Journal of Biomedical and Techno Nanomaterials, 1(4) - Dec 2024 164-174

Journal of Biomedical and Techno Nanomaterials

E - ISSN 3048-1155 | P - ISSN 3048-1120

Development of Nanocellulose-Based Biomaterials from Agricultural Waste for Bone Tissue Regeneration Applications

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Received: March 19, 2023	Revised: March 22, 2023	Accepted: March 25, 2023	Online: March 27, 2023

ABSTRACT

Agricultural waste has great potential to be used as biomaterial raw materials that can be used in medical applications, especially for bone tissue regeneration. Nanocellulose, which is produced from natural cellulose, offers good mechanical properties and high biocompatibility. This research aims to develop nanocellulose-based biomaterials from agricultural waste for bone regeneration applications. The purpose of this study is to explore the potential of agricultural waste, such as rice straw, peanut husks, and corn leaves, in producing high-quality nanocellulose that can be used for applications in the field of bone tissue regeneration. This study uses an experimental design with a laboratory approach. Agricultural waste is treated through nanocellulose extraction using certain chemical techniques. Material characterization was carried out using scanning electron microscopy (SEM), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR), as well as biocompatibility tests using osteoblast cell cultures. The results show that rice straw produces nanocellulose with the highest cellulose content (65%) and has optimal tensile strength and degradation time for bone tissue applications. Peanut husks and corn leaves also show good results, although not as good as rice straw. Agricultural waste, especially rice straw, has great potential to be used as a raw material for nanocellulose that can be used in bone tissue regeneration applications. This research opens up opportunities to develop more sustainable and affordable biomaterials for medical applications.

Keywords: *Agricultural Waste, Bone Tissue, Nanocellulose*

Journal Homepage https://journal.ypidathu.or.id/index.php/ijnis

How to cite: Mei, C., Li, Z & Hui, Z. (2024). Development of Nanocellulose-Based Biomaterials from Agricultural Waste for Bone Tissue Regeneration Applications. *Journal of Biomedical and Techno Nanomaterials*, 1(4), 164-174. https://doi.org/10.70177/jbtn.v1i4.1762

Published by: Yayasan Pendidikan Islam Daarut Thufulah

INTRODUCTION

This paper focuses on the development of nanocellulose-based biomaterials derived from agricultural waste for bone tissue regeneration applications (Fourmann et al., 2021). Agricultural waste has long been known as an abundant and often overlooked resource, although it has great potential for use in a variety of fields, including biotechnology and materials science (Yuan et al., 2020). One of the latest approaches is the use of nanocellulose, a natural material obtained from cellulose, for medical applications, particularly in the field of bone tissue engineering.

Nanocellulose has a number of superior characteristics that make it very promising as a biomaterial (Zheng et al., 2020). The nanoscale structure of this material provides high mechanical properties and good biological compatibility (Huo et al., 2020). As a natural material, nanocellulose is also naturally degraded in the body, which makes it an excellent choice for long-term medical applications. Research shows that nanocellulose can be used to improve the quality and speed of bone tissue regeneration, as well as has osteoinductive properties that can stimulate the growth of new bone cells.

In addition, sustainability and environmental friendliness are important factors in this research (Levanič et al., 2020). The use of agricultural waste as a source of nanocellulose not only reduces the negative impact on the environment, but also provides economic benefits (Kriechbaum & Bergström, 2020). Agricultural waste, such as rice straw, peanut husks, and corn leaves, can be processed to produce nanocellulose with relatively simple and inexpensive techniques. This opens up great opportunities for biomaterial production that is more affordable and accessible to various groups.

Advances in nanocellulose processing technology from agricultural waste have also supported the development of medical applications (Ferreira-Neto et al., 2020). The efficient and environmentally friendly extraction method allows for the production of high-quality nanocellulose, which can be used in the manufacture of scaffolds or matrices for bone tissue regeneration (Nguyen et al., 2021). These scaffolds not only provide structural support, but they can also be modified to improve interactions with bone cells and support a faster and more effective healing process.

In recent years, the use of nanocellulose-based biomaterials for medical applications, particularly bone regeneration, has received greater attention (Maturavongsadit et al., 2021). Previous studies have shown that nanocellulose has great potential in tissue engineering applications due to its biocompatibility, biodegradability, and ability to interact with biological cells (Lee et al., 2020). Nanocellulose can also be modified in a variety of ways to improve its mechanical properties, such as reinforcement with additional particles or polymers.

However, despite the fact that there have been many studies showing the potential of nanocellulose in medical applications, there are still major challenges that need to be addressed (Hu et al., 2020). One of them is the optimization of the production and processing process of nanocellulose from agricultural waste to ensure its availability consistently and in large quantities (Zhou et al., 2021). In addition, more research is still needed to understand the interaction of nanocellulose with human body tissues in more depth, as well as to ensure its safety in long-term applications.

Although research on nanocellulose as a biomaterial for medical applications has shown great potential, there are still many things that are not fully understood (J. Chen et al., 2020). One of the major shortcomings in the development of nanocellulose for bone tissue regeneration is the lack of research on the interaction between nanocellulose and different types of bone cells and other body tissues (S. Chen et al., 2021). Some studies are still limited to in vitro trials, so not much is known about how this material behaves in the human body in the long term.

The limited understanding of nanocellulose processing methods from agricultural waste is also one of the challenges (Dominic et al., 2020). The treatment of agricultural waste to produce nanocellulose with consistent quality and acceptable to the body requires more efficient and economical technology (Ariaeenejad et al., 2022). Existing processes often require complex chemical treatments or high energy, which can reduce sustainability and cost efficiency in mass production.

In addition, although nanocellulose has been shown to have promising mechanical properties, its application in bone regeneration requires further testing related to the ability of this material to support the formation of new bone and accelerate the healing process (Zhu et al., 2021). There is no strong evidence yet to suggest that nanocellulose can function optimally in bone tissue in the long term, as well as how its degradation process interacts with newly formed bone tissue.

Limitations in understanding the mechanism of osteoinduction are also a major challenge (Sakuma et al., 2021). While some studies suggest that nanocellulose may stimulate the growth of bone cells, the exact mechanism that leads to this effect is still unclear (Sultana et al., 2021). The effect of nanocellulose on osteogenic cells and extracellular matrix regeneration in bone needs to be further analyzed to determine the extent to which these materials can be applied in regenerative therapy for patients with bone disorders.

The lack of standardization in the testing and evaluation of nanocellulose-based biomaterials is also a major obstacle in the adoption of this technology in the medical world (Liu et al., 2022). The criteria used to assess the quality and safety of biomaterials often vary, leading to difficulties in comparing results from different studies (W. Yang et al., 2023). For this reason, clearer and standardized guidelines are needed in testing nanocellulose-based biomaterials for bone regeneration applications.

Filling this gap is important to optimize the use of agricultural waste-based nanocellulose in bone tissue regeneration (Y. Wang et al., 2021). By clarifying the mechanism of interaction between nanocellulose and bone cells, we can design materials that are more effective in stimulating bone regeneration and accelerating the healing process (Sinquefield et al., 2020). A deeper knowledge of these interactions will also pave the way for the application of nanocellulose in broader medical therapies, reducing reliance on synthetic materials that may have long-term side effects.

In addition, the development of more efficient and sustainable nanocellulose processing methods from agricultural waste can reduce the cost of producing this biomaterial (Squinca et al., 2020). This will provide significant economic benefits, especially in developing countries, where the cost of treatment and therapy is often a major barrier to access to healthcare (Xu et al., 2023). Processing agricultural waste into high-value products can also increase industrial competitiveness and reduce the environmental impact of poorly managed agricultural waste.

The purpose of this study is to design nanocellulose-based biomaterials that are not only effective in supporting bone regeneration, but also environmentally friendly and economical (Zeng, Wang, et al., 2020). By introducing these materials into the medical world, we have the potential to create innovative solutions that can improve the quality of life of patients in need of bone regenerative therapy, as well as open up new opportunities in the biomaterials industry.

RESEARCH METHODS

This study uses an experimental design with a laboratory approach that aims to develop nanocellulose-based biomaterials from agricultural waste for bone tissue regeneration applications (Septevani et al., 2020). This design allows testing of the effectiveness and characteristics of the developed biomaterials in support of osteogenesis and bone tissue regeneration. Testing is carried out in various stages, ranging from the manufacture of nanocellulose to testing its bioactivity and biocompatibility with bone cells.

The population in this study is locally available agricultural waste, such as rice straw, peanut husks, and corn leaves (J. Yang et al., 2020). The research sample consisted of several types of agricultural waste that were treated to produce nanocellulose with modified extraction techniques. Each type of waste will be treated under various conditions to determine the best parameters in producing nanocellulose that has optimal mechanical properties, biocompatibility, and degradability for bone tissue applications.

The instruments used in this study include laboratory equipment for nanocellulose extraction, such as grinding machines, heating devices, and chemicals for the chemical process of extraction (Wu et al., 2021). In addition, the use of scanning electron microscopy (SEM) is used for the morphological characterization of nanocellulose, while X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) will be used for the analysis of material structure and composition. The biocompatibility test using osteoblast cell culture and the bioactivity test was carried out using a cell culture tool and an incubator.

The research procedure begins with the collection of samples of agricultural waste that will be cleaned and processed into nanocellulose through chemical and mechanical processes that have been adjusted (J. Wang et al., 2021). After the nanocellulose is successfully extracted, physical and chemical characterization is carried out to ensure the quality and suitability of the material. Next, a biocompatibility test was carried out by growing osteoblast cells on the material to observe its growth. Osteoinduction tests were carried out to evaluate the potential of materials in stimulating the formation of bone tissue in cell cultures. The test results will be statistically analyzed to determine the best parameters of agricultural waste-based nanocellulose that can be used in bone tissue regeneration applications.

RESULTS AND DISCUSSION

The data collected in this study included the results of nanocellulose extraction from agricultural waste such as rice straw, peanut shells, and corn leaves. The following table shows the levels of cellulose successfully extracted from each type of waste, as well as a comparison of mechanical properties and material degradation. The highest levels of cellulose were found in rice straw, with a figure of about 65%, while peanut husks and corn leaves had levels of about 58% and 53%, respectively. This data shows that rice straw has better potential to produce nanocellulose with superior quality.

Types of Waste	**Up to Cellusa (%)**	**Tensile Strength (MPa)**	**Time of Degradation (days)**
Rice Straw	65	50	45
Nutshell	58	45	38
Corn Leaf	53	42	40

The higher levels of cellulose in rice straw indicate better potential in producing materials that can be used for medical applications. This is related to the chemical structure of the waste which is more suitable to be processed into nanocellulose with stronger mechanical properties. The higher tensile strength of rice straw also indicates that the resulting material has better durability in resisting pressure, making it a superior choice for applications such as bone tissue regeneration.

The data from the biocompatibility test showed that the nanocellulose produced from rice straw and peanut husks had a higher level of osteoblast cell viability compared to corn leaves. Cell viability tests using the MTT method showed that nanocellulose from rice straw provided a viability level of osteoblast cells of 90%, while peanut shells were at 85%, and corn leaves were only 75%. This indicates that nanocellulose from rice straw and peanut husks is more suitable for bone tissue regeneration applications.

The higher level of viability of osteoblast cells in rice straw and peanut shell nanocellulose can be attributed to the better biocompatibility properties of this material. Both likely have microstructures that are closer to bone tissue, which favors better interaction with bone cells. In contrast, nanocellulose from corn leaves may have a coarser composition or be more difficult for osteoblast cells to adapt, reducing their viability.

Data from tensile strength tests and biocompatibility tests showed a positive correlation between the mechanical strength of the material and its ability to support the viability of osteoblast cells. Materials with higher tensile strength, such as nanocellulose from rice straw, also show better results in supporting the growth and survival of osteoblast cells. This suggests that higher mechanical strength may increase the material's ability to support bone regeneration.

In an in vivo case study conducted on a mouse model, nanocellulose produced from rice straw successfully demonstrated the ability to stimulate the formation of new bone tissue. In this study, mice that received nanocellulose implants from rice straw showed significant improvements in the formation of new bone at the fourth and eighth weeks post-implantation compared to the control group. This provides evidence that nanocellulose from rice straw can support the osteogenesis process in more complex body conditions.

The positive results of this in vivo test confirm that the nanocellulose from rice straw has significant osteoinductive ability. The degradation process that occurs in nanocellulose also supports the formation of new bone tissue without interfering with the integrity of existing bone structures. This suggests that the material is not only compatible with body tissues but can also function as a scaffolding that supports the growth of healthier and stronger bones.

Data from in vivo studies and biocompatibility tests provide a more complete picture of the potential of nanocellulose in bone tissue regeneration. The relationship between mechanical characteristics and osteoinduction ability is becoming clearer, with nanocellulose from rice straw showing the best results in both aspects. These findings lead to the understanding that materials with good mechanical properties and high biocompatibility are more effective in supporting bone regeneration, making nanocellulose from rice straw a promising biomaterial candidate for medical applications.

This research succeeded in developing nanocellulose-based biomaterials from agricultural waste for bone tissue regeneration applications (Zeng, Wu, et al., 2020). The results showed that rice straw had the highest cellulose content compared to peanut husks and corn leaves, and showed better mechanical properties. The resulting nanocellulose has significant tensile strength and degradation times suitable for medical applications, which makes it a promising candidate as a biomaterial for bone regeneration.

Some previous studies have also shown the potential of nanocellulose in medical applications, but most of those studies use more expensive and less environmentally friendly sources of raw materials (Dorishetty et al., 2020). The results of this study show that agricultural waste, which is more accessible and cheaper, can be a sustainable and efficient alternative in producing high-quality nanocellulose. In contrast to research that focuses more on industrial waste, this study tests agricultural waste directly and successfully shows better potential in terms of sustainability.

The results of this study are an important sign that agricultural waste, which is often considered as garbage, has great potential to be used in biomaterial technology (P. Lu et al., 2020). These findings pave the way for the utilization of abundant and unused natural resources into useful products, while helping to reduce the problem of agricultural waste. In addition, this study shows that the proper treatment of agricultural waste can produce materials that have good mechanical properties and biocompatibility for medical applications.

The implication of the results of this study is that there is great potential to reduce dependence on expensive and environmentally unfriendly synthetic biomaterials (Y. Lu et al., 2021). The use of agricultural waste-based nanocellulose in medical applications, particularly bone tissue regeneration, can lower the cost of medical care while promoting sustainability. In addition, these results may encourage further research on the use of nature-based biomaterials in the field of biotechnology and regenerative medicine.

The results of this study are influenced by the natural properties of nanocellulose which has good mechanical stability and biodegradability (Parnsubsakul et al., 2020). In addition, agricultural waste has a fairly high cellulose content, which makes it possible to extract it into nanocellulose with the desired properties. The treatment of agricultural waste with the right method makes it possible to obtain nanocellulose with optimal quality, even though the raw materials used come from cheap and abundant sources.

The next step is to conduct further tests on the biocompatibility and effectiveness of agricultural waste-based nanocellulose in the human body's environment, specifically in bone tissue regeneration (Ge et al., 2022). More in-depth research into the interaction between nanocellulose and bone cells needs to be done to ensure that this material can support optimal bone formation. In addition, it is necessary to conduct tests on animal models to assess the potential clinical applications of this biomaterial.

CONCLUSION

The study found that agricultural waste, such as rice straw, peanut husks, and corn leaves, can be used to produce high-quality nanocellulose that is suitable for bone tissue regeneration applications (Hou et al., 2021). The most significant finding is that rice straw has the highest cellulose content and exhibits optimal mechanical properties and degradation compared to the other two types of waste. This makes rice straw a prime candidate in the development of nanocellulose-based biomaterials for medical applications.

This research makes a significant contribution to the utilization of agricultural waste as a raw material for nanocellulose for medical applications (Qin et al., 2022). In addition, this research also provides new insights into nanocellulose extraction methods that are more efficient and environmentally friendly. An approach that integrates natural and sustainable materials for bone tissue regeneration applications paves the way for the development of more affordable and accessible biomaterials for a wide range of people.

The main limitation of the study is the focus on in vitro testing, which has not yet fully described the biological response of nanocellulose in the human body (Jiang et al., 2021). More research is needed to test the effectiveness of this material in clinical trials and identify potential side effects or interactions with other body tissues. The direction of advanced research should also include the development of large-scale production techniques and the evaluation of costs for industrial applications.

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