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Polylactide based Nanoclay-composites: A Short Review

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Abstract

Packaging is an essential component of modern society, allowing products to be transported safely and efficiently from manufacturers to consumers. However, packaging also contributes significantly to environmental pollution, including the production and disposal of packaging materials. The production of packaging materials, such as plastic, paper, and metal, requires a significant amount of energy and resources. The manufacturing process also generates greenhouse gas emissions, contributing to climate change. Additionally, the disposal of packaging materials can result in litter and pollution, particularly in oceans and waterways. Poly (lactic acid) (PLA) is derived from renewable resources such as corn starch, sugarcane, or other starch-rich crops. PLA is well-established in the market, and it is commonly used in a variety of products, including food packaging, disposable tableware, agricultural films, textiles, and medical implants. PLA is a versatile material with properties that can be tailored to different applications. It can be made into films, fibers, and injection-molded products, and it can be processed using conventional plastic manufacturing techniques. One of the main advantages of PLA is its biodegradability. When exposed to the right conditions, such as high temperatures and humidity, PLA will break down into water, carbon dioxide, and organic compounds. This makes PLA a more environmentally friendly option than traditional plastics, which can take hundreds of years to decompose. Nanoclay refers to a type of clay material with extremely small particle size, typically less than 100 nanometers, that can be added to polymers to improve their mechanical and thermal properties. PLA and nanoclay have been the subject of this review due to their potential to improve the properties of PLA and make it a more versatile and sustainable food packaging material.

Keywords: Polylactide, Green nanocomposite, Biodegradable, Food packaging, Nano-clay.

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1. Introduction

One of the biggest environmental concerns associated with packaging is plastic waste. Plastic is durable and inexpensive, but it takes hundreds of years to decompose, and much of it ends up in the environment. Plastic packaging litter can harm wildlife and contribute to the buildup of plastic waste in landfills and the ocean. Microplastics, tiny particles of plastic that result from the breakdown of larger plastic items, are also a growing concern as they are found in many marine and freshwater environments, with potential impacts on human health and ecosystems. To address the environmental impacts of packaging, there have been increasing efforts to reduce packaging waste and promote more sustainable packaging options.

These efforts include reducing the amount of packaging used, designing more eco-friendly packaging, using more recycled materials, and promoting recycling and composting of packaging waste [1]. Governments and international organizations are also implementing policies to address packaging waste, including banning certain single-use plastics and promoting extended producer responsibility, where manufacturers are responsible for the disposal of their products and packaging. Individuals can also make a difference by choosing products with less packaging or eco-friendly packaging, and properly disposing of packaging waste through recycling or composting. According to Thyavihalli, concerns have been raised about environmental conservation and natural resource scarcity [2].

Additionally, the depletion of oil reserves, the greenhouse effect, and the widespread use of non-biodegradable materials have prompted researchers to investigate new biodegradable, renewable, and recyclable materials Polylactide (PLA) has been suggested as a viable alternative to synthetic plastics derived from petroleum by-products. PLA is a renewable and biodegradable plastic made from agricultural products such as sugar beet and corn [2]. It possesses high mechanical strength and stiffness, and its composites can be manufactured using conventional manufacturing techniques. As a result of these factors, PLA is an excellent material for fabricating biodegradable composites. PLA's inherent properties enable it to stand alone. Salehiyan, demonstrated that PLA is brittle in nature due to its low thermal stability, low crystallization rate, low impact resistance, and low impact resistance. PLA's inherent characteristics and properties make it an attractive candidate for use as a blend component or as a matrix material in composites. Nevertheless, due to minimal glass transition temperature, poor thermal dimensional stability, as well as mechanical ductility, its scope of application is restricted [3-6]. This short review will demonstrate the potential of incorporating nanoclay into polylactic acid to enhance its properties and improve its suitability for various applications, particularly in the field of sustainable packaging. As research in this area continues, it is expected that new and innovative ways of using nanoclay in PLA-based materials will emerge, further expanding the potential of this sustainable polymer.

2. Polylactide (PLA) and Nanoclay

Polylactide (PLA) is a thermoplastic polymer made from renewable resources such as corn starch, sugarcane, or tapioca roots. It is a linear aliphatic that refers to the structure of the polymer backbone, which is made up of linear carbon chains that are saturated with hydrogen atoms. This gives PLA its strength and stiffness. This polymer is categorized as semicrystalline polymer, meaning that it has both ordered, crystalline regions and disordered, amorphous regions. The degree of crystallinity in PLA depends on its molecular weight, processing conditions, and cooling rate, among other factors. The amorphous regions of PLA are less ordered and more flexible, giving the material its ability to be molded and shaped when heated. This property makes it a popular choice for 3D printing applications. PLA is a versatile and sustainable thermoplastic that can be used in a variety of applications, including packaging, textiles, medical implants, and more [7].

Nano-clay refers to a type of clay that has been processed into extremely small particles with dimensions typically less than 100 nanometers (nm). The small size of the particles provides unique properties, such as high surface area and high aspect ratio, which make them useful in a variety of applications [8]. Nano-clays are typically produced by processing natural clay using mechanical or chemical methods. The resulting nano-clays can be used as reinforcing fillers in polymers, coatings, and other materials to improve their mechanical, thermal, and barrier properties. They are also used in environmental applications, such as water treatment and soil remediation, due to their ability to adsorb pollutants and contaminants.

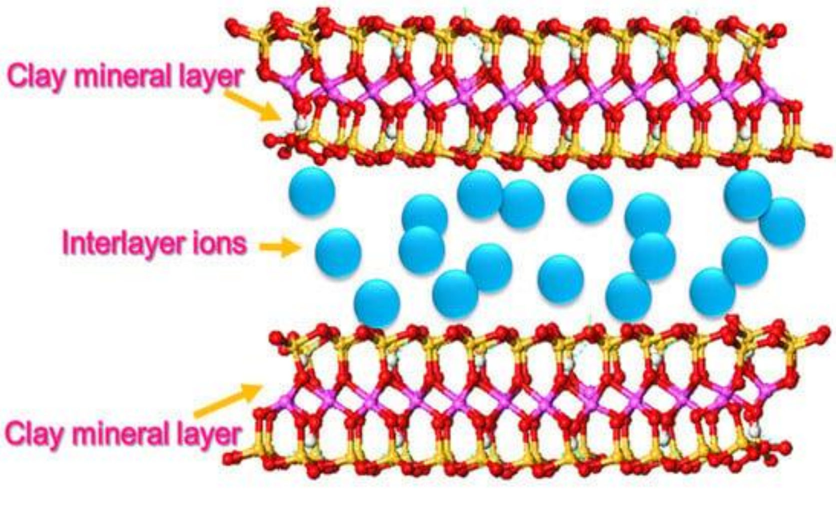

Fig. 1. Entrapment of ions in layered nano-silicate nanostructure [9].

Some common types of nano-clays include montmorillonite, halloysite, and kaolinite. Each type has different properties that make them suitable for different applications as depicted in **Fig. 1** [9-10]. Idumah and co-workers provide an overview of the advancements in nanotechnology and its implications on polymeric/clay nanoarchitectures (PCN). They discuss various preparation techniques for PCN synthesis, as well as different approaches to modify nanoclay namely 1) Solution blending, 2) Melt blending, and 3) In-situ blending. The paper also presents emerging pathways utilized for characterization of montmorillonite/polymer nano-architectures with a focus on understanding the relationship between matrix and reinforcement. In **Fig. 2**, the authors show the structures of form polymeric/clay nanoarchitectures (PCN). They mentioned that different preparation techniques for PCNs can lead to varying properties, depending on how the materials are modified. Additionally, it was observed that there is a strong relationship between matrix and reinforcement in these materials which affects their applications. Finally, processing approaches were seen to have an impact on both the properties as well as potential uses of montmorillonite/polymer nanoarchitectures [10].

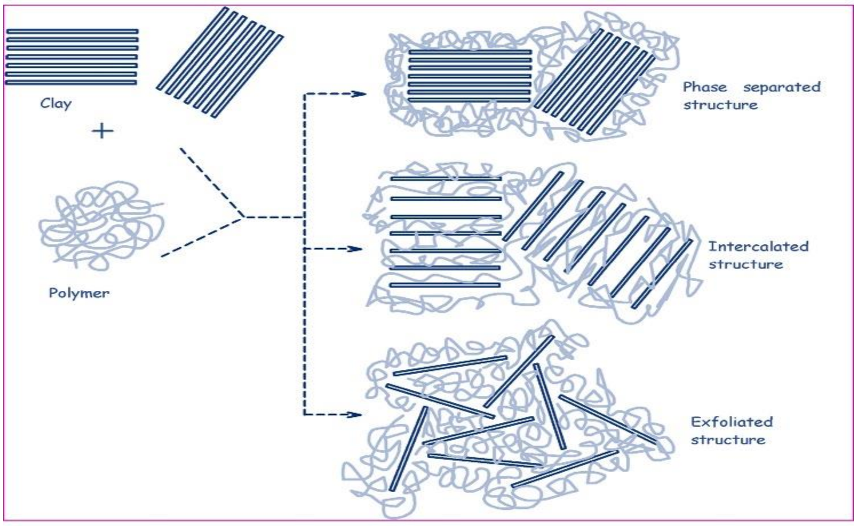

Fig. 2. Feasible forms of PCNs [10].

Fig. 3. Original food tray and digital mock-up prepared from it [11].

3. Characterization of Polylactide Based Nanoclay-composites

Oliver-Ortega et al. discusses the use of PLA, a biopolymer, as an alternative to petrol-based plastics for food packaging. The study also looks at how nano-clays can be used to improve PLA's barrier properties and make it more competitive with other materials such as PET. A pre-dispersed methodology is proposed in this research which could help obtain better dispersion of these composites instead of common melt procedures. The mechanical performance and sustainability are simulated using a food tray model (**Fig. 3**) showing that these materials have lower environmental impact than traditional plastic products [11]. This paper showed that the pre-dispersed and concentrated compound, technically named masterbatch, was suitable for obtaining intercalated structures with higher dispersion of polar nano-clays. Additionally, it was found that these materials had better mechanical performance and sustainability when simulated in a food tray model compared to traditional plastic products.

Additionally, the X-ray Diffraction (XRD) analysis highlighted that the pre-dispersed and concentrated compound was suitable for obtaining intercalated structures with higher dispersion of polar nano-clays (**Fig. 4**). It showed evidence of some degree of intercalation between the polymer matrix and nanoclay aggregates which could be observed at high magnification levels [11]. Coppola et al., in his paper has discussed the implications for the use of PLA/clay nanocomposites in additive manufacturing applications. The study found that different polymer matrices and resulting nanocomposite morphologies can strongly influence 3D printed specimen properties, such as storage modulus at ambient temperature or above glass transition temperatures. It was also observed that the presence of clay increased thermal stability and acted as a nucleating agent which could be beneficial to certain types of printing processes. The paper also showed how increasing print temperature influenced elasticity depending on both type of PLA grade used and its corresponding nanocomposite morphology (exfoliated vs intercalated) [12].

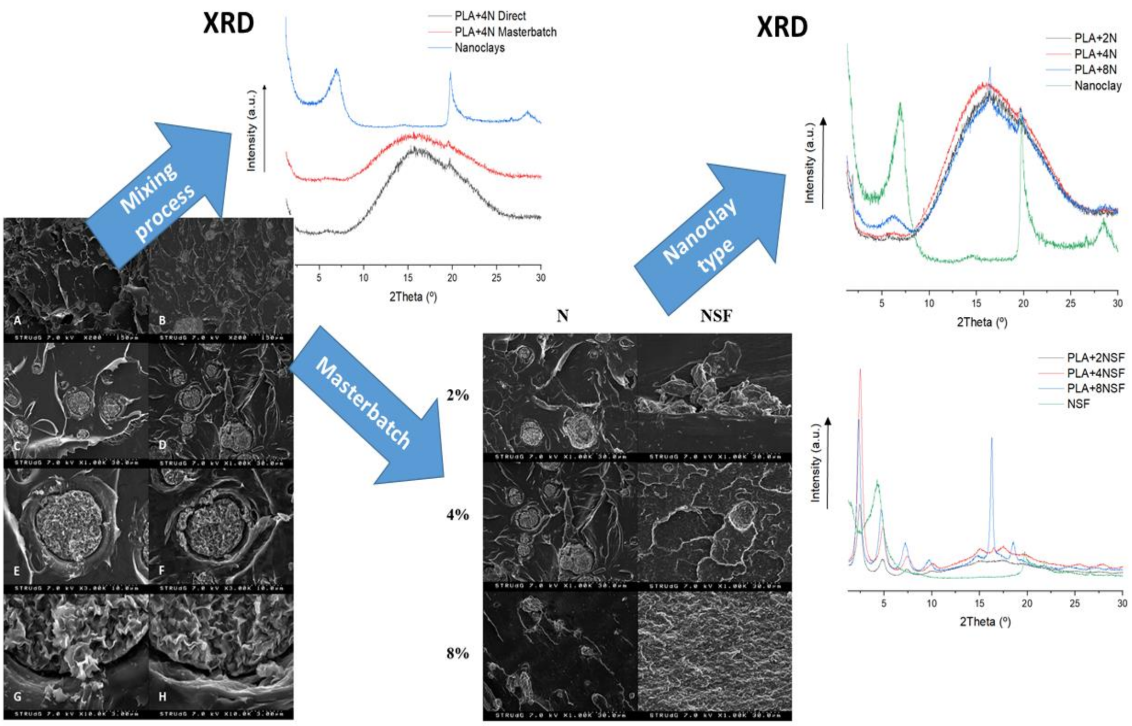

Fig. 4. XRD diffractographs and SEM images of PLA nanocomposite with the different methodologies and the nano-clays used [11].

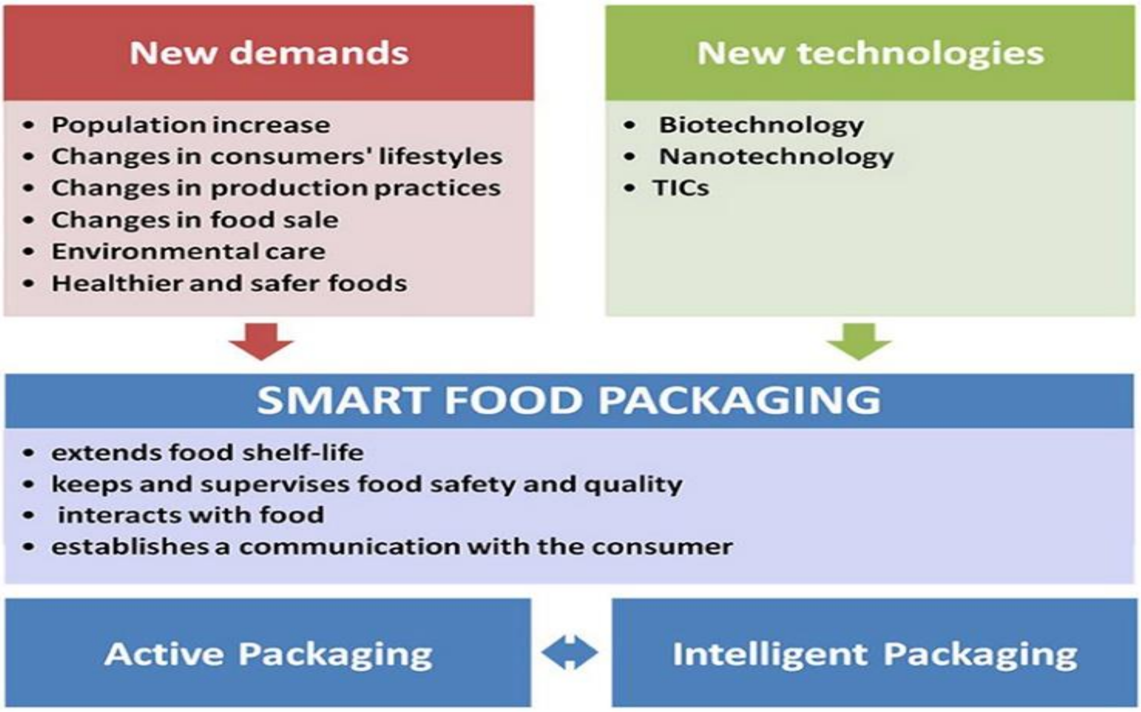

Fig. 5. Outline of the driving forces that lead to the development of smart food packaging [13].

Kausar and co-workers focus on the fundamentals and effects of nanoclay reinforcements in green polymer matrices. They discuss various naturally derived polymers such as cellulose, starch, natural rubber and polylactide that are used to fabricate these nanocomposites. The fabrication approaches discussed include solution route, melt processing and in situ polymerization among others. These materials have light weight properties along with being ecofriendly which makes them suitable for sustainability uses like food packaging or biomedical applications like tissue engineering [9]. The effects of compatibilization and clay nanoparticles on gas permeability in nanocomposites made from poly-lactic acid (PLA) and thermoplastic starch (TPS) has been discussed by Alikarami and friends [14].

The compatibilization is a process used to improve compatibility between two different materials, while clay nanoparticles are extremely small particles that can be added to other substances. The results showed that adding 1% nanoclay into PLA phase reduced oxygen permeability by 55%, due to its tortuosity effect which helps disperse it evenly throughout the matrix. Practically, this research could help create more efficient packaging solutions with improved barrier properties for food products or medical supplies [14]. In recent studies, nano-clay has been added to PLA to create composites that have improved strength, stiffness, and thermal stability. The addition of nanoclay can also reduce the rate of biodegradation of PLA, which is useful in some applications where longer product life is desired. Nano-clay can also improve the barrier properties of PLA against gases and liquids, making it more suitable for food packaging and other applications where barrier properties are important. Additionally, nano-clay can improve the processability of PLA, allowing it to be molded into more complex shapes [15].

4. Conclusions

Green nanocomposites technologies are now growing rapidly and expanding along with 2030 Agenda for Sustainable Development Goals (SDGs) and 10-10 MySTIE Framework. Targeting on main TWO (2) areas; good health and well-being, and affordable and clean energy, polymer composites with the proposed biodegradability and less usage of plastic seems promising enough to contribute to the aim progress by the United Nations (UN). The development of green nanocomposites (biodegradable materials) will benefit society as its ability to move towards sustainable green and become a strong basis in producing such materials. Despite all the potential benefits of polylactide based nanoclay-composites, there are some challenges to using nanoclay in PLA composites. For example, nanoclay particles can agglomerate during processing, which can lead to uneven distribution of the particles and reduced properties of the resulting composite. There is also a risk that the addition of nanoclay could negatively impact the biodegradability of the PLA composite. In conclusion, the addition of nanoclay to PLA has the potential to improve its properties and expand its range of applications. However, further research is needed to optimize the process of creating PLA-nanoclay composites and to ensure that the resulting materials are still biodegradable and environmentally friendly.

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