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Derleme Makalesi -Review Article

A Review on Edible Film and Coating Applications for Fresh and Dried Fruits and Vegetables

Taze ve Kuru Meyve ve Sebzelerde Yenilebilir Film ve Kaplama Uygulamaları

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ABSTRACT

Techniques in food packaging are varying depending on the global trends, changes in technology, sense of responsibility for nature, and consumer expectations. One of the new techniques using in the packaging industry in recent years is edible films and coatings. Edible films and coatings are biomaterials that are applied as a thin layer on food and can be consumed with food. Films and coatings obtained from different sources are applied to foods with different application techniques. Films and coatings can be applied to fresh fruits and vegetables, as well as dried foods. However, the investigation on the application operations of films and coating on food particularly fresh fruits and vegetables are taking a very important role. In this review, according to research in the last 20 years, not only the effects of the films and coatings on food (fresh and dried fruits and vegetables) properties but also applied procedures are summarized and discussed.

Keywords- Edible Film, Edible Coating, Fruit, Vegetable

ÖZ

Gıda paketlemede kullanılan teknikler küresel trendlere, teknolojideki değişimlere, doğaya karşı sorumluluk bilincine ve tüketici beklentilerine bağlı olarak değişmektedir. Ambalaj endüstrisinde son yıllarda kullanılan yeni tekniklerden biri de yenilebilir film ve kaplamalardır. Yenilebilir film ve kaplamalar, yiyeceklerin üzerine ince bir tabaka halinde uygulanan ve yiyeceklerle birlikte tüketilebilen biyomalzemelerdir. Farklı kaynaklardan elde edilen film ve kaplamalar farklı uygulama teknikleri ile gıdalara uygulanmaktadır. Filmler ve kaplamalar, taze meyve ve sebzelerin yanı sıra kuru gıdalara da uygulanabilir. Bununla birlikte, özellikle taze meyve ve sebzeler olmak üzere gıdaların üzerine film ve kaplama uygulama operasyonlarının araştırılması çok önemli bir rol oynamaktadır. Bu derlemede, son 20 yılda yapılan araştırmalara göre film ve kaplamaların sadece gıda (taze ve kuru meyve ve sebzeler) özelliklerine etkileri değil, uygulanan prosedürler de özetlenmiş ve tartışılmıştır.

Anahtar Kelimeler- Yenilebilir Film, Yenilebilir Kaplama, Meyve, Sebze

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I. INTRODUCTION

The fact that foods are made up of living tissues affects their ability to maintain their quality against time, temperature, and physical effects. Food spoilage occurs due to physical, chemical, and biological reasons. The purpose of food packaging is to protect the food from mechanical, chemical, and microbiological effects. Foods are packaged and a separate environment is created around them in order to minimize the spoilage of foods and extend their shelf life. The purpose of edible film and coating application is to separate the food from its surrounding environment, prevent food spoilage and losses, and extend the shelf life of the food [1]. The transfer and storage process of perishable fruits and vegetables is important. In these processes, it is necessary to deliver the food to the consumer with a minimum loss of quality. Edible films and coatings are beneficial during transfer and storage as they can reduce respiration rate, enzymatic browning, and water loss [2].

Edible films and coatings are layers of material applied to the product as a thin film which can be consumed with the product. Edible film technology is one of the latest techniques used in food safety, developed as an alternative for commercial packaging materials, such as glass, tin and polymers used in active packaging. Edible films and coatings have been accepted as GRAS (Generally Recommended as Safe) with the approval of the U.S. Food and Drug Administration [3].

Edible films and coatings can be produced from various products. Basically, a film-forming material such as carbohydrate, protein or lipid can be used, and water, ethanol and acetone can be used as solvents. Plasticizers, surfactants and additives (essential oils, antioxidants, antimicrobial agents, flavoring agents, colorants, vitamins and chemical preservatives) can be added to film or coating solution [4-6].

The feature that distinguishes between films and coatings is that the edible coating (EC) is a coating applied directly on the food, whilst, edible film (EF) is the material that is formed as a thin film layer and put on the food. The difference between EC and EF is that EC is prepared as a solution and applied on food in liquid form by various methods, while EC is applied by wrapping on food after casting or extrusion and forming a solid layer [7]. Due to the simple production technology of edible films and coatings, also being cheap, biodegradable and obtaining from natural compounds, a lot of studies have been performed on the packaging, in the recent years.

The function of edible film and coatings is to protect the product from mechanical damages, physical, chemical and microbiological negative activities [8]. In other words, they make foods more durable. Edible films or coatings cover the food surface and act as a barrier against moisture, oxygen, carbon dioxide, flavor and lipid transfer [9]. Edible film coatings prevent mechanical damage and enzymatic browning reactions on food [10,11] and protect their phenolic content and antioxidant activities [12]. Song et al. [13] reported that the edible coating slowed the respiration rate and microbial growth. Some researchers observed that the edible films and coatings improve the color in foods [14]. Edible films and coatings preserve the textural, sensory and mechanical properties of the food, as well as improving food quality and shelf life [15].

In recent years, edible coating and films have been used with modified atmosphere packaging technique (MAP). The successful applications of combinations of MAP technique and edible coating have been reported in the literature [16-18]. With the application of edible film, the modified atmosphere is formed inside the fruit and vegetable. Thus, maturation and browning of the coated fruit and vegetable is prevented and the permeability of the packaging material is also lessened [19].

Since fresh fruits and vegetables are sensitive, perishable food products, spoilage due to many mechanical, microbial and chemical effects occur from their harvesting process until coming to consumer's table. This spoilage not only harm the quality of the food, but also cause food losses to a large extent. Approximately one third (1.3 billion tons) of food produced in the world each year is being lost or wasted [20]. It is remarkable that %21.6 percentage of fruit and vegetable is being lost from post-harvest up to the retail level in 2019 [21]. In order to prevent food losses, it is necessary to take precautions to protect food in ensuring food safety.

In this review study, edible films and coating types formed with various natural sources on fresh and dried fruits and vegetables in literature, application techniques and effects of these applications on the final product have been analyzed and compared with each other.

II. COATING MATERIALS

Most polysaccharides, proteins and lipids can be classified as matrix surface portion for edible films and coatings.

A. Polysaccharide

Polysaccharides used for edible films or coatings include cellulose and derivatives, starch and derivatives, pectin derivatives, seaweed extracts (alginates, carrageenan and agar), dextrin, exudate gums (acacia gum, gum tragacanth, gum ghatti, gum karaya), seed gums, microbial fermentation gums (Xanthan gum, Gellan gum and exopolysaccharides), and chitosan [22,23].

Polysaccharides are coatings that are predicted to be an effective oxygen barrier, mainly due to their hydrogen-bond network form. Polysaccharides are usually very hydrophilic, therefore have poor water vapor and gas barrier properties. Although polysaccharide polymer coatings do not provide a good water vapor barrier, these coatings function as agents that retard moisture loss from food products [24]. Polysaccharide coatings are colorless, oil-free and have low calorie content. It can be applied for extending the shelf life of fruits, vegetables, shellfish or meat products, significantly reduce dehydration, darkening, and spoilage from oxidation [25,26].

B. Lipid

The main function of lipid coatings is to prevent moisture transport due to their low polarity. Lipid films are excellent barriers against water due to their hydrophobic structure. In contrast, the hydrophobic property of lipids creates thicker and more brittle films. Therefore, lipid films and coatings should be used together with film-forming substances, such as proteins or cellulose derivatives. Lipids also increase the visual appeal of food products and provide brightness to the food. Lipid-based films have poor mechanical properties. Production of edible films and coatings from lipids requires solvents and high temperatures. Lipids in the liquid phase show less resistance than solids in gas and steam transmission [24,25].

Lipid edible films and coatings are of great interest for their ability to provide a barrier against moisture, oxygen, carbon dioxide, oil, and flavor/aroma migration between food and the environment. Lipid films also enable mechanical integrity or processing properties of the food to be improved. It gains extra functionality by the inclusion of food additives such as antioxidants, antimicrobials or flavorings [27]. Lipid coatings are divided into three groups: lipids, waxy substances and resins [28]. Beeswax, mineral oil, vegetable oil, surfactants, acetylated monoglycerides, shellac, terpene, carnauba, candelilla wax and paraffin wax, vegetable wax, triglycerides are sources of lipid-based edible films and coatings [29-31].

C. Protein

Protein coatings are usually hydrophilic, sensitive to moisture absorption, therefore, can be affected by relative humidity and temperature [32]. Mechanical and barrier properties of protein-based films are better than polysaccharide and lipid-based films. Protein films exhibit poor water barrier properties similar to polysaccharide films. Protein-based films and coatings are brittle materials. Also, protein-based films are prone to cracking due to biopolymers' strong cohesive energy. Adding plasticizers to the film can increase the extensibility and viscoelasticity of the films [33].

Protein films and coatings are obtained from the proteins that are divided into two groups as fibrous and globular. Fibrous proteins are insoluble in water and obtained from animal tissues (e.g. casein, whey protein, collagen, gelatin, and keratin). On the other hand, globular proteins are soluble in water or in aqueous solutions of acids, bases or salts and are obtained from plant origin (e.g. wheat gluten, soy protein, peanut protein, corn zein, cotton seed protein) [32].

D. Composite

Composite coatings are formed as multi-layer structures having two or more biopolymers [8]. Composite coatings are combinations of biomolecules where proteins, polysaccharides and lipids come together, and polysaccharide, lipid and protein coatings as the matrix give the structure its own unique properties. Other components can be added to the coating for other targeted properties such as crosslinkers, reinforcements etc. The best way for a coating to have the desired properties is to combine them to form a composite solution with the desired properties. Binary film combinations used for forming films can be in the form of protein-protein,

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carbohydrate-carbohydrate, protein-carbohydrate, protein-lipid or carbohydrate-lipid [34]. Triple film combinations can consist of carbohydrates, proteins and lipids [35].

III. COATING METHOD

A. Edible Coating Formation Method

The method of dipping is the most widely used film forming method [36]. It is carried out by dipping and taking the foods off the coating solution. Dipping process is carried out in three steps as immersion of food in the coating solution, draining the food taken off from the solution, drying the coating [37]. Coating solution forms a thin film layer on the food surface. This method is the best for foods with rough and uneven surfaces. It is also a method that allows the recovery of excessive coating material [38].

The method of spraying is used when a thin layer of coating is required and only one surface is desired to be coated. It is a more controllable coating application method than pan or fluidized bed coating. However, spray coating requires that the lower surface of the product to be covered with a separate process after coating and drying of the upper surface. The product must be rotated for covering the lower part of the food during coating application. Spray coating is preferred for foods with large surface areas. The spray nozzle plays a critical role in the coating process for design data such as flow rate, droplet size, spray distance and angle, and overlap speed. The coating fluid pressure, fluid viscosity, temperature, surface tension, and nozzle shape or design all affect spraying efficiency [39].

Fluidized bed coating is a technique which is used to apply a very thin layer on very small or very low-density particles. Agglomeration of the powder rising in the system with fluidized bed coating technique increases the dispersion and solubility of the coating material. The powder is fluidized by hot air and liquid binder is sprayed at the same time. This process causes particles to stick, agglomerate and dry the agglomerates in both batch and continuous processing systems [39].

Pan coating is being used to apply thin or thick layers on hard and almost-spherical particles. It prevents moisture and lipid loss and provides additional flavor to the food that is coated. The pan coating method is one of the methods preferred by the pharmaceutical and confectionery industries to cover their products with the coating material. The product to be coated is placed in a large, rotating bowl which is called as pan. Coating solution is added to the rotating pan with a ladle or sprayed. The product is rotated in the pan to distribute the coating solution evenly over the surface of the food [38]. Schematic models of edible coating and film forming methods are seen in Figure 1 and Figure 2.

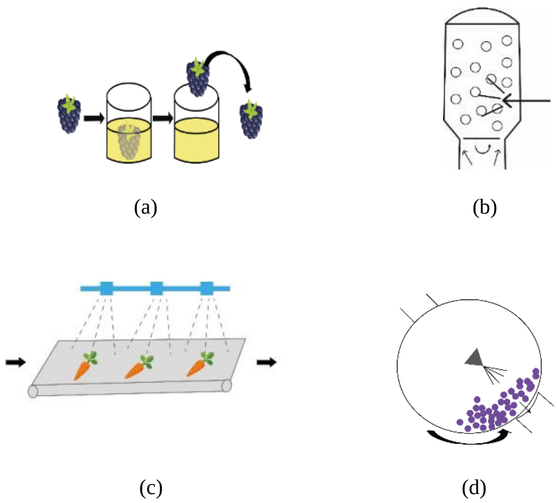

Figure 1. Schematic models of edible coating methods (a) dipping, (b) fluidized bed, (c) spraying, (d) pan coating

B. Edible Film Formation Method

Casting method is the most widely used film coating method in laboratory and pilot scale. Polymer and a solvent are used to create a coating solution. Film is prepared from biopolymers in three steps as dissolving the biopolymer in a suitable solvent, pouring the solution into a container, drying the casting solution. Casting

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method was developed more than a hundred years ago. By using this method, solutions are spread on flattened plates such as acrylic, silicone or teflon plates, followed by a drying process under ambient or controlled conditions. Hot air oven, microwave dryer and vacuum drying methods are used to easily evaporate the solvent and peel off the film [37].

Biopolymers are plasticized in the extrusion process. It is the process of heating and plasticizing extrusion polymers under glass transition temperature under low water content conditions based on their thermoplastic properties [40]. Extrusion process is used to produce flexible films [41]. Biopolymers are plasticized by heat pressure and cutting force in the barrel of the extruder to form a homogeneous melt in the extruder. In addition to film formation, this soft and rubbery melt can be formed into other forms using heat and pressure after cooling or shaped using conventional processing techniques such as thermal pressure molding or injection molding [42].

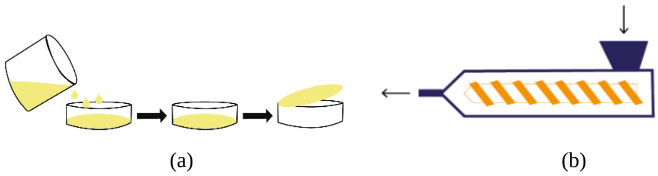

Figure 2. Schematic models of edible film forming methods (a) casting, (b) extrusion.

IV. APPLICATION OF EDIBLE FILMS AND COATINGS TO FRUITS AND VEGETABLES

Which people applied edible film applications to fresh and dried fruits and vegetables between 1999 and 2020, and which materials were used and their preferred coating method are summarized in Table 1 and Table 2. Among the examples of edible films and coatings applied to fresh vegetables and fruits in recent years in the literature; carrots, potatoes, peppers, tomatoes, pomegranates, strawberries, apples, guava, broccoli, pumpkin, avocado, apricot, pear, banana, mushroom, blackberry and pineapple can be mentioned. Coating can be applied to fresh cut or whole fruits and vegetables.

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Table 1. Edible film applications for fresh fruits and vegetables

Food product	Coating material	Coating Method	Important Effects	Source
Baby carrot	Chitosan	Spraying and dipping	Preventing surface whitening,Ensuring color preservation, protecting product texture and sensorial properties during storage	[43]
Banana	Rice starch	Spraying	Extending shelf life, reducing weight loss, increasing hardness, affecting gas mass transfer	[44]
Carrot/zucchini	Whey protein/pectin	Dipping	Preventing spoilage during storage, reducing weight loss, preventing microbial growth, protecting antioxidant activity	[12]
Tomato	Iodide-doped chitosan	Dipping	Providing valuable nutritional elements without any change in antioxidant activity, extending shelf life of tomatoes	[45]
Guava	Chitosan-cassava starch	Dipping	Excellent microbiological properties	[46]
Pomegranate aril	Chitosan	Dipping	Visual color quality, extending shelf life, protecting nutritional and sensorial quality	[47]
Mango	Corn starch	Extrusion	Providing mechanical and barrier properties, maintaining physical and chemical quality	[11]
Pumpkin	Modified starch	Dipping	Better color, high pro-vitamin A content	[48]
Broccoli	Chitosan	Dipping	Decrease in total mesophilic and psychotropic bacteria	[49]
Apricot	Protein isolate-chitosan	Dipping	Beneficial effect on weight loss and protecting hardness	[50]
Peach	Mango peelflour	Casting	Providing water vapor permeability barrier feature,increasing antioxidant activity and polyphenol content. Blocking gas transfer	[51]
Tomato	Mango kernel starch	Dipping	Extending shelf life	[52]
Avocado	Moringa leaf extract, chitosan and carboxymethyl cellulose	Dipping	Lower respiratory rates, progressive higher quality values, keeping fruit quality, long shelf life	[53]
Huanghua pears	Shellac and Semperfresh (sucrose-polyester based coating)	Dipping	Changes in brittleness and hardness, lower activities of cell wall hydrolases	[54]
Cashew apples	Corn starch	Dipping	Delaying loss quality, extending shelf life in cold storage	[55]
Strawberry	Chitosan	Casting	Physical and microbiological protection of fruit, excellent bactericide fungicide activity	[56]
Guava	Hydroxypropyl methylcellulose and beeswax	Dipping	Preventing maturation, extending shelf life	[57]
Blueberry	Sodium alginate, pectin	Dipping	Positive effect on hardness and microbial growth, reducing growth kinetics of yeast and mesophilic aerobic bacteria	[58]
Mushroom	Chitosan/Zein	Casting	Extending shelf life, delaying weight loss, preventing darkening,maintaining color and reducing respiration rate	[59]
Apple	Soy protein isolate	Dipping	Extending shelf life by controlling weight loss and firmness	[60]
Pineapple	Chitosan, pullulan, flaxseed, nopal cactus and aloe gum	Dipping	Maintaining quality, extending shelf life, reducing weight loss, delaying the change of total soluble solid content and color	[61]

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Along with the dehydration and drying processes, the water in the food is moved away and perishable products become durable. However, all drying techniques damage the structure of fruits and vegetables that are sensitive to heat and reduce their quality [13]. Researchers have stated that the application of edible film or coating applied to dried food before the drying process improved the nutritional and sensory properties of the food, and, vitamin losses and oxidation is prevented, as such [62,63].

Among the examples of edible films and coatings applied to dried fruits and vegetables in the literature; apple, strawberry, apricot, papaya, pineapple, pumpkin and mango can be mentioned. Vegetables and fruits are dried in sliced form or cut as cubes or by applying a coating as a whole.

Table 2. Edible film applications for dried fruits and vegetables

Food product	Drying method	Coating Material	Coating Method	Important Effects	Source
Dried apple slices	Osmotic dehydration/convective Drying	Pectin	Dipping	Reducing shrinkage, lowering water content at the surface and increasing water activity	[64]
Dried strawberry	Osmotic dehydration/chamber drier	Sodium alginate/carregeenan / guar gum	Dipping	Preventing comprehensive intake of soluble substances, high dehydration efficiency, prevent leakage losses	[65]
Dried apple cubes	Osmotic dehydration/oven drying	Maltodextrin	Dipping	Negative dry substance gaining, reducing mass transfer rate, barrier against solute intake, better barrier to moisture loss, brittleness, springiness and cohesiveness change significantly	[66]
Dried apple cubes and slices	Osmotic dehydration/chamber drier	Low methyled pectin	Dipping	Effect on the mass transfer	[67]
Dried apricot	Sun drying	Corn zein	Dipping	Microbialdevelopment and delaying color changes, oxygen barrier effect	[68]
Dried papaya cubes	Osmotic dehydration/oven drying	Chitosan	Dipping	Increasing water loss and reducing solid acquisition, increasing the efficiency of the drying process,	[69]
Partially dehydrated pineapple slice	Osmotic dehydration/vacuum impregnation	Caseinate/chitosan	Dipping	Extending shelf life	[70]
Pried pumpkin slices	Forced air oven	Native and modified maize and cassava starch	Dipping	Better color, high pro-vitamin A content	[48]
Dried apple Slices	Osmotic dehydration/tray drier	Carboxymethyl cellulose	Dipping	Decrease in color change	[71]
Dried papaya slices	Convective drying	Pectin	Dipping	Increased vitamin C preservation and color protection	[63]
Dried pineapple slices	Osmotic dehydration/convective drying	Pectin/whey protein isolate	Dipping	Oxygen barrier, vitamin preservation, protecting biologically active nutritional elements	[72]
Dried apple cubes	Fluidized bed dryer	Hydroxyethylcellulose/polyethylene glycol	Fluidized bed	Decrease in color and phenolic compound loss	[73]
Dried pumpkin slices	Osmotic dehydration/microwave vacuum dryer	Starch	Dipping	Delaying color change, reducing carotenoid loss, oxygen barrier	[62]
Dried apple, melon mango and pineapple slices	Oven drying	Pectin/honey	Dipping	Higher dehydration efficiency, polyphenol concentration, antioxidant activity, high vitamin C content, microbiological quality improvement	[74]

Dried carrot	Vacuum drying	Chitosan	Dipping	Maintain color,affect rehydration properties	[75]
Dried apple cubes	Osmotic dehydration/Convective hot-air drying	Pectin	Dipping	Improving color properties, increased vitamin C retention, total phenoliic content and total antioxidant activity	[76]
Raisin		Chocolate	Pan coating		[77]

Any film and coating technique can be applied to fresh vegetables and fruits. Dried fruits and vegetables are generally coated by the dipping method because of their irregular shape. However, the dipping technique has some disadvantages. In the dipping method, much more covering solution is spent than spraying. Spraying can be used if thinner coating is desired. Spray coating also may be preferred for foods with a large surface area. Fluidized bed coating may be preferred instead of panning to reduce the formation of clusters on the coating surface.

V. PROPERTIES OF FILMS AND COATINGS AND THEIR IMPORTANT EFFECTS ON FOOD PROPERIES

Edible films and coatings have been accepted as safe substances (GRAS) by the U.S. Food and Drug Administration, and do not contain any toxic ingredients or indigestible substances that could affect human health. It protects the food from mechanical impacts by covering the food surface evenly. It has oxygen permeability. It reduces the respiration rate, acts as a barrier preventing the transfer of water vapor preventing moisture loss in food. Coating does not adversely affect the taste of the food, it contributes to the development of these properties by preventing the loss of aroma, taste and nutrient components. It protects the color, sensory and textural properties of food. It provides biochemical and microbial surface stability on the food surface, prevents decay by ensuring protection against microorganism and pest contamination. Coating properties can be improved by adding flavor, odor, aroma, vitamins, nutrients, antimicrobials and antioxidants to the coating [3,78].

VI. CURRENT AND FUTURE TRENDS

Nowadays, interest in the use of natural food ingredients with antimicrobial and antioxidant properties, aiming to reduce the use of chemical compounds in the food industry, has recently increased. Extracts and essential oils obtained from herbs and spices show antimicrobial and antioxidant effects, being interesting ingredients in the food industry [34]. Xing et al. [78]and Aldana et al. [79] combined essential oil with edible films and coatings. Kalaycıoğlu et al. [80] and Tesfay and Magwaza [53] conducted a commercially available antimicrobial film and coating study using plant and spice extracts.

In the last decade, edible film production have been carried out by using biopolymers with food waste. The use of agricultural wastes as edible films provides advantages in both environmental and economic ways [31]. Dash et al. [81] produced edible film using lemon waste.

Nanotechnology has emerged as one of the most interesting and promising fields of study in the food industry. Nano-emulsions and nano-particles can contribute to the barrier properties and functionality of coatings for fruit and vegetable protection as they expand the surface area. Sub-micron structures provide higher dispersion and homogeneity in food pores and surface, allowing many applications [34]. Moghimi et al. [82] produced edible film coating using nano-emulsion and essential oil. Costa et al. [83] produced carrot coating using silver and montmorillonite nano-particles.

The latest techniques applied to edible films and coatings are the application of antioxidants, antimicrobials, functional ingredients, nutrients, bioactive compounds, flavors and additives by micro-encapsulation and nano-capsulation. Nanotechnology, nano-scale additives, nutrients and bioactive compounds are being used to improve food in terms of the nutrients. Micro and nano-encapsulation of active compounds with edible coatings helps in the controlled release of these compounds under certain conditions. In this way, foods can be protected from moisture, heat or other extreme conditions, and, their stability and vitality can be increased [26,32]. Bustos et al. [84] produced antimicrobial film with micro-capsulated essential oil. Mohkam et al. [85] examined the properties of the film created by vitamin nano-capsulation. Mendez et al. [86] developed an antimicrobial nano-laminate coating together with plant extract.

VII. CONCLUSIONS

Edible film and coating materials and technology play a very important role in the preservation of fresh and dried fruits and vegetables, as well as increasing their quality. Although edible films and coatings have been used for more than 700 years, studies on coating materials and techniques have been developing in the recent years, considerably. One of the challenges in this field is the problems encountered in operating laboratory scale applications to the industrial scale. Comprehensive economic analysis studies should be performed in order to solve these problems. Fresh cut food industry is expected to continue growing rapidly in the upcoming years, and, there is still a need for improved technologies for extending shelf life. In addition to extending shelf life of fresh cut products, it is necessary to increase the coating studies to prevent chemical and physical spoilage in dried fruits and vegetables. The production process of foods is a process that must be followed from the raw material stage to the consumer's table and its safety must be protected. Improper practices in the food supply chain adversely affects food safety and human health. The cold chain plays an important role in the production, storage and transportation of fresh or dried fruits and vegetables. Providing cold chain conditions is very important in controlling microbiological hazards. In order to preserve the quality properties of the food, the storage and packaging process can be supported by edible film.The protective property of edible film for foods should be utilized in storage and logistics operations.While the number of people suffering from hunger in the world is very high, food should be better preserved and food losses should be prevented. According to the latest reports released by the United Nations, %8.9 of the world's population (690 million people) suffers from hunger, and if the world's hunger continues at this pace, 840 million people (%9.8 of world's population) will starve by 2030 [87]. In order to prevent those food losses, applications should be provided for more food with a long shelf life.Factors such as the problems experienced due to climate changes, natural disasters, pandemic diseases and increasing energy need may decrease the supply of food and agricultural products, at the same time, food demand may increase with the increase of human population, increase in income and change in diet. All these factors will trigger food crisis and food supply will be difficult. With the greater problems humanity will face in the future, the production of durable foodstuffs will be inevitable. Applications that reduce food loss and waste need to be developed and expanded.

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