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MODERN SOLUTIONS IN PRODUCTION OF BIOPOLYMERS, EMPLOYED IN PACKAGING FOR FOOD INDUSTRY

NOWOCZESNE ROZWIĄZANIA W PRODUKCJI BIOPOLIMERÓW WYKORZYSTYWANYCH W OPAKOWANIACH DLA PRZEMYSŁU SPOŻYWCZEGO

ABSTRACT: The constantly increasing need of environmental protection causes the growth of demand on manufacture of environment-friendly packaging which would prolong the shelf –life of the products inside, and which would be produced from solid and sustainable packaging materials. It is important nowadays to avoid food wastage and contamination of the environment. The answer to the mentioned requirements may be found in the innovative approaches such as edible films, biopolymers or the application of additives, allowing longer use of food. Active packagings create a new path of food packaging, concentrated on creation of multi-functional system via formulation of active substances in polymer matrix of polymer packaging. The discussed packaging has a great potential for the application in contact with food due to their positive effect on ecological problems and other unique properties. The aim of the present paper is to discuss the modern solutions in production of biopolymers, employed in production of food packaging and development of more and more functional packaging. In the review, the activities connected with the creation of more ecological and functional, environment-friendly packagings have been submitted and the related barriers have been indicated.
Key words: active packaging, biopolymers, edible films, essential oils

STRESZCZENIE: Rosnąca z każdym rokiem potrzeba ochrony środowiska powoduje zwiększające się zapotrzebowanie na produkcję opakowań przyjaznych dla środowiska i przedłużających ich termin do spożycia, trwałych i ze zrównoważonych materiałów opakowaniowych. Ważne jest dzisiaj aby unikać marnowania żywności i zanieczyszczenia środowiska. Odpowiedzią na te wymagania są innowacyjne podejścia, takie jak: folie jadalne, biopolimery czy zastosowanie dodatków, które pozwolą dłużej korzystać z żywności. Opakowania aktywne to nowa ścieżka pakowania żywności, koncentrująca się na tworzeniu wielofunkcyjnego systemu poprzez formułowanie substancji aktywnych w matrycach polimerowych opakowań. Opakowania takie mają ogromny potencjał do zastosowania w kontakcie z żywnością ze względu na ich pozytywny wpływ na problemy ekologiczne i inne unikalne właściwości. Celem niniejszego artykułu jest przedstawienie nowoczesnych rozwiązań w wytwarzaniu biopolimerów wykorzystywanych do produkcji opakowań do żywności oraz tworzeniu opakowań bardziej funkcjonalnych. W przeglądzie pokazano działania związane z powstawaniem coraz bardziej ekologicznych i funkcjonalnych opakowań przyjaznych dla środowiska oraz wskazano jakie bariery z tym są związane.
Słowa kluczowe: opakowania aktywne, biopolimery, folie jadalne, olejki eteryczne

INTRODUCTION

Food packaging is one of the crucial stages in food production which ensures maintaining of the quality of food products during their storage, transport and distribution. Due to the properties, a low cost and availability of the resources for production, the petroleum-derived plastics are most frequently used materials in production of packaging (Porta et al., 2020).

Food packaging is an indispensable medium for supply of the food products to the consumer. They increase the stability of the product via ensuring a physical barrier against the unfavourable environmental factors such as microbiological and chemical contamination; they also facilitate the service, storage and transport of the product (Perera et al. 2023). The packaging made from classical plastics is not, however, biodegradable and consumes non-renewable raw materials such as petroleum (Borah, Dutta, 2019). Additionally, the application of plastics is so universally popular that there is no possibility of controlling their use. It refers, in particular, to packaging used in food industry, with a very short life cycle. It causes the appearance of the problems with the increasing number of the collected wastes and the proceeding contamination of natural environment (Wróblewska-Krepsztul et al., 2017). The wastes and the resulting threats constitute the problem, connected with the natural environment protection that is increasing year by year. The disposal of the waste and, especially of multi-material packaging produced by the industry, is a difficult and meaningful problem of the present time (Wróblewska-Krepsztul, Rydzkowski, 2019).

Therefore, the science is nowadays focused on the searches for the alternatives to petroleum and on the pressure aimed at the decrease of the effect of the above product on the environment. The studies are more and more concentrated on development of biodegradable food packaging produced from materials on the basis of biopolymers. New packaging materials, for example, biodegradable packaging or edible packaging, may satisfy the world demand on environment-friendly and natural food in the future. Food packaging sector has become greatly developed during the recent years owing to the progress in food packaging technologies, such as active packaging, aseptic packaging, smart (intelligent) packaging, bioactive packaging, edible packaging which are the research trends in development. The progress in the mentioned packaging technologies may prevent the deterioration of food via maintaining the food standard at the highest possible level; it may help in satisfying the needs of the consumers in the whole food supply chain and also, in meeting the requirements, resulting from the rules concerning food packaging (Borah, Dutta, 2019). The development in the packaging industry brought the increase in functionality of packaging materials, being employed in food industry what, unfortunately, did not improve their ecological friendliness.

Nowadays, there are the searches for packaging which would be less harmful to the environment, in accordance with the principle of "zero waste". The appropriate disposal of packaging waste may considerably reduce their accumulation at the landfills. To counteract the climate crisis and degradation of the environment, the European Union forces introduction of the changes in production of packaging, leading to climate-neutral economy up to 2050 (Mikus, Galus, 2023).

Plastics waste and food deterioration all over the world are recognized as the crucial environmental and economic problems, requiring solution. At present, only a small percent of food waste is composted and the residues of non-utilized food constitute the most of solid municipal waste which is degradable (Tomić et al., 2023). One of the methods of coping with the polymer waste includes production of bio-composites. They are not, however, the appropriate solution because after their utilization, they create the problematic waste, as well. Degradation and decomposition of composites consisting of polymers, reinforced with e.g. carbon fibres, are difficult. Moreover, production of the mentioned polymer materials is expensive. Additionally, recycling of such type of materials is problematic due to a long decomposition period and generation of toxins which are released during the degradation process (Czarnecka-Komorowska et al., 2022).

Food may be subjected to physical, chemical, biochemical and microbiological deterioration. It is estimated that the quantity of the wasted food per year could become a food for one eight of the world's population and might become a solution for the problem of satisfying the increased global demand on food (Tomić et al., 2023). Therefore, there are developed and improved the packaging owing to which the longer food storage is possible; consequently, the amount of the produced waste is decreased and the environment is less contaminated.

The environmental problems caused by traditional polymers forces the searches for alternative packaging materials. Biodegradable films based on biopolymers have become such alternative. In 2020, the quantity of bioplastic materials, employed in food packaging was equal to 0.99 million tons what constitutes 47% of the total production of bio-originated plastics. The raw materials used in production of biopolymers are relatively easily available and production of biopolymers utilizes agricultural waste what, in combination with advantages for the environment, makes that production of biopolymers is

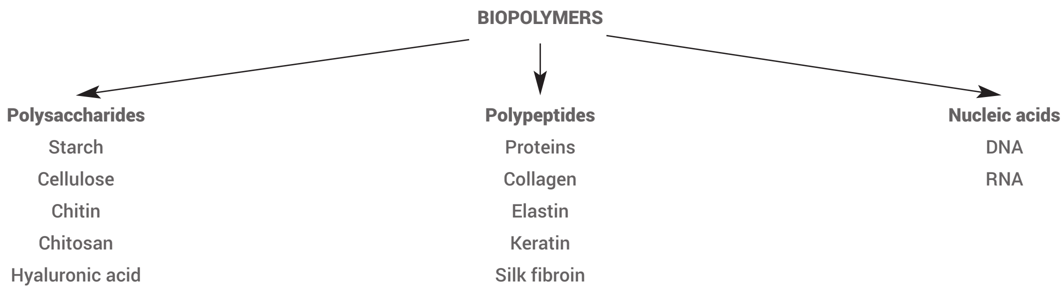

FIG.1. THE SELECTED EXAMPLES OF BIOPOLYMERS (SIONKOWSKA, A., & LEWANDOWSKA, K. (2016). BIOPOLYMERS, PROJECT "STRENGTHENING OF DIDACTIC POTENTIAL OF THE NICOLAS COPERNICUS UNIVERSITY (UMK) IN TORUŃ IN MATHEMATICS AND LIFE SCIENCES", IMPLEMENTED UNDER THE SUBACTION 4.1. OF THE OPERATING PROGRAMME: HUMAN POTENTIAL)

profitable. Contrary to the traditional food packaging, the functionalised packaging systems – which have been developed with the aim to add various bioactive compounds to matrix materials – may lead to a wide spectrum of biological effects such as antibacterial and antioxidative effect. Simultaneously, they may also protect food products from other detrimental environmental factors. Active materials are obtained via settlement of the bioactive material, usually of vegetal origin, in polymer. The essential oils are found in the centre of attention as active compounds, mainly due to their antibacterial and antioxidant properties (Gil, Rudy, 2023).

BIOPOLYMERS

Plastics penetrating the environment in a form of big or small fragments may cause various environmental problems. They may change a way of ecosystems' acting and be harmful for living organisms. Finally, they may get to food chain what may become harmful to human health. At present, it is impossible to stop the penetration of plastics to the environment in various forms. Therefore, the limitation of environment contamination caused by plastics, also in a form of microplastics is increasingly important (Dirpan et al., 2023). Bioplastics are the alternative to traditional plastics used in packaging industry. They have the similar or even the same properties as the traditional plastics and, moreover, they offer the additional profits for the environment such as reduced carbon footprint or the additional options of waste management such as composting (Wiszumirska et al., 2023). Biopolymers are polymers, consisting of monomeric units which are covalently bound, creating the molecules which resemble chains. The prefix bio- means that a given substance is of natural origin and often, it is a biodegradable material. Therefore, biopolymers have a capability of degrading or degrading, as affected by natural organisms, leaving the organic by-products such as CO_2 and H_2O, being safe for the environment. Biopolymers have been recognized as the materials alternative to plastics produced from petroleum because they are subjected to biodegradation, are renewable and occur universally (Othman, 2014). Biopolymers may be considered as the meaningful alternative to synthetic polymers in food packaging industry due to their biodegradability, biocompatibility, easy renewability and general good mechanical properties, comparable to the properties of the traditional polymers (Moeini et al., 2021). In Fig.1 the selected examples of biopolymers have been shown. Earlier, the most universal type of biopolymers for the application in food packaging included natural biopolymers, for example starch, cellulose, chitosan and agar which derived from carbohydrates and also, gelatine, alginate, whey protein and collagen which originate from protein. At present, the development of technology has brought about the generation of synthetic biopolymers which include: polylactic acid (PLA), polycaprolactone (PCL), polyglycolic acid (PGA), polyvinyl alcohol (PVA) and polybuthylene succinate (PBS). The advantages of synthetic biopolymers cover the potential to create the sustainable industry, and also, improvement of different properties such as stability, elasticity, high polish, transparency and resistance to stretching (tensile strength) (Othman, 2014).

Gradually with the time, biodegradable materials are subjected to a complete degradation whereas the non-degradable plastics remain in the environment for the hundreds of the years (Dirpan et al., 2023). The application of the polysaccharide-based (cellulose, starch and alginate) biodegradable polymers has a potential in respect of the environmental sustainability, reprocessing or environment protection (Nath et al., 2023). The application of biopolymers as packaging materials becomes, therefore, the new trend all over the world owing to their main advantages, in comparison to plastics, such as biodegradability, environment-friendly character, non-toxicity and biocompatibility. The mentioned natural biopolymers have the excellent, coating-forming and coherent structures; it is possible to produce thin protective layers from the discussed materials (Perera et al., 2023).

In manufacture of biodegradable packaging materials, we may employ natural polymers and their derivates. Biodegradable polymers are easily subjected to degradation and protect the environment. Apart from chemical and physical methods, microorganisms play the important role in degradation of polymers. Biodegradation affects the surface of plastics and, also, modifies physical, chemical and mechanical properties. Chemical and structural changes affect the structure and composition of polymers (Agarwal et al., 2023). According to W. Zhang et al., tannic acid has a promising application as being a non-toxic, easily available and cheap green cross-linking agent for multifunctional biomaterials in obtaining of biodegradable packaging films for food. The addition of tannic acid may significantly affect the activity of various degradable food packaging films. In particular, it may improve generally the effect of film for food packaging based on biopolymers, including the barrier properties in relation to UV light, barrier properties for gases, mechanical features, sensitivity to water and antioxidant and antibacterial properties. Moreover, the combination of tannic acid with other additives or plasticisers may synergistically improve properties of film. What important, films intended for food packaging based on tannic acid cross-linked biopolymer reveal also the surprising results in respect of fresh food preservation (Zhang et al., 2023).

There are certain limitations in the application of biopolymers in food packaging. The mentioned limitations include a low barrier property, mechanical qualities, and heavy technological properties; additionally, they have relatively high prices as compared to the traditional petroleum-originating products (Taherimehr et al., 2021). According to the studies, it was found that the coatings with chitosan may prolong effectively the shelf-life of many fresh food products within the frames of the strategy of edible organic food preservation, mainly due to the improvement of the structure of cross-linked web of molecules with chitosan via addition of phenolic acids of vegetal origin (Zhang et al., 2023).

There are also polymer films and coating on the basis of proteins which are the intriguing material for the application in food packaging. The protein-based polymers showed the unique physical and chemical properties in respect of forming films and coatings. They have excellent barrier properties which protect food from oxygen, humidity and other environmental factors which may lead to deterioration of the quality and spoilage of the product. They have also perfect coating-forming properties, biodegradability, compostability and friendliness to the environment. Moreover, they have very good mechanical properties such as tensile strength and elasticity, owing to which they are suitable for packaging of various types of food. The most of the proteins, employed in polymer materials such as casein, whey protein, soy protein, zeina, gelatine are sustainable and environment-friendly. Certain active components such as nanoparticles of metals/metal oxides, antioxidants and/or antibacterial/antiviral agents may be included to films/coatings in order to prevent effectively or delay the microbiological contamination, oxidation of lipids, and to ensure food safety and prolong the shelf life of foods. The discussed films are usually less transparent as compared to synthetic films and their properties may be affected by humidity, pH and temperature. They are however more expensive in respect of production in comparison to the commercial synthetic materials. The further research is necessary in order to improve the properties, to lower the manufacturing costs and increase the scale of production, with the aim to utilize fully the potential of the discussed protein-

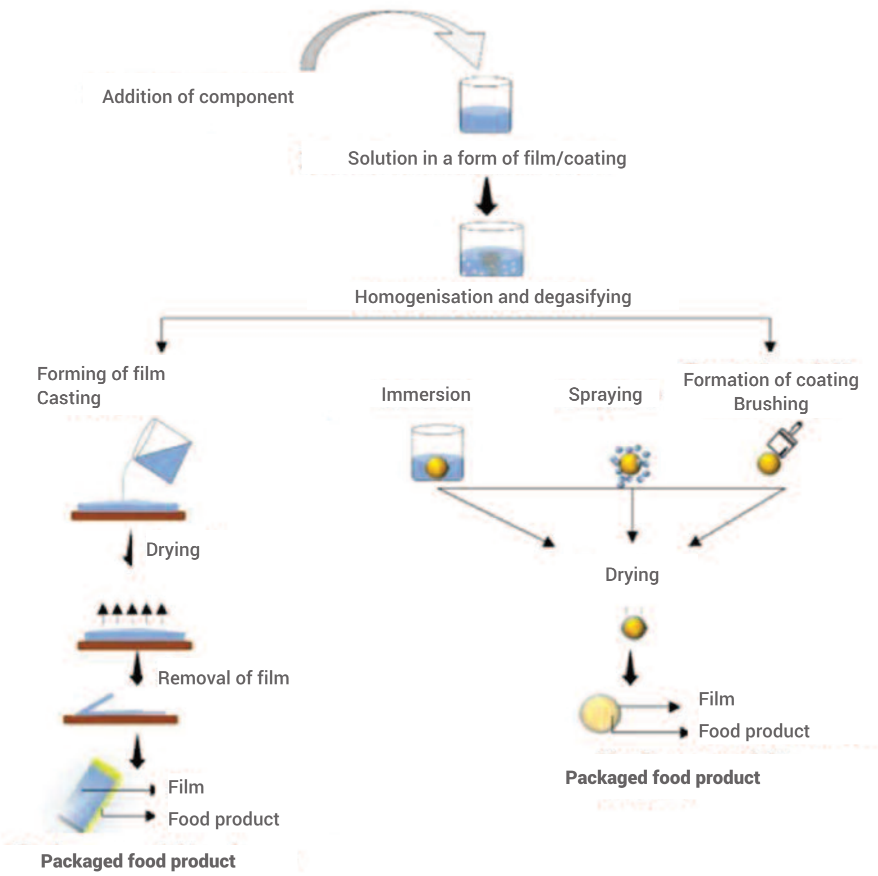

FIG.2. SCHEME OF MANUFACTURE OF EDIBLE FILMS (NAIR, S.S., TRAFIAŁEK, J., & KOLANOWSKI, W. (2023). EDIBLE PACKAGING: A TECHNOLOGICAL UPDATE FOR THE SUSTAINABLE FUTURE OF THE FOOD INDUSTRY. APPLIED SCIENCES, 13 (14), 8234)

based polymers. The application of protein films in food packaging is the subject of the current studies and their technology is still developed. We should conduct the studies of new, natural, biodegradable, profitable and environment-friendly proteins as polymers with the improved physical-chemical and mechanical qualities, originating from different sources such as insects, algae and microorganisms in order to generate the new films for food packaging at the high scale (Bhaskar et al., 2023).

EDIBLE POLYMERS

Edible films are the initially formed thin layers which are then put on the food surface via wrapping; on the other hand, the coatings are, in general, the solutions which are laid directly on the surface of the products and then, remain there for creation of a thin layer (Koirala et al., 2023). They are considered as the alternative to synthetic polymers as they help to prolong the shelf life of the products, protect the food from mechanical and microbiological damages, limit the loss of humidity and volatile substances, inhibit the biochemical processes of deterioration (i.e. they help in minimization of lipid oxidation, limit the loss of the product's weight, slowed-down breathing and enzymatic browning of food products) and improve the appearance of food and improve its nutritive, biological and sensory quality (Yadav et al., 2023). The advanced edible films and coatings may also serve as a matrix for supply of active components such as natural antimicrobial agents, nutraceuticals, the agents preventing browning reaction and natural flavouring compounds (Amon-Rips, Poverenov, 2016). In manufacture of edible films and coatings, the biopolymers are employed, i.e. polysaccharides, lipids and proteins which form the basic materials used owing to their biodegradable and compostable properties and also, due to a slow release of substances where the active contribution to food preservation is dependent on packaging (Dutta, Sit, 2023). In Fig.2, the exemplified scheme of edible film production has been presented.

The current idea of packaging has been changed in such a way that they cannot be limited only to protective, barrier materials but they should also include other functions such as antioxidant effect, antimicrobial properties of oxygen trapping and also, the presence of sensors, transforming the traditional packaging into active or intelligent packaging; some of them are edible films/coatings. The range of the studies of edible films has been recently increased. Nevertheless, the edible films have been for a long time employed with the aim to protect food and prolong their shelf life. Certain examples include wax or lard, used in fruits, vegetables, meat and fish. Moreover, the scientists have recently studied specific applications of film which are connected with the use of edible films as packaging systems. They include soluble sachets made from polysaccharide and gelatine, coming from soy seeds and used in soups and drinks (to be dissolved in water). Other examples are edible wrappings made from gelatine and pectin, employed in order to decrease the humidity level in Ricotta cheese. Also, the primary packaging of single candies may be replaced with edible films (Gaspar, Braga, 2023). Therefore, the scientists work upon finding the materials which could replace polymer petroleum-based films for food packaging. At present, some polymers of natural origin such as polysaccharides and proteins are employed as ideal materials in a form of films for food packaging. Biodegradable agar-based films for food packaging are a new promising achievement in aspect of sustainable packaging. It has been found that the functional agar-based film reveals a good bioactivity and biocompatibility and may also serve as an excellent carrier of active substances. At the present moment, the discussed films are the most promising candidates to be applied in food packaging due to their perfect properties in respect of water resistance as compared to other universally employed biopolymers. Moreover, they are suitable for prolongation of the shelf life of the packaged food products such as meat, fish, vegetables and fruits. It was also found that the intelligent agar-based colour indicator was suitable for tracing the freshness of packaged food products such as fish and meat (Roy et al., 2023).

Apart from agar, another sea-originating substance is used in production of edible films. It is alginate. It creates the edible coating with good barrier and mechanical properties which allow protection of active components via capsulation. Such coatings are often supplemented with garlic oil as natural antibacterial agent. Alginate is partially sprayed with calcium and mixed with starch in order to obtain high water retention in the coating. It is important in obtaining homogenous mass and coating owing to pressing, with the aim to improve its rheological qualities. Alginates have been used in many applications in biomedical sciences as dressing materials. Sodium alginate, in particular, employed in a form of hydrogel, becomes more and more considered in science due to its physico-chemical properties. Materials produced from alginate are recognised as friendly to humans owing to biocompatibility of tissues what enables their application in biomedical engineering (Wróblewska-Krepsztul et al., 2019).

Additionally, there are produced films and packaging in accordance with the principle zero waste and based on the application of fruit and vegetable residues. Matrix-creating polysaccharides and nutrients present on the fruits make that the mentioned films are the ideal materials for creation of edible films and coating materials; they have also high nutritive values. It brings us to the point where we may partially replace the non-renewable and traditional materials with the residues of agricultural industry owing to their profitable and sustainable nature (Bose e t al., 2023). According to the studies conducted by Said et al., the extracted hybrid citrus pectin, as employed in production of packaging, has preserved its functional structure, occurring in commercially available citrus pectin. Citrus pectin-containing hybrid films and coating showed the improved physical properties, including the increased mechanical resistance and elasticity, with the simultaneous preservation of comparable barrier qualities in comparison to the commercially available film made from citrus pectin. The correlation analysis has additionally confirmed the effect of the composition of pectins on the properties of edible film (Said et al., 2023). The on-going studies of the properties of films, obtained on the basis of natural mixtures (flour, mash and juice) and their comparison with the films, originating from their components, supply the valuable information about the nature of interactions, occurring in polymer matrix. Development of the knowledge on the edible films and coatings coming from fruit and vegetal semi-products is a promising way for scientific research, consistent with the principles of sustainable development (Janowicz et al., 2023).

ESSENTIAL OILS IN PACKAGING INDUSTRY

During the recent years, the studies on the packaging materials have been intensified mainly due to the need of increasing the sustainable nature of packaging, with the simultaneous further reduction of food spoilage. It caused paying attention to renewable materials such as chitosan and cellulose, and the application of natural compounds such as essential oils, with the aim to obtain or strengthen the antibacterial properties of packaging and by this, prolonging the shelf life of the product (Casalini, Giacinti Baschetti, 2023). According to the studies, tulsi oil-containing chitosan film may potentially delay oxidation of lipids present in the fired products, increasing the oxidative stability (Kumar et al., 2023). The application of certain essential oils in biodegradable materials for active food packaging may be somewhat limited due to their strong smell. The addition of the essential oils to packaging material matrix may, however, considerably improve their antibacterial properties owing to generation of interactions with polymer film and limitation of the penetration of antibacterial agents to food (Sharma et al., 2021). The essential oils and packaging film lead to the reduction of the weight loss, colour changes, rate of breathing and prolongation of the shelf life of fruits and vegetables via the delay of their maturation. General effectiveness of the essential oils and packaging film in respect of preservation of the quality of fresh products is dependent on a type of the essential oils and their composition, type of packaging materials, kind of food product, type of pathogens, way of application, etc. The essential oil-containing packaging film may, however, change the sensory qualities of the fresh products. Moreover, due to the complex character of food system, the activity of essential oils may be decreased; therefore, in order to obtain the antibacterial effect, their higher dose may be required; it may, in turn, negatively affect the sensory qualities of food products (Perumal et al., 2022).

In Tab.1, the effect of the selected essential oils on the bacterial pathogens and their application in the selected food products has been presented.

The essential oils have a potential to protect food matrices from various microorganisms and keeping the quality of meat, fish, dairy products, fruits and vegetables. It was also documented that they had a great influence on cooking and prolonged the shelf-life of food products. The basic material of capsulated and nano-capsulated essential oils ensures their constant release in reaction to different releasing factors and it promotes better preservation of food. The essential oils improve active properties of packaging material. Therefore, some approaches to introduction of essential oils to packaging matrix have been developed with the aim to increase the bioactivity and modification of biopolymers' properties in the application to food packaging. From among all biopolymers employed in the packaging sector, a special attention was paid to edible or biodegradable polymers based on polysaccharides. In spite of this fact, the weak mechanical and barrier properties of the mentioned biopolymers limit the spectrum of their applications in various products. The properties of the discussed polymers may be increased via chemical and enzymatic treatment. However, if packaging material comes into close contact with food, the concerns will appear relating to safety. To these ends, we may add hydrophobic substances such as essential oils with the aim to change physical and chemical composition of biopolymer; it will finally improve the effect of packaing as a whole (Rout et al., 2022).

The scientists have stated that essential oils as added to edible seaweeds-based polysaccharide films (agar, alginate, furcellate and carrageenan) have a big potential as edible film owing to their perfect barrier and coating-forming properties. On the other hand, the essential oils as natural bioactive functional materials with strong antibacterial, UV-light barrier and antioxidant properties may be a promising choice in development of edible, functional, active packaging materials with excellent properties. The system of packaging produced from seaweed-based biopolymers with the addition of the essential oils may potentially improve physicochemical, antioxidant and antibacterial properties. The recent studies have demonstrated that the essential oils constitute the important strategy of improving the seaweed-based films and coatings used in food applications. Films and coating, based

TAB.1. THE EXEMPLIFIED EFFECT OF ESSENTIAL OILS ON BACTERIAL PATHOGENS

(ROUT, S., TAMBE, S., DESHMUKH, R.K., MALI, S., CRUZ, J., SRIVASTAV, P.P.,...& DE OLIVEIRA, M.S. (2022). RECENT TRENDS IN THE APPLICATION OF ESSENTIAL OILS: THE NEXT GENERATION OF FOOD PRESERVATION AND FOOD PACKAGING. TRENDS IN FOOD SCIENCE &TECHNOLOGY)

Essential oil	Concentration	Bacterial species	Food product
Oregano and rosemary	Oregano (0.07 µL/g) Rosemary (2.65 µL/g)	*E. coli O157:H7, L. acidophilus LA-5*	Cheese from Minas
Black caraway	1,0%	*Staphylococcus aureus, Escherichia coli*	Meat from chick breast
	0.5% v/v	*Listeria, lactic acid bacteria, Enterobacter spp., Escherichia spp. Pseudomonas spp.*	Gouda cheese
Eucalyptus	0.63-2.00 µl/ml	*Escherichia coli, Shewanella putrefaciens, Pseudomonas aeruginosa, Vibrio parahaemolyticus Staphylococcus aureus*	Water products
	0.8-4 µl/ml	*Escherichia coli, Pseudomonas aeruginosa, Enterobacter sakazakii, Bacillus cereus, Klebsiella ornithinolytica, Staphylococcus aureus, Aspergillus flavus, Aspergillus niger, Aspergillus fumigatus Saccharomyces cerevisiae, Aspergillus brasiliensis, Candida albicans, Trichosporon sp., Candida parapsilosis*	Fruit juice from orangina
Cinnamon	10 µl/ml	*Listeria monocytogenes*	Milk
Clove	0.05-0.8% (v/v)	*Penicillium italicum*	Citrus fruits
Popular thyme (Thymus vulgaris)	0.003-0.4% (v/v)	*Listeria monocytogenes*	Fresh vegetables
Exotic verbena (Litsea Cubeba)	1.5 mg/ml	*Escherichia coli O157:H7*	Vegetal juices

upon seaweeds, activated by the essential oils, are very effective in prolongation of the shelf life of meat, fish, fruit and other food products; this fact indicates their good potential as packaging material (Ebrahimzadeh et al., 2023).

Many coating produced with the additive of the essential oils has been suggested as natural antioxidants and antibacterial agents in meat and meat derivates. Such approach to packaging prolongs the shelf life of the mentioned products owing to delay of their spoilage and limitation of the growth of pathogenic microorganisms, reduction of oxidation of lipids, proteins and pigments and the prolongation of the period during which the products are acceptable from the sensory quality point of view. Due to their preserving effect, the essential oils are the excellent alternative to synthetic antioxidants as they improve the sensory qualities in the majority of the tested kinds of meat. On the other hand, in order to avoid the unfavourable effect on physicochemical and sensory properties of the coated meat and meat products with the essential oils, the additional studies concerning their toxicological effects and their safe rates are necessary. The future studies are indispensable for improvement of the coating properties and technical/manufacturing conditions and for estimation of the correctness of packaging /final product, especially in the case of industrial meat production (Smaoui et al., 2022). In the future, it will be possible to test various combinations of biodegradable polymers and natural antibacterial compound with the aim to produce the dedicated active packaging for other food products (Rusková et l., 2023).

CONCLUSIONS

1. Biodegradable polymers help to minimize the effect of production and application of plastics on the environment, contributing in this way to the support of green economy;
2. The development of biodegradable polymer films becomes more and more necessary as the spreading out of non-degradable plastic packaging makes the considerable damages to environment as well as human life;

3. Food packaging is the area of constant development and the requirements of the consumers have been changed during the recent years, indicating the direction of the packaging materials of natural and sustainable origin;
4. More and more food products and their extracts are employed in manufacture of edible films;
5. The future studies aimed at the improvement of the properties of biodegradable polymers are necessary. There are still visible drawbacks of certain types of edible films, e.g. they are not effective in the case of all kinds of food products because they are penetrable to acids, bases (alkalis) and water;
6. The use of a part of fruit and vegetables as the key components of edible films and coatings allows the re-use of the raw materials with the lowered commercial value, including the deformed and mechanically slightly damaged products;
7. The films, activated with seaweeds/essential oils are the promising alternative to the traditional packaging materials;
8. Bioactive components which play the important role in the increase of functionality of packaging are a very interesting area for the studies. They will contribute to prolongation of the shelf life of food products; owing to this fact, the quantity of the consumed packaging will be decreased and, additionally, the amount of the wasted food will be reduced.

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