Shellac: A natural lipid polymer for food safety and quality monitoring

Chapter · January 2023

DOI: 10.1016/B978-0-323-85791-8.00017-3

Saurav Kumar
Central Scientific Instruments Organisation

Lubhan Cherwoo
McMaster University

Anupma Sharma
Central Scientific Instruments Organisation

Nandkishore Thombare
ICAR-National Institute of Secondary Agriculture

CHAPTER

7

Shellac: A natural lipid polymer for food safety and quality monitoring

Saurav Kumar[a,b], *Lubhan Cherwoo*[a], *Nishtha Puri*[a], *Anupma Sharma*[a], *Nandkishore Thombare*[c], *Amol P. Bhondekar*[a,b]

[a]**CSIR-Central Scientific Instruments Organisation, Chandigarh, India,** [b]**Academy of Scientific and Innovative Research, Ghaziabad, India,** [c]**ICAR-Indian Institute of Natural Resins and Gums, Namkum, Ranchi, Jharkhand, India**

7.1 Introduction

Since millennia, humans have been an agricultural species, our main focus being higher yields and better quality of food generation. This has developed the physiological and behavioral needs of human life. As the human population increases gradually, the need and demand for food have increased simultaneously. In recent centuries, after the industrial revolution, the human population has exploded, which has led to higher demands in food supply. This higher demand was met with incompetent production strategies. The major problems of the food industry include inherent limitations of edible materials like their perishable nature, proneness to microbial contamination, lower shelf life, transport and packaging limitations, and quality and safety concerns. Hence, to improve the condition of the food sector, significant progress has been achieved to enhance the shelf life as well as to reduce the contamination in the postharvest food products. The major contributions being from synthetic chemicals and chemical preservatives, but since these chemicals have a prominent impact on the environment and human health, more and more use of such chemical methods to increase food production and processing has greatly shown toxic and hazardous effects on the environment and human life.

Therefore, the food industry has been in need of development and modernization for protection, preservation, prevention against microbial growth, quality monitoring, safety assessment, packaging and coatings for food items. A search for an alternative is much needed through research in the field of biotechnology and food technology. The field of biotechnology has played a vital role in the development of the food industry, with its sister

Nanotechnology Applications for Food Safety and Quality Monitoring
DOI: https://doi.org/10.1016/B978-0-323-85791-8.00017-3

science nanotechnology being a field of recent attention dealing with molecules and structures at the nanoscale. Processes and technologies to produce products having the capability of improving the quality of human life has been a very prominent area of research. Nanobiotechnology, the interaction of nanotechnology and biotechnology and its application in the field of life sciences offers numerous applications based on its compatibility with biomolecules and biosystems, which makes it one of the emerging areas of research in biomedical applications, drug delivery, molecular imaging, material for food safety and quality monitoring, edible and smart sensors for coating and preservation, packaging materials for the enhanced shelf life of food products, and so on to revolutionize the field of food technology.

Recent trends have seen an increase in natural alternatives for these areas of research. Primarily, natural or nature-derived polymers have been utilized in the food industry. Classes of polymers based on basic biomolecules have great functionality in the food industry based on their physical and chemical properties. Natural polysaccharides like chitosan, cellulose, alginate, chitin, starch, and natural gums. Proteins like zein, whey, soy, collagen, and gelatin. Aliphatic polyesters like polyhydroxybutyrate (PHB), polylactic acid (PLA), polyhydroxyalkanoates (PHA), and polyhydroxy. Lipids like acetoglycerides, beeswax, triglycerides, fatty acids, and other waxes have been in practice for use in the food industry have been used in the food industry.

Lipid-based polymers have been used for preservation, protection, and value addition of nutrients to food items. Lipids are used as food coatings, because of their hydrophobic property, they act as moisture barriers. They can form various structures which can range from simple liposomes to complex lipid nanoparticles depending on their host of applications (Fig. 7.1).

The area of nanotechnology and biotechnology overlap and as a result, give rise to different realms of functionality, like food coatings, biocosmetics, nanosensors, or nanobiomaterials, where this intersection of nanobiotechnology can be put to use. "Shellac nanobiopolymers," stem from the interaction of these two areas and have a number of basic and advanced applications from being used as an antimicrobial coating to being used for production of edible coatings, nanosensors and nutrient enhances (Fig. 7.2). Shellac is a natural biopolymer produced by female lac bugs, most commonly of the species *Kerria lacca*, in its raw form. Chemically this is a mixture of resin, wax, colorant molecules, esters, and polyesters of polyhydroxy acids. Basic chemical structure of shellac constituents of aleuritic acid and terpenic acid parts (Fig. 7.1). It is one of the only natural commercial resins of animal origin, available in various forms and grades of purity.

7.2 Background

7.2.1 Lipid-based polymers in nanotechnology

In recent years, nanopolymers have gained increasing attention in the food industry, their properties like well-controlled release, enhanced distribution and increased permeability have made them an idea operative tool for drug and food delivery, among many, lipid-based

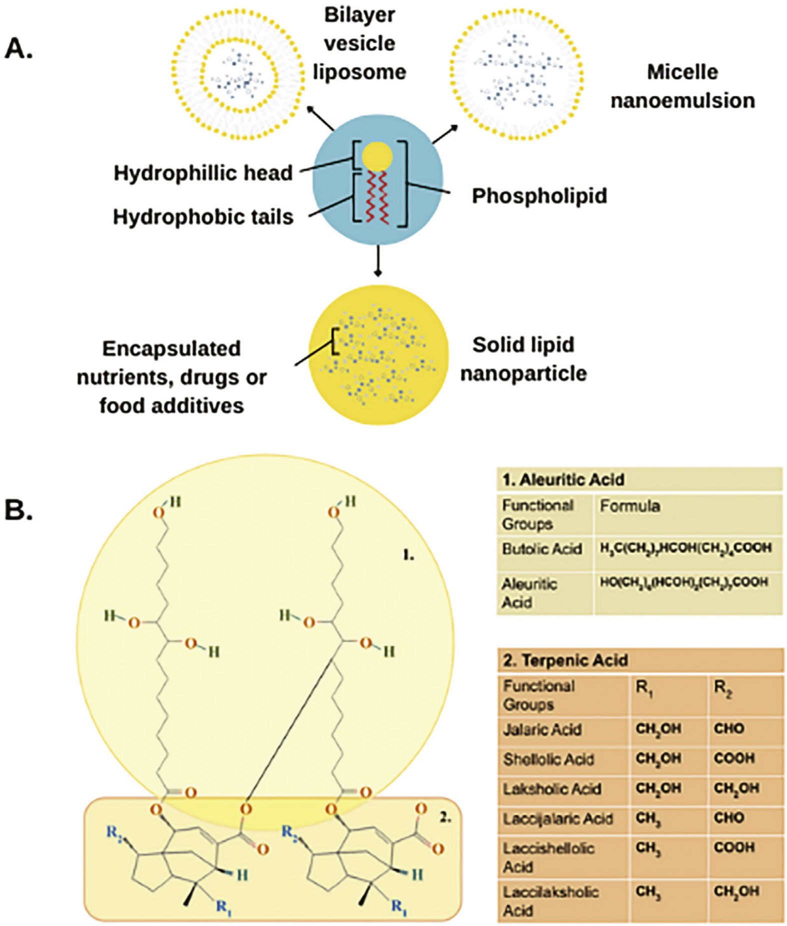

FIG. 7.1 (A) Structures formed by lipids in water. (B) Chemical structure of shellac (*Courtesy: Reproduced from* https://doi.org/10.3389/fnut.2021.783831).

nanopolymers as nanocarriers have been widely studied and used. Lipid/essential oil stabilized nanoemulsions have good biocompatibility thus making them a useful tool in the food industry for delivery of nutraceuticals and flavoring agents, as antimicrobials, biodegradable coatings or packaging films (Huber & Embuscado, 2009). A group studied stability, biocompatibility, and antioxidant activity of PEG-modified liposomes for delivery of resveratrol. Direct sonication of phospholipids with two PEG-surfactants was done to produce unilamellar vesicles of PEG-modified liposomes. These vesicles are useful to safely deliver resveratrol. All of these are lipid polymers modified or used as an additive for their variety of applications (Caddeo et al., 2018).

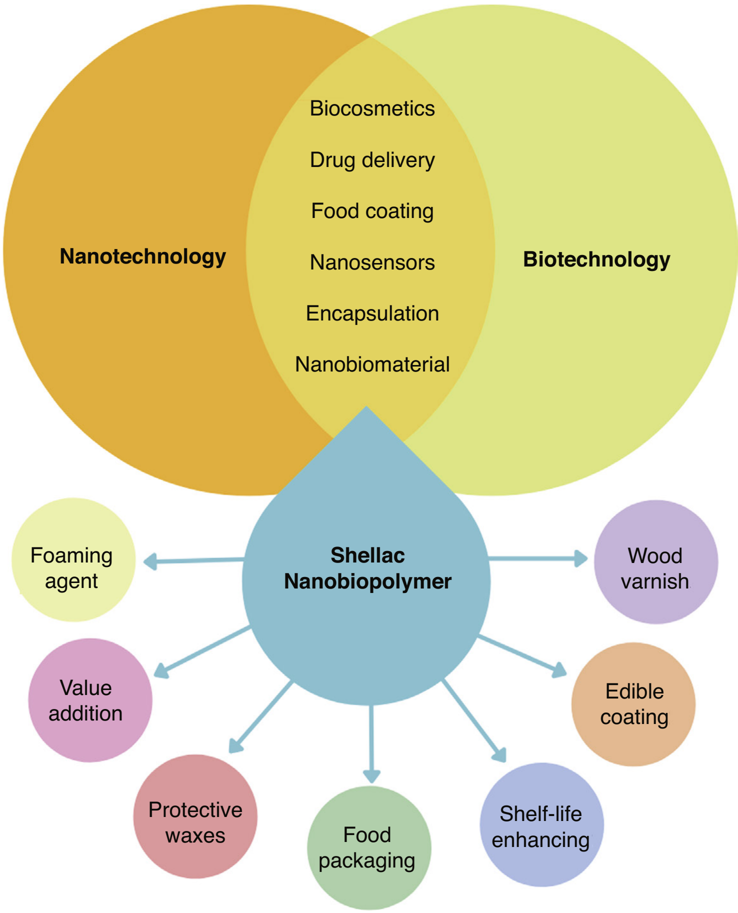

FIG. 7.2 **Interaction of nanotechnology and biotechnology and the role of shellac.**

7.2.2 Lipid-based polymers and blends in food industry

Lipids have a very unique property of being hydrophilic and hydrophobic at the same time, this leads to their various transitional structures. They can form protective layers against moisture preventing microbial and physicochemical deterioration. Their interaction with water leads to different structures they form. Lipids, like *Candelilla* wax, bee wax, vegetable oils, etc. have been used as raw materials in the food industry as edible coatings, packaging and nutrition preserver. Apart from that lipid polymers will provide gloss, decrease moisture loss and reduce the complexity of packaging. Many studies on polysaccharides like chitosan, cellulose, alginate, chitin, starch, and natural gums. Proteins like zein, whey, soy, collagen, and gelatin. Aliphatic polyesters like polyhydroxybutyrate (PHB), polylactic acid (PLA), polyhydroxyalkanoates (PHA), and polyhydroxy. Lipids like acetoglycerides, bees wax, triglycerides, fatty acids, and other waxes have been carried on for application of these natural polymers in the food industry (Adeyeye et al., 2019; Aydin et al., 2017; Lu et al., 2021). Our concerned lipid polymers alone cannot impart mechanical strength and preservative properties together, hence lipid-based blends with polysaccharides are more useful. Naturally derived polymers based on lipids have been employed in the food industry for practical applicability (Grujic et al., 2017; Prameela et al., 2018). Food packaging and coating strategies which include polysaccharides for their oxygen barrier properties, proteins for their relatively good mechanical strength, and lipids for their low water vapor permeability and good moisture barrier properties have been studied (Mohamed et al., 2020; Teixeira-Costa & Andrade, 2021; Trajkovska Petkoska et al., 2021). A lot of these mixtures and blends have characteristic properties which give them functionality in various sectors of food industry like packaging, preservation, microbial growth prevention, nutritive value addition and so on.

7.2.3 Shellac as a versatile lipid-based biopolymer

Shellac is a natural biopolymer produced by purification of resin lac which is secreted by female lac bugs, most commonly of the species *Kerria lacca* (Fig. 7.3). Chemically a mixture of esters and polyesters of polyhydroxy acids. It is one of the only natural commercial resins of animal origin. It is commercially available in a lot of variants and compositions some of which are classified as food grade (Fig. 7.3), each having its variating properties based on their application. Shellac (CAS Number: 9000-59-3) is used in the food industry, it is processed and refined by mechanical method using heat or solvent, which yields orange shellac or by chemical method using bleaching, which yields bleached shellac. Any shellac variety is regarded as safe for use in the food industry if it has less than or equal to 1.5 ppm arsenic,

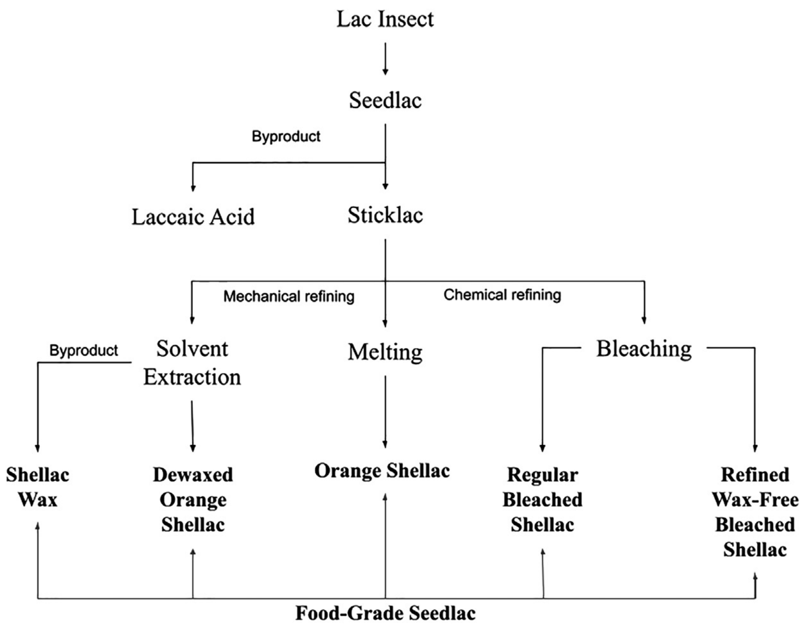

FIG. 7.3 Food-grade shellac extraction from seed lac. *(Courtesy: Reproduced from https://doi.org/10.3109/10915818609141914).*

110 ppm heavy metals, and must be absent of rosin. Shellacs used in the food industry can be wax containing or wax free (dewaxed), based on this four food grade shellac are employed in the food industry orange shellac, dewaxed orange shellac, regular bleached shellac and refined bleached shellac (Liebert, 1986). Shellac has a host of properties being hard, brittle and resinous biopolymers. It is naturally a thermoplastic mostly used as sealants, varnishes, enteric coatings, porous material filler, packaging, food additive, and preservative. Due to its acidic nature it has pH-dependent solubility, soluble at pH above 7.4 and in alcohols like ethanol, partially soluble in ethers, making it resistant to acidic dissolution. It has a character coating property, which when used in combination with its acid resistance makes it an excellent enteric coating material, assisting its applicability in drug delivery and release (Ben Messaoud et al., 2016; Farag & Leopold, 2009; Karak, 2016; Rehding, 2006; Triyono et al., 2021). Studies on shellac for its functionality in the food, pharma, wood and other industries have very prominent and extensively done (Bar & Bianco-Peled, 2021; Muhammad et al., 2020; Patel et al., 2014; Phan The et al., 2008; Wang et al., 2018; Yuan et al., 2021).

Lac has been known in India and China since ancient times, its use tracing back to about 2000 years. Lac has been cultivated for over three centuries of known modern human history using it as a one-product finish for wood items, gramophone vinyl record pressing material, purple-red dye, etc. Making its way into different industries as a coating, dyeing and finishing agent. Due to its vast application it was extensively cultivated manually up until the mid-19th century and then mechanically in the United States, Europe and China(Bryk, 2022; *How shellac is made—material, history, used, processing, product, industry, History, Raw Materials, n.d.*; Stummer et al., 2010).

7.2.4 Application of shellac blends

Shellac, being naturally available and easily processable has gained a lot of attention in the food industry as discussed earlier. Shellac and its blends have been used and researched extensively, shellac with chitosan, gelatin, PEG and PVA as food preservatives for eggs, tomatoes, nuts, and bananas; shellac with lemongrass oil, zein, gelatin, stearic acid, and chitin as quality enhancer for nuts, bananas, drugs, and curcumin; shellac with konjac glucomannan, Persian gum and gelatin as protectant coating and packaging majorly in the past 10 years (Table 7.1).

TABLE 7.1 Shellac and its blends with various materials and their application.

Shellac blends	Title of publication	Target items	Purpose	Year of publication
Shellac and chitosan	Effects of pine needle essential oil combined with chitosan shellac on physical and antibacterial properties of emulsions for egg preservation	Eggs	Preservation	2022
Shellac and lemongrass oil	Assessment of shellac and lemongrass oil blend as edible coating to prolong shelf life of pili nut *(Canarium ovatum)*	Pili nut	Prolong shelf life	2021
Shellac and konjac glucomannan	Fabrication of novel Konjac glucomannan/shellac film with advanced functions for food packaging	Food	Packaging	2019

Shellac blends	Title of publication	Target items	Purpose	Year of publication
Shellac and zein	Preparation, characterization and stability of curcumin-loaded zein–shellac composite colloidal particles	Curcumin	Enhanced photochemical and thermal stability	2017
Shellac and gelatin	Utilization of shellac and gelatin composite film for coating to extend the shelf life of banana	Banana	Extension of shelf life	2017
Shellac and β-carotene	Dispersing hydrophobic natural colourant β-carotene in shellac particles for enhanced stability and tunable colour	Food color	Natural food coloring agent	2017
Shellac, stearic acid and Tween-20	Development of biocomposite films incorporated with different amounts of shellac, emulsifier, and surfactant	Pea starch–guar gum films	Reduce water vapor permeability and enhance mechanical properties	2017
Shellac and chitin	One-pot fabrication of chitin-shellac composite microspheres for efficient enzyme immobilization	Enzyme	Enhance immobilization	2017
Shellac, gelatin and Persian gum	Shellac, gelatin, and Persian gum as alternative coating for orange fruit	Orange	Coating	2017
Shellac and alginate	Physicochemical properties of alginate/shellac aqueous-core capsules: Influence of membrane architecture on riboflavin release	Riboflavin	Controlled release	2016
Shellac and PEG	The effect of polyethylene glycol on shellac stability	Shellac	Stability	2016
Shellac hydrogel	Tough self-assembled natural oligomer hydrogel based on nanosize vesicles cohesion	Hydrogel	Developing soft material	2016
Shellac nanofibers	Electrospun medicated shellac nanofibers for colon-targeted drug delivery	Colon-targeted drug	Targeted drug delivery	2015
Shellac and PVA (Polyvinyl Alcohol)	Preserved effect of nano-Fe^{3+}/TiO_2-modified PVA-based composite preservation coating for eggs	Eggs	Preservation	2014
Shellac and starch	Postharvest shelf-life extension of green chillies (*Capsicum annuum* L.) using shellac-based edible surface coatings	Green chillies	Improvement in shelf life and postharvest quality	2014
Shellac and chitosan	Nanoparticle formation by using shellac and chitosan for a protein delivery system	Protein	Delivery	2012
Shellac and yeast cell microcapsules	Triggered cell release from shellac–cell composite microcapsules	Probiotics	Controlled delivery and release	2012
Shellac and xanthan gum	Stabilisation and controlled release of silibinin from pH responsive shellac colloidal particles	Silibinin	Controlled release	2011
Shellac, AMP and AMN	Enhanced enteric properties and stability of shellac films through composite salts formation Sontaya	Shellac	Enhance enteric property and stability	2007
Shellac and chitosan	The effect of edible eggshell coatings on egg quality and consumer perception	Egg shells	Improved quality and shelf life	2005

7.3 Shellac for nanotechnology in the food industry

There are numerous ways by which nanotechnology can be applicable in the food industry and this number is expected to increase multifold in the near future. Nanotechnology being a rapidly growing field of research has seen exponential growth in research work done in the past decades; it possess possibilities of substantial application in the area of food industry from processing to packaging. Here nanopolymers and biopolymers have been employed to enhance processes and products of the food industry. Shellac plays a pivotal role as a natural biopolymer with adaptable applications in food and other industries, based on its versatile properties toward acidic to alkaline conditions both.

7.4 Films and packaging

Packaging industry has been of great importance in the food industry. Using nanomaterial for packaging has a number of advantages, like improved mechanical properties, increased bioavailability of nutrients, and detection and protection of microbial contamination (Bradley et al., 2011; Llorens et al., 2012). For this purpose, a number of nanocomposites, polymers containing nanoparticles are used. For example, nanoparticles of ZnO and MgO have been used for food packaging; amorphous silica has been used in food and in food containers, engineered water nanostructures, aerosols have been effectively used for; killing foodborne pathogens such as *Escherichia coli*, *Listeria*, and *Salmonella* on steel food production surfaces. Novel use of biopolymers has been under way in the food packaging and storage industry, where various shellac, a natural biopolymer; based coating formulations have been tested for their protective properties and preservative against microbial growth. A group developed a shellac-based films with combination of shellac along 2-hydroxyethyl methacrylate (HEMA), 2-ethylhexyl acrylate (EHA), and 1, 4-butanediol diacrylate (BDDA) in different concentrations and studied mechanical properties like tensile strength and elongation at break, water absorptivity, thermal properties and biodegradability of these films. They demonstrated that shellac grafted BDDA showed highest tensile strength and elongation at break values, shellac grafted HEMA films showed highest biodegradability and water uptake (Ghoshal et al., 2010). Another group developed Konjac glucomannan-shellac film for potential use in food packaging, their study revealed that shellac composed films had better mechanical and thermal stability with an enhanced water hydrophilicity (Du et al., 2019). These studies demonstrated use of shellac and shellac composed polymers as film material for food packaging.

7.5 Edible coatings and shelf-life enhancer

Edible coatings can be single or multiple layers of biopolymers, which have the ability to enhance shelf life, reduce lipid oxidation, reduce ethylene release, protect and preserve from microbial action, and degradation. Edible coatings can be functionalized for antimicrobial and antioxidant properties. Coatings and shelf-life enhancers are developed using nanomaterial composites like gelatin–chitosan/(Ag/ZnO), gelatin–anthocyanin/kafirin (Khafar et al., 2018), starch, alginate, carrageenan, chitosan, agar, and lard coatings. Among these biopolymeric coatings like that of shellac–PVP, shellac–aloe vera, shellac–lemongrass oil, or shellac–gelatin have been developed for their wide applicability. A group demonstrated that an electrospun eugenol loaded core-sheath PVP/shellac film improved thermal stability, moisture resistance, and prolonged shelf life of postharvest strawberries (Li et al., 2020).

A study used shellac–gelatin composite films to develop an edible surface coating to enhance shelf life and prolong ripening of banana fruits. They found shellac–gelatin (60:40) composite film to achieve good shelf-life extension and storage functionality (Soradech et al., 2017).

Another study developed a shellac and aloe vera gel edible coating for shelf-life enhancement of tomato. This edible coating restricted changes in respiration and ethylene synthesis which led to delayed deterioration in tomato quality and taste. The shelf life of stored tomatoes showed an enhancement of 12 days for shellac–aloe vera gel coating and 10 days for shellac coating alone (Chauhan et al., 2015).

Furthermore, there are a variety of techniques used to apply shellac coatings, few are discussed below.

7.5.1 Electrospraying and electrospinning

Electrospraying is a method to produce nanofibers using an electrohydrodynamic process on a polymer solution which when released from a thin nozzle under high voltage stretches, elongates and solidifies to form nanofibers (Fig. 7.4a). Electrospinning is a subcategory of electrospraying, the main section of the electrospinning device includes a high-voltage power supply, a syringe pump, a spinneret, and a conductive collector. The process involves release of polymer solution molecules from nozzle, under high voltage, upon electrification; the jet stream initially

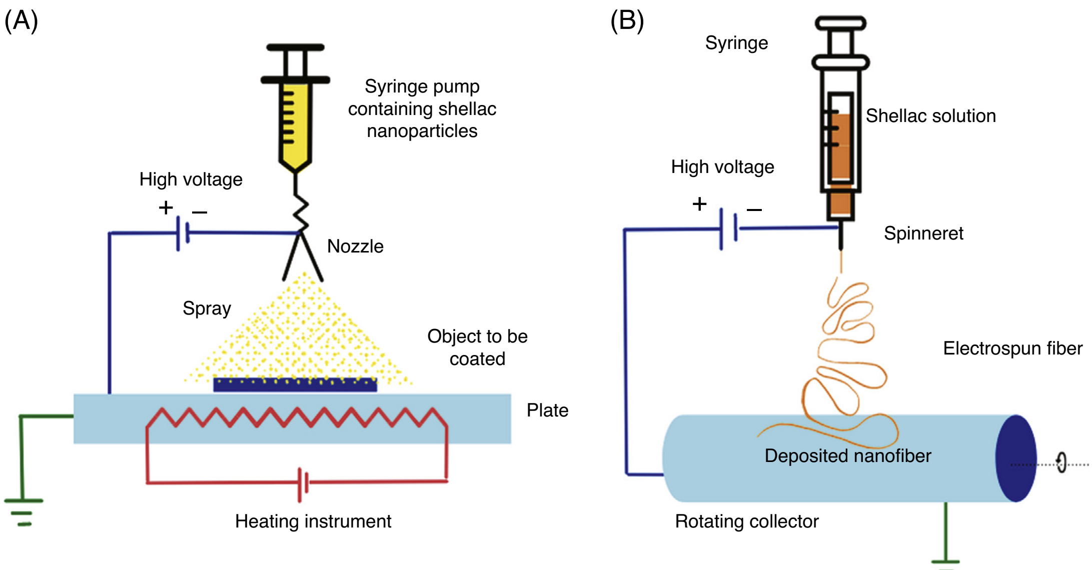

FIG. 7.4 (A) Electrospraying method of coating shellac and (B) electrospinning method of coating shellac.

stretches straight out then upon elongation starts a whipping motion due to bending instabilities. As the jet stream is elongated into finer diameters, it solidifies quickly, on the rotating collector (Fig. 7.4b). Generally, this is difficult and complicated to perform for natural polymers due to the behavior of the polymer solutions or melts and specific conditions required to form solutions and maintain liquid state. Shellac being easily soluble and stable in anhydrous ethanol solution and low in molecular weight gives it an upper hand to make an electrospinning solution. Shellac also acts as filler for nanofibers imparting thicker nanofiber with other polymers like polylactic acid (PLA), due to polymer chain entanglement. This effect can be reduced using ethanol as sheath fluid, which forms thinner shellac nanofibers without compromising their quality (Thammachat et al., 2010; Wang et al., 2019; Wu et al., 2014; Xue et al., 2019).

7.5.2 Dip coating

An easy, simple, cheap, repeatable, and reproducible method used to add a thin layer of film onto a substrate. This is performed by simply dipping the substrate that we need to coat into the polymer solution and removing it at a constant speed into a hydrous atmosphere. After which a thin homogeneous layer of shellac is coated onto the substrate. This is then dried at room temperature, additional treatments of hardening can be given or another layer of shellac can be coated by repeating the sample process after drying the primary layer completely (Fig. 7.5). To enhance the performance of coating magnesium substituted hydroxyapatite can be used in combination with shellac as the primary coat and magnesium substituted hydroxyapatite as the secondary coat this can increase the bonding strength and provide stability for the developed coating (Aravindakshan et al., 2021; Neacşu et al., 2016).

7.5.3 Manual coating

Here a semisolid or liquid is coated onto a solid food item to preserve its freshness, increase aesthetics and prolong shelf life of the food item. This is performed by simplifying by rubbing a semisolid/liquid polymer solution like that of waxed food grade shellac onto fruits using a sterile applicator cloth (Fig. 7.6) (Fernandes, 2018).

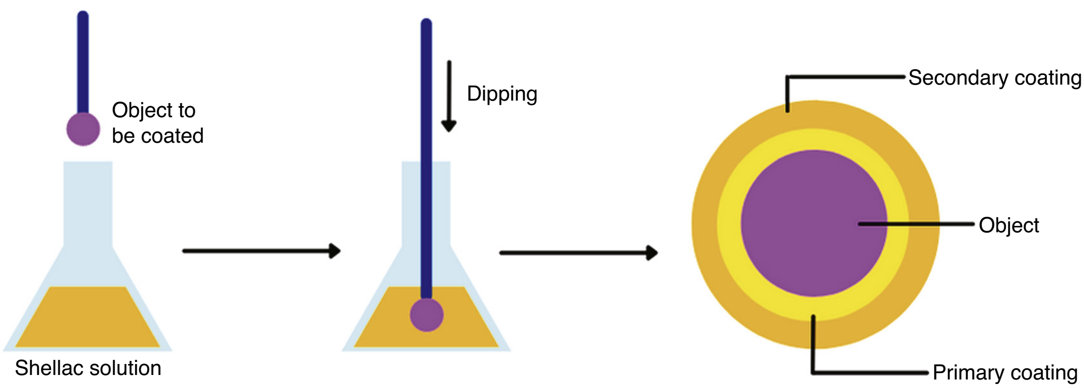

FIG. 7.5 Dipping method for shellac coating.

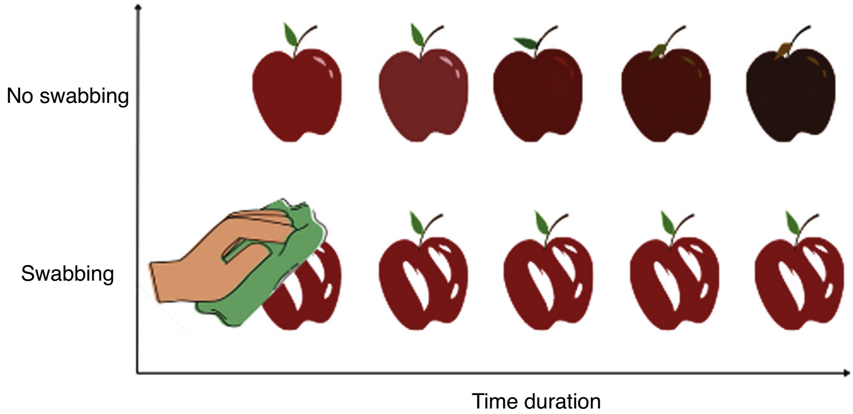

FIG. 7.6 Swabbing method for shellac coating.

7.6 Quality enhancer and preservation

The food industry has begun using nanotechnology to develop nanoscale ingredients to improve color, texture, and flavor of food. For example, nanoparticles of TiO_2, SiO_2, and amorphous silica have been used as food additives, TiO_2 is generally used as a coloring in the powdered sugar coating on doughnuts (Kessler, 2011). Nanomaterials are also being used as ingredients and additives (e.g, vitamins, antimicrobials, antioxidants) in nutrients and health supplements for enhanced absorption and bioavailability (Chaudhry et al., 2008). A group studied the microbial growth and quality of "Fuji" apple, with nanoemulsion of carnauba–shellac wax homogenized with lemongrass oil, for 5-month postharvest. Using uncoated samples as a control, they concluded that CSW/LO coated samples had 2.5% less weight loss, retained their hardness, had decreased bacterial and negligible fungal growth, and also had better sensory appreciation (Jo et al., 2014). Another group studied the effect of various coatings on egg shelf life and microbial protectiveness. They tested eggs with ozone, ultrasound, and coating with shellac and lysozyme chitosan blend. Concluding that all were effective to stop any microbial growth to some extent, while some decreased the microbial count with respect to the control uncoated egg for a total of 5 weeks of storage. Shellac had a neutral outcome, it preserved the initial microbial load and stopped any further growth, also shellac and lysozyme chitosan blend enhanced the shelf life (Yüceer & Caner, 2020). These studies clearly show the application of shellac as a protective and preservative coating for quality enhancement, protection, and preservation.

7.7 Food nanosensors

Nanomaterials and nanopolymers have been used as nanosensors for food safety and quality assessment. Generally used to sense microbial contaminants, they are used as sensors in food production and at packaging facilities to facilitate a microbe free environment. These polymers can be designed to monitor food quality during transport and storage, thus can potentially detect nutrient deficiency in edible plants. The antimicrobial properties of these nanomaterials enable them to be a food protectant. Commercial use of nanosensors has been reported to check storage conditions during food transport in refrigerated trucks for temperature control (Bouwmeester et al., 2009). A study developed by a disposable electrochemical sensor from shellac and graphite mixture for detection of sulfamethoxazole in food samples. Sulfamethoxazole is a common metabolic residue in the food web. This sensor was made using a conductive ink formulated from shellac on a waterproof paper substrate with gelatin. This sensor had a recovery analysis of 91% and 110% when used for water and milk samples. This study depicts an example of the use of shellac for developing nanosensors for use in the food industry (Melo Henrique et al., 2021).

7.8 Food safety and other applications

We can be exposed to nanoparticles from materials used in the food industry as they come in direct contact with our food, hence their safety assessment and toxicity testing is a very important field of study. Once these nanoparticles get absorbed by our digestive system, they may travel anywhere in the body and accumulate in various organs of the body, leading to potentially nanotoxicity. Food technologists and engineers are trying to improve the safety of our food and nanotechnology opens the door to a whole new array of products. Therefore, there is a need for better food safety standards; here nanotechnology can help in detecting these nanotoxins. As a result, the use of nanotechnology by the food and related industries is expected to increase significantly, impacting the food system at all stages from food production to processing, packaging, transportation, storage, security, safety, and quality (Berekaa, 2015; Kessler, 2011).

7.9 Market potential of shellac in food safety and quality monitoring

According to the United Nations, approximately 1.3 billion tons of food is lost each year. Some estimates also suggest that a lot of food is lost during the postharvest phase which significantly impacts world hunger, hence reducing this loss is not just important economically, but morally too. According to the United Nations, it is also estimated that food production will need to rise by 70% in the next few decades to compensate for the growing human population, but with postharvest loss prevention that percentage can become more attainable without destroying our natural resources. According to the UN Food and Agriculture Organization (FAO), main challenges that farmers and other postproduction agencies face are called major bottlenecks in the food industry (Fig. 7.7) (*The future of food and agriculture*, n.d.).

Major proportion of these identified challenges may be positively dealt by judicious market supply chain, transportation channel and real time monitoring of postharvest products. Apart from this effort, there is dire requirement of increasing the shelf life of the food product and smart packaging to address the cumulative bottleneck of the food/edible items industry. Practically, chemicals and preservatives are easy to apply and procure, but have a significant negative impact on the consumers health as well as the environment. Natural polymer and lipid membranes are the promising material to deal with the

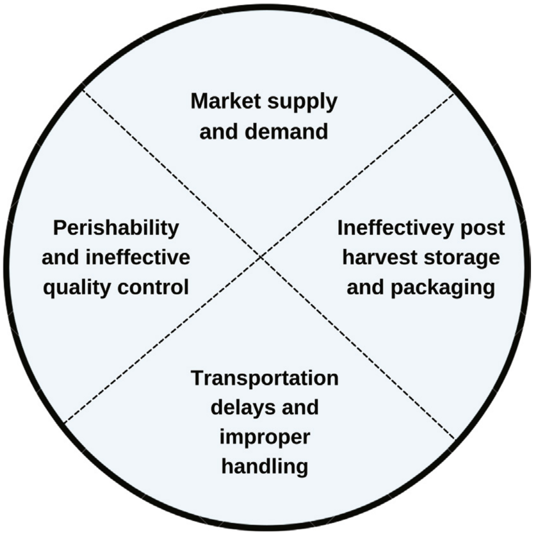

FIG. 7.7 **Major bottlenecks in the food industry.**

perishability of the food items and also give value addition to the product. Shellac is one of the fundamentally suitable material which offers tremendous application to almost all the spectrum of food items, fruits, and vegetables. Also, the material possesses antimicrobial property which offers significant protection against fungus and bacteria alike. Moreover, shellac can be engineered with other existing edible polymers like zein, cellulose, starch, gelatine, aloe vera, etc. to enhance the shelf life of fruits and vegetables. Although, shellac is an ancient and one of the most studied material as a natural biopolymer, it has also gained good spotlight in recent years due to its potential contribution in sustainable future and human health. Recent trends in the area of shellac research show a paradigm shift in the publication as well as citations. (Fig. 7.8) shows representation of publication

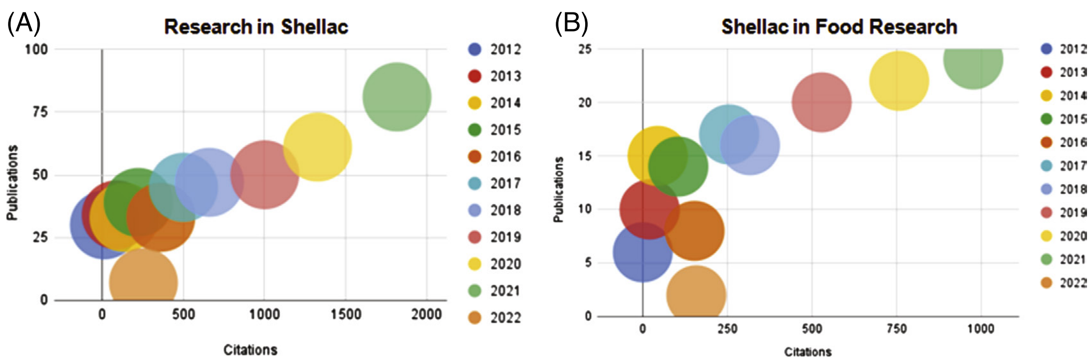

FIG. 7.8 (A) Statics of recent 10-year research work on shellac and (B) statics of recent 10-year research work on shellac in the food industry.

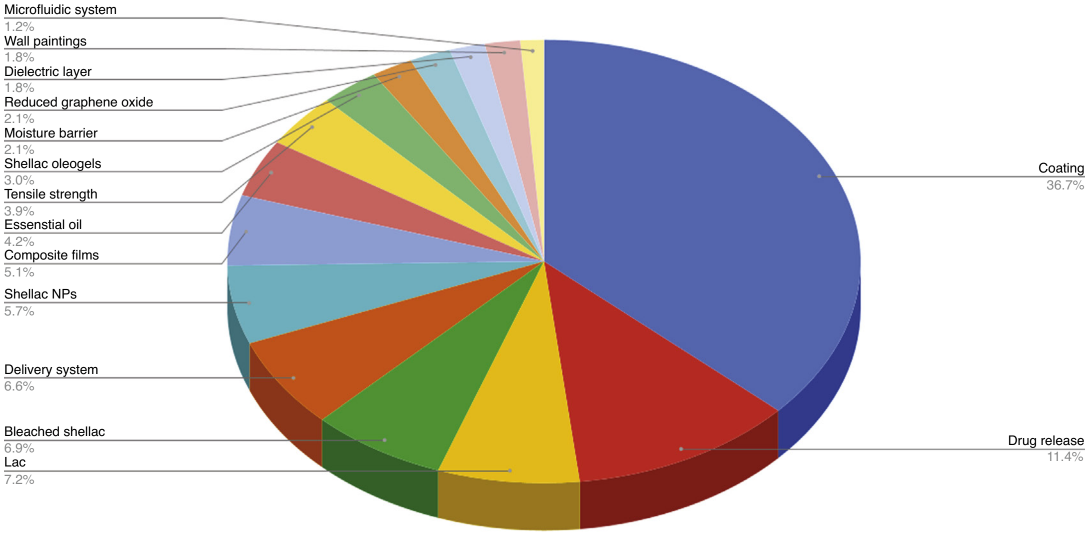

FIG. 7.9 Industrial application of shellac 2012–2022.

in the last 10 years along with its citation (*source: www.webofscience.com*). The empirical figures of the citation number show increment from 13 in the year 2012 to 1860 in the year 2021. Also, if we consider the research trends in shellac in the food industry the figures noticeably increasing, where the citations of the works changes from 20 in the year 2013 to 977 in the year 2021. There is no other natural material which offers this much increment in their research in the food industry and edible products.

Shellac, a designated GRAS and FDA (*CFR—Code of Federal Regulations Title 21*, n.d.) approved material has opened gates for enormous applications in the food, pharma, cosmetic industry, and many other industries (Fig. 7.9).

Shellac has a long history where it has been used directly or indirectly for the consumption as a food additives or in other form. From its use as medicinal component to bitterness masking in pharma drug to shelf-life enhancement of fruits, vegetables, and value addition of edible items, in all spectrum it has been a successful material. Statistically, applications of shellac used in the food industry in the last 10 years as an edible coating have occupied a share of 36.7% of research work, drug release have covered 11.4% of the share, while protective/preservative layer, nanoparticles and tensile strength enhancer have a total of 14.7% of share, these areas of research have been prevalent as depicted by research trends. Areas like edible coating, food safety, films, shelf life, shellac NPs, and food additives have shown novel and unique applicability. (Fig. 7.10A) shows various areas of research carried out in shellac, while (Fig. 7.10B) shows areas of research where shellac has been used as coating or film material like edible and composite coatings, food coatings for fruits and vegetables, storage packaging material, and shelf life extending coatings. (Fig. 7.10C) shows various applications of shellac nanoparticles in the food industry like shellac NP composites, xanthan–shellac NPs, thermally stable shellac NPs, and fabrication/characterization of shellac NPs for the food industry. (Fig. 7.10D) shows shellacs' role in food safety and security major areas of

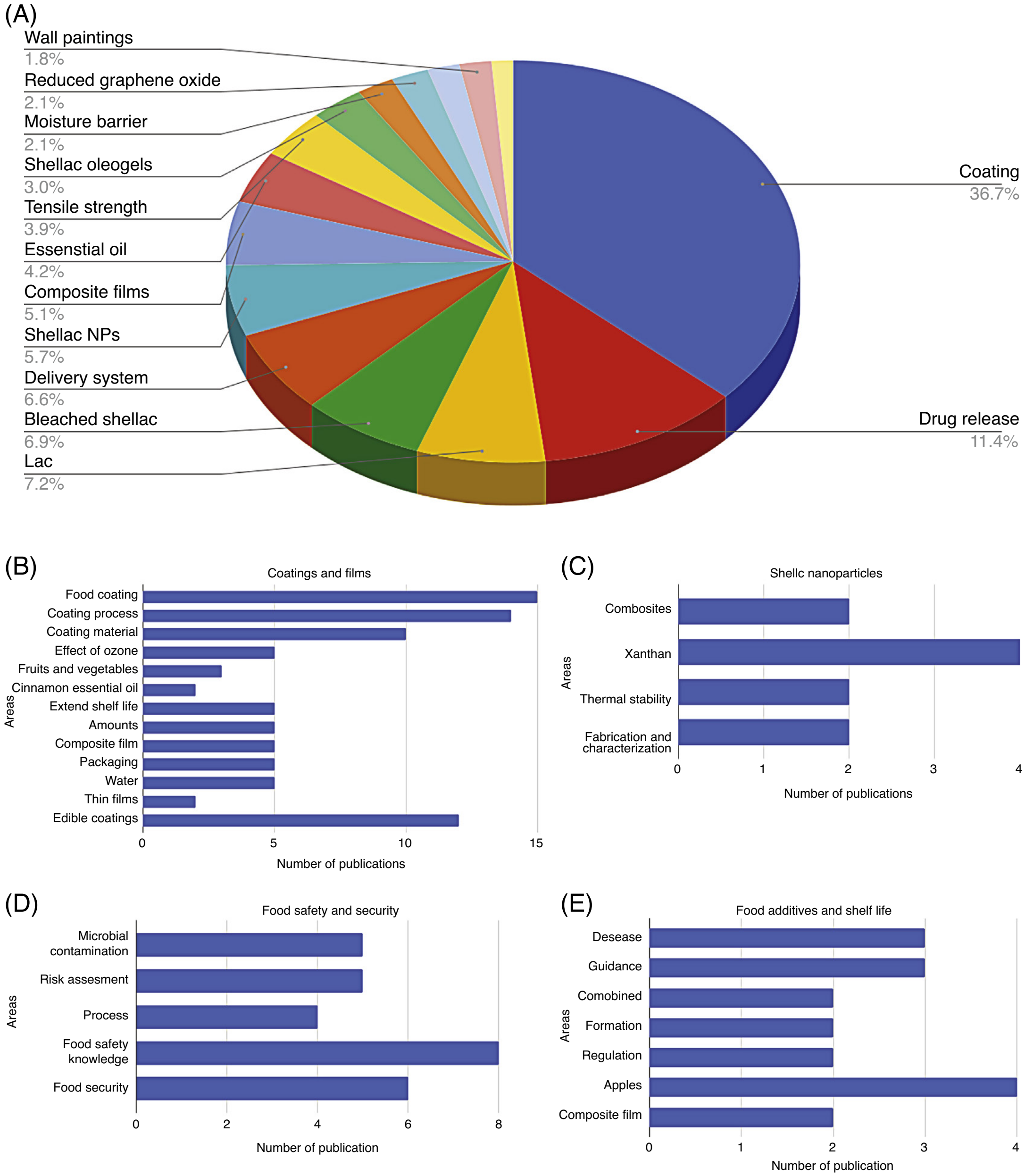

FIG. 7.10 (A) Shellac presence in the food industry 2012-2022. (B) Shellac as coating and food films. (C) Shellac NPs in food industry. (D) Shellac in food safety and security. (E) Shellac as food additive and shelf-life enhancer.

research being in microbial contamination, risk assessment and food safety. Lastly, (Fig. 7.10E) shows shellac as food additive and shelf-life enhancer with major areas of work for apples, films, regulations, formations and combined polymers.

7.10 Commercial presence of shellac

Shellac-based patents have gained wide attention and applicability in the market. Shellac has seen applicability as edible protective coatings with more than 50% of patents filed in this area, drug encapsulation material, and maskant patents comprising of 25%, while dental material, wood varnish, stimuli responsive release materials, skin care material, taste enhancing additives, and sanitization liquid component having significant patents as well. This depicts a trend in new products using shellac as the main compositional material toward coatings and drug delivery/maskants (Table 7.2). Table 7.2 is a symbolic representation of the presence of shellac-based material in the food industry and edible product line. The pres-

TABLE 7.2 Recent shellac-based patents in the food industry.

Patent	Author	Year
Edible protective coating	Xiagdong Gan and Michael Mcnelly	2022
Shellac microcapsule formulations and compositions for topical intestinal delivery of vitamin b3	Karin Schwarz	2021
Enteric coating material	Xú dù jiàn and Wángjūndé	2021
Coating layer for food, which comprises a chocolate and a shellac layer	Yángméi, Zhānglìyuàn, Gǔ Bǎoyù, Yángxiǎochōng, Zhānghǎibīn, and Sūnyúnfēng	2021
System and method for manufacturing shellac floss	Sherif Shawki Zaki Hindi	2021
Food-contactable super-hydrophobic coating	Tang Yali and Liu Lingxue	2021
Cannabis delivery with protective glaze coating	Stephen A. Santos, William E. Barrie and Karen M. Murphy	2020
Biocompatible lac nanoparticles	Chén Dōng, Kǒnglínlín, Sūnzéyǒng, and Wáng Xíngzhèng	2020
Shellac and paclitaxel coated catheter balloons	Michael Orlowsk	2019
Metal cans coated with shellac-containing coatings	Amanda Ghantous, Christopher Most, and Robert McVay	2019
Shellac for increasing heat resistance of varnish, and modification method thereof	Yunnan Chu Shanyuan	2016
Solvent free shellac coating composition	Margaret Mc Wheeny	2016
Polyesterification of shellac as an alternative coating material	Lestari Hetalesi Saputri	2016
Cementitious system comprising accelerator particles coated with crosslinked shellac	Wolfgang Seidl	2016
Shellac-coated particles of active ingredients with controlled release properties at high pH-values, process for their manufacture and use thereof	Wolfgang Seidl	2016
Shellac-based skin care lotion	William E. Barrie	2015

Patent	Author	Year
Shellac as taste improver for food and drink	Daisuke Mori, Wen Kashima, and Yutaka Kashima	2015
Edible food coating using starch–polyol and a shellac-containing layer	Koichi Murayama, Yoshihiro Komoda, Daisuke Mori, and Yutaka Kashima	2015
Shellac enteric coatings	Charles A. Signorino, Terry L. Smith, and Stephen Levine	2011
Stable shellac enteric coating formulation for nutraceutical and pharmaceutical dosage forms	Thomas Durig and Yuda Zong	2011
Sprayable hand cleaner made of edible shellac and micelle surfactants	Michelle Diaz	2010

ence of this material over the wide spectrum of nutraceutical to pharmaceutical, from fruit/vegetable to confectionary items, from taste masking to smart sensor offers huge market potential in the coming years.

7.11 Scopes and future application

Shellac is a useful commodity, whose origin is in the Indian subcontinent and South–North Asia. It is a biological commodity, and it has a positive effect on nature, so it is important and beneficial. With the rise in the application of shellac across the various industrial sectors its quality estimation and instrumentation to maximize its production may also accelerate. The role of shellac-based materials in edible smart sensor research due to its nontoxic nature and green packaging products due to its natural origin is most explored area of this material in the recent past. The material also offers huge potential in taste masking due to its chemical nature and availability of plenty of functional group. Also, the material offer tremendous compatibility toward polymers of natural origin and chemically synthesized ones. Hence, it is not wrong to mention it as a naturally available material which can be engineered to be explored for a plethora of applications.

References

Adeyeye, O. A., Sadiku, E. R., Babu Reddy, A., Ndamase, A. S., Makgatho, G., Sellamuthu, P. S., Perumal, A. B., Nambiar, R. B., Fasiku, V. O., Ibrahim, I. D., Agboola, O., Kupolati, W. K., Daramola, O. O., Machane, M. J., & Jamiru, T. (2019). The Use of Biopolymers in Food Packaging. In *Green Biopolymers and their Nanocomposites*, 137–158. https://doi.org/10.1007/978-981-13-8063-1_6.

Aravindakshan, R., Saju, K. K., & Aruvathottil Rajan, R. (2021). Investigation into Effect of Natural Shellac on the Bonding Strength of Magnesium Substituted Hydroxyapatite Coatings Developed on Ti6Al4V Substrates. *Coatings*, *11*(8), 933. https://doi.org/10.3390/coatings11080933.

Aydin, F., Kahve, I., & Ardic, M. (2017). Lipid Based Edible Films. *Available Online Www.Jsaer.Com Journal of Scientific and Engineering Research 86*. *Journal of Scientific and Engineering Research*, *4*(9), 86–92. www.jsaer.com.

Bar, H., & Bianco-Peled, H. (2021). The unique nanostructure of shellac films. *Progress in Organic Coatings*, *157*, Article 106328. https://doi.org/10.1016/j.porgcoat.2021.106328.

Ben Messaoud, G., Sánchez-González, L., Probst, L., Jeandel, C., Arab-Tehrany, E., & Desobry, S. (2016). Physico-chemical properties of alginate/shellac aqueous-core capsules: Influence of membrane architecture on riboflavin release. *Carbohydrate Polymers*, *144*, 428–437. https://doi.org/10.1016/j.carbpol.2016.02.081.

Berekaa, M. M. (2015). Nanotechnology in food industry; advances in food processing, packaging and food safety. *Int J Curr Microbiol App Sci*, *4*(5), 345–357.

Bouwmeester, H., Dekkers, S., Noordam, M. Y., Hagens, W. I., Bulder, A. S., de Heer, C., ten Voorde, S. E. C. G., Wijnhoven, S. W. P., Marvin, H. J. P., & Sips, A. J. A. M. (2009). Review of health safety aspects of nanotechnologies in food production. *Regulatory Toxicology and Pharmacology*, *53*(1), 52–62. https://doi.org/10.1016/j.yrtph.2008.10.008.

Bradley, E. L., Castle, L., & Chaudhry, Q. (2011). Applications of nanomaterials in food packaging with a consideration of opportunities for developing countries. *Trends in Food Science & Technology*, *22*(11), 604–610. https://doi.org/10.1016/j.tifs.2011.01.002.

Bryk, N. (2022). *Shellac | Encyclopedia.com*. Encyclopedia.Com. https://www.encyclopedia.com/science-and-technology/chemistry/organic-chemistry/shellac#2896800097

Caddeo, C., Pucci, L., Gabriele, M., Carbone, C., Fernàndez-Busquets, X., Valenti, D., Pons, R., Vassallo, A., Fadda, A. M., & Manconi, M. (2018). Stability, biocompatibility and antioxidant activity of PEG-modified liposomes containing resveratrol. *International Journal of Pharmaceutics*, *538*(1–2), 40–47. https://doi.org/10.1016/j.ijpharm.2017.12.047.

CFR - Code of Federal Regulations Title 21. (n.d.). Retrieved March 18, 2022, from https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=73&showFR=1

Chaudhry, Q., Scotter, M., Blackburn, J., Ross, B., Boxall, A., Castle, L., Aitken, R., & Watkins, R. (2008). Applications and implications of nanotechnologies for the food sector. *Food Additives & Contaminants: Part A*, *25*(3), 241–258. https://doi.org/10.1080/02652030701744538.

Chauhan, O. P., Nanjappa, C., Ashok, N., Ravi, N., Roopa, N., & Raju, P. S. (2015). Shellac and Aloe vera gel based surface coating for shelf life extension of tomatoes. *Journal of Food Science and Technology*, *52*(2). https://doi.org/10.1007/s13197-013-1035-6.

Du, Y., Wang, L., Mu, R., Wang, Y., Li, Y., Wu, D., Wu, C., & Pang, J. (2019). Fabrication of novel Konjac glucomannan/shellac film with advanced functions for food packaging. *International Journal of Biological Macromolecules*, *131*, 36–42. https://doi.org/10.1016/j.ijbiomac.2019.02.142.

Farag, Y., & Leopold, C. S. (2009). Physicochemical Properties of Various Shellac Types. *Dissolution Technologies*, *16*(2), 33–39. https://doi.org/10.14227/DT160209P33.

Fernandes, M. (2018). *Fruit Waxing - What it is? Are they Safe to Eat?* Medindia. https://www.medindia.net/dietandnutrition/fruit-waxing.htm

Ghoshal, S., Khan, M. A., Khan, R. A., Gul-E-Noor, F., & Sarwaruddin Chowdhury, A. M. (2010). Study on the Thermo-Mechanical and Biodegradable Properties of Shellac Films Grafted with Acrylic Monomers by Gamma Radiation. *Journal of Polymers and the Environment*, *18*(3), 216–223. https://doi.org/10.1007/s10924-010-0182-3.

Grujic, R., Vukic, M., & Gojkovic, V. (2017). Application of Biopolymers in the Food Industry. In *Advances in Applications of Industrial Biomaterials* (pp. 103–119): Springer International Publishing. https://doi.org/10.1007/978-3-319-62767-0_6.

How shellac is made - material, history, used, processing, product, industry, History, Raw Materials. (n.d.). Http://Www.Madehow.Com/. Retrieved March 18, 2022, from http://www.madehow.com/Volume-4/Shellac.html

Huber, K. C., & Embuscado, M. E. (2009). *Edible Films and Coatings for Food Applications*. New York: Springer. (K. C. Huber & M. E. Embuscado (Eds.). https://doi.org/10.1007/978-0-387-92824-1.

Jo, W.-S., Song, H.-Y., Song, N.-B., Lee, J.-H., Min, S. C., & Song, K. Bin (2014). Quality and microbial safety of 'Fuji' apples coated with carnauba-shellac wax containing lemongrass oil. *LWT - Food Science and Technology*, *55*(2), 490–497. https://doi.org/10.1016/j.lwt.2013.10.034.

Karak, N. (2016). Biopolymers for paints and surface coatings. In *Biopolymers and Biotech Admixtures for Eco-Efficient Construction Materials* (pp. 333–368): Elsevier. https://doi.org/10.1016/B978-0-08-100214-8.00015-4.

Kessler, R. (2011). Engineered Nanoparticles in Consumer Products: Understanding a NewIngredient. *Environmental Health Perspectives*, *119*(3). https://doi.org/10.1289/ehp.119-a120.

Khafar, E. A. A., Zidan, N. S., El, H., & Aboul-Anean, D. (2018). The Effect of Nano Materials On Edible Coating and Films' Improvement. *Avai International Journal of Pharmaceutical Research & Allied Sciences*, *7*(3), 20–41. www.ijpras.com.

Li, Y., Dong, Q., Chen, J., & Li, L. (2020). Effects of coaxial electrospun eugenol loaded core-sheath PVP/shellac fibrous films on postharvest quality and shelf life of strawberries. *Postharvest Biology and Technology*, *159*, Article 111028. https://doi.org/10.1016/j.postharvbio.2019.111028.

Liebert, M. A. (1986). Final Report on the Safety Assessment of Shellac. *JOURNAL OF THE AMERICAN COLLEGE OF TOXICOLOGY*, *5*(5), 309–327.

Llorens, A., Lloret, E., Picouet, P. A., Trbojevich, R., & Fernandez, A. (2012). Metallic-based micro and nanocomposites in food contact materials and active food packaging. *Trends in Food Science & Technology*, *24*(1), 19–29. https://doi.org/10.1016/j.tifs.2011.10.001.

Lu, H., Zhang, S., Wang, J., & Chen, Q. (2021). A Review on Polymer and Lipid-Based Nanocarriers and Its Application to Nano-Pharmaceutical and Food-Based Systems. *Frontiers in Nutrition*, *8*. https://doi.org/10.3389/fnut.2021.783831.

Melo Henrique, J., Rocha Camargo, J., Gabriel de Oliveira, G., Santos Stefano, J., & Campos Janegitz, B. (2021). Disposable electrochemical sensor based on shellac and graphite for sulfamethoxazole detection. *Microchemical Journal*, *170*, Article 106701. https://doi.org/10.1016/j.microc.2021.106701.

Mohamed, S. A. A., El-Sakhawy, M., & El-Sakhawy, M. A.-M. (2020). Polysaccharides, Protein and Lipid -Based Natural Edible Films in Food Packaging: A Review. *Carbohydrate Polymers*, *238*, Article 116178. https://doi.org/10.1016/j.carbpol.2020.116178.

Muhammad, D. R. A., Sedaghat Doost, A., Gupta, V., bin Sintang, M. D., Van de Walle, D., Van der Meeren, P., & Dewettinck, K. (2020). Stability and functionality of xanthan gum–shellac nanoparticles for the encapsulation of cinnamon bark extract. *Food Hydrocolloids*, *100*, Article 105377. https://doi.org/10.1016/j.foodhyd.2019.105377.

Neacşu, I. A., Nicoară, A. I., Vasile, O. R., & Vasile, B.Ş. (2016). Inorganic micro- and nanostructured implants for tissue engineering. In *Nanobiomaterials in Hard Tissue Engineering* (pp. 271–295): Elsevier. https://doi.org/10.1016/B978-0-323-42862-0.00009-2.

Patel, A. R., Rajarethinem, P. S., Grędowska, A., Turhan, O., Lesaffer, A., De Vos, W. H., Van de Walle, D., & Dewettinck, K. (2014). Edible applications of shellac oleogels: spreads, chocolate paste and cakes. *Food Funct*, *5*(4), 645–652. https://doi.org/10.1039/C4FO00034J.

Phan The, D., Debeaufort, F., Luu, D., & Voilley, A. (2008). Moisture barrier, wetting and mechanical properties of shellac/agar or shellac/cassava starch bilayer bio-membrane for food applications. *Journal of Membrane Science*, *325*(1), 277–283. https://doi.org/10.1016/j.memsci.2008.07.052.

Prameela, K., Murali Mohan, C., & Ramakrishna, C. (2018). Biopolymers for Food Design: Consumer-Friendly Natural Ingredients. In *Biopolymers for Food Design* (pp. 1–32): Elsevier. https://doi.org/10.1016/B978-0-12-811449-0.00001-3.

REHDING, A. (2006). On the record. *Cambridge Opera Journal*, *18*(1), 59–82. https://doi.org/10.1017/S0954586706002102.

Soradech, S., Nunthanid, J., Limmatvapirat, S., & Luangtana-anan, M. (2017). Utilization of shellac and gelatin composite film for coating to extend the shelf life of banana. *Food Control*, *73*, 1310–1317. https://doi.org/10.1016/j.foodcont.2016.10.059.

Stummer, S., Salar-Behzadi, S., Unger, F. M., Oelzant, S., Penning, M., & Viernstein, H. (2010). Application of shellac for the development of probiotic formulations. *Food Research International*, *43*(5), 1312–1320. https://doi.org/10.1016/j.foodres.2010.03.017.

Teixeira-Costa, B. E., & Andrade, C. T. (2021). Natural Polymers Used in Edible Food Packaging—History, Function and Application Trends as a Sustainable Alternative to Synthetic Plastic. *Polysaccharides*, *3*(1), 32–58. https://doi.org/10.3390/polysaccharides3010002.

Thammachat, T., Sriamornsak, P., Luangtana-Anan, M., Nunthanid, J., Limmatvapirat (1), C., & Limmatvapirat, S. (2010). Preparation and Characterization of Shellac Fiber as a Novel Material for Controlled Drug Release. *Advanced Materials Research*, *152–153*, 1232–1235. https://doi.org/10.4028/www.scientific.net/AMR.152-153.1232.

The future of food and agriculture. (n.d.).

Trajkovska Petkoska, A., Daniloski, D., D'Cunha, N. M., Naumovski, N., & Broach, A. T (2021). Edible packaging: Sustainable solutions and novel trends in food packaging. *Food Research International*, *140*, Article 109981. https://doi.org/10.1016/j.foodres.2020.109981.

Triyono, J., Adityawan, R., Dananjaya, P., Smaradhana, D. F., & Masykur, A. (2021). Characterization and biodegradation rate of hydroxyapatite/shellac/sorghum for bone scaffold materials. *Cogent Engineering*, *8*(1). https://doi.org/10.1080/23311916.2021.1884335.

Wang, K., Wen, H.-F., Yu, D.-G., Yang, Y., & Zhang, D.-F. (2018). Electrosprayed hydrophilic nanocomposites coated with shellac for colon-specific delayed drug delivery. *Materials & Design*, *143*, 248–255. https://doi.org/10.1016/j.matdes.2018.02.016.

Wang, S.-C., Liang, J.-W., Yao, Y.-B., Tao, T., Liang, B., & Lu, S.-G. (2019). Electrospinning-Derived PLA/Shellac/PLA Sandwich—Structural Membrane Sensor for Detection of Alcoholic Vapors with a Low Molecular Weight. *Applied Sciences*, *9*(24), 5419. https://doi.org/10.3390/app9245419.

Wu, Y. H., Yu, D. G., Huang, S. M., Zha, D. P., Wang, M. L., & Wang, S. J. (2014). Ultra-Thin Shellac Fibers Fabricated Using Two Different Electrospinning Processes. *Advanced Materials Research*, *1015*, 51–55. https://doi.org/10.4028/www.scientific.net/AMR.1015.51.

Xue, J., Wu, T., Dai, Y., & Xia, Y. (2019). Electrospinning and Electrospun Nanofibers: Methods, Materials, and Applications. *Chemical Reviews*, *119*(8), 5298–5415. https://doi.org/10.1021/acs.chemrev.8b00593.

Yuan, Y., Zhang, X., Pan, Z., Xue, Q., Wu, Y., Li, Y., Li, B., & Li, L. (2021). Improving the properties of chitosan films by incorporating shellac nanoparticles. *Food Hydrocolloids*, *110*, Article 106164. https://doi.org/10.1016/j.foodhyd.2020.106164.

Yüceer, M., & Caner, C. (2020). The effects of ozone, ultrasound and coating with shellac and lysozyme–chitosan on fresh egg during storage at ambient temperature. Part II: microbial quality, eggshell breaking strength and FT-NIR spectral analysis. *International Journal of Food Science & Technology*, *55*(4), 1629–1636. https://doi.org/10.1111/ijfs.14422.

Nanotechnology Applications for Food Safety and Quality Monitoring

Edited by
Arun Sharma
P.S. Vijayakumar
Pramod K Prabhakar
Ritesh Kumar

NANOTECHNOLOGY APPLICATIONS FOR FOOD SAFETY AND QUALITY MONITORING

Edited by

ARUN SHARMA
Assistant Professor, Department of Food Engineering, National Institute of Food Technology Entrepreneurship and Management (NIFTEM), Kundli, Sonipat, Haryana, India

P.S. VIJAYAKUMAR
Scientist (E), Institute of Nano Science and Technology (INST), SAS Nagar, Punjab, India

PRAMOD K. PRABHAKAR
Assistant Professor, Department of Food Science and Technology, National Institute of Food Technology Entrepreneurship and Management (NIFTEM), Kundli, Sonipat, Haryana, India

RITESH KUMAR
Principal Scientist, Council of Scientific and Industrial Research–Central Scientific Instruments Organisation (CSIR–CSIO), Chandigarh, India; Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, India

ELSEVIER

ACADEMIC PRESS
An imprint of Elsevier
elsevier.com/books-and-journals

Academic Press is an imprint of Elsevier
125 London Wall, London EC2Y 5AS, United Kingdom
525 B Street, Suite 1650, San Diego, CA 92101, United States
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

ISBN: 978-0-323-85791-8

For Information on all Academic Press publications visit our website at https://www.elsevier.com/books-and-journals

Publisher: Nikki P Levy
Acquisitions Editor: Nina Bandeira
Editorial Project Manager: Lena Sparks
Production Project Manager: Rashmi Manoharan
Cover Designer: Christian J Bilbow

Typeset by Aptara, New Delhi, India