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A review of edible coatings containing nanoemulsions and their effect on the quality and shelf life of cheese

Saba Yazdi[1], Leyla Alizadeh[1]*

[1] Department of Food Quality Control and Hygiene, Science and Research Branch, Islamic Azad University, Tehran, Iran

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ABSTRACT

Cheese is a major dairy product widely consumed worldwide, prized for its high nutritional value, serving as a valuable source of high-quality proteins, lipids, vitamins (e.g., A, B2, and B12), and minerals (particularly calcium and phosphorus). However, fresh cheeses face challenges, including a short shelf life of about 15 to 18 days due to high humidity and the availability of nutrients. During storage, contamination by bacteria, molds, and yeasts often occurs, leading to microbial spoilage, the development of off-flavors, and a decrease in quality. To address these issues, edible coatings have emerged as a novel solution to increase shelf life and maintain quality characteristics. These coatings are thin layers made from natural macromolecules, such as polysaccharides, proteins, and lipids. They are applied by dipping, spraying, or rolling, primarily to minimize weight loss due to moisture loss and prevent microbial contamination. Recent research has focused heavily on incorporating nanoemulsions (NEs) into edible coatings due to their high stability and small particle size. Nanoemulsions are kinetically stable colloidal systems with droplet sizes typically ranging from 200 to 600 nm. They are heterogeneous systems composed of two immiscible phases, oil and water. The use of essential oils (EOs) in the food industry is traditionally limited by their low water solubility, strong taste, and high volatility. Nanoemulsions offer a more suitable alternative to pure essential oils.

1. Introduction

Cheese is a major dairy product widely consumed worldwide due to its high nutritional value and the presence of probiotic bacteria (1). Cheeses are generally nutrient-dense foods and are a valuable source of high-quality proteins, lipids, vitamins (e.g. vitamins A, B2 and B12) and minerals (particularly calcium and phosphorus) (2). The shelf life of fresh cheeses is about 15 to 18 days due to high humidity and availability of nutrients (3). Cheese surfaces can be colonized by undesirable microorganisms during the different processing stages, with ripening being the most affected (4). One of the main losses during cheese commercialization happens during storage, where the contamination of cheese by bacteria, molds and yeasts is common, and therefore the development of off-flavors can happen, decreasing the quality of the cheese, mainly when stored without packaging (5). Cheese packaging is done to minimize weight loss due to moisture loss and prevent microbial contamination and spoilage without affecting the cheese composition (3). One of the new solutions to increase the shelf life and maintain the quality characteristics of cheese is the use of edible coatings. Edible coatings are thin layers of natural macromolecules, including polysaccharides, proteins, and lipids, that can be applied to a variety of foods. (1) Edible coatings can be applied to food surfaces by dipping, spraying, or rolling (Figure 1) and protect the food from the transmission of gases, water vapor, dissolved solids, and mechanical shock (6). In recent years, much attention has been paid to the development and application of edible coatings on cheese. The

* Corresponding Author: Leyla Alizadeh
Email: Lm.alizadeh2014@gmail.com

use of essential oils in the food industry is limited due to their low solubility in water, strong taste and high volatility. Therefore, to prevent the degradation of essential oils and increase their dispersion in water, nanoemulsions are a more suitable alternative to essential oils. Nanoemulsions are heterogeneous systems that consist of two immiscible oil and water phases. The active surface of the small droplets of nanoemulsions reduces the interfacial tension of the two water and oil phases and creates relatively stable emulsions. Due to the better distribution of nanoemulsions in food products compared to pure essential oils, more favorable antimicrobial activity can be expected from them (7). Moreover nanoemulsions are transparent and less expensive, mask the taste or smell of core material, and therefore have a lower effect on the organoleptic properties of food. Besides these, by increasing the surface area, nanoemulsion also increased the physicochemical and biological activity of essential oils which permits the use of lower concentrations (8). Therefore, this article reviews the studies conducted in the field of edible coatings and the application of edible coatings containing nanoemulsions on cheese. It also examines the advantages, limitations, and future prospects of this technology.

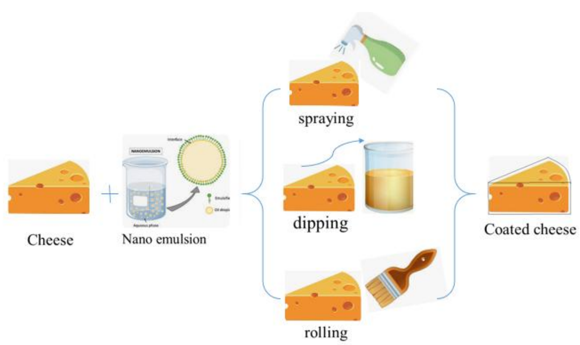

Figure 1. How to coat cheese

2. Edible coatings used in cheese are divided into three main groups:

2.1. Polysaccharide Coatings

These polymeric carbohydrates unveil biodegradability and biocompatibility and are non-toxic for living organisms. Furthermore, some polysaccharides have been approved by the Food and Drug Administration (FDA) of the United States of America (USA) and given generally recognized as safe (GRAS) status (9). Polysaccharides have limitations in film-forming, mechanical, barrier, and protective properties. Therefore, they need to be improved by reasonable material modifications (chemical or physical modification) (10).

2.2. Protein Coatings

The materials to develop protein-based coatings and packaging films can be divided into two classes: plant proteins and animal proteins. Proteins referred to in this review are broadly classified under cereal, milk, oilseeds, collagen and gelatin based. Proteins-based edible coating has excellent gas barrier properties and good mechanical properties. However, the hydrophilic nature of proteins makes the protein-based films have poor water barrier properties. The application of plasticizers and treatments can improve the protein-based films and coatings. The addition of physically and chemically active compounds into protein-based films can increase the functional properties, which can inhibit or delay the growth of microorganisms and the oxidation of lipids thereby increasing its shelf-life (11). Coatings composed of protein are inherently hydrophilic and therefore do not provide resistance to water vapor, but they have good organoleptic and mechanical properties (12).

2.3. Lipid coatings

These coatings are exceptional barriers to moisture migration. The materials used in the manufacture of films and coatings include waxes, paraffins and acetoglycerides. The main disadvantages of these types of coatings are the limitation of the appearance (13) and perception of the final food product and the formation of relatively inelastic surfaces (12). Lipid compounds used as edible polymers include acetylated monoglycerides, paraffin wax, beeswax, and surfactants. Other substances in the lipid category are essential oils. These substances are hydrophobic and some of them have antibacterial properties due to the presence of terpenoids as well as terpenes (12). Figure 2 shows the types of edible coatings.

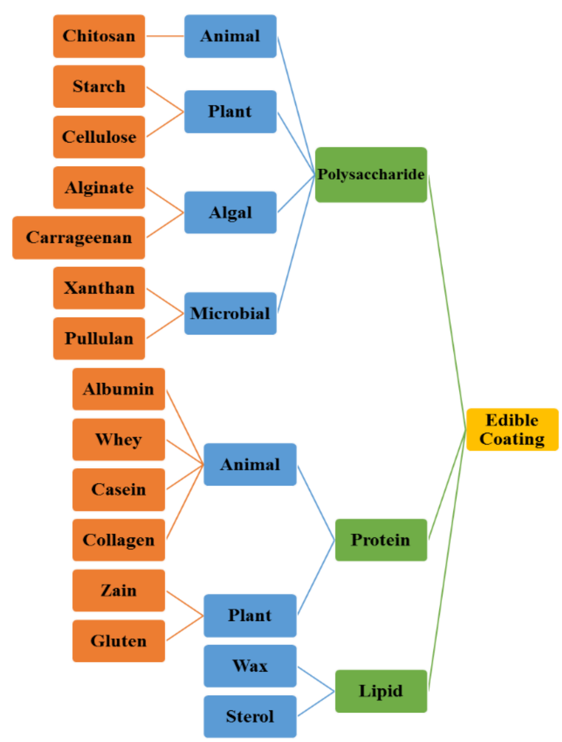

Figure 2. Types of edible coating

3. Characteristics of Edible Coatings

- Edible coatings should be water-resistant and impermeable to water vapor to keep the product intact and provide a coating that adequately covers the product.
- The coating should not decompose high levels of oxygen or accumulate high levels of carbon dioxide inside the package. Because at least 1 to 3% oxygen is required around the product to prevent anaerobic respiration.
- The coating should maintain structural integrity, improve appearance, and improve mechanical handling properties.
- The coating material should be non-sticky and easily emulsifiable.
- The coating should not create unwanted odors and should never interfere with the quality of the fresh goods.
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4. Nanoemulsion Manufacturing Methods

Nanoemulsion can be described by small droplet size and kinetically stable colloidal systems with improved functional properties compared to conventional emulsion systems. Nanoemulsion formulations with various active ingredients are used to develop biodegradable coating and packaging films with improved product quality, functional properties, outstanding nutritional value and shelf life of food products. Nanoemulsions have been formulated for a long time and are generally known as submicron mini-emulsions, ultrafine emulsions, or finely dispersed emulsions that exhibit the Tyndall effect. Antimicrobial nanoemulsions are oil-in-water emulsion systems stabilized by surfactants with alcohols and used as co-surfactants with particle sizes ranging from 200 to 600 nm. (14) Various low-energy and high-energy methods, such as phase inversion, high-pressure homogenization, ultrasonication, and microfluidization, etc., have been investigated to produce nanoemulsions with diverse properties and functions (15).

4.1. Low-energy methods

Low-energy emulsification techniques use less energy to produce nanoemulsion particles and are more energy efficient because they use the inherent chemical energy of the systems and require only gentle agitation. Phase inversion emulsification and self-emulsification, also known as spontaneous emulsification, are two low-energy emulsification techniques. The main features of these methods are minimal energy consumption and the production of very small globules or droplets .(15)

4.2. High-energy methods

Mechanical equipment is needed to generate strong disruptive forces for size reduction during high-energy emulsification. Microfluidizers, homogenizers, and ultrasonicators can provide these forces, but they are expensive and produce high operating temperatures (15).

5. Performance of edible coatings containing nanoemulsions on cheese quality

5.1. Microbial properties

Essential oils in their nanoemulsion formulations have more surface area, which makes them more effective against a wide range of bacteria and protects the active components against physicochemical stress (16). For example, in a study, it was shown that sodium alginate edible coatings based on nanoemulsion containing Myrtle essential oil (Myrtus communis L.) had inhibitory effects on Listeria monocytogenes in fresh Kassar cheese during 24-day storage at 4°C, such that nanoemulsion coatings containing 1.0% and 2.0% Myrtle essential oil reduced the population of Listeria monocytogenes in cheese during storage by 0.42 log cfu/g and 0.88 log cfu/g, respectively (17).

5.2. Physicochemical Properties

It was observed that edible coatings did not alter the physicochemical properties (pH, ash, protein, chloride, water activity and color) that take place during the ripening of cheese (18). For example, coating the Cheddar cheese with xanthan gum and flaxseed mucilage showed significant effects on chemical properties such as acidity, pH and moisture of cheese (19). It was also shown in a study that an alginate-based edible coating containing oregano and rosemary essential oils was effective in reducing mass loss and minimizing changes in the quality of fresh cheese (20).

5.3. Textural Properties

Reduction of osmotic pressure and structural changes that preserve texture are also other advantages of edible coatings on cheese (21). In a study, it was shown that an edible coating of whey protein isolate nanofibrils and carvacrol and its application to freshly sliced cheese produced the softest cheese texture, which may be attributed to its favorable water retention ability (22).

5.4. Sensory Properties

Appearance and color are one of the most important visual features in dairy products (23). One of the concerns about the use of natural essential oils in edible coatings is their possible impact on the sensory properties of cheese. However, recent studies have shown that by choosing the appropriate concentration of nanoemulsion, undesirable effects can be minimized. In a study, an edible coating of Swiss cheese using sweet whey showed that coated cheeses achieved the highest acceptance scores compared to the control sample at 20, 40, and 60 days of storage (24).

Table 1. Types of edible coatings effective on cheese

Type of coating	Source Base	Nanoemulsion/ composition	Cheese type	effects on quality	Source
Polysaccharide	Sodium Alginate	Myrtus communis	Kashaar	Inhibition of *Listeria monocytogenes* growth	(17)
Polysaccharide + protein	Alginate + Whey Protein Isolate	Ginger	Kashaar	Reduction of acidity	(25)
Polysaccharide	Chitosan	Natamycin	Iranian UF cheese	Improving sensory properties	(26)
Protein	Whey Protein Isolate Nanofibrils	Carvacrol	Cheddar	Improvement of fat	(27)
Polysaccharide	Chitosan + Guar	Orange Essential Oil	Mongolian	Reduction of weight loss	(27)
Polysaccharide	achira starch	garlic/oregano oils	double cream cheese	Increase shelf life	(28)
Polysaccharide + protein	gelatin + chitosan	rosemary	-	Increase shelf life	(29)
Polysaccharide + protein	Alginate + Collagen	Betanin + Cumin Essential Oil	Liqvan	Reduction of microbial load	(12)

6. Challenges and Limitations

The selection of the appropriate coating material and its development method is of great importance and at the same time challenging. The selected materials should be edible, palatable and biodegradable. Also, their bonding and adhesion properties are key for bonding to food surfaces. Apart from this, the selected materials should have suitable barrier properties, high strength, tensile strength and low breakage. They should have minimal impact on the organoleptic properties of the food product (30). In addition, lack of material with the required functionalities and the investment cost for the installation of coating equipment are also some of the factors that hinder the edible coating application (31). In addition, concerning the potential toxicity of food-grade nanoemulsion, at the moment there are no defined standardized checking protocols. However, factors such as droplet size, emulsifier, charge and concentration of bioactive compounds can affect nanoemulsion toxicity (32). One major edible coating drawback is the number of active agents released. These active ingredients transfer from packaging to food product by a diffusion process due to the concentration gradient. If a high concentration of antimicrobial is released, then it will also affect the food product. The color and flavor of food may change, and food may become toxic and non-consumable. Therefore, the antimicrobial compound release should be within the permissible limit to serve their purpose (33).

7. Future Outlook

The growing consumer desire for organic and sustainable food items is another significant factor, as they are made from renewable resources and are simple to incorporate into the current food manufacturing processes. The exploration of novel materials and future advancements in formulation techniques are anticipated to define the trend toward edible films and coatings. Researchers and industry experts are expected to concentrate on improving these films' and coatings' mechanical qualities, barrier capabilities, and stability in order to boost their usefulness and acceptability for usage in a variety of food applications (13). Studies on the characteristics and applications of edible coatings on other products are still limited when compared to applications on dairy products (34). Also, the development of edible coatings must address both environmental issues and nutritional needs (35). On the other side, nanoemulsion is an innovative edible coating technique that is receiving much interest. In comparison to traditional emulsions, nanoemulsion has numerous advantages that make it more efficient at maintaining coating stability and enhancing product quality. Moreover, the oxidation of bioactive substances was slowed by nanoemulsion, and dispensing became simple and the sensory qualities of products were improved. Nevertheless, there is a lack of research to understand the characteristics of nanoemulsions, including their beneficial effects on human health and their potential for application in the food industry (36), and to make plant-based nanoemulsion coatings technologically feasible and economically available, advanced and thorough research is required regarding functionality, composition, sensory and mechanical properties, and the application aspect of coatings on real food (37). Generally, edible films/coatings are promising systems for food packaging, but more research and incentives are needed to achieve the best solution, in an environmentally and economically sustainable way (38).

8. Conclusion

The imperative for consumers demanding food products with longer shelf lives that have undergone minimal processing and contain fewer or no preservatives underscores the necessity for innovative preservation technologies. This review affirms that edible coatings containing nanoemulsions (NEs) represent a novel and effective solution to significantly increase the shelf life of cheese. The primary mechanism enabling this success lies in the advantages NEs hold over conventional essential oils (EOs). EOs are typically limited by low water solubility, high volatility, and strong taste. Nanoemulsions, functioning as kinetically stable colloidal systems with small particle sizes (200 to 600 nm), resolve these limitations. NEs provide better dispersion and a dramatically increased surface area for active components, leading to more favorable antimicrobial activity at lower concentrations. The application of NE-infused coatings has demonstrated measurable improvements across multiple quality attributes of cheese, such as: microbial safety and shelf life, physicochemical and textural integrity and sensory acceptance. Despite the promising outcomes, the widespread commercial implementation of NE-based edible coatings faces several substantial challenges that must be overcome, such as: material selection and functionality, economic barriers, safety and standardization and control of active agent release. Future advancements in this field are anticipated to be driven by the consumer desire for sustainable and organic food items, as these coatings are made from renewable resources. In conclusion, edible coatings integrated with nanoemulsions offer a promising, efficient path toward developing cleaner-label, higher-quality, and longer-lasting cheese products. The continued focus on overcoming material limitations, standardizing safety protocols, and ensuring sustainable implementation will define the success of this technology in revolutionizing the food preservation sector.

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