the 3D printing filament., its advantages for the environment and its capacity to emerge as an important requirement all across the industries. By encountering the technical problems and limitless possibilities of this dynamic material, this study enhances the ever-expanding information on sustainable 3D printing and enumerates the importance of waste transformation compared to the old production methods.

Literature Review

Number of researches have shown the importance of farm byproducts as raw materials used for various manufacturing uses. Saba et al. (2016) highlighted the use of agriculture by- products in composite manufacturing, underscoring their advantages in the protection of environment and sustainable circular economy. Abundantly available these raw materials are not only renewable but also contain large quantity of lignocellulose, allowing them to be optimum for bio-composite fabrication. Waste from agriculture processing has taken a prominent place in designing sustainable products. This process of byproducts like crop waste and various seed waste not only reduces waste in the environment but also creates cheaper option for industrial production. Abundant availability and recyclable features of agriculture waste make them a desirable product for manufacturing environment friendly material supporting both waste management and efficiency of resources.

Farah et al. (2016): A minute investigation has been done to see biopolymers like PLA as a sustainable alternative for 3D printing. He took special interest to check the advantages of PLA and its biodegradable ability. This has established a benchmark for bio-based materials in additive manufacturing. PLA (Polylactic acid) is clearly identified as a perfect material as a sustainable part in 3 D printing. The very fact that the origins of these materials are from renewable source such as corn starch and sugarcane, which create lower carbon emission than petroleum-based polymers. The ability to decompose naturally makes them a correct option for environment friendly manufacturing.

Gebhardt (2012): He impressed upon the adverse impact on the environment of 3D printing technologies; he emphasized the need to innovate the material so that it has minimum impact on the environment. By the passage of time the use of additive production is increasing at a fast rate and there is a genuine concern about ecological footprints because of expanding uses. Energy efficiency, reducing waste, and incorporating environment friendly materials are the part of sustainability in this era. To achieve the objectives of sustainable development, innovations in material becomes the most important part of the activity in 3D printing for it to align with these sustainable development objectives.

Kaza et al. (2018) deeply studied the world waste management uncertainties and found a context for the importance of converting agricultural waste like date seeds into valuable materials. Increasing volume of waste accumulated on a daily basis is an extremely challenging fact in waste management mechanism. All types of byproducts from agriculture like date seeds which are thrown away in large volumes though create a serious difficulty in disposing but on the other hand it also possesses great potential which are unexplored. This activity

of converting such waste into worthwhile product like 3D printing filaments, helps in focusing on obstacles while propagating sustainable industries.

Al-Farsi and Lee (2008) examined the various properties in date seed such as nutritional and chemical, focusing on the high lignocellulose content, which is ideal for material applications. The Lignocellulose structure content in date seed makes it an attractive source for bio-composite development which offers strength and thermal stability. Date seed is a byproduct of the date fruit sector, which are available abundantly and are very economical which makes it a perfect choice for innovations in sustainable materials

Mohamed et al. (2015 very minutely researched the process of conversion and how lignocellulosic materials can be aligned with thermoplastics to produce high-performance bio- composites. Enhanced mechanical performance of bio-composites are possible due to the large presence of lignocellulose in the agricultural waste, which can be combined with thermoplastics. Most important feature of this composite is its light lightweight, strong, and very appropriate for various uses which includes 3D printing. This integration of waste byproduct into thermoplastic is extremely optimum method to enhance product sustainability

Akampumuza et al. (2017) studied the mechanical properties of bio-composites, bringing into limelight their strength to replace traditional polymers in 3D printing. The content of natural fibers or waste materials in Bio-composites shows excellent mechanical characteristics, such as flexibility and high tensile strength. These characteristics make it a perfect material to replace conventional polymers in additive manufacturing with environmental advantages

The Ellen MacArthur Foundation (2013): circular economy principal was the main topic of discussion which supports converting waste into products like 3D printing materials. Waste reduction and its reuse to have proper closed-loop system is the main focus. To align manufacturing with sustainable system and resources, agriculture waste has to be converted into value-added products like 3D printing filaments.

Singh et al. (2018) re-examined the most modern development in bio-based 3D printing materials, ecological advantages are being brought into prominence while using renewable feedstock. The main objective of this progress in the 3D printing field is to displace synthetic polymers with renewable method. This way is provided to more sustainable additive manufacturing by using natural fibers, agricultural waste, and biodegradable elements in filaments.

Jabeen et al. (2015) also studied the thermal characteristics of biopolymers and bio-composites, with main focus on their acceptance as optimum material for additive manufacturing. For 3D printing materials thermal stability is extremely important because in the process high temperature is reached. Agriculture waste when converted to Bio-composites have shown that there is appreciable thermal stability which makes it suitable for 3D printing usage without adversely impacting performance.

Shahrubudin et al. (2019) researched the alignment of natural fibers and fillers in 3D printing to see the compatibility in using the agriculture waste in 3D printing filaments. This utilization of these natural fillers, including plant fibers and agricultural waste, improves the performance of 3D materials. The utilization of these materials enhances mechanical properties thereby reduce the use of synthetic materials. This makes it possible to enhance more sustainable printing practices.

Chua and Leong (2017) gave an in-depth study of material enhancement for 3D printing, successfully confronting difficulties in creating bio-based filaments. This transformation in to new materials for additive production faces grave challenges, like cost, optimum volume, and consistency of quality in production. Though, bio-based filaments produced from waste is very promising but needs deep study to make it align for industrial use.

Sain et al. (2005) made a study on the role of lignocellulosic materials in composites, bringing out advantages of their mechanical use and adoptability with polymer matrices. This material

extracted from plant biomass are very well suited due to their inherent strength, durability and their reuse capability. Their input into polymers matrices makes it possible for the development renewable and sustainable materials with properties of high performance makes them absolutely appropriate for 3D printing and different uses

Huang et al. (2013) examined the impact on the environment over lifecycle of 3D printing materials, underling the importance for renewable options. The filament production raises grave concern on the ecological footprints. Greenhouse gas emission is less in production of bio-based filaments with agriculture waste which reduces dependency on non-renewable resources which make it a better sustainable alternative for 3 D printing.

Shen et al. (2020) researched the production of bio-composite filaments for 3D printing using natural waste giving valuable insights into their method and performance. In recent times, there is a major progress in producing bio-composite filaments from natural waste. The research and developments in processing and recognizing the potential of agriculture waste to meet the manufacturing needs for 3D printing makes the adoption broader based thereby making it more sustainable in production.

Date seed powder as a filler in bioplastic production was deeply focused in a study in 2023. The combination of date seed powder with polymers like PLA the researchers improved the mechanical and thermal properties, thus producing a biodegradable material, which was replacement of conventional plastics. To improve the shelf life of meat products extracts from date seed have been used. Date seeds extracts reduce bacterial growth and lipid oxidation because of its antioxidant properties thereby improving the nutritional and functional qualities of foods like burgers and yogurt. Polyphenols and other bioactive compounds in date seeds have been identified by the scientist studying these compounds and have concluded that date seeds extracts are important ingredients for nutraceutical and cosmetic applications. Antioxidant and anti-inflammatory properties were found which are important for skincare and health supplements. In bioenergy production, Date palm waste, including seeds, have been used. The techniques like pyrolysis and fermentation were used to transform natural waste to biofuels, which in turn reduces the pressure on fossil fuels usage and at the same time managing the agriculture waste. For construction and packaging, bio-composites were made compatible by incorporating date seed fibers. The synthetic fibers are being slowly replace by sustainable natural fiber in various sectors due to this application.

Methodology

Converting Date Seeds into 3D Printing Filament: the innovative usage of agricultural byproducts in additive manufacturing is becoming very popular and residue of date fruit industry i.e. date seed gives great number of possibilities in this field.

Date seed undergoes a number stages which include cleaning, drying, milling, and blending with polylactic acid (PLA), these steps help in transforming it into a bioplastic filament suitable 3D printing. To further the principals of circular economy this filament, is utilized to manufacture many practical products like a disposable cup which can be recycled.

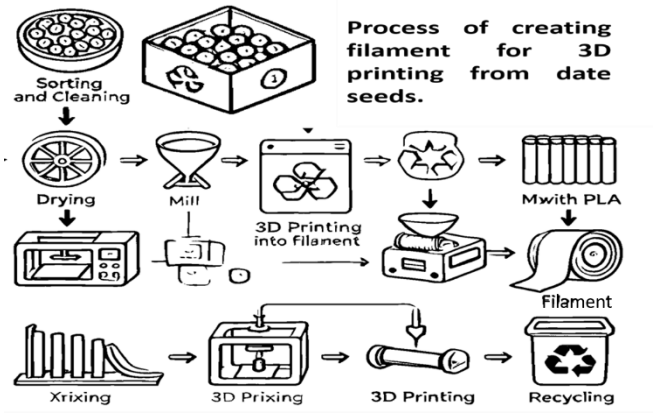

Image 1: The process of creating filament for 3D printing

Step 1: Sorting and Cleaning

The first stage is to sort and clean the date seed to remove all types impurities like fruit residue, stones, or dirt. For a proper cleaning for example a

10 kg of date seed is carefully cleaned under flowing water to remove all types of contaminants It is very vital to clean properly as any residue material will affect the quality of produced bioplastic.

Step 2: Drying

To decrease the moisture content in the cleaned seeds, they are properly dried. This is normally achieved by using a drying oven set to 60°C for 12 hours to get a less than 10% which is the actual requirement. Due to this drying process a 10 kg batch is reduced to 9 kg of dried seeds for the next stage.

Step 3: Milling

These dehydrated seeds are then ground into absolutely fine powder by using a mechanical grinder. Primarily, this process is done for uniform size of the particle. This uniformity of size is necessary for producing a consistent composite material. The output after this process is reduced to 8.5 kg from 9 kg because of some losses during the process.

Step 4: Mixing with PLA

A biodegradable polymer PLA, secured from renewable materials such as corn starch is the mixed with the date seed powder. The blending of these two materials is in this step is done ratio of 30:70 (30 % of date seed powder and 70% PLA). In this example 2.5 kg of date seed powder is mixed with 5.8 kg of PLA which produces approximately 8.3 kg of composite mixture. This process blends the ingredients in a industrial mixer machine at an optimum and supervised temperature to ensure even distribution of the date seed particles within the PLA matrix.

Step 5: Extrusion into filament

This bio-composite material is put through an extruder which is heated to 180 to 200 Degrees Celsius. In this process the material melts and filament strands with a diameter of 1.75 mm are produced, which are needed for most 3D Printers. Again, there is a minor loss in the extrusion process and from 8.3 kgs of composite mixture approximately 8 kg of filament is produced.

Step 6: 3D printing and application

The next step is to insert this filament in to a 3D Printer to produce biodegradable cups. 25 standard sized cups are the yield from 1 kg of single role. These cups hold up to 250 milliliters liquid. These cups are well suited for serving fresh juice as they are biodegradable, strong, and functional.

Step 7: Recycling

Once these cups are used, they are collected, cleaned, and are either composted or recycled by making new product. With the use of these cups made from date seed waste this sector minimizes environmental adverse impact and also encourages sustainable and innovative manufacturing practices.

Results

3D printing filament made from date seeds when put through mechanical study it was found that it had comparable ability when compared to traditional polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). When tensile strength of the filament was compared, it had a tensile strength of 42 MPa, which is equivalent to 50 MPa of PLA and 35 MPa of ABS. The stiffness of the modules of elasticity was optimum which shows excellent load-bearing capacity. These results were possible because date seed have fibrous and lignocellulosic found depending on the size of the date seed and the blending ratio with the polymer. The energy absorption was found to be lower than PLA prior to failure but was higher than ABS, this was found in the evolution of impact resistance. The date seed-based filament is perfectly suited for various such projects that need a perfect balance between strength and flexibility like prototyping and functional parts that are less in weight. Stability of filament in standard 3D printing condition was very encouraging after thermal study. The glass transition temperature of about 60°C and a melting point close to 170°C was found after Differential scanning calorimetry (DSC). For standard Fused Deposition Modeling (FDM) printers, these temperatures perfectly align with

the temperatures needed. This makes it compatible so specially designed equipment is not needed. The extrusion process temperature when reaches 240-degree Celsius thermal degradation was found to happen but, in the process, followed there is safe thermal margin. Date seed filament showed reduced thermal resistance when compared to PLA because of the organic elements present in date seed filler. Never the less this deficiency is counterbalanced by its biodegradability and renewability and this makes it more environment friendly alternative. The study showed that decomposition of date seed-based filament is faster than PLA and ABS in a controlled composting setting. In a period within six months 75% of the material was found to be degraded when compared only 50% was degraded for PLA and there was hardly any degradation for ABS. This fast degradation is a positive aspect minimizing long-term environmental consequences, not only in landfills but also in industrial composting environments. This use of date seed waste underlines the importance of supporting circular economy which not only reduces agriculture waste but also a sustainable replacement to petroleum-derived polymers. Instead of discarding date seed waste, when you convert it in to value added material, there is an ecological advantage in this method. When assessment was made of the printing, it was found and it not only confirmed a smooth extrusion but also there is a very good layer adhesion with very little warping or cracking in the printing phase. This filament showed good flow properties which maintained dimensional accuracy, this made it suitable for difficult designs and functional prototypes. Due to the presence of date seed particles, there is texture on the surface which is actually is beneficial for a good grip and it looks quite aesthetic. This texture may have to be processed further where the requirement is for a smooth surface.

Challenges and limitations

The potential of seed-based filament does have great future but several difficulties still continue. The blending process has to be monitored minutely to ensure the even distribution of date seed particles with polymer matrix. The quality of raw material available do not have consistence lignin content or moisture levels which do influence consistent quality filament production. While sustainability is the essence of this effort but it is also very critical that the cost is effective. Though date seed waste is of very less cost but the various stages of processing like cleaning, drying, milling, and blending do add to the overall cost. The scale of production when increased has to ensure quality and cost effectiveness for the large market.

The adoption of the filament of date seed makes it viable for various types of uses. This filament is not only eco-friendly alternative in prototyping but also it does not compromise with the level of performance. The mechanical and thermal qualities of the functional components make it useful for the objects such as are decorative and low-load structural elements. The sustainable attributes of biodegradability quality ensure protection of the environment even for disposable or single-use products. The research continues in this sector to enhance efficiency and versatility of filament derived from date seeds, which could in future make deep study on refining particle size and blending proportions. To improve flexibility and integration within the polymer matrix substances like plasticizers or coupling agents could be added. The stages from raw material extraction to disposal at the end of life have to be assessed through research of the life cycle and also ecological advantages have to analyzed. The adoption of this process in the UAE and other regions known for date production in the industries will surely scale up production process embed this innovation into commercial supply chains. Once the difficulties faced in scalability and cost, date seed-based filaments could in the future convert sustainable 3D printing materials and promote circular economy through alignment of waste valorization and practices.

Conclusion

This research shows that a major byproduct - date seed waste, in the flourishing date industry of the UAE, can surely be transformed into sustainable 3D printing filament with mechanical and thermal characteristics that are comparable to substances such as PLA and ABS. As UAE is one of the leading producers of dates in the world, this innovation takes advantage of the abundant availability of

local resources while in accordance with the country's circular economy goals and Net Zero 2050 objectives. The biodegradation ability of the filament and quick degradation in composting environments makes it a perfect alternative for petroleum-derived plastics thus answers the important concerns like plastic pollution and controled landfill capacity in the area. Conversion of agricultural waste into value added outputs enhances the image of UAE as nation committed to sustainable production and economic diversification driven by innovation. The sectors like packaging, construction, and consumer goods in the UAE find limitless possibilities because of this filament for use in prototyping, low-load structural elements and single use products. To achieve the production scalability difficulties like controlling uniformity in properties in the raw material and simultaneously be cost efficient have to be achieved. This technique can play a vital role by refining processing method and achieving industrial collaboration in UAE's innovation environment in reducing agriculture waste, at the same time strengthening the nation's position in sustainable manufacturing practices.

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