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HALINA MAKAŁA / ORCID 000-0003-2739-0374 / halina.makala20@gmail.com

ACTIVE AND INTELLIGENT FOOD PACKAGING REVIEW PAPER, PART 2

ABSTRACT: In the present paper, the role and tasks of food packaging were discussed. The definitions, functions, forms and principles of intelligent and active packaging acting have been presented. The application of intelligent and active packaging in food industry has been characterized. The newer and newer generations of active and intelligent packaging are the future of food packaging systems. The development and application of new packaging generations will be greatly dependent on perceiving the benefits, coming from their utilization by the consumers. At present, the costs connected with the introduction of intelligent element into packaging are high.
Key words: active and intelligent packaging, application, food

STRESZCZENIE: W artykule przedstawiono rolę i zadania opakowań do żywności. Podano definicje, funkcje, formy oraz zasady działania opakowań inteligentnych i aktywnych. Scharakteryzowano zastosowanie opakowań inteligentnych i aktywnych w przemyśle spożywczym. Powstające coraz to nowsze generacje opakowań aktywnych i inteligentnych stanowią przyszłość opakowalnictwa żywności. Rozwój i stosowanie nowych generacji opakowań będą w dużej mierze zależały od postrzegania korzyści płynących z ich wykorzystania przez konsumentów. W chwili obecnej koszty związane z wprowadzeniem elementu inteligentnego do opakowania są wysokie.
Słowa kluczowe: opakowania aktywne i inteligentne, zastosowanie, żywność

Active packaging is also defined as interactive packaging, i.e. such packaging in which the product, package and the surrounding are mutually affecting each other. Their properties are oriented to the product and its highest quality and, also, extension of its stability and the expiration date. Contrary to the traditional packaging of the products, they are able to control and monitor the occurring changes as well as to react directly to the mentioned changes [21, 25, 30].

The main task of active packaging is to change the conditions inside of them in order to preserve the quality of the packed product. The introduction of the active packaging systems is supported by the possibility of prolonging the stability period and expiration date of foodstuffs and a potential limitation of the application of additives, including, inter alia, preservatives. We may distinguish two basic types of the active packaging: ones absorbing the undesired substances and the other ones which emit favourable substances. The basic absorbents include oxygen, ethylene and carbon dioxide absorbents and those ones which absorb water excess. The most frequently emitted substances are: carbon dioxide, water, antioxidants and preservatives. The mentioned substances constitute usually the built-in part of packaging material or are found inside the packaging in a form of sachets, stickers or labels [1, 6, 7].

New generation packaging which includes active packaging has the influence on the packaged product, changes the conditions of the packaged foodstuff and, simultaneously, it

controls the quality of the product. The condition which decides on the possibility of classifying a packaging as the active one consists in covering the packaging materials with the coating, containing active substances, or introducing the active substances directly to the polymer matrix. The discussed substances should have a bactericidal or bacteriostatic effect on bacteria, yeasts or fungi, responsible for food poisoning [27]. Active packaging occur usually in a form of small additives or sachets, containing powdered iron and calcium hydroxide, placed in the packaging or in a form of active constituents, added directly to the packaging, e.g. to packaging films [12].

Apart from the protection of the product, active packaging plays the additional protective functions against external conditions. Their main functioning principle is cooperation with the packaged product. Interaction; product – packaging is very important and extends the storage period or improves sensory properties of the product. There are two methods of introducing the active substances into the discussed types of packaging – they are placed in small bags in the packaging or they are directly introduced to the packaging material [6, 33, 36, 41].

The active packaging has been created in order to prolong the shelf life of food products and to extend the period of a high quality of the products. The technologies employed in the active packaging contain physical, chemical or biological agents which change the run of interactions between the packaging and the product, with the aim to monitor the condition of their state in which they are found. The most popular active components include absorbers and emitters, being found inside the packaging or being built-in directly in the packaging [8].

The activity of the packaging consists in the following:

- inclusion of chemical or enzymatic substances to the packaging or to the packaging material; the mentioned substances are aimed at adsorption and/or removal of oxygen from the atmosphere inside the packaging;
- application of carbon dioxide-producing or absorbing substances in the packaging;
- control of ethylene content in the packaging by the utilization of adsorption, using oxidizing agent or organometallic compound;
- introduction of ethanol-emitting substance in a volatile form to the inside of the packaging as a factor, inhibiting microflora development;
- application of preservatives, bactericidal substances or antioxidants, secreted from the packaging material;
- use of humidity regulators;
- application of the technology, enabling control of smell and taste (flavour);
- introduction of light absorbents to the packaging;
- application of foils, emitting mineral substance, protecting the colour of the product;
- improvement of the film surface in order to change its permeability ("smart foils" and "intelligent foils") [1, 3, 6, 9].

In food industry, the following systems of active packaging have been employed:

- oxygen, carbon dioxide and ethylene absorbents;
- carbon dioxide emitters;
- smell emitters and absorbents;
- regulators of relative humidity (water content of packaging atmosphere);
- substances with the antibacterial effect; and
- antioxidants [3].

Active packaging enables modification of the composition of environment inside the packaging due to limitation of the concentration of CO_2, fragrances and ethylene, i.e. absorption of the mentioned compounds. Another task of the discussed packaging consists in the emission of the inhibitors of microbial growth (ethanol, nisin, CO_2, lysozyme, SO_2, sorbic and benzoic acids and their salts) to the foods inside the packaging [4, 6, 8, 36]. The above mentioned properties of packaging have the influence on the longer storage of the product inside the given packaging [33, 39]. Such packaging cannot, however, mislead the consumer by adulteration of the food. We should also pay attention to the fact that owing to the active packaging it is possible to prepare more quickly a meal in microwave kitchen [31].

The example of innovative solutions in the field of active packaging may be the Ageless absorbers which may have

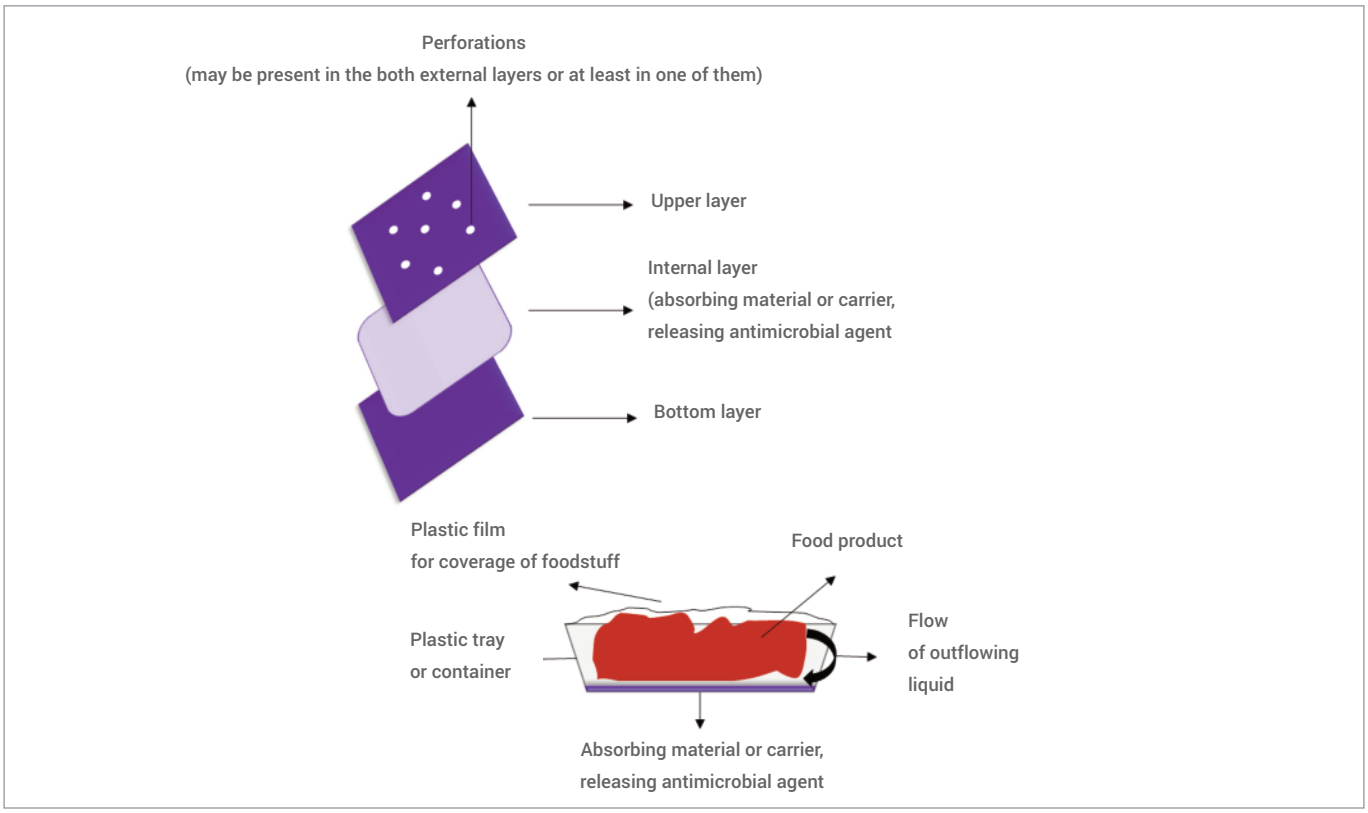

FIG.2. OUTLAY OF CONSTRUCTION AND APPLICATION OF ABSORBING MATERIAL (CARRIER, RELEASING ANTIMICROBIAL AGENT) [30]

different forms. They may include stickers, sachets or labels which are place in the packaging ot of the packaging seal. They are mainly employed in relation to foodstuffs. The discussed system is aimed at preventing the process during which the oxidation of fats occurs.

Technologies employed in active packaging are based upon the utilization of physical, chemical or biological factors, changing the run of interactions between the packaging and product with the aim to monitor the state in which they are found.

The most popular active components include absorbents and emitters being found inside the packaging or being directly built-in in the packaging [8].

The selected types of active packaging and their functions in food chain are given below:

– oxygen absorbers – they occur in a form of sachets, labels, films, bottle closure; they cause inhibition of product decomposition and vitamin degradation
– ethylene absorbers – they appear on a form of sachets and films; they cause prolongation of products freshness and regulation of fruit and vegetable ripening
– relative humidity regulators – they are found in a form of sachets and films; they cause maintenance of high sensory qualities of the product
– antibacterial agents – they occur as sachets and films; they cause inhibition of microbial growth
– antioxidants – they are found in a form of sachets and films, they cause inhibition of oxidation processes [8, 35].

OXYGEN ABSORBERS

The undesired oxygen presence in atmosphere of packaging may be a result of insufficient removal of oxygen during the packaging process and, also, its presence in food, or penetration of oxygen via the packaging, or introduction of the air as a result of insufficient sealing of the closure; it may be also a result of micro-perforation of packaging material [20, 28].

High oxygen content causes lowering of nutritive value of food and abbreviation of its shelf-life. It also accelerates the

processes of degradation of many food products, inter alia, of meat, butcher's products, seasonings; it causes degradation of vitamins and rancidity of oils and/or solid fats (butter, lard), nuts and fat products and also, is favourable for bacterial growth [17, 29, 35, 42, 48].

To monitor and control actively the oxygen residues, the absorbers are employed; their presence allows reduction of oxygen content even to 0.01%. The oxygen absorbers in the food chain cannot contain any toxic substances or emit the undesired aromas or gases. Their compactness is also important in aspect of minimizing the use of space in the packaging.

At present, the discussed type of packaging utilizes, inter alia, sachets, liners and, also, absorption films. They are produced from the components with a low molecular weight, covered with polymers, indirectly built-in in the packaging by the method of injection moulding (injection-moulded polymers). Before their use, the discussed components cannot have any contact with the oxygen and they are stored in hermetically sealed packages or require activation by the participation of water, effect of light etc. [6, 7, 17, 18].

ANTIBACTERIAL PACKAGING

Antibacterial packaging is one of the types of active packaging [25, 30]. Its function is to inhibit the growth of pathogenic microorganisms, contaminating food, by the addition of a component or use of polymer with the antimicrobial properties. The antimicrobial components are as follows: organic acids, bacteriocins, enzymes, vegetal essential oils. The main antimicrobial constituents of the discussed packaging are benzoic acid, sorbic acid and their salts, nisin, lysozyme, essential oils and others. The mentioned components differ from each other by mechanism of action; they affect the cellular wall or metabolism or genotype of microorganisms; they inhibit the growth of microorganisms via modification of the conditions of the environment. They contain antibacterial components which are released to the environment of the packaging or directly on the product, or they contain immobilised substances with the antibacterial effect. When properly built-in to the matrix of packaging, they prevent of limit the development of many microorganisms, e.g. *Listeria monocytogenes*, *Salmonella typhimurium*, *Staphylococcus aureus*, and of moulds: *Penicillium, Aspergillus niger*. The effectiveness of antibacterial packaging is dependent on the choice of antimicrobial components to the packaging matrix and the type of foodstuff to be packed. Thus, it is possible to counteract the growth of undesired microflora on the surface of the product, or control the mentioned growth [25, 34, 35, 44].

In the packaging sector, there are frequently utilized such active compounds as bactericides, limiting the growth of Gram-positive bacteria, extracts of seasonings, essential oils, enzymes and organic acids which inhibit the growth of Gram-positive bacteria, Gram-negative bacteria and moulds. The mentioned substances should be effective in limiting or complete inhibition of bacterial growth but they must be safe for humans and environment-friendly [27, 49, 51].

Mizielińska et al. [27] studied the antibacterial properties of coated packaging film, obtained in industrial trials. Vegetal extracts, as obtained in laboratory experiments, were added to nitrocellulose varnish. Laminate of PE/PET film was coated with cover-creating carrier with the extract under the industrial conditions. As a result of the conducted experiments, the authors confirmed that the coating of nitro-cellulose varnish, containing extract of buckwheat husks, green tea, coconut and paprika waste reduced, to a certain degree, the number of Gram-negative and Gram-positive cells. The best results were obtained for coatings with the extract of coconut waste and of paprika waste; they reduced the number of *S. aureus* and *E. coli* cells only by 1 log order. Unfortunately, the obtained coatings did not limit the growth of *B. cinerea* cells.

CONSUMER VS. ACTIVE AND INTELLIGENT PACKAGING AT THE MARKET OF FOOD PRODUCTS

Packaging is one of the more important attributes of the product, affecting the purchase preferences of the consumers. The knowledge of the consumers' attitude towards the new generation of the packaging is a valuable source of information for the producers during development of marketing strategies, connected with the design and introduction of new products to the market [3].

Packaging is also one of the criteria for the choice of the food product, connected with its functional properties [10, 16, 20, 23]. Due to the increasing interest of the clients in the consumption of the fresh products with the prolonged shelf-life and controlled quality, the producers must ensure modern and safe packaging. It is a challenge to the sector of food packaging; it functions also as a driving force on development of new and improved technological conceptions of packaging [46, 49, 51]. The producers of packaging are looking for the new solutions which enable improvement of the properties of packaging materials such as appropriate barrier properties in relation to gases, protection from UV irradiation, prolongation of shelf-life (storage period), transparency and ecology-friendliness [3, 4, 29, 37, 40].

The expectations of the consumers as well as the producers in relation to the innovative packaging at the food market refer to the following packaging properties:

- new construction, shape and graphic form,
- possessing the function of product protecting;
- active,
- functional,
- with the improved barriers properties,
- environment-friendly (bio-renewable raw materials and bio-degradable materials) [2].

From the conducted survey studies concerning the application of innovative packaging of food products [3] it is followed that the respondents indicated the following products for which this type of packaging would be most suitable, i.e. first of all, meat, butcher's products, milk products and frozen foodstuffs. The mentioned groups of the products are mostly endangered with the lowering of their quality. The aim was also to ensure the safety of the discussed products during the transport and storage from the farmer's field to the consumer's table. At the same time, more than 50% of the respondents stated that they were not willing to pay more for the products in the active and intelligent packaging.

The studies of Pałkowska and Stenka [31] on the evaluation of perception of active and intelligent packaging by the consumers showed that a small group of the society possessed the knowledge and awareness relating to the mentioned above packaging. In connection with this fact, it is difficult to state whether the food purchased by the discussed respondents was found in the mentioned above packaging. Only small group of the examined persons was able to indicate the sectors where the application of active and intelligent packaging was possible. It concerned mainly food sector, pharmaceutical sector and cosmetic industry.

SUMMING UP

Nowadays, the food packaging is changing very dynamically. The packaging becomes more and more functional and innovative; in their manufacture, active substances affecting the packaged product as well as biodegradable raw materials are employed. Due to the interactions of the packed products and the packaging, the quality of packaging plays a key role in preservation of the product's safety and consumer's health. In connection with it, we should remember about the principles of Good Manufacturing Practice (GMP) on relation to the materials and products intended for the contact with food and observing other legal regulations the aim of which is to limit a health risk.

The rising newer and newer generations of active and intelligent packaging are the future of food packaging industry. The changes in the consumer preferences have led to innovations and development of new packaging technologies. A big advantage resulting from the implementation of active and intelligent packaging in the food industry consists in the prolongation of the period of food shelf-life, ensuring its safety, better control of the storage conditions and, also, better perception of a given mark by the consumers.

At present, the costs connected with the introduction of active or intelligent packaging to the food industry for common use are high. We hope that together with the development of the studies and popularization of the discussed currently innovative solutions, the costs could be lowered.

The research and development in the field of active and intelligent materials are very dynamic and are developing in combination with the searches for the environment-friendly solutions. The cooperation between the research centres and

industry may be a very significant element to reach the success. It may ensure the advantage of active and intelligent packaging in comparison to traditional packaging which is nowadays employed in packaging of food products.

BIBLIOGRAPHY

1. Baran J. 2016. *Opakowania aktywne i inteligentne w łańcuchu dostaw żywności – przykłady zastosowania i opinie konsumentów. [w]. Zarządzanie i bezpieczeństwo w łańcuchu żywnościowym*. p. red. nauk. Walaszczyk A., Jałmużna I., Lewandowski J.. Monografie Politechniki Łódzkiej, Łódź 2016, 7-17. (In English: *Active and intelligent packaging in food supply chain – examples of application and opinions of the consumers [In] Management and safety in food chain*) Monographs of Łódź University of Technology
2. Bartkowiak A. 2020. *Trendy w opakowaniach do żywności z przykładami pakowania produktów mięsnych*. Prezentacja: Szczecin, 3.06.2020. Zachodniopomorski Instytut Technologiczny w Szczecinie. (In English: *Trends in food packaging with the examples of meat product packaging*. Presentation: Szczecin 3.06. 2020. West Pomeranian University of Technology in Szczecin)
3. Barska A., Wyrwa J. 2016. *Konsument wobec opakowań aktywnych i inteligentnych na rynku produktów spożywczych. Zagadnienia Ekonomiki Rolnej*, 4 (349), 138-161. (In English: *Consumer and active and intelligent packaging at the market of food products. Problems of Agricultural Economy*).
4. Cichoń M., Lesiów T. 2013. *Zasada działania innowacyjnych opakowań inteligentnych w przemyśle żywnościowym*. Artykuł przeglądowy. Nauki inżynierskie i technologie. Engineering Sciences and Technologies, 2(9), 9-32. (In English: *The principle of functioning of innovative intelligent packaging in food industry*. Review paper.)
5. Cierpiszewski R. 2015. *Opakowania inteligentne*, Acta Poligraphica, 6, 9-18. (In English: *Intelligent packaging*).
6. Cierpiszewski R. 2016. *Opakowania aktywne i inteligentne*, Uniwersytet Ekonomiczny w Poznaniu, Poznań 2016, 96-101, 159-164. (In English: *Active and intelligent packaging*. University of Economy in Poznań)
7. Dainelli, D., Gontard, N., Spyropoulos, D., Zondervan-van den Beuken, E. and Tobback, P. (2008). *Active and intelligent food packaging: legal aspects and safety concerns*. Trends in Food Science & Technology, 19, 103–112.
8. Fajczak-Kowalska A., Rudowska P., Ziemiński P. 2016. *Opakowania aktywne i inteligentne w łańcuchu żywnościowym. [w]. Zarządzanie i bezpieczeństwo w łańcuchu żywnościowym*. p. red. nauk. Walaszczyk A., Jałmużna I., Lewandowski J.. Monografie Politechniki Łódzkiej, Łódź 2016, 33-49. (In English: *Active and intelligent packaging in food chain [in] Management and safety in food chain*. Monographs of Łódź University of Technology)
9. Fang, Z.; Zhao, Y.; Warner, R.D.; Johnson, S.K. 2017. *Active and intelligent packaging in meat industry*. Trends Food Sci. Technol. 61, 60–71.
10. Ghaani, M., Cozzolino, C.A., Castelli, G., Farris, S. 2016. *An overview of the intelligent packaging technologies in the food sector*. Trends in Food Science & Technology, vol. 51, 1-11. DOI: 10.1016/j.tifs.2016.02.008.
11. https://www.transparencymarketresearch.com/fresh-meat-packaging-market.html
12. Janicki A. 2013. *Opakowania aktywne i inteligentne*. Systemy Logistyczne Wojsk. 39. 81-93. (In English: *Active and intelligent packaging*. Logistic Military Systems)
13. Jeznach M., Bilska B., Tul-Krzyszczuk A., Pawlak A. 2017. *Rola opakowań aktywnych w ograniczaniu marnotrawstwa mięsa w gospodarstwach domowych*. Żywność. Nauka. Technologia. Jakość, 24, 4 (113), 126 – 136. (In English: *Role of active packaging in limiting of meat waste in households*. Food. Science. Technology)
14. Kaźmierczak M. 2017. *Innowacyjne opakowania jako inteligentne rozwiązania na przykładzie branży spożywczej*. Zeszyty Naukowe ASzWoj. 2 (107), 78-97. ISSN 2543-6937. (In English: *Innovative packaging as intelligent solutions on the example of food sector*)
15. Kondratowicz J., Kościelak E. 2005. *Sposoby pakowania produktów, które muszą być przechowywane w niskich temperaturach*. Chłodnictwo, tom 40, 8. (In English: *The methods of packaging of the products which have to be stored at low temperatures*. Refrigeration, vol.40, 8.)
16. Kondratowicz J. 2006. *Czynniki kształtujące jakość mięsa drobiowego przechowywanego w warunkach chłodniczych*. Chłodnictwo 3(16), 44-49. (In English: *Factors affecting the quality of poultry meat stored under the refrigeration conditions*).
17. Koskela, J., J. Sarfraz, P. Ihalainen, A. Määttänen, P. Pulkkinen, H. Tenhu, T. Nieminen, A. Kilpelä, J. Peltonen. 2015. *Monitoring the quality of raw poultry by detecting hydrogen sulfide with printed sensors*. Sensors and Actuators B 218, 89-96.
18. Kot vel Ławecka K., D. Banaszewska, B. Biesiada-Drzazga. 2019. *The effect of packaging systems on selected quality characteristics of poultry meat*. Acta Sci. Pol. Zootechnica 18(2), 3-12.
19. Kozak W., M. Biegańska. 2012. *Integratory TTI (ang. Time-Temperature Integrators) jako innowacyjny element opakowania*. Opakowanie 9, 88-93. (In English: *TTI integrators as innovative element of packaging*. Packaging 9, 88-93).
20. Kucharyk S., Rudy M., Gil M., Stanisławczyk R., Mroczek K. 2019. *Niekonwencjonalne metody utrwalania produktów mięsnych oraz ich wpływ na zdrowie człowieka i środowisko*. Polish Journal for Sustainable Development 23 (2), 53-62. (In English: *Unconventional methods for preservation of meat products and their effect on human health and environment*)
21. Makała H. 2010. *Trendy na rynku opakowań do żywności. Opakowania aktywne i inteligentne*. Opakowanie 11, 23-25. (In English: Trends on the market of food packaging. Packaging 11, 23-25)
22. Makała H. 2011. *Trendy w opakowaniach mięsa i przetworów mięsnych*. Postępy Nauki i Technologii Przemysłu Rolno-Spożywczego 66, 1, 153-173. (In English: *Trends in packaging of meat and meat products*. Achievements of Science and Technology of Agri-Food Industry)
23. Makała H. 2016. *Wybrane kierunki zastosowania opakowań inteligentnych do żywności*. Gospodarka Mięsna 8 : 34-38. (In English: *The selected directions of the application of intelligent packaging in food sector*)

24. Makała H. 2021 *Współczesne rozwiązania i trendy w pakowaniu mięsa i przetworów mięsnych*. Przemysł Spożywczy 5, 75, 34-40. (In English: *The contemporary solutions and trends in packaging of meat and meat products*. Food Industry 5, 75, 34-40)
25. Martyn A., Z. Targoński. 2010. *Antymikrobiologiczne opakowania żywności*. ŻYWNOŚĆ. Nauka. Technologia. Jakość 5 (72), 33 – 44. (In English: Antimicrobial food packaging. FOOD. Science.Technology. Quality 5 (72), 33-44)
26. Martynkewicz A. 2008. *Individuelle Hülle für jedes Packgut. Fleischwirtschaft* (11), 51-54.
27. Mizielińska M., Ordon M., Pankowski J., Bienkiewicz G., Malka M., Lisiecki S., Bartkowiak A. *Badanie antymikrobiologicznych właściwości folii otrzymanych w próbach przemysłowych*. Przemysł Chemiczny. 96 (6), 2017, 1322-1324. (In English: *Studies on the antimicrobial properties of films obtained in the industrial trials*. Chemical Industry, 96 (6), 2017, 1322-1324)
28. Mucha-Szajek E., Borowy T., Jasiurkowski M. 2020. *Innowacyjne opakowanie foliowe*. Mięsne Technologie 07. (In English: *Innovative film packaging*. Meat Technologies 07)
29. Müller P., Schmid M. *Intelligent Packaging in the Food Sector: A Brief Overview*. Foods 2019, 8, 16; DOI:10.3390/foods8010016.
30. Otoni CG, P.J.P. Espitia, R. J. Avena-Bustillos, T. H. McHugh. 2016. *Trends in antimicrobial food packaging systems. Emitting sachets and absorbent pads*. Food Research International 83, 05, 60-73. DOI: 10.1016/j.foodres. 2016.02.018 AGR: IND605267808
31. Pałkowska A., Steinka I. 2013. *Opakowania aktywne i inteligentne w świadomości konsumentów*. Zeszyty Naukowe Akademii Morskiej w Gdyni 80, 11, 35-42. (In English: *Active and intelligent packaging in awareness of the consumers*. Scientific Publications of Marine Academy in Gdynia)
32. Pavelková, A. 2013. *Time temperature indicators as devices intelligent packaging*. Acta Univ. Agric. Silvic. Mendel. Brun. 61, 245-251.
33. Panja P., Mani A. and Thakur P. K. 2022. *Current status of active and intelligent packaging in food technologies. Current status of active and intelligent packaging in food technologies*. In book: Trends & Prospects in Post Harvest Management. 299-320.
34. Pirsa, S.; Sani, I.K.; Mirtalebi, S.S. 2022. *Nano-biocomposite based color sensors: Investigation of structure, function, and applications in intelligent food packaging*. Food Packag. Shelf Life 31, 100789.
35. Popowicz R., T. Lesiów. 2014. *Zasada działania innowacyjnych opakowań aktywnych w przemyśle żywnościowym*. Artykuł przeglądowy. Nauki inżynierskie i technologie. Engineering sciences and technologies 1(12), 82-101. (In English: *The principle of functioning of innovative active packaging in food industry*. Preview article)
36. Realini, C. E. and Marcos, B. 2014. *Active and intelligent packaging systems for a modern society*. Meat Science, 98, 404-419.
37. Ripoll G., P. Albertí, I. Casasús, M. Blanco. 2013. *Instrumental meat quality of veal calves reared under Tyree management systems and color evolution of meat stored in three packaging systems*. Meat Science 2 (93), 336-343.
38. Rozporządzenie Komisji (WE) nr 450/2009 z dnia 29 maja 2009 r. w sprawie aktywnych i inteligentnych materiałów i wyrobów przeznaczonych do kontaktu z żywnością. (In English: Commission Regulation (EC) No 450/2009 of 29 May 2009 on active and intelligent materials and articles intended to come into contact with food)
39. Sakowska A., M. Konarska, D. Guzek, D. Głąbska, A. Wierzbicka. 2014. *Charakterystyka wybranych systemów pakowania mięsa w odniesieniu do preferencji konsumentów i aspektów ekonomicznych*. Zeszyty Naukowe SGGW w Warszawie. Problemy Rolnictwa Światowego 14 (29), 2, 203-213. (In English: *Characteristics of the chosen systems of meat packaging in relation to consumer preferences and economic aspects*. Scientific Publications of Warsaw University of Life sciences (SGGW) in Warsaw, Problems of the World Agriculture)
40. Sohail, M.; Sun, D.-W.; Zhu, Z. 2018. *Recent developments in intelligent packaging for enhancing food quality and safety*. Crit. Rev. Food Sci. Nutr. 1-13.
41. Song, T.; Qian, S.; Lan, T.; Wu, Y.; Liu, J.; Zhang, H. 2022. *Recent Advances in Bio-Based Smart Active Packaging Materials*. Foods, 11, 2228. https://doi.org/10.3390/ foods11152228
42. Świderski F., A. Sadowska. 2011. *Pakowanie mięsa w warunkach zmodyfikowanej atmosfery i próżni*. Postępy Techniki Przetwórstwa Spożywczego 1, 98-102. (In English: *Meat packaging at a modified atmosphere and vacuum*. Achievements of Food Processing Technology.)
43. Timofeeva L., Kleshcheva N. 2011. Appl. Microbiol. Biotechnol. 89, 475.
44. *Trends in antimicrobial food packaging systems: Emitting sachets and absorbent pads*. 2016. Food Research International, 83, 60-73.
45. Tsironi T., E. Gogou, E. Velliou. 2008. *Application and validation of the TTI based chill chain management system SMAS on shelf life optimization of vacuum packed chilled tuna*. International Journal of Food Microbiology 128, 108-115.
46. Vanderroost, M., Ragaert, P., Devlieghere, F. and Meulenaer, B. D. 2014. *Intelligent food packaging: The next generation*. Trends in Food Science & Technology, 39, 47-62.
47. Yam K., P. Takhistow, J. Miltz. 2005. *Intelligent Packaging: Concepts and Applications*, Journal of Food Science 70, 1-10.
48. Zdanowska-Sąsiadek Ż., M. Michalczuk, M. Marcinkowska-Lesiak, K. Damaziak. 2013. *Czynniki kształtujące cechy sensoryczne mięsa drobiowego*. Bromat. Chem. Toksykol. XLVI, 3, 344 – 353. (In English: *Factors, affecting the sensory properties of poultry meat*).
49. Zhen, N.; Wang, X.; Li, X.; Xue, J.; Zhao, Y.; Wu, M.; Zhou, D.; Liu, J.; Guo, J.; Zhang, H. 2022. *Protein-based natural antibacterial materials and their applications in food preservation*. Microb. Biotechnol. 15, 1324-1338.
50. Zmarlicki, S. 2000. *Proces w zakresie pakowania żywności w modyfikowanej atmosferze oraz pakowania aktywnego*. Przemysł Spożywczy 11, 31-35. (In English: *The process of food packaging in a modified atmosphere and of active packaging*. Food Industry, 11, 31-35)
51. Xie, Z.; Yu, S.; He, M.; Yu, S.; Zhao, H.; Xiao, H.; Song, Y. 2020. *Preparation of Antimicrobial Collagen Casings with High Mechanical Properties*. Am. J. Biochem. Biotechnol. 16, 407-416.