APPLICATIONS OF BIO NANOCOMPOSITES IN AGRICULTURAL SECTOR AND BIOMEDICAL SECTOR

Dr. Pon. SathyaMoorthy* and Dr. S.K. Rajkishore[1]

*Agricultural Engineering College and Research Institute, TNAU, Kumulur – 12
[1]Agricultural Engineering College and Research Institute, TNAU, Coimbatore – 03
Corresponding Email: sathyamoorthy.pon@tnau.ac.in

Abstract:

Bio nanocomposites, which combine biodegradable polymers with nanomaterials, are emerging as versatile and sustainable solutions across various industries. In agriculture, these materials offer innovations in eco-friendly packaging, controlled release systems for pesticides and fertilizers, soil remediation, and plant growth enhancement. Bio nanocomposites enable the development of biodegradable films and delivery systems that reduce environmental impact while improving crop yield and sustainability. In biomedicine, bio nanocomposites demonstrate significant potential in drug delivery, tissue engineering, wound healing, and medical implants. Their biocompatibility and biodegradability make them ideal for creating advanced biomedical devices and therapeutic platforms. As research continues, the integration of nanomaterials with natural polymers in bio nanocomposites holds promise for addressing global challenges in both the agricultural and healthcare sectors, driving forward innovation in sustainable and effective solutions.

Introduction:

Bio nanocomposites are an innovative category of advanced materials in which the polymer matrix, consist of natural or synthetic polymers or biomolecules that represents the biological component. Whereas the Nano-scale materials are the value-added elements. These composite materials are incorporated with enhanced physical, chemical, and mechanical properties compared to their individual components (Kassai, 2022). Unlike traditional composites, bio nanocomposites stand out due to their exceptional surface-to-volume ratio, resulting from the nanoscale of their components.

These materials are created by incorporating a wide range of systems, including both organic and inorganic materials, where one of their components are less than 100 nm in size. A key aspect of bio nanocomposite fabrication is the use of biodegradable natural or synthetic polymers. The resulting nanocomposites typically combine a natural polymer (biopolymer) with an inorganic component, forming structures at or below the nanometre scale.

The combination of naturally occurring polymers (biopolymers) with inorganic nano-elements gives rise to a distinct category of materials known as bio nanocomposites (BNCs). These materials, also referred to as “nanobiocomposites,” “green composites,” or “bio hybrids,” were first introduced in 2004 (Agbakoba et al., 2023).

Components of Bio nanocomposites

Polymer Matrix (Biopolymers) the polymer matrix serves as the structural framework for the bio nanocomposite. It can be made from both natural and synthetic polymers, but in the case of bio nanocomposites, it is typically derived from biodegradable or renewable

biological sources (Alcantara and Dardar, 2018). Common biopolymers used include:

Natural Polymers: Starch, cellulose, chitosan, protein-based polymers (e.g., soy protein, collagen), alginate, and pectin.

Synthetic Polymers: Polylactic acid (PLA), polyhydroxyalkanoates (PHA), and polycaprolactone (PCL), which are biodegradable and have applications in sustainable materials.

Nanomaterials (Nano phases) theNano-sized materials embedded within the polymer matrix impart unique properties to the composite. These nanomaterials can be organic or inorganic and typically have dimensions smaller than 100 nm. The main types of nanomaterials used in bio nanocomposites include:

Inorganic Nanomaterials:

Nano clay (e.g., montmorillonite, kaolinite): Provides enhanced mechanical properties and is often used for its reinforcement capabilities.

Nanoparticles (e.g., silver, gold, titanium dioxide): These provide specific functional properties like antimicrobial activity, UV protection, or enhanced strength.

Carbon-based Nanomaterials: Carbon nanotubes (CNTs), graphene, and nanofibers offer excellent mechanical, thermal, and electrical conductivity.

Organic Nanomaterials:

Nano cellulose: Derived from plant fibres, it is an eco-friendly and renewable nanomaterial known for its high strength and lightweight properties.

Chitosan Nanoparticles: Derived from chitin, often used for its biocompatibility and biodegradability.

Functional Additives (Optional)
In some cases, additional functional materials are incorporated into the bio nanocomposite to enhance or tailor its properties (Vejan et al., 2021). These can include:

Plasticizers: To improve the flexibility and processability of the composite.

Crosslinkers: To improve the mechanical strength by linking polymer chains.

Bioactive Molecules: In biomedical applications, bioactive compounds such as drugs, antioxidants, or antimicrobial agents might be integrated for specific functionalities.

Characteristics of Bio nanocomposites:

The combination of biopolymers and nanomaterials in bio nanocomposites results in a material with a unique set of properties that cannot be achieved by either component alone (Zubair et al., 2020). These properties often include:

- Enhanced mechanical strength
- Improved thermal stability
- Increased biodegradability
- Better barrier properties (e.g., for moisture or gases)
- Functional properties such as antimicrobial, antioxidant, or UV resistance

Applications of bio nanocomposites:

Bio nanocomposites have applications in a wide range of industries, including agriculture (e.g., for biodegradable packaging and controlled release fertilizers), biomedicine (e.g., in drug delivery and tissue engineering), and environmental engineering (e.g., in water purification and soil remediation). The most significant fields benefiting from bio nanocomposites are agriculture and biomedicine, where they offer sustainable solutions to contemporary challenges.

Applications of bio nanocomposites in the Agricultural Sector

Bio nanocomposites are paving the way for environmentally friendly alternatives to traditional agricultural practices. These materials, often derived from renewable sources such as plant fibres, starches, and proteins, are used in various applications (Gamage et al., 2022).

Eco-friendly Packaging: Bio nanocomposite films made from biopolymers and nanoparticles are being developed as biodegradable alternatives to plastic packaging. These materials are not only biodegradable but also offer enhanced strength, flexibility, and barrier properties, making them ideal for food storage and transport.

Pesticide Delivery Systems: Bio nanocomposites can be engineered to encapsulate and control the release of pesticides or fertilizers, reducing the risk of chemical runoff and minimizing environmental impact. This controlled release can lead to better crop yields while reducing the need for frequent chemical applications.

Soil Remediation: Some bio nanocomposites are designed to absorb and neutralize toxic substances from the soil. By incorporating materials like clay nanoparticles, these composites can help decontaminate soils polluted by heavy metals or other pollutants, improving soil health and supporting sustainable farming practices.

Plant Growth Enhancement: Certain bio nanocomposites are being tested for use as growth promoters. By integrating bioactive compounds with nanomaterials, these composites can improve seed germination rates and enhance plant resistance to stressors like drought or disease.

Application of bio nanocomposites in Biomedical Sector

The biomedical field is another area where bio nanocomposites are showing immense promise, particularly due to their biocompatibility, biodegradability, and ability to deliver functional properties for medical applications (Alsaimi et al., 2023)

Drug Delivery Systems: Nanocomposite materials are being utilized to create advanced drug delivery platforms. By incorporating nanomaterials into biopolymers, scientists can design systems that release drugs in a controlled manner, targeting specific sites within the body and improving therapeutic outcomes while minimizing side effects.

Tissue Engineering: Bio nanocomposites are being explored as scaffolds for tissue regeneration. By mimicking the mechanical properties of natural tissues and promoting cell growth, these composites can be used to support the development of new tissues, such as bone, skin, or cartilage, which can be essential in regenerative medicine.

Wound Healing: Bio nanocomposites, particularly those containing silver

nanoparticles, are being developed for use in wound dressings. These composites exhibit antimicrobial properties, which help prevent infection and accelerate healing. Moreover, their bioactive components can enhance tissue regeneration.

Medical Implants: The integration of bio nanocomposites into medical implants, such as joint replacements or dental implants, can improve the longevity and functionality of these devices. Their enhanced biocompatibility reduces the likelihood of rejection, while their mechanical strength ensures better performance in the body.

Conclusion

Bio nanocomposites are at the forefront of innovation in both agriculture and biomedicine. Their ability to combine sustainability with cutting-edge performance opens up numerous possibilities, offering eco-friendly solutions in agriculture while providing advancements in medical treatments. As research and development in this field continue to grow, we can expect these materials to play an even larger role in addressing global challenges and improving quality of life.

Table 1: Applications of Bio nanocomposites:

S.No.	Bio nanocomposites	Applications/uses
1.	Wheatglutenligninnanoparticles	Foodpackaging,agriculturalbags industries
2.	PVApineapplenanofibers Stryphnodendronadstringensbarkextract	Tissueengineering
3.	Ceramic matrix composite_starch_cellulose nanocrystals biomaterials	Goodopticaltransparencyinpackaging applications
4.	HalloysiteNano clay(HNC) as afiller in solublesoybeanpolysaccharide(SSPS)- based films	Decrease water vapor and oxygen permeability,foodandnonfoodPackaging industries
5.	Cellulosenanowhiskers_polycaprolactone	Automotive,medicalandfoodpackaging applications
6.	ZnO-Ag/ZnO_ceramicmatrixcomposite / ZnO_carrageenan	Activepackagingfilms toextend shelf-lifeoffood
7.	Ceramicmatrixcompositegraphene Nano platelets	Effectivefillerinbiopolymerbasedfilms
8.	ZnO_neem_oil_chitosan	Food packaging
9.	Biodegradablethermoplasticstarch(TPS)	Goodtensilestrengthandloweredwater permeability
10.	ThermoplasticSTbacterialcellulose nanofibers	Excellentreinforcementagentsfortheproduction ofstarch-based bio nanocomposites

References:

Yu, J., Wang, D., Geetha, N., Khawar, K. M., Jogaiah, S., &Mujtaba, M. (2021). Current trends and challenges in the synthesis and applications of chitosan-based nanocomposites for plants: A review. *Carbohydrate polymers*, *261*, 117904. https://doi.org/10.1016/j.carbpol.2021.117904.

Agbakoba, V. C., Hlangothi, P., Andrew, J., & John, M. J. (2023). Preparation of cellulose nanocrystal (CNCs) reinforced polylactic acid (PLA) bionanocomposites filaments using biobased additives for 3D printing applications. *Nanoscale advances*, *5*(17), 4447–4463. https://doi.org/10.1039/d3na00281k.

Alcântara, A. C. S., &Darder, M. (2018). Building Up Functional Bionanocomposites from the Assembly of Clays and Biopolymers. *Chemical record (New York, N.Y.)*, *18*(7-8), 696–712. https://doi.org/10.1002/tcr.201700076

Zubair, M., &Ullah, A. (2020). Recent advances in protein derived bionanocomposites for food packaging applications. *Critical reviews in food science and nutrition*, *60*(3), 406–434. https://doi.org/10.1080/10408398.2018.1534800

Vejan, P., Khadiran, T., Abdullah, R., & Ahmad, N. (2021). Controlled release fertilizer: A review on developments, applications and potential in agriculture. *Journal of controlled release : official journal of the Controlled Release Society*, *339*, 321–334. https://doi.org/10.1016/j.jconrel.2021.10.003

Kasaai M. R. (2022). Bio-nano-composites containing at least two components, chitosan and zein, for food packaging applications: A review of the nano-composites in comparison with the conventional counterparts. *Carbohydrate polymers*, *280*, 119027. https://doi.org/10.1016/j.carbpol.021.119027

Gamage, A., Thiviya, P., Mani, S., Ponnusamy, P. G., Manamperi, A., Evon, P., Merah, O., &Madhujith, T. (2022). Environmental Properties and Applications of Biodegradable Starch-Based Nanocomposites. *Polymers*, *14*(21), 4578. https://doi.org/10.3390/polym14214578

Alosaimi, A. M., Alorabi, R. O., Katowah, D. F., Al-Thagafi, Z. T., Alsolami, E. S., Hussein, M. A., Qutob, M., &Rafatullah, M. (2023). Recent Biomedical Applications of Coupling Nanocomposite Polymeric Materials Reinforced with Variable Carbon Nanofillers. *Biomedicines*, *11*(3), 967. https://doi.org/10.3390/biomedicines11030967