Review Article

A Review on the Physicomechanical Properties of Polysaccharide-Based Edible Films Incorporating Essential Oil-Loaded Pickering Emulsions

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Abstract

Pickering emulsion-based edible biodegradable films have emerged as a promising sustainable alternative to conventional food packaging materials. These films exhibit enhanced mechanical properties, including tensile strength, flexibility, and water vapor barrier performance, which are critical for maintaining food integrity throughout storage and transportation. A key advancement in this field is the incorporation of essential oils into the emulsion matrix, which, despite their hydrophobic nature, significantly improve the functional and mechanical properties of polysaccharide-based films. This review examines the physicomechanical properties of polysaccharide-based edible biodegradable films incorporating Pickering emulsions, with a focus on flexibility, tensile strength, water vapor permeability, and moisture retention capacity. Furthermore, it explores the role of these films in extending food shelf life and analyzes how interactions between essential oils and polysaccharides influence their structural and barrier properties. Findings demonstrate that Pickering emulsions containing essential oils substantially enhance the mechanical and moisture barrier performance of edible biodegradable films. Solid stabilizing particles contribute to increased tensile strength, while essential oils improve flexibility—though excessive concentrations may compromise structural integrity. Additionally, these emulsions reduce water absorption and solubility, thereby improving film stability in humid conditions. Finally, this review examines the current challenges and identifies key research opportunities in the development of essential oil-loaded Pickering emulsion systems for polysaccharide-based biodegradable films, while outlining their potential for scalable industrial applications.

Keywords: Edible film, Essential oil, Packaging, Pickering emulsion

Introduction

The environmental impact of packaging materials, particularly plastics, poses a significant challenge to ecosystems. Conventional packaging contributes to pollution, often ending up in landfills or oceans, where it can take centuries to decompose. A sustainable alternative that is gaining attention is the use of edible biodegradable films (EBFs) as active packaging to replace traditional packaging methods (Eshagh, Abbaspour-Fard, Tabasizadeh, & Hosseini, 2019). EBFs are made from biodegradable materials such as starches, proteins, or other plant-based compounds, and serve as protective barriers for food products (Olawade, Wada, & Ige, 2024). This innovative approach not only reduces the environmental footprint associated with packaging waste but also offers additional benefits. EBFs can extend the shelf life of food, prevent spoilage, and enhance food safety (Rajesh & Subhashini, 2021).

Aromatic compounds are generally classified into two main categories: simple aromatic hydrocarbons, such as benzene, toluene, and xylene, which are composed solely of carbon and hydrogen; and oxygen- or nitrogen-containing aromatic derivatives, such as phenols, flavonoids, alkaloids, and compounds found in essential oils (Mirzaee Moghaddam & Rajaei, 2021). Essential oils, extracted from the plants, not only have appealing fragrances but also exhibit significant physical and chemical properties. These oils are used as effective agents in improving the physicomechanical properties of Pickering emulsion-based edible biodegradable films (EBFs) (De Farias *et al.*, 2025). The incorporation of essential oils into these films can enhance properties such as tensile strength, flexibility, and resistance to water vapor permeability. Additionally, these compounds may positively influence the moisture content and solubility of the films (Ponnampalam *et al.*, 2022). In the context of food packaging, the use of essential oils in the form of Pickering emulsions represents an innovative approach to enhancing the mechanical properties of the films and improving their performance in food preservation (Pandita *et al.*, 2024). These films can serve as biodegradable alternatives to conventional packaging materials in the food industry, helping to maintain food quality while offering suitable physical and functional properties (Tajari, Sadrnia, & Hosseini, 2024).

Emulsions, which are colloidal dispersions of two immiscible liquids, play a significant role across various industries, with different types used in a wide range of products (Tan & McClements, 2021). One specific category is Pickering emulsions, which are stabilized by solid particles at the liquid–liquid interface. In the field of essential oils, Pickering emulsions have gained prominence due to their unique advantages. Essential oils, which are typically hydrophobic, can be difficult to incorporate uniformly into aqueous-based systems. Pickering emulsions overcome this limitation by providing a stable and efficient method for dispersing essential oils in water-based formulations. The solid particles at the interface prevent coalescence and contribute to the enhanced stability of the emulsion (Shahbazi, Rajaei, Tabatabaei, Mohsenifar, & Bodaghi, 2021).

In recent years, the development of EBFs has emerged as a groundbreaking solution to mitigate the environmental burden of conventional plastic packaging. However, a critical challenge remains: enhancing the physicomechanical and functional properties of EBFs to match or surpass those of synthetic polymers while maintaining biodegradability and food safety. Unlike conventional emulsion-based films, Pickering emulsions ensure superior stability, controlled release of bioactive compounds, and enhanced mechanical strength (Cheng *et al.*, 2024). Furthermore, the synergistic integration of essential oils not only improves tensile strength, flexibility, and barrier properties but also introduces antimicrobial and antioxidant functionalities, extending food shelf life more effectively than passive biodegradable films (Zhang, Jiang, Rhim, Cao, & Jiang, 2022). This review article explores the innovative approach of Pickering emulsions containing essential oils in polysaccharide-based biodegradable films to address key limitations in current biodegradable packaging. By optimizing the structural integrity and performance of EBFs through this novel emulsion system, this research provides a sustainable and versatile alternative to traditional packaging. Finally, a discussion is presented on current challenges and future opportunities in this field. These findings pave the way for next-generation smart packaging, where biodegradability, enhanced food preservation, and advanced material properties coexist, representing a significant leap forward in eco-friendly food packaging innovation.

Polysaccharides

Edible biodegradable films and coatings are composed of polymeric matrices made from edible biodegradable polymers, such as polysaccharides and proteins. These thin matrices are used in food packaging applications. Their primary functions include preventing gas exchange, microbial spoilage, and the loss of moisture and solutes from food products, while preserving the physicochemical and sensory properties of the food Notably, these polymer matrices are designed to be consumed along with the packaged food, offering a unique interactive experience (Ogwu & Ogunsola, 2024).

The preparation of these matrices involves the use of edible biopolymers, many of which are derived from renewable resources or agro-industrial byproducts (Iñiguez-Moreno *et al.*, 2024). Due to their natural origin, these biopolymers are inherently biodegradable, contributing to their environmentally friendly profile. The adoption of such biopolymers presents a promising approach to reducing reliance on non-biodegradable plastic packaging materials. Additionally, the use of naturally sourced polymers provides a significant economic benefit to the food industry (Dutta & Sit, 2024).

In recent years, there has been a notable increase in the interest in polysaccharide-based EBFs and coatings. This growing interest can be attributed to the ease of chemically modifying polysaccharides, which offers researchers the flexibility to effectively tailor the properties of these matrices (Mirzaee Moghaddam, Tavakkoli, Minaee, & Rajaee, 2007). Polysaccharides are broadly classified into starch and non-starch categories, with non-starch polysaccharides exhibiting greater hydrophilicity (Li *et al.*, 2023). The incorporation of these hydrophilic polysaccharides into aqueous solutions increases viscosity, enabling tailored adjustments to the hardness, crispness, and adhesiveness of biopolymer matrices. Non-starch polysaccharides include cellulose and its derivatives, seaweed extracts, microbial fermentation gums, exudate gums, and seed gums (Sahraeian, Rashidinejad, & Niakousari, 2023). This section briefly discusses some of the polysaccharides that have been recently investigated by food scientists for the development of innovative EBFs and coatings (Anis, Pal, & Al-Zahrani, 2021). Some of the commonly used polysaccharides in edible films include the following.

Carrageenan

Carrageenan, a water-soluble polysaccharide extracted from red seaweeds, is a partially sulfated galactan that forms stable films due to its strong film-forming abilities, particularly in the kappa and iota types (Abdallah, Ghazouani, & Fattouch, 2024). These polysaccharides create a three-dimensional network through physical interactions, leading to gelation and stable film formation. Carrageenan-based EBFs are widely used in food packaging to prevent gas exchange, microbial spoilage, and moisture loss (Kokkuvayil Ramadas, Rhim, & Roy, 2024). While refined kappa-carrageenan can be costly, semi-refined versions provide a more cost-effective alternative, demonstrating both the versatility and economic potential of carrageenan-based films (Ciancia, Matulewicz, & Tuvikene, 2020).

Chitosan

Chitosan, derived from chitin found in the exoskeletons of crustaceans, is a biopolymer with significant potential for use in EBFs for food packaging (Malm *et al.*, 2021; Heydarian, Ahmadi, Dashti, & Normohammadi, 2022). It possesses antimicrobial properties, is biodegradable, and exhibits excellent film-forming ability. The cationic nature of chitosan enables it to interact with negatively charged components such as proteins and nucleic acids, enhancing its antimicrobial effectiveness (Nasaj *et al.*, 2024). This makes chitosan particularly effective in extending the shelf life of food by inhibiting microbial growth. Additionally, its biodegradability contributes to sustainable packaging solutions, positioning chitosan as a promising material for both food preservation and environmentally friendly packaging (Priyadarshi & Rhim, 2020).

Alginate

Alginate, a polysaccharide derived from brown seaweeds, is widely used in EBFs due to its biocompatibility, gel-forming ability, and excellent film-forming properties (Bukhari, Rawi, Hassan, Saharudin, & Kassim, 2023). Alginate-based EBFs are flexible, transparent, and offer strong oxygen barrier capabilities, contributing to food preservation. The ability of alginate to form gels in the presence of calcium ions enhances the mechanical strength of the films (Eslami, Elkoun, Robert, & Adjallé, 2023). These films are effective in controlling moisture migration, preventing dehydration, and maintaining food quality. Due to its biodegradability, alginate is considered a sustainable material, making it a promising choice for food packaging applications (Jayakody, Vanniarachchy, & Wijesekara, 2022).

Cellulose derivatives

Cellulosic derivatives, such as carboxymethyl cellulose, hydroxypropyl cellulose, methylcellulose, hydroxypropyl methylcellulose, and microcrystalline cellulose, are key materials in EBFs for food packaging (Yildirim-Yalcin, Tornuk, & Toker, 2022). These derivatives enhance viscosity, improve stability, and modify film properties such as thickness and mechanical strength. Hydroxypropyl methylcellulose, in particular, is well known for its excellent film-forming ability. The use of these materials in EBFs supports sustainable packaging while enabling the customization of film properties to meet the specific requirements of different food products (Y. Liu *et al.*, 2021).

Agar

Agar, derived from seaweed, is widely used in EBFs due to its unique gelling properties. It forms stable films and coatings that serve as effective barriers against gas exchange, microbial spoilage, and moisture loss, thereby helping to preserve food and extend shelf life (Fadiji, Rashvand, Daramola, & Iwarere, 2023). Agar solidifies at low temperatures, making it ideal for film formation without compromising food quality. Its natural origin and biodegradability align with the growing demand for sustainable packaging, and food scientists are increasingly exploring its potential to enhance food preservation and packaging practices (Mostafavi & Zaeim, 2020).

Starch

Starch, a polysaccharide derived from plants, is widely used in the production of EBFs for food packaging. It is known for its film-forming ability, biodegradability, and versatility in modifying film properties (Pei *et al.*, 2024). Starch-based EBFs are flexible, transparent, and offer moisture barrier properties, which help maintain food quality. The film-forming capability of starch can be enhanced through crosslinking or blending with other materials, such as plasticizers or natural polymers (Jayarathna, Andersson, & Andersson, 2022). Starch films are particularly effective in controlling moisture migration and preventing dehydration, making them suitable for packaging a variety of food products. Given its renewable origin and biodegradability, starch is considered a promising candidate for sustainable food packaging solutions (Chen *et al.*, 2023).

Konjac glucomannan

Konjac glucomannan, derived from the konjac plant, is widely used in EBFs due to its thickening and gelling properties. It forms stable films that serve as effective barriers against moisture loss, microbial spoilage, and gas exchange, thereby enhancing food preservation (Moeini, Pedram, Fattahi, Cerruti, & Santagata, 2022). These films are flexible, transparent, and biodegradable, making them a sustainable packaging option. The unique properties of konjac glucomannan offer significant potential for enhancing food preservation and packaging practices in the food industry (Ni *et al.*, 2021).

Essential oils

Essential oils play a crucial role in the food industry due to their ability to enhance flavors, aromas, and overall sensory experiences. These compounds are widely used in various food and beverage products, offering unique and natural profiles that cannot be achieved through other means. In the food industry, essential oils are categorized based on their intended use (Yu, 2025). They may function as natural flavorings, enhancing or mimicking specific flavors in food products. Additionally, essential oils can serve as food additives, providing antimicrobial properties or acting as antioxidants to extend the shelf life of food (Upadhye, Mujawar, & Kashte, 2025). Some essential oils are also incorporated into food and beverage packaging materials to impart desirable aromas and prevent the transfer of unwanted flavors (Mirzaee Moghaddam & Rajaei, 2021). The extraction of essential oils for the food industry follows similar methods as those used in other industries (Bolouri *et al.*, 2022). Steam distillation is commonly employed, ensuring that the essential oils retain their natural flavors and aromas while removing any unwanted components. Cold-press extraction is also utilized for citrus fruits, where the oils are obtained by mechanically pressing the rinds. Solvent extraction is less common in the food industry but may be used for specific applications (Giacometti *et al.*, 2018). Table 1 presents the essential oils and their properties.

Table 1- Origin of the plant or herb, the plant part utilized, and the primary constituents of essential oils

Essential oil	Source plant/herb	Part of the plant	Major components	Reference
Lavender	*Lavandula angustifolia*	Flowers	Linalool, linalyl acetate	(Rusanov, Vassileva, Rusanova, & Atanassov, 2023)
Peppermint	*Mentha piperita*	Leaves	Menthol, menthone	(Beigi, Torki-Harchegani, & Ghasemi Pirbalouti, 2018)
Lemon	*Citrus limon*	Peel	Limonene, β-pinene	(Akarca & Sevik, 2021)
Tea Tree	*Melaleuca alternifolia*	Leaves	Terpinen-4-ol, γ-terpinene	(Brun, Bernabè, Filippini, & Piovan, 2019)
Eucalyptus	*Eucalyptus globulus*	Leaves	Eucalyptol, α-pinene	(Almas, Innocent, Machumi, & Kisinza, 2021)
Rosemary	*Rosmarinus officinalis*	Leaves	A-Pinene, camphor	(Katar *et al.*, 2019)
Cinnamon	*Cinnamomum verum*	Bark tree	Cinnamaldehyde, eugenol, benzaldehyde, linalool, various terpenes	(Gotmare & Tambe, 2019)
Oregano	*Origanum vulgare*	Leaves	Carvacrol, thymol, p-cymene, γ-terpinene, β-caryophyllene	(Kosakowska *et al.*, 2021)
Clove	*Syzygium aromaticum*	Flowers	Eugenol, eugenyl acetate, caryophyllene, various other sesquiterpenes and aldehydes	(Yadav, Gupta, Bharti, & Yogi, 2020)
Lemon Myrtle	*Backhousia citriodora*	Leaves	Citral (a compound that gives it a lemony scent), linalool, myrcene, citronellal	(Southwell, 2021)
Perilla	*Perilla frutescens*	Leaves	Perillaldehyde, limonene, caryophyllene, myrcene	(Ahmed & Al-Zubaidy, 2020)
Basil	*Ocimum basilicum*	Leaves	Linalool, methyl chavicol (also known as estragole), eugenol, cineole, various other monoterpenes and sesquiterpenes	(Dhama *et al.*, 2023)
Ginger	*Zingiber officinale*	Rhizomes of the ginger plant	Gingerol, zingiberene, β-sesquiphellandrene, various other sesquiterpenes and monoterpenes	(Akshitha, Umesha, Leela, Shivakumar, & Prasath, 2020)
Lemongrass	*Cymbopogon citratus*	Leaves	Citronellal, geranial (also known as citral), limonene, myrcene	(Kumoro, Wardhani, Retnowati, & Haryani, 2021)
Thyme	*Thymus vulgaris*	Leaves and Flowers	Thymol, carvacrol, p-cymene, linalool, various terpenes	(Wesolowska & Jadczak, 2019)
Grapefruit	*Rutaceae*	Peel	Limonene, myrcene, α-pinene, other terpenes	(Molnar, Gašo-Sokač, Komar, Kovač, & Bušić, 2024)
Tangerine	*Rutaceae*	Peel	Limonene, myrcene, γ-terpinene, α-pinene, other terpenes	(Ngo, Tran, Nguyen, & Mai, 2020)
Cumin	*Cuminum cyminum*	Seeds	Cuminaldehyde, γ-terpinene, β-pinene, cymene, various other terpenes	(Tavakoli-Rouzbehani *et al.*, 2021)
Cardamom	*Elettaria cardamomum*	Seeds	A-terpinyl acetate, 1,8-cineole (eucalyptol), limonene, sabinene, various other terpenes	(Alam, Hussain, Ahmad, Ali, & Khan, 2023)
Ho Wood	*Cinnamomum camphora*	Wood	Camphor, limonene, cineole	(Kanyal *et al.*, 2023)
Marjoram	*Origanum majorana*	Leaves and Flowers	Terpinen-4-ol, γ-terpinene, cis-sabinene hydrate, linalool, other terpenes	(Prerna & Vasudeva, 2016)

Pickering emulsion

Emulsions play a crucial role in various industries and are primarily classified based on the type of emulsifying agent used, resulting in two main categories: conventional emulsions containing emulsifiers and Pickering emulsions (de Carvalho-Guimarães *et al.*, 2022). Emulsions are colloidal systems consisting of two immiscible liquids, typically oil and water, stabilized either by emulsifying agents or solid particles. In conventional emulsions, emulsifiers reduce the interfacial tension between the immiscible phases, thereby promoting stability (Nazari, Rajaei, & Mirzaee Moghaddam, 2025). In contrast, Pickering emulsions are stabilized by solid particles, such as colloidal particles or nanoparticles. Several factors influence the stability of Pickering emulsions, including particle concentration, size, and surface properties (Chevalier & Bolzinger, 2013). Higher particle concentrations generally enhance stability, while smaller particle sizes improve stabilization due to increased surface area. Moreover, the wettability of the particles and their interaction with the liquid phases also affect stability (Yang *et al.*, 2023). More hydrophilic particles tend to stabilize oil-in-water emulsions more effectively, while more hydrophobic particles are preferable for water-in-oil emulsions (Tabatabaei *et al.*, 2022).

The use of nanoparticles in enhancing the stability of Pickering emulsions

The use of nanoparticles in the stability of Pickering emulsions has emerged as a key strategy for enhancing their performance in various applications. Nanoparticles, typically made from inorganic materials, organic polymers, or biopolymers, act as highly effective stabilizers by adsorbing at the oil-water interface, where they reduce interfacial tension and prevent coalescence of droplets (Lashari *et al.*, 2022). Their small size and high surface area provide better interaction with the emulsion phases, ensuring more stable and long-lasting emulsions. By controlling the size, surface charge, and composition of these nanoparticles, it is possible to fine-tune the stability of Pickering emulsions under different environmental conditions, such as variations in pH, temperature, and ionic strength (Kour *et al.*, 2024). Furthermore, the incorporation of nanoparticles can enhance the emulsions' mechanical strength, making them more resistant to destabilization and improving their performance in food, pharmaceutical, and cosmetic formulations (Shahbazi *et al.*, 2021). Ultimately, the ability of nanoparticles to provide both physical and chemical stabilization makes them invaluable in the development of robust Pickering emulsions with improved shelf-life and functional properties (Mirzaee Moghaddam, Khoshtaghaza, Salimi, & Barzegar, 2014).

Fundamentals of Pickering emulsion-based EBF

Pickering emulsions represent a class of emulsions stabilized by solid particles rather than traditional surfactants. In the context of EBF, these emulsions utilize the ability of solid particles to adsorb at the oil–water interface, thereby preventing droplet coalescence and enhancing overall emulsion stability (Tabatabaei *et al.*, 2022). The solid stabilizers, which may include natural or synthetic materials such as cellulose, starch, silica, and clays, play a pivotal role not only in stabilizing the emulsion but also in reinforcing the mechanical properties of the resultant EBF (Cheng *et al.*, 2024). These solid stabilizers are advantageous due to their biocompatibility and their ability to impart desired structural integrity to the films, which is particularly important for applications in food packaging. The incorporation of Pickering emulsions into EBF has been shown to enhance several critical physicomechanical properties, including tensile strength, flexibility, and water vapor permeability (Niro, Medeiros, Freitas, & Azeredo, 2021).

The solid particles contribute to the formation of a more cohesive and mechanically robust film structure, improving its resistance to mechanical stress while maintaining the flexibility required for practical use. Additionally, these emulsions can significantly improve the barrier properties of the films, such as moisture retention, which is essential for controlling moisture release and extending the shelf life of packaged food products. The ability to control moisture migration within the film is particularly important for preventing spoilage and maintaining the quality of food items. The integration of Pickering emulsions into EBF not only addresses the challenges associated with incorporating essential oils but also facilitates the development of films with tailored properties for specific food packaging needs. These films are not only biodegradable and environmentally friendly but also offer a promising alternative to conventional synthetic packaging materials, aligning with the growing demand for sustainable and natural food packaging solutions (Hussain, Akhter, & Maktedar, 2024).

Synthesis methods

EBF are thin, flexible films usually composed of biopolymers such as proteins, polysaccharides, or lipids, which can be derived from plant and animal sources. Film ingredients are carefully selected to meet specific performance and barrier requirements for various food applications. Common methods for film preparation include solution casting, extrusion, and compression molding. In solution casting, the film-forming materials are dissolved in a solvent, and then the solution is cast in a thin layer and dried to form the film (Borbolla-Jiménez *et al.*, 2023). Extrusion involves processing a paste-like mixture through a die to create a continuous sheet, while compression molding compresses the material into a film using heat and pressure (Seoane-Viaño, Januskaite, Alvarez-Lorenzo, Basit, & Goyanes, 2021).

The preparation of Pickering emulsions containing encapsulated essential oils for application onto edible films involves a sophisticated process that merges the principles of emulsion science and colloid chemistry (Sharkawy, Barreiro, & Rodrigues, 2020). In this innovative approach, solid particles, often in the form of colloidal materials or nanoparticles, play a pivotal role as stabilizers, forming a protective interfacial layer around oil droplets (Jiang, Sheng, & Ngai, 2020). To initiate the emulsification process, essential oils, renowned for their aromatic and functional properties, are carefully chosen and incorporated into the oil phase. These oil droplets are then dispersed in an aqueous phase containing the selected stabilizing particles. The emulsification process can be facilitated through mechanical methods such as homogenization or ultrasonication (Figure 1). Once the Pickering emulsion is formed, it can be applied to food films, with the stabilized droplets acting as carriers for the encapsulated essential oils. The choice of solid particles, their concentration, and their surface properties are critical factors influencing the stability and functionality of the resulting emulsion and, consequently, the performance of the food film. This innovative methodology not only addresses the challenges associated with essential oil stability but also opens up avenues for creating functional and sustainable food packaging materials, contributing to the broader efforts in enhancing the quality and shelf life of food products.

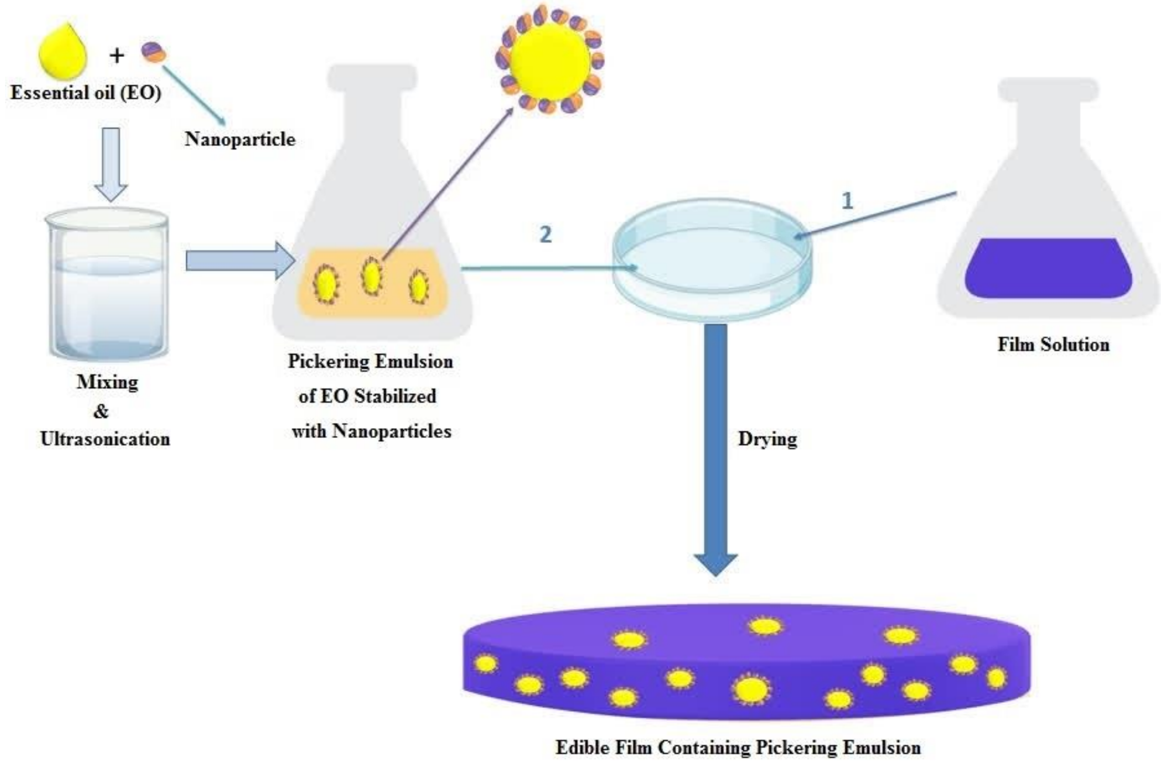

Fig. 1. Schematic of the process of producing EBF containing essential oil Pickering emulsions

Incorporation of essential oils in Pickering emulsion-based EBF

The incorporation of essential oils into Pickering emulsion-based EBF represents a promising strategy for enhancing the physicomechanical properties of these films. Pickering emulsions, which are stabilized by solid particles at the oil-water interface, offer significant advantages in terms of reinforcing the structural integrity and stability of EBF Unlike conventional emulsions that rely on surfactants, Pickering emulsions create a more robust network, providing greater resistance to droplet coalescence and preserving the structural and mechanical properties of the film matrix (Zhang *et al.*, 2024). This unique stabilization mechanism is crucial in preventing the loss of essential oils, which are prone to volatilization, thereby improving the overall functional performance of EBF. The addition of essential oils to Pickering emulsions can significantly influence the physicomechanical properties of the resulting EBF (Amrani, Pourshamohammad, Tabibiazar, Hamishehkar, & Mahmoudzadeh, 2023).

In particular, the tensile strength and flexibility of the films are affected by the type and concentration of essential oils. The solid particles used to stabilize the emulsion also play a critical role in enhancing the mechanical strength of the films, as they help create a more cohesive and uniform structure (Cai *et al.*, 2023). This improvement is especially important in the context of EBF, which must maintain their integrity under mechanical stress, such as stretching or bending. Additionally, the films must remain flexible enough to allow for practical applications in food packaging (Low, Siva, Ho, Chan, & Tey, 2020).

Water vapor permeability is another key property influenced by the incorporation of essential oils into Pickering emulsion-based EBF. Essential oils, when incorporated into the film matrix, can reduce the permeability of the films to water vapor, which is crucial for extending the shelf life of moisture-sensitive food products. This improved barrier property helps preserve the quality of the food by limiting moisture loss (Almasi, Azizi, & Amjadi, 2020). Furthermore, the hydrophobic nature of many essential oils contributes to the water-resistant characteristics of the films, providing an additional layer of protection for food items that require moisture control (Low *et al.*, 2020). Solubility is another critical aspect that is affected by the incorporation of essential oils into the films. The solubility properties of the films influence their performance in various environmental conditions.

By controlling the solubility and dissolution rates, the films can be tailored to release essential oils in a controlled manner, which is beneficial for active food packaging applications (Amrani *et al.*, 2023). The controlled release of bioactive components, such as the antimicrobial and antioxidant properties of the essential oils, can be optimized by adjusting the concentration of solid stabilizers and the oil phase composition (Jafarzadeh & Jafari, 2021). Overall, the incorporation of essential oils into Pickering emulsion-based EBF offers a versatile approach to enhancing the physicomechanical properties of these films. By improving mechanical strength, flexibility, and water vapor permeability, these films not only provide functional benefits for food preservation but also contribute to the development of more sustainable and bioactive packaging solutions. The potential for controlled release of bioactive components further aligns with the growing demand for natural, biodegradable, and functional food packaging materials that are capable of preserving food quality while reducing environmental impact (Nilsen-Nygaard *et al.*, 2021).

Impact of Pickering emulsions containing essential oils on physicomechanical properties of EBF

The incorporation of essential oils into EBF, particularly those based on Pickering emulsions, significantly influences their physicomechanical properties, which are critical for performance in food packaging applications. Essential oils, rich in bioactive compounds such as terpenes, aldehydes, and phenolic compounds, interact with the polymeric matrices of EBF, thereby altering their mechanical, structural, and barrier properties (Versino *et al.*, 2023). These changes depend on various factors, including the type and concentration of the essential oils, the composition of the matrix, and the method of incorporation.

Physical properties affecting the effectiveness of EBFs

Moisture of EBF

Moisture absorption and retention are fundamental properties for EBF, as they directly affect the shelf life and stability of food products. The addition of essential oils can influence the hygroscopic nature of the films. Generally, essential oils, especially those with hydrophobic properties, reduce the moisture absorption capacity of the films. This reduction in moisture uptake is beneficial for food packaging, as it prevents the film from absorbing excess moisture from the surrounding environment, which could lead to the deterioration of food quality (Mirzaee Moghaddam, Khoshtaghaza, Salimi, & Barzegar, 2014).

Moisture in EBF refers to the amount of water present within the film's structure. It is a critical parameter influencing the mechanical, sensory, and functional properties of the film. Moisture content is typically expressed as a percentage of the film's total weight or in terms of thermal properties. The process of moisture release or absorption can have significant effects on the behavioral and functional characteristics of EBF (Zoghi, Khosravi-Darani, & Mohammadi, 2020). The moisture content (MC) of a film is commonly calculated using the equation (1):

$$W\% = \frac{W_{0-}W_1}{W_0} \times 100 \qquad (1)$$

where, W_0: The initial weight of biodegradable film, and W_1: The weight of the film after drying.

The incorporation of Pickering emulsion containing essential oils into EBF can influence its moisture content. Essential oils

(EOs), known for their hydrophobic nature, tend to reduce the overall hydrophilicity of the film. This reduction in hydrophilicity affects the interaction of water molecules with the polymer chains, leading to a decrease in moisture content (Cui *et al.*, 2023).

Solubility of EBF

Solubility is a critical property of EBF that determines its ability to dissolve or disperse when exposed to environmental conditions, particularly in the presence of water. The solubility of EBF is influenced by its composition and the interactions within the polymer matrix. Essential oils, when incorporated into the film, can alter solubility behavior by interacting with the polymer chains. These interactions can reduce the film's solubility, making it more resistant to dissolution when exposed to moisture or aqueous environments. This reduction in solubility can be beneficial in food packaging applications, where films are designed to maintain their structural integrity and functionality under varying humidity or moisture conditions. By adjusting the concentration of essential oils, the solubility of EBF can be precisely controlled, ensuring the desired performance in food preservation and packaging (Nahalkar, Rajaei, & Mirzaee Moghaddam, 2025a). Dissolution in the context of EBF refers to the process of breaking down and dispersing the film's components in a solvent or liquid medium. It is a critical aspect influencing the release of bioactive compounds, flavor agents, or other additives incorporated into the film matrix. The rate and extent of dissolution are key factors in determining the functionality and performance of EBF in various applications (Díaz-Montes & Castro-Muñoz, 2021). The dissolution rate (DR) of a biodegradable film can be expressed using equation (2):

$$Ws\% = \frac{W_{1-}W_2}{w_1} \times 100 \quad (2)$$

here, W_1: Initial weight of dried EBF, and W_2: Weight of dried film after immersion.

The inclusion of Pickering emulsion containing essential oils in EBF can significantly influence its dissolution characteristics. Essential oils, being inherently hydrophobic, may slow down the dissolution process due to their limited affinity for water (Barradas & de Holanda e Silva, 2021).

Water vapor permeability of EBF

Water vapor permeability (WVP) is a critical property for EBF, as it determines the rate at which moisture can pass through the film. The incorporation of essential oils into Pickering emulsion-based EBF can influence WVP, depending on the type and concentration of oils used. Essential oils, due to their hydrophobic nature, generally reduce the water vapor permeability of films. This is especially important for food packaging applications, where preventing excessive moisture exchange between the film and the product is essential for extending shelf life and preserving the quality of the food. The reduction in WVP is achieved through the hydrophobic interactions between the essential oils and the polymer matrix, which create a more compact and less permeable film structure (Nahalkar, Rajaei, & Mirzaee Moghaddam, 2025b). The measurement of WVP provides insights into the barrier properties of the film, affecting its suitability for various applications, especially in food packaging (Hammam, 2019). The WVP of a biodegradable film can be calculated using the equation (3):

$$\text{WVP} = \frac{\Delta W \times FT}{S \times \Delta p} \quad (3)$$

where, ΔW is the weight reduction of the vial (g), FT is the thickness (mm), S is the area (m^2), and Δp is the pressure difference (kPa). The incorporation of Pickering emulsion containing essential oils in EBF can alter its water vapor permeability. Essential oils, known for their hydrophobic nature, can enhance the hydrophobicity of the film matrix, potentially reducing water vapor transmission (Zhang *et al.*, 2022).

Table 2 presents research findings on the changes in solubility, moisture, and water vapor permeability of EBF in response to Pickering emulsions containing essential oils.

Table 2- Some recent studies on the effect of Pickering emulsion containing essential oils on moisture, solubility, and water vapor permeability of EBF

Biodegradable film	**Essential oil**	**Pickering particle**	**Application**	**Analyzed food product**	**Reference**
Chitosan/gelatin	Cinnamon	Zein nanoparticles	Reducing water vapor permeability	-	(Fan *et al.*, 2023)
Chitosan	Cinnamon	Cellulose nanocrystal	Improving film resistance to water	Pork meat	(J. Liu *et al.*, 2022)
Konjac glucomannan	Oregano	Zein–pectin nanoparticle	Reducing water vapor permeability	_	(Zhang *et al.*, 2022)
Carrageenan/agar	Tea tree	Nanocellulose fibers	Slightly improving the water vapor barrier, water resistance	–	(Roy & Rhim, 2021)
Chayote tuber starch	Cinnamon	Zein-pectin nanoparticle	Reducing the moisture content of EBF, reducing water vapor permeability of EBF	Ground beef	(Wu *et al.*, 2023)
Chitosan	Lemon myrtle	Alkali lignin	Resistance to moisture	_	(Liu, Swift, Tollemache, Perera, & Kilmartin, 2022)
Pearl millet starch	Clove bud	Kudzu cellulose nanocrystals	Water barrier	_	(Bangar, Whiteside, Dunno, Cavender, & Dawson, 2023)
Anthocyanidin/chitosan	Cinnamon-perilla	Collagen	Reducing water vapor permeability, increased hydrophobicity	Chilled fish fillet	(Zhao, Guan, Zhou, Lao, & Cai, 2022)
Konjac glucomannan and Pullulan	Tea tree	Cellulose nanofibrils	Improving water resistance	_	(Bu, Huang, *et al.*, 2022)
Konjac glucomannan	Corn germ oil-oregano essential oil	Zein-pectin nanoparticle	Water resistance	_	(Du *et al.*, 2023)
Sodium alginate	Lemongrass	Cellulose nanofibers	Improving water repellency	–	(Wardana, Wigati, Van, Tanaka, & Tanaka, 2023)
Chitosan	Clove	Zein and sodium caseinate	Reducing water vapor permeability	_	(Hua *et al.*, 2021)
Konjac glucomannan	Oregano	Chitin nanocrystal	Water vapor permeability firstly decreased and then increased	–	(Xu *et al.*, 2023)
Chitosan	Grapefruit	Amphiphilic octenyl succinic anhydride konjac glucomannan	Improved water resistance and water vapor permeability	_	(Bu, Sun, *et al.*, 2022)
Tapioca starch/polyvinyl alcohol	Thymus vulgaris	Cellulose nanocrystals	Lower water vapor transmission coefficient	Fish fillets	(Guo *et al.*, 2024)
Starch	Ginger	Tempo-oxidized cellulose nanocrystals	Reducing water vapor permeability	Tomato	(Chen *et al.*, 2023)
Hydroxypropyl methyl cellulose	Cinnamon	Zein/carboxymethyl tamarind gum	Reducing water vapor permeability	Cherry tomatoes	(Yao *et al.*, 2023)
Persian gum-Gelatin	Thyme	Persian gum-Gelatin	The reduction of films' permeability to water vapor and moisture enhances their functionality	Fish fillets	(Sayadi, Abedi, & Oliyaei, 2025)
Chitosan/silk fibroin (CS/SF)	Cinnamon essential oil	Cellulose nanocrystals	Reduced the water vapor transmission rate	-	(Wang *et al.*, 2024)
Pectin (PEC) and konjac glucomannan (KGM)	Clove essential oil	Cellulose nanocrystals	Reduced permeability to water vapor	Grape	(Wang *et al.*, 2024)

The moisture, solubility, and WVP properties of EBF incorporating Pickering emulsions containing essential oils play a crucial role in determining their effectiveness for active food packaging. The presence of Pickering emulsions generally reduces moisture absorption, as the solid stabilizing particles, along with the hydrophobic nature of essential oils, create a protective barrier that limits water penetration and prevents excessive swelling of the film. Furthermore, the solubility of the film in water decreases due to the nanoemulsion structure and the water-repellent characteristics of essential oils, which hinder direct interaction between water molecules and the film matrix, thereby enhancing its mechanical stability in humid environments. Additionally, WVP, a key factor in controlling moisture transfer in packaged foods, is significantly reduced in films containing Pickering emulsions, as the stabilizing particles act as a physical barrier that complicates the diffusion path of water vapor molecules, while the presence of essential oils decreases surface polarity, further restricting moisture transmission. The extent of these effects depends on various factors such as the type and concentration of essential oils, the size and distribution of stabilizing particles, and the composition of the biopolymeric matrix, all of which can be optimized to enhance the barrier properties and functional performance of the film in food packaging applications (Bangar *et al.*, 2023; Du *et al.*, 2023; Fan *et al.*, 2023; Hua *et al.*, 2021; Roy & Rhim, 2021).

Effects on mechanical properties of EBF

Mechanical properties of EBF, including tensile strength, elongation, and Young's modulus, play a crucial role in their functionality and performance as food packaging materials. The incorporation of emulsion-based Pickering emulsion containing essential oils can have significant effects on the mechanical properties of these films. Tensile strength is a measure of a film's resistance to breaking under tension, while elongation represents the ability of the film to stretch without breaking (Javadi Farsani, Mirzaee Moghaddam, & Rajaei Najafabadi, 2023). Young's modulus, also known as the elastic modulus, is an indicator of a film's stiffness and its ability to return to its original shape after deformation (Mirzaee Moghaddam, 2019). These mechanical properties are important for ensuring the integrity and durability of the EBF during storage, handling, and transportation.

Table 3 presents research findings on the mechanical changes in EBF in response to Pickering emulsions containing essential oils. When essential oils are incorporated into EBF through emulsion-based Pickering, they can influence the film's mechanical properties in several ways. Firstly, the presence of the emulsion droplets within the film matrix can affect the film's microstructure and morphology, leading to changes in its mechanical behavior. The dispersed droplets act as physical barriers, altering the overall film structure and potentially influencing the interaction between polymer chains (Farajpour, Djomeh, Moeini, Tavakolipour, & Safayan, 2020). Secondly, the essential oils themselves can interact with the film matrix, affecting its mechanical properties. Essential oils are known to have plasticizing effects on polymers, reducing their rigidity and increasing their flexibility (Abedi, Sayadi, & Oliyaei, 2024). This plasticizing effect can lead to an increase in elongation and a decrease in tensile strength. However, the specific impact of essential oils on the mechanical properties of the films can vary depending on several factors such as the type of oil used, its concentration, and the compatibility between the oil and the film matrix (Mirzaee Moghaddam & Rajaei, 2021).

Incorporating emulsion-based Pickering particles into EBF can also offer advantages in terms of mechanical properties. The emulsion droplets act as reinforcing agents, enhancing the film's mechanical strength and stiffness. The droplets can improve the interfacial adhesion between polymer chains, resulting in a stronger film structure. This reinforcement effect can lead to increased tensile strength and Young's modulus (Mirzaee Moghaddam *et al.*, 2007). It should be noted that achieving the desired mechanical properties in EBF with emulsion-based Pickering emulsions requires careful formulation and optimization. The choice of emulsion stabilizers, the concentration of essential oils, and the processing conditions play vital roles in determining the mechanical performance of the films (Moghaddam & Rajaei, 2021).

Table 3- Some recent studies on the effect of Pickering emulsions containing essential oils on the mechanical properties of EBF

Biodegradable film	**Essential oil**	**Pickering particle**	**Application**	**Analyzed food product**	**Reference**
Chitosan	Cinnamon	Zein nanoparticles	Improvement of mechanical properties	–	(Fan *et al.*, 2023)
Chitosan	Cinnamon	Cellulose nanocrystal	Reduces its mechanical strength	Pork meat	(Liu *et al.*, 2022)
Konjac glucomannan	Oregano	Zein–pectin nanoparticle	Increased the elongation at break	–	(Zhang *et al.*, 2022)
Carrageenan/agar	Tea tree	Nanocellulose fibers	Maintained mechanical strength with slightly improved flexibility	–	(Roy & Rhim, 2021)
Chayote tuber starch	Cinnamon	Zein-pectin nanoparticle	Increased elongation at break and reduced tensile strength	Ground beef	(Wu *et al.*, 2023)
Chitosan	Lemon myrtle	Alkali lignin	Resisted mechanical stress	–	(Liu *et al.*, 2022)
Potato starch and polyvinyl alcohol	Clove	Clove essential oil	Reduced tensile strength and elongation percentage	Pork meat	(Zhao *et al.*, 2023)
Pearl millet starch	Clove bud	Kudzu cellulose nanocrystals	Improved the mechanical resistance of the film	Chilled fish fillet	(Bangar *et al.*, 2023)
Konjac glucomannan and Pullulan	Tea tree	Cellulose nanofibrils	Improving the mechanical properties of films	–	(Bu, Huang, *et al.*, 2022)
Gelatin/agar	Clove	Copper-modified zinc oxide nanoparticles	Improving the mechanical properties of films	Pork meat	(Roy, Priyadarshi, & Rhim, 2022)
Carboxymethyl cellulose/polyvinyl alcohol	Ginger	Ginger essential oil	Increased elongation at break and reduced tensile strength	Bread	(Fasihi, Noshirvani, & Hashemi, 2023)
Konjac glucomannan	Corn germ oil-oregano essential oil	Zein-pectin nanoparticle	Highest tensile strength	–	(Du *et al.*, 2023)
Chitosan	Clove	Zein and sodium caseinate	Increased tensile strength and break elongation	–	(Hua *et al.*, 2021)
Konjac glucomannan	Oregano	Chitin nanocrystal	Reduced the mechanical properties of the films	–	(Xu *et al.*, 2023)
Chitosan	Grapefruit	Amphiphilic octenyl succinic anhydride konjac glucomannan	Improved mechanical strength	–	(Bu, Sun, *et al.*, 2022)
Tapioca starch /polyvinyl alcohol	Thymus vulgaris	Cellulose nanocrystals	Enhanced the film's elongation at break	Fish fillets	(Guo *et al.*, 2024)
Starch	Ginger	Tempo-oxidized cellulose nanocrystals	Improved tensile strength	Tomato	(Chen *et al.*, 2023)
Persian gum- Gelatin	Thyme	Persian gum- Gelatin	Reduced the tensile strength, and elongation of the films	Fish fillets	(Sayadi *et al.*, 2025)
Carrageenan	Oregano essential oil	Nanocellulose	The tensile strength of the films significantly decreased, whereas the elongation at break increased	-	(Amanda, Ismadi, Ningrum, Nabila, & Prasetyo, 2024)
Chitosan/silk fibroin (CS/SF)	Cinnamon essential oil	Cellulose nanocrystals	Increasing the mechanical stability of films	-	(Wang *et al.*, 2024)
Pectin (PEC) and konjac glucomannan (KGM)	Clove essential oil	Cellulose nanocrystals	Highest tensile strength	Grape	(Wang *et al.*, 2024)

In general, the incorporation of Pickering emulsions can significantly influence the film's tensile strength, elongation at break, and flexibility, depending on the nature and concentration of stabilizing particles and essential oils. The presence of solid stabilizing particles enhances the mechanical strength of the film by reinforcing the polymer matrix and creating a more cohesive structure, while the encapsulated essential oils may act as plasticizers, potentially increasing flexibility but reducing tensile strength if present in high concentrations. Additionally, the distribution and size of emulsion droplets within the film matrix can impact its homogeneity and resistance to mechanical stress. The interactions between the biopolymer network, stabilizing particles, and essential oils determine the overall mechanical behavior, which can be fine-tuned to achieve the desired balance between strength, flexibility, and durability. By optimizing these parameters, Pickering emulsion-based films can be engineered to provide superior mechanical performance, ensuring their suitability for various food packaging applications while maintaining their functional and protective properties (Bangar *et al.*, 2023; Du *et al.*, 2023; Fan *et al.*, 2023; Guo *et al.*, 2024; Hua *et al.*, 2021; Roy & Rhim, 2021; Xu *et al.*, 2023).

Possible uses in food packaging

The incorporation of Pickering emulsion-based EBF containing essential oils into food packaging presents significant advancements in extending shelf life and maintaining product quality. These films offer a biodegradable and functional alternative to conventional synthetic packaging by providing enhanced barrier properties against moisture transfer and mechanical degradation (Yue *et al.*, 2024). The incorporation of essential oils into the emulsion system enhances the physicomechanical characteristics of the films while also boosting their capacity to manage water vapor permeability and solubility, thus guaranteeing optimal functionality across diverse storage environments. One of the primary applications of these films is in the packaging of perishable food products, where moisture retention and controlled gas exchange are critical for preventing spoilage (Deng *et al.*, 2024). The reduced water vapor permeability of these films, due to the incorporation of hydrophobic essential oils, minimizes excessive moisture transfer, thereby preventing undesirable textural changes in food products such as bakery items, dairy, and fresh produce. Additionally, their improved mechanical strength enhances the integrity of the packaging, making it more resistant to physical stress during transportation and storage (Zomorodian, Javanshir, Shariatifar, & Rostamnia, 2023).

Beyond primary food packaging, these films can be utilized as protective coatings for fresh-cut fruits, vegetables, and processed meat products (Gupta, Lall, Kumar, Patil, & Gaikwad, 2024). By forming a uniform and stable edible barrier, they regulate moisture loss, reduce dehydration rates, and maintain product freshness for extended periods. Moreover, their controlled solubility ensures that the film structure remains intact until consumption, preventing premature degradation in humid environments. Another critical application of Pickering emulsion-based EBF is in active packaging systems, where selective permeability plays a role in preserving food quality. The ability to fine-tune the physicomechanical properties of these films by adjusting the concentration and type of essential oil allows for the development of tailored packaging solutions suitable for different food matrices. By optimizing film composition and emulsion characteristics, these packaging systems can be designed to offer improved flexibility, adhesion, and resistance to environmental stressors, further enhancing their potential for commercial implementation in the food industry. The integration of Pickering emulsion technology into EBF aligns with the growing demand for sustainable and eco-friendly packaging alternatives. These films not only reduce reliance on petroleum-based plastics but also provide functional advantages that contribute to the overall quality and longevity of packaged food products (Yin & Woo, 2024).

Challenges and future perspectives

The development and application of Pickering emulsion-based edible EBF containing natural essential oils in food packaging face several challenges that need to be addressed to ensure their commercial viability. One of the primary challenges is achieving a balance between the physicomechanical properties and functional performance of the films. While essential oils enhance hydrophobicity and moisture barrier properties, their inclusion may also impact the mechanical integrity of the films, potentially reducing tensile strength and increasing brittleness.

Optimizing emulsion stabilization, film composition, and processing conditions is essential to maintain desirable mechanical properties while ensuring barrier performance is not compromised. Another significant challenge is the uniform dispersion and controlled release of essential oils within the polymer matrix. Due to the volatile nature of essential oils, their retention in the film structure is often limited, resulting in inconsistent physicomechanical performance over time. Strategies like encapsulation in biopolymeric carriers, nanoemulsification, or using interfacial stabilizers can improve essential oil retention and controlled release, thus enhancing the long-term effectiveness of these films in food packaging applications.

Scalability and industrial feasibility also remain crucial considerations. Transitioning from laboratory-scale formulations to large-scale production requires careful evaluation of material costs, processing efficiency, and compatibility with existing food packaging technologies. Developing cost-effective, high-throughput manufacturing processes that preserve the physicomechanical integrity of the films is key for widespread industry adoption. Additionally, regulatory approval and compliance with food safety standards must be addressed to ensure the films are suitable for direct food contact.

Future research should focus on integrating advanced characterization techniques to gain a better understanding of the interactions between Pickering emulsions, essential oils, and biopolymeric matrices. Investigating the molecular mechanisms behind film formation, mechanical reinforcement, and moisture resistance will offer deeper insights into optimizing formulation strategies. Moreover, incorporating multifunctional biopolymers or hybrid emulsifier systems could enhance the film's stability, mechanical strength, and environmental adaptability, making them more suitable for diverse packaging applications. Sustainability considerations will also be central to the future of Pickering emulsion-based edible films. Using biodegradable and renewable biopolymers as film-forming agents, alongside green processing techniques, can align these packaging materials with global sustainability goals. Furthermore, exploring bio-based emulsifiers and natural stabilizers will contribute to the development of more eco-friendly formulations, reducing reliance on synthetic additives.

Conclusion

The integration of Pickering emulsion-based edible biodegradable films with essential oils represents promising advancement in the field of food packaging, offering enhanced physicomechanical properties while maintaining natural and biodegradable characteristics. These films demonstrate improved mechanical strength, reduced water vapor permeability, and enhanced resistance to moisture-induced degradation, making them viable alternatives to conventional synthetic packaging materials. The stabilization of essential oils within Pickering emulsions ensures a more uniform distribution of hydrophobic compounds, leading to consistent physicomechanical performance and extended functional efficacy. Despite these advantages, several challenges must be addressed to fully exploit the potential of these films in commercial applications. The optimization of formulation parameters, including the type and concentration of stabilizing particles, essential oils, and biopolymeric matrices, is critical for achieving desirable mechanical flexibility and moisture resistance. Additionally, controlling the interactions between film components and environmental factors remains a key aspect of improving long-term stability and performance. Future research should focus on the development of advanced stabilization strategies, such as the incorporation of multifunctional biopolymers, nanoemulsions, or hybrid emulsifier systems, to enhance the physicomechanical robustness of these films. Moreover, investigating the molecular mechanisms governing film formation and structural integrity will provide valuable insights into optimizing their physicomechanical characteristics. The integration of biodegradable and renewable materials, coupled with eco-friendly processing techniques, will further contribute to the sustainability of these packaging systems. Overall, Pickering emulsion-based edible EBF enriched with essential oils offer a sustainable, high-performance solution for food packaging applications. However, continued advancements in material science, processing technologies, and regulatory considerations are essential to facilitate their widespread industrial adoption. By addressing existing limitations and leveraging innovative approaches, these films have the potential to revolutionize the future of sustainable food packaging, aligning with consumer demand for safer and more environmentally friendly alternatives.

Authors Contribution

H. Mirzaee Moghaddam: Supervision, Conceptualization, Methodology, Technical advice

A. Nahalkar: Data acquisition, Software services

A. Rajaei: Validation, Visualization, Text mining, Review and editing services

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مقاله مروری

مروری بر خواص فیزیکومکانیکی فیلم‌های خوراکی بر پایه پلی‌ساکارید شامل امولسیون‌های پیکرینگ حاوی اسانس

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چکیده

فیلم‌های خوراکی زیست‌تخریب‌پذیر حاوی امولسیون پیکرینگ به‌عنوان جایگزینی پایدار و نویدبخش برای مواد بسته‌بندی غذایی مرسوم مطرح شده‌اند. این فیلم‌ها دارای خواص مکانیکی بهبودیافته‌ای از جمله استحکام کششی، انعطاف‌پذیری و قابلیت ممانعت بخار آب هستند که برای حفظ یکپارچگی مواد غذایی در طول نگهداری و حمل‌ونقل اهمیت دارند. یکی از پیشرفت‌های کلیدی در این حوزه، استفاده از اسانس‌ها در ماتریس امولسیون است که با وجود ماهیت آب‌گریز خود، خواص عملکردی و مکانیکی فیلم‌های بر پایه پلی‌ساکارید را به‌طور قابل‌توجهی ارتقا می‌دهند. این مقاله به بررسی خواص فیزیکومکانیکی فیلم‌های خوراکی زیست‌تخریب‌پذیر بر پایه پلی‌ساکارید که شامل امولسیون‌های پیکرینگ حاوی اسانس هستند می‌پردازد، با تمرکز ویژه بر انعطاف‌پذیری، استحکام کششی، نفوذپذیری بخار آب و ظرفیت نگهداری رطوبت. همچنین نقش این فیلم‌ها در افزایش ماندگاری مواد غذایی مورد بررسی قرار گرفته و نحوه تعامل میان اسانس‌ها و پلی‌ساکاریدها در تأثیرگذاری بر ساختار و ویژگی‌های ممانعتی فیلم‌ها تحلیل می‌شود. یافته‌ها نشان می‌دهند که امولسیون‌های پیکرینگ حاوی اسانس‌ها به‌طور قابل‌توجهی عملکرد مکانیکی و ممانعتی نسبت به رطوبت را در فیلم‌های خوراکی زیست‌تخریب‌پذیر ارتقا می‌دهند. ذرات پایدارکننده جامد موجب افزایش استحکام کششی می‌شوند، در حالی‌که اسانس‌ها، انعطاف‌پذیری را بهبود می‌بخشند. علاوه بر این، امولسیون‌ها جذب آب و حلالیت را کاهش داده و در نتیجه پایداری فیلم در شرایط مرطوب را افزایش می‌دهند. در نهایت، این مرور، به بررسی چالش‌های موجود و شناسایی فرصت‌های پژوهشی کلیدی در توسعه سیستم‌های امولسیون پیکرینگ حاوی اسانس، برای فیلم‌های مذکور پرداخته و همچنین ظرفیت بالقوه آن‌ها برای کاربردهای صنعتی در مقیاس وسیع را تبیین می‌کند.

واژه‌های کلیدی: اسانس، امولسیون پیکرینگ، بسته‌بندی، فیلم خوراکی

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