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ADDITIVE MANUFACTURING TECHNOLOGY

FOR MODERN PACKAGING

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Dear Readers!

On April 23rd -25th 2024 Ptak Warsaw Expo will host the 9th edition of Warsaw Pack, an international trade fair for packaging and packing technology. The event has been attracting thousands of visitors every year.
According to the organizers, the 8th edition of Warsaw Pack was visited by almost 20 thousand participants from Poland and abroad. This included international entrepreneurs from Germany, France, Spain, Portugal, Italy, Great Britain, the Czech Republic and Slovakia, among others. Establishing business relationships with them for many of the event's participants involved investments in development and expansion into new markets. The ninth edition of the event will be even more focused on building international business relationships.
The thematic scope of Warsaw Pack includes companies involved in packaging and packing technologies, packaging and labelling machinery, packaging materials and films, marking and coding systems, logistics and warehousing services, innovative packaging solutions, process automation in the sector as well as testing and quality control in the industry.
See you in Nadarzyn!

Anna Naruszko, M.Sc. Graduate of the Institute of Printing at Warsaw University of Technology (currently the Department of Printing Technologies, Faculty of Mechanical and Industrial Engineering, Warsaw University of Technology). Editor-in-chief of the monthly trade magazines "Poligrafika" and "Opakowanie", CEO of Alfa-Print Sp. z o.o, publisher of these magazines and of the scientific quarterly "Packaging Review".

Drodzy Czytelnicy!

W dniach 23-25 kwietnia 2024 r. w Ptak Warsaw Expo spotkamy się na 9. edycji Warsaw Pack, międzynarodowych targów techniki pakowania i opakowań. Wydarzenie to od lat cieszy się popularnością wśród tysięcy odwiedzających.
Jak informują organizatorzy, ósmą edycję Warsaw Pack odwiedziło prawie 20 tys. uczestników z Polski i zagranicy. W tym gronie znaleźli się nastawieni na międzynarodową współpracę przedsiębiorcy m.in. z Niemiec, Francji, Hiszpanii, Portugalii, Włoch, Wielkiej Brytanii, Czech czy Słowacji. Nawiązanie z nimi relacji biznesowych dla wielu uczestników wydarzenia wiązało się z inwestycjami w rozwój i ekspansją na nowych rynkach. Dziewiąta edycja wydarzenia będzie jeszcze bardziej nastawiona na budowanie międzynarodowych relacji biznesowych.
W zakresie tematycznym Warsaw Pack znalazły się przedsiębiorstwa zajmujące się technologiami pakowania i opakowań, maszynami do pakowania i etykietowania, materiałami opakowaniowymi i foliami, systemami oznakowania i kodowania, usługami logistycznymi i magazynowymi, innowacyjnymi rozwiązaniami w dziedzinie pakowania, automatyzacją procesów w sektorze czy testowaniem i kontrolą jakości w branży.
Do zobaczenia w Nadarzynie!

Mgr inż. Anna Naruszko. Absolwentka Instytutu Poligrafii Politechniki Warszawskiej (obecnie Zakład Technologii Poligraficznych, Wydział Mechaniczny Technologiczny PW). Redaktor naczelna miesięczników branżowych „Poligrafika" i „Opakowanie", prezes zarządu Alfa-Print Sp. z o. o, wydawcy tych miesięczników oraz kwartalnika „Packaging Review".

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ADDITIVE MANUFACTURING TECHNOLOGY FOR MODERN PACKAGING

TECHNOLOGIA WYTWARZANIA PRZYROSTOWEGO W PRODUKCJI NOWOCZESNYCH OPAKOWAŃ

ABSTRACT: Appropriate packaging is essential to protect products from external contamination, physical damage or food spoilage. The latest innovations in the packaging industry are mainly limited to the development of new polymeric barrier materials and composite or green, environmentally friendly materials. However, recently, new active, and/or intelligent (smart) packaging is being developed that can extend the shelf life of a product, keep it in good condition and help control the quality of food products. This review presents the latest developments and applications of additive manufacturing in the production of smart food packaging.
Key words: intelligent/smart packaging, three-dimensional (3D) printing, additive manufacturing, material extrusion, polyhydroxyalkanoate, polylactide, polyester

STRESZCZENIE: Odpowiednie opakowanie jest niezbędne, aby chronić produkty przed zanieczyszczeniami z zewnątrz, uszkodzeniami fizycznymi lub zepsuciem się żywności. Najnowsze osiągnięcia w branży opakowań ograniczają się głównie do opracowania nowych polimerowych materiałów barierowych oraz kompozytowych lub ekologicznych materiałów przyjaznych dla środowiska. Jednak ostatnio opracowywane są nowe opakowania aktywne i/lub inteligentne (smart), które mogą wydłużyć okres przydatności do spożycia produktu, utrzymać go w dobrym stanie i pomóc kontrolować jakość produktów spożywczych. W niniejszym artykule przedstawiono najnowsze osiągnięcia i zastosowania wytwarzania przyrostowego w produkcji inteligentnych opakowań do żywności.
Słowa kluczowe: inteligentne opakowanie, druk trójwymiarowy (3D), produkcja przyrostowa, wytłaczanie materiału, polihydroksyalkanian, polilaktyd, poliester

1. INTRODUCTION

Appropriate packaging is essential to protect products from external contamination, physical damage, or food spoilage. Therefore, the packaging industry has been experiencing rapid growth. The observed technological progress in the packaging market is primarily due to lifestyle changes, rising consumer spending, and improving exports on a global scale. The requirements for modern packaging are determined by constant changes related to demographics, lifestyle, level of health safety, ecology and production environment, as well as the development of new markets [1]. Recently, innovations in the packaging industry have mainly been limited to the development of new barrier materials, i.e. new polymeric materials, composite materials, or new green and environmentally friendly materials [2]. However, recently, many scientists and manufacturers have met the expectations of consumers and developed new active, and/or intelligent (smart) packaging. This type of packaging can extend the product's shelf life, keep it in good condition, and help control the quality of food products. Intelligent packaging refers to packaging designs that use various sensors to provide information about the state of the contents, and active packaging maintains quality by adding, for example, antibacterial or antioxidant agents. Sensors, chemical or temperature indicators, gas emission indicators, and microbial growth indicators are all components of intelligent packaging solutions. The new antibacterial packaging, designed to improve food safety, is also interesting. This type of packaging extends the growth retardation of microorganisms or reduces the growth rate and final number of microorganisms [3]. There is a wide range of consumer opinions about intelligent and/or active food packaging. Smart package technology is perceived by consumers as a way to guarantee food quality and safety while also delivering real-time consumption information, minimising food loss, and decreasing food waste – a huge problem in the XXI century, taking into account the millions of tons of food that are wasted year [4]. However, consumers are worried about the expenses of this packaging, nevertheless. They have stated that they would accept a 10% increase in the product's overall cost as a reasonable margin [5]. On the one hand, smart packaging is used for food authentication (geographical origin, animal or plant species identification, production method, etc.), which would reassure customers that the products they get are from reliable companies. On the other hand, the food sector, however, is now generally unable to implement smart packaging since the existing technology employed would result in a significantly bigger rise in product costs than the 10% reported by consumers. Manufacturers and scientists are working to create fresh approaches to lower production costs. Currently, it seems that three-dimensional (3D) printing, or rather additive manufacturing, is a leading technology for creating packaging that meets consumer expectations. Although the additive manufacturing has been utilised in several industry sectors for about 20 years, interest in and application of the technology have significantly increased in the last years [6]. Additive manufacturing has ushered in a new era of innovation that has been spurred by its unique potential because of its availability, versatility, performance, and affordability. This has not gone unnoticed in the packaging industry. Additive manufacturing is gaining popularity due to its singular capacity to produce sophisticated designs that can be utilised for mass manufacturing while having a favourable influence on the economy and environment. This method permits changes in the composition and structure of the material through the printed product, modifying the physicochemical characteristics of the packaging adapted to the expected requirements. Innovative package designs have been produced using this technology, which includes die cuts and forms that are personalised smart packaging. Coaxial extrusion printing has been utilised to create smart food packaging systems that can track the quality of packed food and the environment in real-time to fulfil the rising consumer demand for safe food [7]. This review reports on the latest developments and applications of additive manufacturing in the production of smart food packaging to provide the reader with a comprehensive background for understanding the current state of knowledge.

2. ADDITIVE MANUFACTURING

Additive manufacturing has transformed the product creation process in numerous industries. In contrast to traditional processing methods such as subtractive manufacturing, injection moulding, extrusion or casting, additive manufacturing constructs objects layer by layer from a sliced digital model.

Because of this distinctive process approach, additive manufacturing provides a manufacturing possibility with a high level of design flexibility. Conventional manufacturing techniques frequently limit the complexity of geometries, with internal ones often being impossible to manufacture. By using additive manufacturing, designers can produce intricate shapes as well as customised products that were previously unfeasible or economically impractical to manufacture. The complexity of components usually can be increased to a certain level with no influence on the production costs, depending on the chosen additive manufacturing process. This enables designers to incorporate even minor details into products without diminishing their complexity for the sake of lower production costs [8]. The ability to produce a wide variety of components without requiring extensive preparation beyond the computer-aided design (CAD) model, printable material, and the machine itself is the biggest advantage of additive manufacturing. In contrast, conventional manufacturing can be both time-consuming and costly to start production. For instance, in manufacturing, a single component may require special tools or moulds with lead times of several weeks. Additive manufacturing can eliminate such obstacles in many cases, enabling designers to obtain a physical object that corresponds to their CAD model within only a few hours of production time. Such a degree of flexibility allows for real on-demand and on-site manufacturing, which can be advantageous to the entire supply chain.

Due to these advantages, the use of additive manufacturing can be profitable from a purely economic point of view. This is particularly true for low-volume productions when it is not cost-effective to invest in expensive mass production equipment such as moulds or tools. The literature provides several use cases in the industry, for example in the medical, dentistry, aerospace, and automotive industry [9,10]. In the context of packaging, additive manufacturing is experiencing an increase in attention. Its capability of high design flexibility leads to various possibilities, for example, the creation of individualised or intelligent packaging [11]. Despite these advantages, additive manufacturing may not be appropriate for all types of applications due to certain limitations in comparison to traditional manufacturing. These drawbacks should be taken into account when considering its usage. A major drawback is the limited range of available materials, which lag significantly behind those available for traditional manufacturing processes. There are different additive manufacturing processes, which are designed to work with specific materials. Material extrusion (commonly known as fused deposition modelling (FDM) – trademarked by Stratasys Inc or fused filament fabrication (FFF) [12]) for example works with thermoplastic polymers, vat photopolymerisation (stereolithography) with UV-reactive resins that result in thermosets. In order to produce a wide range of materials, several machines using different manufacturing mechanisms are required [13].

Other factors determined by the additive manufacturing process are the mechanical properties as well as the production speed of products. In general, the time to produce a single part is significantly longer than using mass production methods such as injection moulding, which makes them not suitable for manufacturing large volumes of identical parts. Such mass production machines can produce thousands of parts in a very good as well as reproducible quality within a few minutes or even seconds per part. With additive manufacturing however, it usually takes hours to produce a component, while the manufacturing time per part usually cannot be reduced. On top of that, the manufacturing principle of the layer-by-layer build-up leads to significant anisotropic properties regarding the dimensional accuracy, mechanical properties as well as the surface quality [14]. Accordingly, the definition and introduction of standardised quality control, monitoring and assurance methods for additive manufacturing processes is a big challenge [8].

To sum up, additive manufacturing can offer advantages over traditional processing methods. The largest benefits are the design freedom and the possibility to manufacture final products, prototypes as well as tools on demand without any special preparation or expensive tooling. The customisability inherent in additive manufacturing, makes it a cost-effective manufacturing method for a lot of low production volume use cases.

The primary challenge to overcome is the implementation of standardised, reliable, and reproducible component quality, including suitable quality control and assurance techniques. These standards must be developed and adjusted over years of industrial use, regarding existing additive manufacturing processes and materials as well as the upcoming ones in this innovative field of the industry [15].

Material extrusion is one of the methods of additive manufacturing and a fast growing, relatively simple, technology for producing almost any 3D object of any shape, with relatively high resolution and low cost using CAD. Additive technologies are dynamically developing in many industries in prototyping processes, but also in the production of highly complex elements, small-batch production and in the field of innovative solutions to the problems and limitations of traditional technologies, but also increasingly in the case of personalised consumer products such as packaging or everyday items. The process involves creating components by adding building materials, usually layer by layer. The rapid development of additive manufacturing technology has enabled the development of the market for (bio)degradable polymer "inks" in the form of fibres (filament), granules, powders, solutions, and gels for the manufacture of specific products. Thermoplastics are the only group of plastics that can be processed by both extrusion and injection moulding. Above a certain temperature limit, thermoplastics undergo a plasticised state, in which they are capable of large deformations. This enables pressure moulding as well as additive manufacturing. The combination of additive manufacturing technology with (bio)degradable polymers and/or renewable raw materials gives almost unlimited application possibilities [16,17].

As additive manufacturing is increasingly used for personalised consumer goods and processing can affect mechanical and thermal properties, especially in the case of (bio)degradable polymers, the behaviour of printed materials under different environmental conditions is being studied. The extrusion process often causes a decrease in viscosity and a decrease in the average molar mass, which impairs the mechanical properties. Mixing time, temperature and drying also affect the degradation of polylactide (PLA)-based plastics [18]. Therefore, it is important to determine the influence of printing conditions and direction on the properties of the polymer. Research was carried out to find out the relationship between the processing conditions and the direction of additive manufacturing on the geometry of the element (printing orientation: orientation of the product relative to the printer's working platform, arrangement of the filament in accordance with the algorithm used – in the horizontal and vertical direction) and hydrolytic degradation tests to see how the printed objects behave during degradation. The usefulness of cosmetic applications of materials including dumbbell-shaped bars, and packaging prototypes obtained by additive manufacturing was also investigated [17].

Commercially available (bio)degradable filaments, often protected by patents, do not contain precise information about the composition, and therefore their response to unfavourable environmental factors (abiotic and biotic) is unspecified. Therefore, it is important to know the composition of the filament made of (bio)degradable polymers and to predict the properties of printed objects in order to be able to accurately understand the impact of environmental conditions on the properties of finished products and match appropriate raw materials to specific applications. Ex-ante testing of polymeric materials to identify and minimise potential failures of new (bio)degradable polymer products before they emerge is extremely important [19].

Processing (additive manufacturing) causes not only an increase in the crystalline phase of the polymer after printing compared to the initial filament, but also an increase related to contact with the heated printer build platform. After printing, a slight increase in glass transition temperature (T_g) was also observed due to an increase in ordering, which may also increase the stiffness of the material. Not only does the contact time with the 3D printer platform lead to an increase in the crystalline phase during printing, but also smaller surface areas of the dumbbell-shaped bars that accumulate more heat, resulting in an increase in the degree of ordering [11].

Similar relationships were observed in the case of printing prototypes of cosmetics packaging (container) from PLA/PHA (PHA – polyhydroxyalkanoate) and PLA. Its individual parts during material extrusion had a different time of contact with the printer's working platform. The bottom of the container and the lid had a longer contact time (15-18 min) and during this time they were subjected to increased temperature causing the growth of the crystalline phase in contrast to the walls set vertically to the platform (melting enthalpy (ΔH_m) and cold crystallisation enthalpy (ΔH_{cc}) were lower for the walls of the container). Therefore, the processing conditions, in particular the printing orientation of the individual parts of the container, influenced its properties, which may then affect the lifetime and degradation process of the entire container [20].

The use of (bio)degradable polymers, especially in medical applications, requires a proper understanding of their properties and behaviour in different environments. Components made of such polymers can be exposed to changing environmental conditions, which can cause defects. During standard tests of hydrolytic degradation, dumbbell-shaped bars made of PLA and PLA/PHA obtained by material extrusion technology showed an unexpected phenomenon of shrinkage, which was about 50% of the length of dumbbell-shaped bars, regardless of the printing direction. Typically, polymers such as PLA break down already in the initial stage of hydrolytic degradation (at 70°C after 7 days). However, in this case, no significant degradation occurred after 70 days of hydrolytic degradation at 70°C. The phenomenon of shrinkage during degradation resulted in the entrapment of amorphous oligomers and hydroxy acids in the polymer matrix. Low-molar-mass degradation products, due to lower water penetration into the matrix, remained in it, increasing the molar mass dispersion, while causing less disintegration of the dumbbell-shaped bars. The additional stress caused by cutting the dumbbell-shaped bars in half disturbed the degree of ordering of the polymer structure and led to a further increase in the molar mass distribution, which suggests that the cutting of both PLA and PLA/PHA dumbbell-shaped bars (both directions of printing) obtained by material extrusion technology in the vertical direction led to shrinkage compared to uncut, which further limited water penetration [21].

Determining the safe service life of products made of (bio)degradable polymers, and optimising and understanding the physico-chemical changes in their structure is crucial for their numerous applications. The continual development of new materials that are stronger, lighter or more versatile than previous ones must not only lead to improved safety, but also reduce environmental concerns as the complexity of recovering the value inherent in a used product increases. Today's product design challenges lead to the development of polymeric materials that are stable in use, yet susceptible to microbial attack during organic recycling. For each application of polymeric materials, understanding which polymeric materials are optimal for their target applications allows accurate prediction of behaviour and quality assessment throughout their lifecycle, under real-world conditions. Potential failures can be avoided if all factors are taken into account at an early stage of new product development, also obtained by material extrusion.

2.1 FILAMENTS FOR PACKAGING

There are a range of additive manufacturing techniques, such as material jetting and vat photopolymerisation but extrusion based additive manufacturing technology seem to be more appropriate for food packaging applications as this can be made from a variety of thermoplastic biocompatible materials. Some of the bio-based or (bio)degradable polymers that are used in additive manufacturing include, PLA, PHA, polycaprolactone (PCL), poly(butylene adipate-*co*-butylene terephthalate) (PBAT), poly(butylene succinate-*co*-butylene adipate) (PBSA) and poly(butylene succinate) (PBS) [22]. Natural polymers such as cellulose and chitosan are also suitable for additive manufacturing packaging applications. However, since these are not thermoplastic polymers and the heating of a filament is used in the extrusion-based additive manufacturing process, processing temperatures must be controlled to avoid degradation. In most cases these are mixed with other (bio)degradable polymers. PLA is among the most popular filament materials commonly used for material extrusion printers. The popularity of PLA is due to its bio-based origin, biocompatibility, and (bio)degradability as it is derived from renewable resources, such as corn starch or sugarcane, and therefore offers not only good degradability and biocompatibility, but also it has excellent printability and good dimensional accuracy and less prone to retraction [23]. Moreover, polymers like PLA can also be used to additive manufacture objects that will be in contact with food as it is approved by the US Food and Drug Administration (FDA) for food and pharmaceutical applications. PLA-based filaments have been used in additive manufacturing of intelligent food packaging applications [24]. PHA is a class of biodegradable and compostable polymers produced by bacteria during fermentation processes using renewable raw materials and is also used in additive manufacturing applications. In general, PHA can offer the possibility to modify their properties such as varying in toughness and flexibility depending on the specific combinations of different monomer units included in the polymer chain and therefore creating PHA based polymers with properties similar to other thermoplastics. PHA filaments can be degraded in both industrial composting and soil environments. A common approach to modify and improve the inadequate properties of (bio)degradable polymers is to produce polymer blends. For instance, PLA is blended with PHA to produce a filament with improved mechanical properties and tailored biodegradability. Various filaments made from a combination of PLA and PHA are available on the market as a fully compostable alternative that can be home-composted [25]. PBAT is another biodegradable polymer that has been used for the production of filaments for additive manufacturing applications. PBAT is derived from fossil fuels but can undergo degradation in a composting environment. Films based on PBAT and silver containing nanoparticles were fabricated by additive manufacturing for antimicrobial food packaging applications [26]. Natural polymer such as chitosan has been reported for 3D-printed intelligent food packaging systems [27]. These additive manufactured chitosan-based films exhibit colour changes and were produced for both antibacterial and antioxidant properties, as a way of controlling the quality, freshness and preservation of cold meat. In another example, Zhou et al. reported an intelligent food packaging system based on cellulose nanofibers that was fabricated by coaxial additive manufacturing [28]. The system provides dual functions of both maintaining fruit freshness as well as visual monitoring.

Although the additive manufacturing process generates less plastic pollution compared to the conventional manufacturing processes, it nevertheless still is associated with a lot of plastic waste, both in the initial extrusion process to produce filaments, during printing, or failed prototypes, support materials and because most printed parts are single-use models that are discarded. Moreover, the availability of cheap consumer additive manufacturing has increased in the last 20 years, following the expiration of previous patents for additive manufacturing machines such as material extrusion technique. This leads to demands for the use of more environmentally friendly filaments that fit into the sustainability initiative's mantra of replacing petroleum-based raw materials with bio-based compostable filaments. There are efforts to tackle this issue by producing filaments from recycled plastics, especially from non-biodegradable polymers, to reduce the consumption of virgin plastics and promote a circular economy [29]. In addition, this initiative contributes to reducing the waste and energy consumption associated with the production of new polymers. In this process, the polymer material is collected, shredded, remixed, and then homogenised back into reusable recycled filament. PLA is one of the polymers that are recycled [30]. Recycled PLA from food packaging and bottles is converted into filaments and is commercially available.

3. ACTIVE AND INTELLIGENT PACKAGING

Modern food packaging can be divided into (i) active packaging or (ii) intelligent packaging [31]. The term active packaging refers to packaging in which certain additives called “active compounds” are introduced directly into the packaging material, in a leaflet or on a label, or placed directly in the packaging to interact directly with the product and/or its environment to extend its shelf life. “Active compounds” contain active functional groups that, interact with food, slowing down its spoilage. Active packaging containing substances is most often used [32]: antioxidants, (i.e., plant or oil extracts, flavonoids or even green tea extracts); antimicrobials (i.e., nisin, chitosan, and propolis glycolic); carbon dioxide (CO_2) emitters (sodium bicarbonate, citric acid, and ferrous carbonate); oxygen (O_2) scavengers (the most commonly used group of O_2 absorbers are solutions based on the oxidation of iron or palladium, which are deposited in a sachet placed in the package) and ethylene scavengers (i.e. activated carbon, titanium dioxide, and potassium permanganate). Intelligent packaging, on the other hand, is defined as a solution based on the interaction between the packaging and the product (or its environment) to inform the consumer about the freshness of the product. Unlike active packaging, these intelligent packages are designed to detect and record information related to food quality [31]. It is extremely useful to increase the efficiency of information transfer throughout the product distribution chain and even in the consumers’ homes by using intelligent temperature or pH sensors or radiofrequency identification (RFID) tags. The main purpose of freshness indicators is to signal when the quality of the packaged product is no longer acceptable. Changes in their appearance are usually consistent with chemical or microbiological changes to which the product is subjected.

Packaged products may release into the atmosphere e.g. CO_2, amines, or ethylene. They can also release microbial metabolites. The released substances react with the indicator and change its colour, which proves the freshness of the product. Freshness sensors based on colorimetric indicators, capable of changing colour by reacting with volatile compounds produced on packaged food, have become the simplest, most practical, and instrument-free solution that can detect the level of freshness of the packed product with the naked eye [33]. Similarly, the mechanism works for temperature indicators. Because temperature is one of the critical factors affecting the quality and safety of food products from the moment of production to final consumption. Temperature and time are important factors in the rate of microbial activity in food, often deviating from specifications during production, distribution, and storage. Time and temperature indicators can be used to assess the effectiveness of pasteurisation and sterilisation. As critical temperature ranges are established to control food quality, it is important to monitor the length of time food is held at or above the critical temperature. The temperature indicators integrated with intelligent packages monitor the temperature in or around food packages, as well as the time the food has been exposed to undesirable temperatures. These indicators display an irreversible visual signal. The indicators are in the form of labels or small devices made of interconnected foil layers that can be included in the package. Thanks to this, they can show the effect of time and temperature on the product, which allows for correlating potential changes in food quality with them. The scientific literature describes many examples of indicators sensitive to pH or temperature changes, prepared by immobilisation of natural food dyes obtained from various sources, such as: anthocyanins, curcumin, alizarin, shikonin, and betalains on polymeric materials. However, their applications on different food types, including meat, seafood, and dairy products are usually specific, e.g. anthocyanins are most often used to determine the freshness of pork or chicken, and alizarin is more often used to determine the freshness of fish [34]. Recently, in an innovative approach to food quality control, a tactile label that becomes rough when food is no longer fresh is an example of a non-colorimetric indicator of food freshness [5]. The discussion on modern packaging must include RFID, which is currently the most important technology. RFID is a technology that uses electromagnetic fields to automatically identify and track product data. An RFID tag is a small device that can be attached to an object so that the object can be identified and tracked [35]. The tag is composed of a microchip, an antenna, and a substrate or encapsulation material. The microchip stores data whereas the antenna transmits and receives the data. The microchip and antenna attached to the substrate are referred to as the inlay. The RFID device transmits digital data, often an inventory number used to identify the item, back to the reader when it receives an electromagnetic interrogation pulse. The chip modulates the waves that the device sends back to the reader which converts the new waves into digital data. The inventory of products or supply chain may be tracked using this number.

4. ADDITIVE MANUFACTURING IN MODERN PACKAGING

To monitor the internal atmosphere within a food package and assist in food quality control, a sensor with composite polymer filaments containing the O_2-sensitive luminophore platinum (II) tetrakis(pentafluorophenyl)porphyrin was recently developed [36]. The luminophore gradually changed from a bright red colour to a pale pink colour with increasing O_2 concentration. Silicon dioxide (SiO_2) nanoparticles were coated with the luminophore and subsequently mixed with either polyethylene (low-density polyethylene, LDPE) or PLA to create the composite filament that was used in the additive manufacturing process. A material extrusion 3D printer was then used to print a 3D array of O_2-sensitive luminophore/SiO_2/LDPE or luminophore/SiO_2/PLA dots on a poly(ethylene terephthalate) (PET). As these indicators monitor O_2 concentration in the internal packaging atmosphere, they can be incorporated into all types of food packaging to indicate a breach in package integrity. To monitor the package integrity of bottled liquid food products, a 3D-printed temperature-sensitive conductive filament was incorporated into a PET bottle cap that was used to measure the open and closed states of a sealed bottle as well as the temperature. The cap was created out of an exterior cap that made it possible to attach it to a bottle and a spring that kept the contacts and the filament-based sensor apart. An electrical circuit is made by connecting the top and bottom contacts to the top and bottom of the cap and the spring, respectively. The method was developed by utilising an additive manufacturing process. To create a conductive filament, powdered conductive graphite was combined with a PLA matrix. The rise in filament resistance with rising ambient temperature served as the foundation for the sensing mechanism. By closing the gap between the top and bottom contacts, the circuit was completed, and this relationship was used to determine whether the cap was in the open or closed. When the cap is closed, it registers a resistivity of between 20-40 °C, but when it is open, it only registers a resistance of at all temperatures. This cap is designed to analyse the open or closed condition of the cap to monitor the package integrity of temperature-sensitive liquid products, such as carton-packaged or bottled milk or drinks. Smartphones can connect to it to check the data that is stored there [24]. Another example of a proposed smart component created by additive manufacturing is an RFID sensor comprised of an antenna atop a liquid crystal elastomer, prepared from 1,4-bis-[4-(6-acryloyloxhexyloxy)benzoyloxy]-2-methylbenzene, *n*-butylamine and photoinitiator (I-369) temperature-sensitive array and a T-match impedance. This RFID device measures food quality by monitoring ambient temperature. A 3D printer was used to posit the temperature-sensitive liquid crystal elastomer into a substrate to create a flat element array above the sensor's ground plane. The elastomer array reversibly actuated the RFID in response to the changes in ambient temperature. As the ambient temperature rises, the flat liquid crystal elastomer elements become dome-shaped, resulting in an increase in the space between the RFID antenna and the ground plane. When the temperature is decreased, the array returns to its original flat configuration, resulting in a decrease in the distance between the RFID antenna and the ground plane. Any temperature above critical causes the RFID change in operating frequency, which is communicated to nearby reader devices. This simple RFID device can be attached to packaged foods that pass through the cold supply chain, i.e., frozen products, dairy products, or eggs [37]. Additive manufacturing offers extraordinary opportunities in the design of complex devices. Recently scientists used additive manufacturing technology to print a colorimetric sensor for detecting *Escherichia coli* O157:H7 [38]. The developed biosensor was based on gold nanoparticles, which were able to determine the concentration of *E. coli* bacteria using the colour change of the nanoparticles. A 3D printer was used to create a mould for manufacturing a microfluidic device consisting of two mixing channels, a separation chamber and a detection chamber. The biosensor was made by mixing nanoparticles, catalase and antibodies capable of detecting bacteria in the mixing channel of a microfluidic device to form an AuNP-bacteria-PS complex (AuNP – gold nanoparticle, PS – polystyrene). A cross-linking agent (mixture of hydrogen peroxide (H_2O_2), tyramine and horseradish peroxidase) was added to the obtained complex, which changed the colour of the complex from red to blue. Then, the mixture obtained in this way was introduced into the detection chamber (package), where, with the increase in the concentration of *E. coli* bacteria, the colour of the gold nanoparticle complex changed from blue to red. Depending on the intensity of the colour, the concentration of the target bacteria is determined. Additive manufacturing has also been used to construct a biosensor for detecting the bacterium causing gastroenteritis – *Salmonella typhimurium* [39]. The 3D-printed biosensor consisted of a filter that prevented the device from being blocked by large particles and allowed the unhindered passage of bacteria to the second part – a linear microchannel for observing and counting fluorescent spots. The biosensor used a fluoroimmunoassay, a type of enzyme immunoassay that uses fluorogenic markers. *S. typhimurium* antibodies and iron-based magnetic nanoparticles were used to separate the target bacteria by forming magnetic nanoparticle (MNP)-bacteria complexes. These complexes then reacted with fluorescent microspheres to form fluorescent MNP-bacteria complexes that were injected into the microchannel of the printed devices. This biosensor worked with a smartphone to detect the target bacterium online. The light from the smartphone served as the excitation source, while a video processing application monitored the fluorescence intensity moving along the microchannel and calculated the local concentrations of *S. typhimurium* in real time. Vat photopolymerisation (stereolithography) was also used to create a temperature-sensitive CO_2 sensor by in situ optical printing of photocrosslinkable poly(1-allyl-3-vinyl imidazolium bromide) with a high number of imidazolium functional groups. The stereolithography technique was chosen because of the extreme precision of printing, thanks to which it was possible to print the ultra-miniature sensors of Fabry-Pérot polymer interferometers. This miniaturised sensor can remotely and simultaneously measure CO_2 concentrations and temperatures in very small spaces, making it promising for many applications, from off-gas detection to food quality control [40].

5. CONCLUSIONS AND FUTURE OUTLOOK

Additive manufacturing is playing an increasingly important role in creating smart packaging that is equipped with advanced features and interactive elements. This technology allows sensors, electronics, and other components to be integrated into the printing process itself, opening up new opportunities for manufacturers and consumers. Additive manufacturing allows the creation of smart packaging with built-in sensors that can monitor various parameters. For example, packages can be equipped with temperature, humidity, or force sensors. This data can be used to track the storage conditions of products to ensure their quality and safety. In the future additive manufacturing, could make it possible to fabricate packaging with interactive elements such as print buttons, touch screens, or other user interfaces without having to assemble additional parts. This allows for the creation of integrated packages, such as RFID, which enables communication with mobile devices or other systems. Smart packaging produced using additive manufacturing can also have the ability to track and monitor products in real time. Thanks to built-in identification technologies such as QR codes, barcodes, or RFID tags, manufacturers can track the origin, history, and authenticity of products. This can contribute to combating counterfeiting and ensuring transparency and trust for consumers. In addition, additive manufacturing enables the personalisation of smart packaging, which can be important in marketing and customer interaction. The manufacturer can create unique patterns, logos, or labels that will distinguish the product on the store shelf and attract the attention of customers. This individualisation of packaging can be especially important for brands that focus on uniqueness and differentiation in the market. So far, there are few reports on the use of additive manufacturing to create intelligent packaging, but it seems that in the next few years, technology may be leading in the market. Additive manufacturing technology is more energy efficient and minimises the amount of waste because only the material necessary to create the object is used. In addition, additive manufacturing enables the creation of packages from recycled materials or biodegradable plastics, which contributes to reducing the negative impact on the environment. All in all, additive manufacturing creates new opportunities for smart packaging. It allows the integration of sensors, electronics, and interactive elements in the printing process itself, which enables the creation of monitoring, interactive and personalised packaging. Smart packaging based on additive manufacturing can contribute to improving product quality and ensuring the safety, traceability, and authenticity of products.

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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

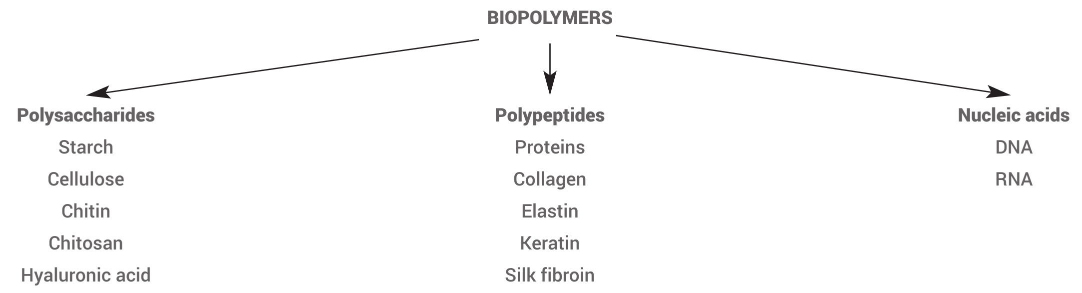

FIG.1. THE SELECTED EXAMPLES OF BIOPOLYMERS (SIONKOWSKA, A., & LEWANDOWSKA, K. (2016). BIOPOLYMERS, PROJECT "STRENGTHENING OF DIDACTIC POTENTIAL OF THE NICOLAS COPERNICUS UNIVERSITY (UMK) IN TORUŃ IN MATHEMATICS AND LIFE SCIENCES", IMPLEMENTED UNDER THE SUBACTION 4.1. OF THE OPERATING PROGRAMME: HUMAN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

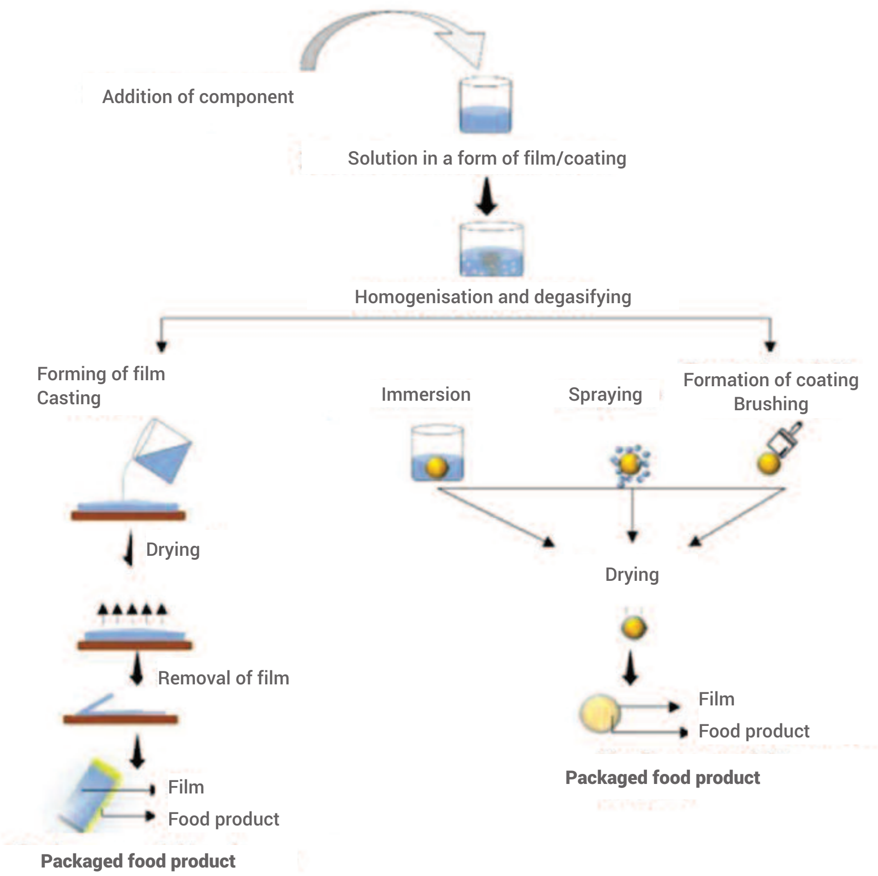

FIG.2. SCHEME OF MANUFACTURE OF EDIBLE FILMS (NAIR, S.S., TRAFIAŁEK, J., & KOLANOWSKI, W. (2023). EDIBLE PACKAGING: A TECHNOLOGICAL UPDATE FOR THE SUSTAINABLE FUTURE OF THE FOOD INDUSTRY. APPLIED SCIENCES, 13 (14), 8234)

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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ENVIRONMENTAL PROTECTION IN CONTEMPORARY MARKETING – THEORETICAL BACKGROUND AND MARKET PRACTICE ON THE EXAMPLE OF PACKAGING

OCHRONA ŚRODOWISKA WE WSPÓŁCZESNYM MARKETINGU – PODSTAWY TEORETYCZNE A PRAKTYKA RYNKOWA NA PRZYKŁADZIE OPAKOWANIA

ABSTRACT: This paper presents theoretical and practical aspects of packaging compliant with the environmental protection principles in marketing communication. There were indicated models valid from the perspective of technical knowledge, such as recyclability, biobased materials, biodegradability, compostability and upcycling. Focus was placed on the attitudes, level of knowledge and awareness of the buyer, which translate into the effectiveness of various ways of communicating about a product or brand.
Key words: environmental protection, effectiveness of marketing communication, buyers' attitude, purchasing decisions

STRESZCZENIE: Analiza prezentuje teoretyczne i praktyczne aspekty stosowania opakowania zgodnego z zasadami ochrony środowiska w komunikacji marketingowej przedsiębiorstwa. Wskazano uprawnione z perspektywy wiedzy technicznej modele takie jak przydatność do recyklingu, biopochodność, biodegradowalność, kompostowalność czy upcycling. Szczególnie skupiono się na postawach, poziomie wiedzy i świadomości nabywcy przekładających się na efektywność rozmaitych sposobów komunikacji dotyczącej produktu czy marki.
Słowa kluczowe: ochrona środowiska, efektywność komunikacji marketingowej, postawy nabywców, decyzje zakupowe

4. DISCUSSION

The 2022 study was preceded by earlier analyzes conducted in the Department of Market, Marketing and Quality (Katedra Rynku, Marketingu i Jakości) in previous years by the same research team, also related to the environmentally compliant packaging as an element of marketing communication. Therefore, it was decided to supplement this study to some extent with the previous results relevant to the discussed topic, which was marked in the text.

In the case of the analysis of the significance level for the buyer of individual packaging features when making a purchase decision, the most desirable solution is undoubtedly recyclability. Over one third of respondents considered this feature to be the most desirable and positively influencing the purchasing decision. The area of average values includes extending the life cycle by ensuring multiple use of the packaging and its biodegradability. On the other hand, the possibility of upcycling is almost irrelevant for the buyer, which results directly from

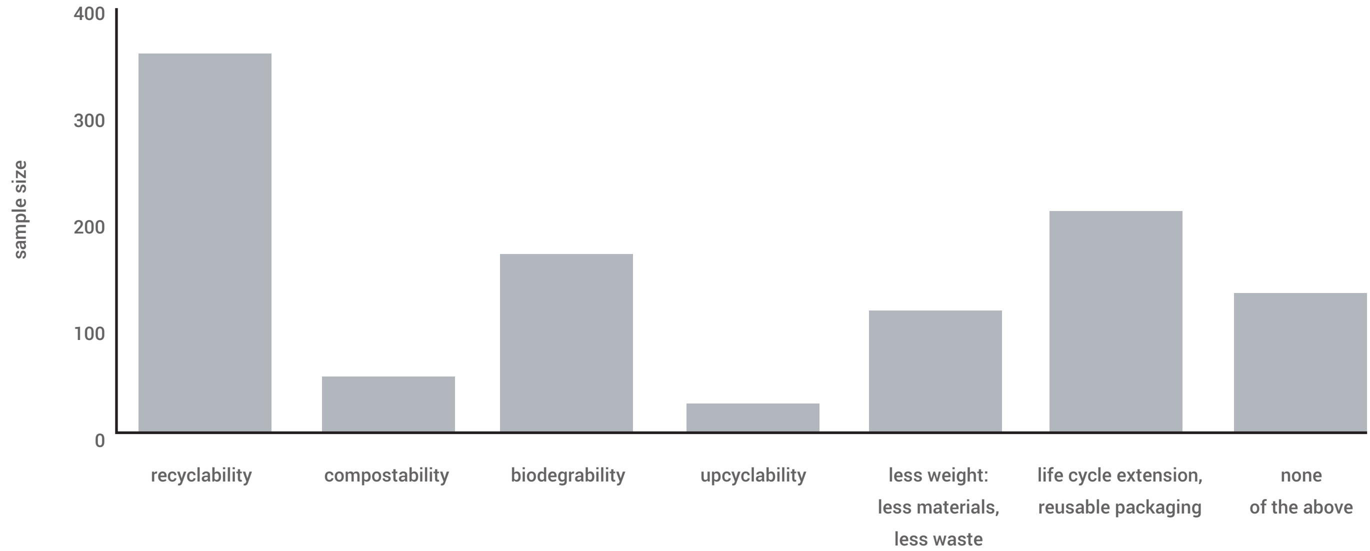

CHART 1. THE LEVEL OF SIGNIFICANCE FOR THE BUYER OF INDIVIDUAL PACKAGING FEATURES WHEN MAKING A PURCHASING DECISION.

SOURCE: MILLER ET AL. 2020

the relatively low level of knowledge of this concept observed in the research (Chart 1.).

Compliance of packaging with the principles of environmental protection as an important element when making a purchasing decision is declared by 55% of respondents (Chart 2.), which is a surprisingly good result for a representative sample. It means that more than half of Polish consumers are not only interested in environmental issues, but also take them into account when making purchasing decisions.

The results divided into individual cohorts are relatively even, which means the general interest and positive attitude towards packaging with environmental values appears regardless of demographic characteristics, and thus also the practical basket of purchased products. What's more, discrepancies are noticeable in the division into individual age groups and place of residence, these results were higher than those recorded for the entire study population. A particularly high percentage of respondents declaring a high importance of environmental protection issues can be observed in the age group of 55 (62%) and more and among inhabitants of medium-sized cities (65%). Half of the respondents notice the information provided by the producers on the environmental value of packaging: the results range from 52% to 49% and are relatively similar in the case of individual groups of respondents (Chart 3). Again, the result for the representative group is better than expected by the authors of the study and confirms the generally good situation of the Polish market.

The answers to the question whether the respondent has seen product advertisements on the Internet, in the press, on television or in any other place in recent months, mentioning the environmental friendliness of product packaging, are 33% for yes and 67% for no (Chart 4.), so despite the increasing more messages of this type (campaigns Żywiec – Po stronie natury, Nałęczowianka – Uwierz w recykling, Rossmann – Czujesz klimat?), they are noticeable only to one third of the

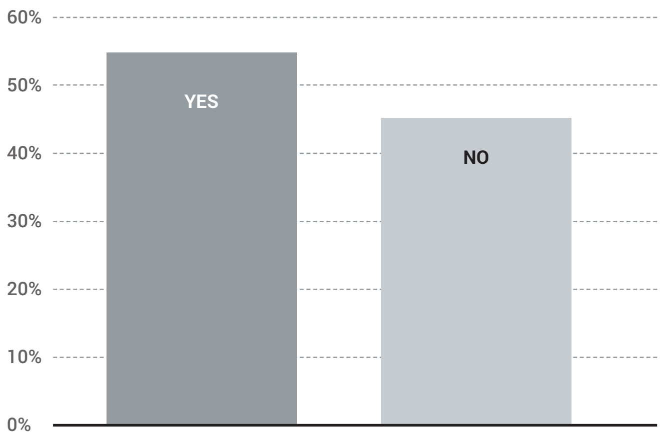

CHART 2. IS THE ENVIRONMENTAL PERFORMANCE OF THE PACKAGING IMPORTANT TO YOU WHEN CHOOSING THE PRODUCT YOU BUY? – TOTAL RESULTS

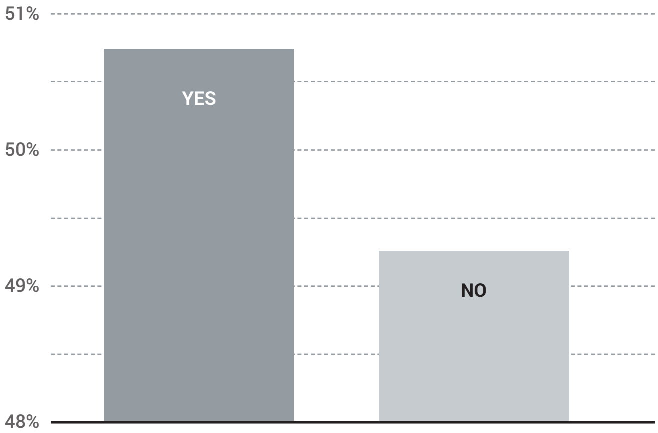

CHART 3. DO YOU THINK THAT THE PACKAGING PRESENT IN POLISH STORES CONTAINS INFORMATION ABOUT THEIR ENVIRONMENTAL FRIENDLINESS? – TOTAL RESULTS

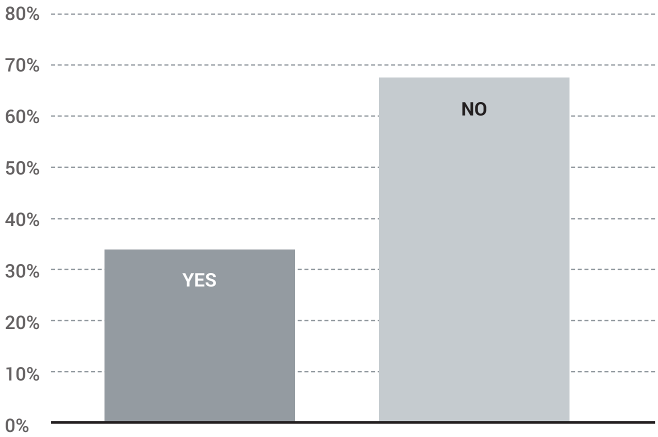

CHART 4. IN THE RECENT MONTHS, HAVE YOU SEEN ON THE INTERNET, IN THE PRESS, ON TELEVISION OR IN ANY OTHER PLACE PRODUCT ADVERTISEMENTS THAT MENTION THE ENVIRONMENTAL FRIENDLINESS OF THE PACKAGING OF THESE PRODUCTS? – TOTAL RESULTS

respondents. In addition, the results for the group of 55 and older are slightly lower in this case, which may lead to the conclusion that the products that these buyers are interested in are promoted to a lesser extent through environmental values or communication is focused on younger groups and, in the first place, it builds brand awareness for them. This is not a desirable phenomenon in the context of the particularly high level of interest of this group in environmental protection issues – it can be called a wasted opportunity.

The next question was filtered: it was asked only to respondents who gave a positive answer to the previous one. It concerned the elements of the above-mentioned advertisements, which they particularly paid attention to or remembered – chart 5. Undoubtedly, the colors used turned out to be the strongest stimulus here, which attracted the attention of 49% of respondents. Differences in this matter between the sexes were also quite clear: color was noticed by 54% of women and 43% of men, which may indicate the need to differentiate stimuli in

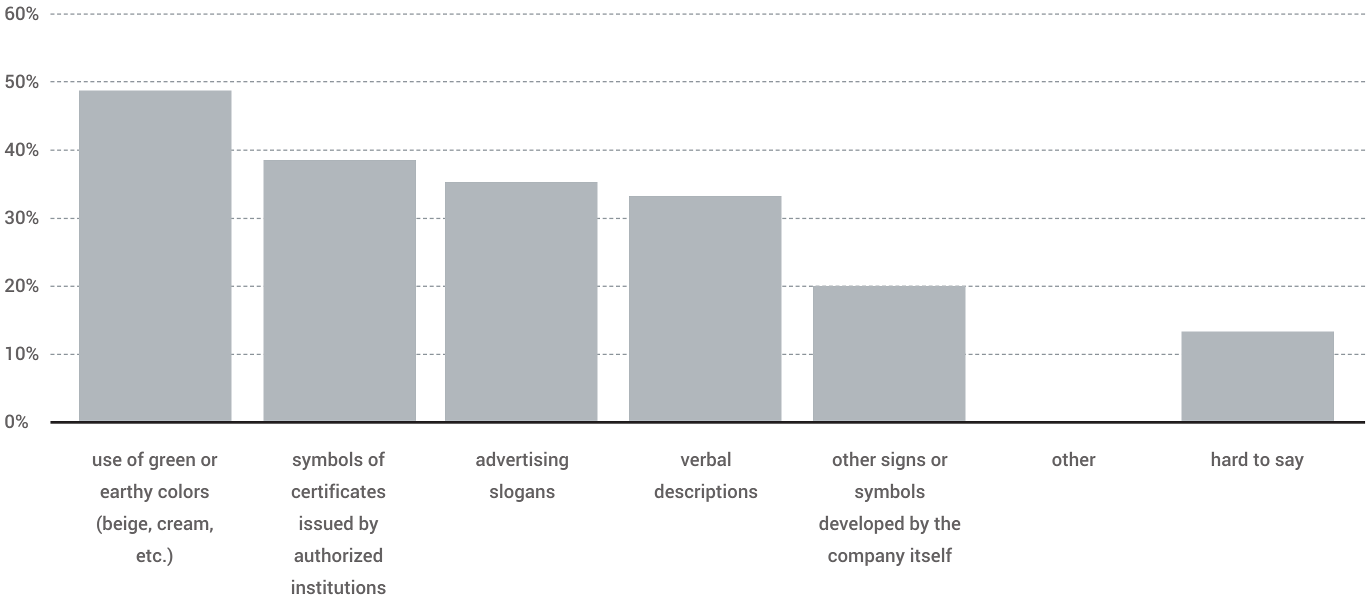

CHART 5. WHICH INFORMATION IN THESE ADS CAUGHT YOUR EYE FIRST, I.E., YOU PAID THE MOST ATTENTION OR REMEMBERED IT – TOTAL RESULTS

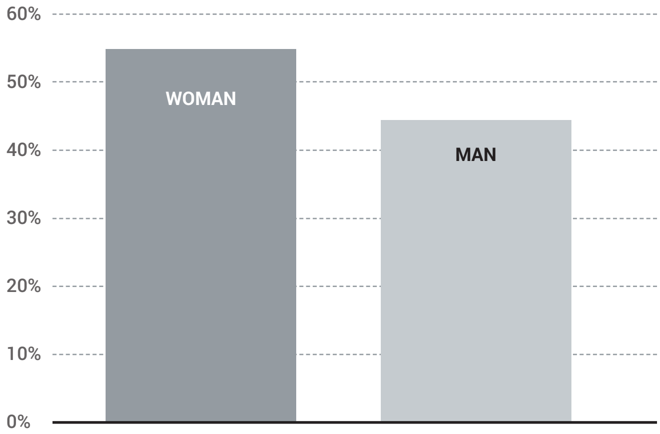

CHART 6. WHICH INFORMATION IN THESE ADS CAUGHT YOUR EYE FIRST, I.E., YOU PAID THE MOST ATTENTION OR REMEMBERED IT? – RESULTS DIVIDED INTO WOMEN AND MEN

the case of products intended specifically for each gender – chart 6.

The second group of questions included in the study concerned the credibility of the elements of environmental marketing communication used by enterprises from the consumer's perspective. The initial question about the general credibility of the information about the environmental value of the packaging placed on the products gave interesting results. In all cohorts, a negative answer prevailed, however, mainly motivated not by the lack of knowledge, but by the lack of trust in the producer and the uncertainty as to the ethical behavior of the producer – Chart 7.

The respondents considered the markings of certificates issued by authorized institutions to be the most reliable element (Chart 8). An interesting observation here concerns a relatively small percentage of respondents who consider the color of the packaging to be the most reliable, compared to the answers to other questions of this study, clearly confirming that although in theory buyers do not consider the color to be the most reliable, in practice they often focus on their assessment of the environmental value of the packaging.

On the other hand, subsequent questions indicate that they often misinterpret the most important element for them, i.e., the certification symbols. Both observations may lead to the conclusion that there is a discrepancy between declarations and actual reactions, and the practical effectiveness of the most reliable forms is relatively low. This, in turn, requires corrective actions by the responsible institutions and organizations, especially regarding the answer to one of the following questions indicating a lack of trust in the company itself as the author of the communication.

In the next step, the comparison model examined the level of respondents' confidence in individual visual elements indicating

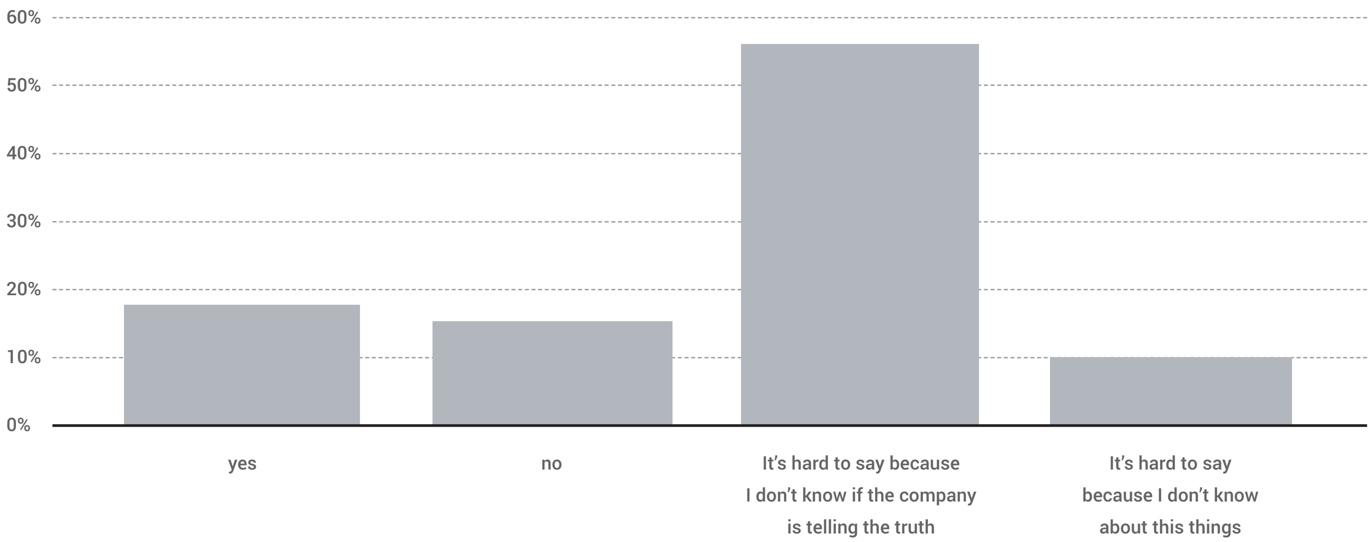

CHART 7. IS THE INFORMATION ON THE ENVIRONMENTAL PERFORMANCE OF THE PACKAGING GENERALLY RELIABLE FOR YOU? – TOTAL RESULTS

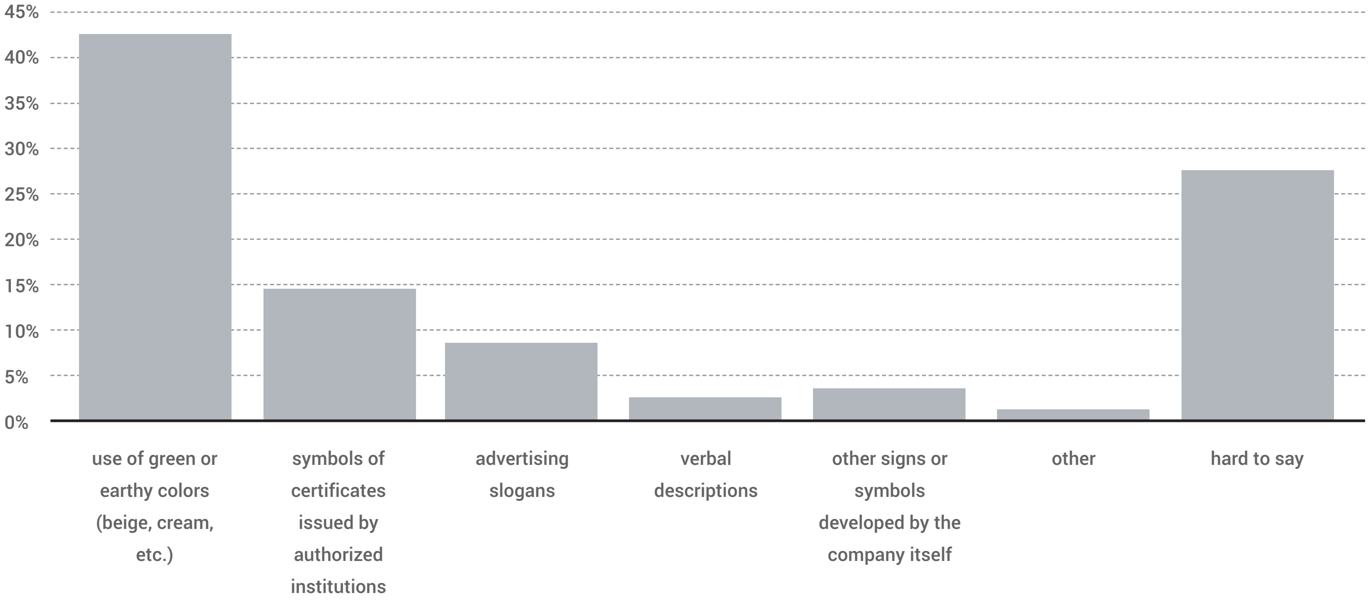

CHART 8. WHAT IS THE MOST RELIABLE INFORMATION ABOUT THE ENVIRONMENTAL PERFORMANCE OF PACKAGING FOR YOU? – TOTAL RESULTS

the compliance with environmental criteria, arranged in pairs of objects with slightly different specificity. The goal here was not only to observe general regularities, but also to indicate a more effective model from the buyer's perspective.

In the case of a verbal description, a short version is more credible than extensive, precise information. 15% of the respondents were in favor of the first option, while as many as 42% were in favor of the second (34% described them as equally credible, and 9% of respondents considered them unreliable) – Chart 9. The distribution of these values is slightly different by age: in in the group of respondents aged 55 and more, only 10% consider extensive information to be credible. The result allows to conclude that a condensed description is more credible, and therefore more effective in influencing the buyer, and not the extended, more precise version, but probably less understandable due to the accumulation of technical terms, especially for an older recipient. Therefore, the initial assumption that a factual, yet demanding, in-depth description is of significant value for the buyer was not confirmed.

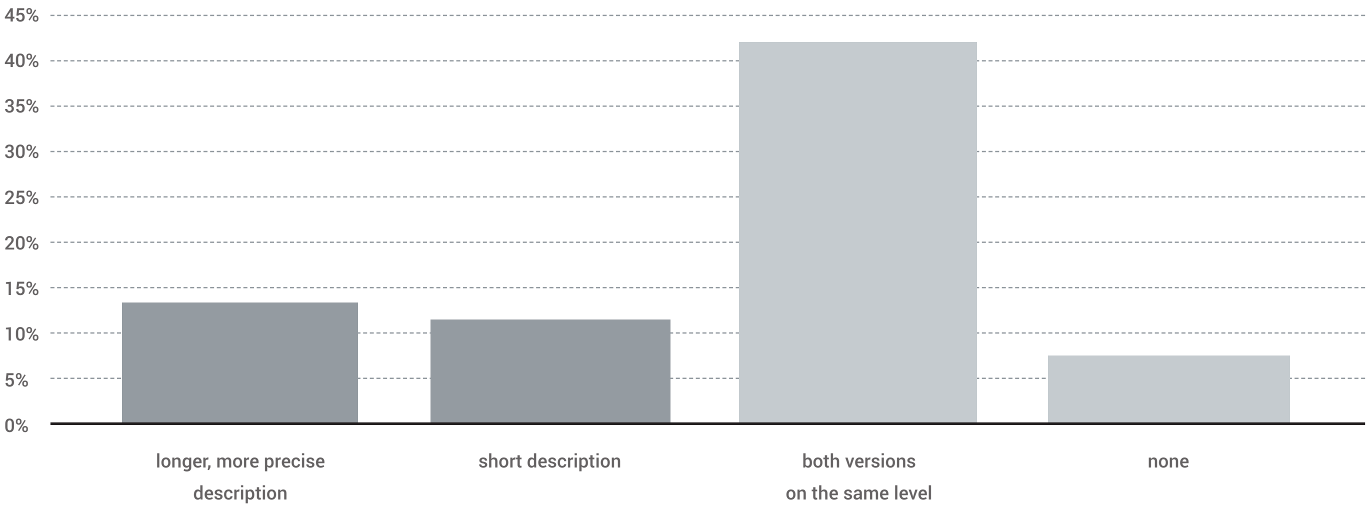

CHART 9. WHICH OF THE FOLLOWING ILLUSTRATIONS, IN YOUR OPINION, PRESENTS MORE RELIABLE INFORMATION ABOUT THE ENVIRONMENTAL PERFORMANCE OF THE PACKAGING? – TOTAL RESULTS

Regarding promotional slogans, it can be noticed the precise version is slightly more credible: it was indicated by 33% of the respondents, while the result for the more metaphorical version is 28% – chart 10. (27% of respondents indicated similar credibility, and the lack of credibility of both 12%), with the results for younger groups and people with higher education differing from the average for the entire group. In the 18-24 age group, a more precise password is credible for 41% (less precise for 22%, both for 14%, and neither for 23%), and in the 25-34 age group as much as 49% (less precise 24%, both 15, and none 13). Also, among people with higher education, a more precise password is credible for 41% (less precise for 25%, both for 24%, and neither for 10%). The values for the more precise solution are also higher in the case of inhabitants of a big city 40% (less precise 22%, both at a similar level 26%, neither 12%).

Thus, the feeling of credibility here is quite clearly correlated with age, place of residence and level of education: for younger buyers, residents of big cities and university graduates, greater precision is more important, which is worth considering in marketing communication addressed especially to these groups – in practice, for example, for products for young people.
The analysis of the color issue and the emotional (eliminating the effort associated with rational analysis in the circumstances of limited time and data verification) reasons for the reaction to it clearly confirmed the initial assumption that buyers pay special attention to this element – even if initially theoretically they did not consider it the most important. In this case, two objects appeared in the list, in the case of which the only differentiating element is the color: green and purple. The English-language text, however, is identical, appearing first as a metaphorical slogan and then as a more extensive description (Picture 1.). The green version was considered the more credible version of the marketing message by 43% of respondents, while 3% were in favor of the purple one (the results for the options: both like credibility and both unbelievable are 27% each) – chart 11. No significant differences were observed in this case, broken down by gender, place of residence or level of education, such a result should therefore be considered universal for the entire population, regardless of additional individual conditions.
Regarding certification marks and other occasional markings, the results of a more detailed analysis exclude the initial declaration of most respondents that they pay more attention to the first group. In practice, it turns out that in this pair of objects, the producers' own signs are more credible for a much larger percentage of respondents: 32% versus 15% (Chart 12.). This trend is particularly visible among younger respondents from the 25-34 age group: 42% versus 14%. This proves a clear discrepancy between the need or theoretical declaration of

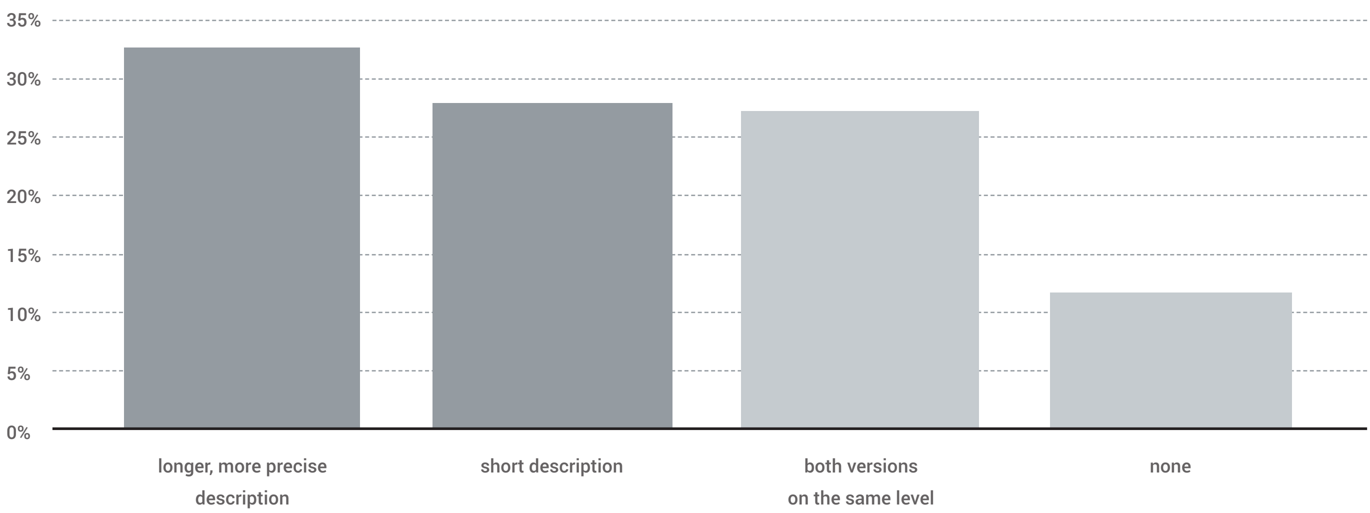

CHART 10. WHICH OF THE FOLLOWING ILLUSTRATIONS, IN YOUR OPINION, PRESENTS MORE RELIABLE INFORMATION ABOUT THE ENVIRONMENTAL PERFORMANCE OF THE PACKAGING? – TOTAL RESULTS

PICTURE 1. DIFFERENT COLOR VERSIONS OF THE SAME PACKAGING – COLOR AS THE KEY INFORMATION FOR THE BUYER

SOURCE: PRODUCER'S PRESS SERVICE

acting in accordance with the principles of environmental protection and the practical knowledge of such solutions.

CONCLUSIONS

The conducted analyzes confirmed that the most common models of packaging compliant with environmental criteria are recycling and the use of bioplastics. This conclusion is crucial for the marketing communication of enterprises related to the product or its elements compliant with the principles of environmental protection (Karwowska, Pawluk 2021).

Regarding the buyer and the consumer, a positive conclusion is the relatively high level of knowledge and acceptance of the respondents towards this type of packaging. Particularly important are the opinions on the use of packaging made of recycled material in the category of products perceived as sensitive and requiring a special level of safety: food, medicines, products for infants and young children (Karwowska, Pawluk 2021).

About bioplastics, the results are very promising. In the scale of the entire surveyed group, a product in a bio-based packaging would be chosen by 69% of respondents, including primarily people guided by the criteria of eco-friendliness (32%) and naturalness (31%). This is an interesting result, especially since 26% of the remaining respondents do not consider this issue, but do not exclude the purchase. Only 5% of respondents would clearly not choose this type of packaging, of which the clear majority (4%) due to the higher price, not the parameters – this situation may change with the dissemination of this type of solutions and a decrease in unit prices (Karwowska, Pawluk 2021).

For the buyer, the difference between packaging made of industrial bioplastics (and those of a less mass, artisan nature is relatively imperceptible and does not affect the attitude towards packaging. Clear differences in opinions can be

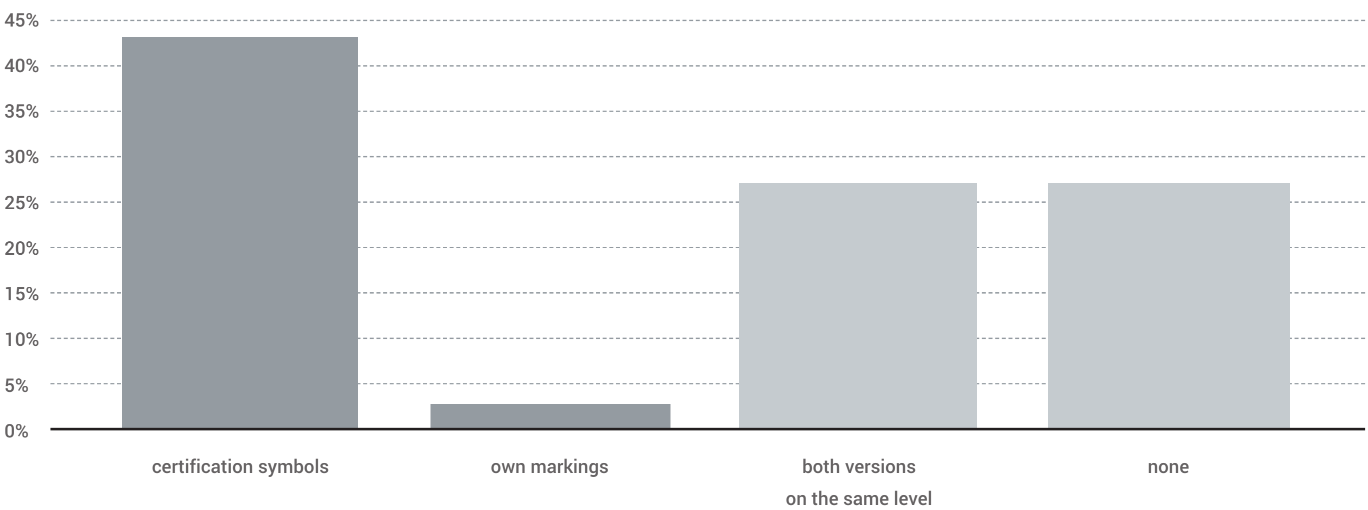

CHART 11. WHICH OF THE FOLLOWING ILLUSTRATIONS, IN YOUR OPINION, PRESENTS MORE RELIABLE INFORMATION ABOUT THE ENVIRONMENTAL PERFORMANCE OF THE PACKAGING? – TOTAL RESULTS

observed when divided into individual demographic cohorts. For example, women are a clearly more positive group towards bioplastics packaging. It seems, therefore, that products packaged in this way for them currently have a greater market potential. For all types of products, the highest percentage of respondents excluding their purchase in bio-based packaging was observed here in the group with primary/vocational education. Interestingly, while respondents with the lowest education are generally more skeptical about bioplastic packaging, their level of distrust clearly decreases in the case of food products and products for infants and young children, which directly affect the user's safety (Karwowska, Pawluk 2021).

Interestingly, in the case of packaging made of recycled materials, the opposite pattern was observed: with an overall relatively high level of acceptance, packaging for products for infants and young children was the most sensitive respondents. It is in relation to the use of recycled materials in their production that they remain most skeptical. Therefore, a general conclusion can be drawn that, in the opinion of respondents, packaging made of bioplastics is safer than standard ones, while those made of recycled materials are less safe (Karwowska, Pawluk 2021).

It should be stated that the compliance of the packaging with the principles of environmental protection as an important element when making a purchasing decision is declared by 55% of the respondents, and the information provided by the producers on the environmental qualities of the packaging is noticed by 52% of the respondents. Thus, more than half of Polish consumers (at least on a theoretical level) not only pay attention to environmental issues in relation to packaging but are also guided by them in making purchasing decisions, and this result is relatively similar for individual groups of respondents, with a slight advantage for buyers older (Karwowska, Pawluk 2022).

In contrast to this, advertisements about the environmental friendliness of product packaging on the Internet, in the press, on television or elsewhere have been noticed in the recent months by only 33% of the survey participants, and such a situation should be considered a waste of market potential by companies – the possibility of effectively reaching the buyer. In the noticed advertising materials of various types, the strongest eye-catching stimulus turned out to be color, which drew the attention of 49% of respondents, and broken down by gender – 54% of women and 43% of men (Karwowska, Pawluk 2022).

Particularly interesting are the opinions of the respondents regarding the credibility of the elements of environmental marketing communication. A negative assessment prevailed in all demographic groups: respondents are not convinced about the veracity of the company's declaration. It seems that

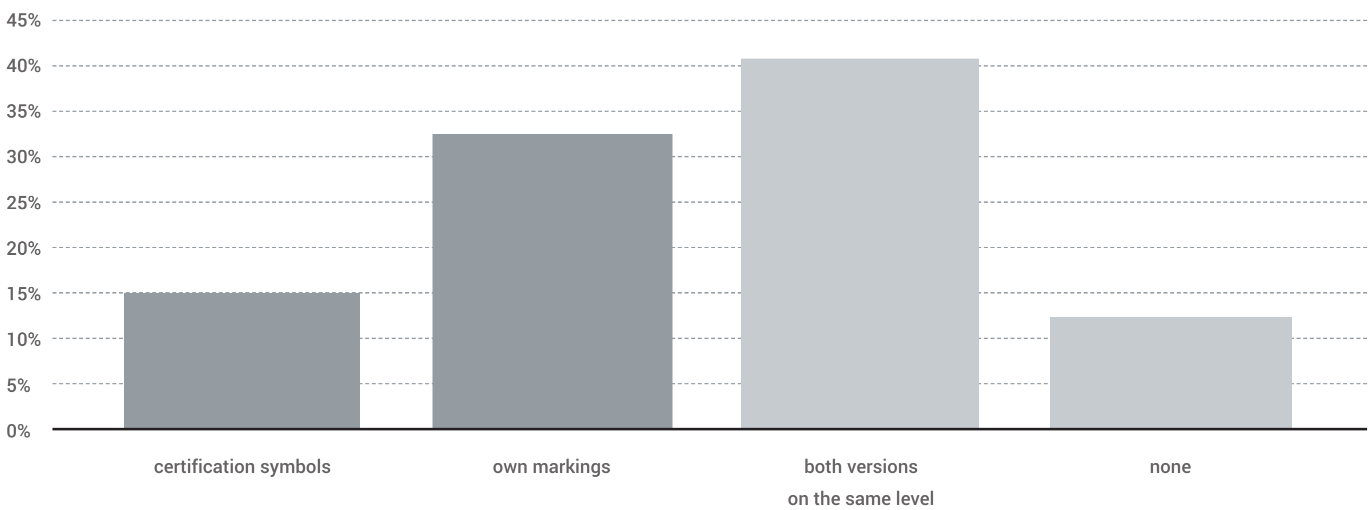

CHART 12. WHICH OF THE FOLLOWING ILLUSTRATIONS, IN YOUR OPINION, PRESENTS MORE RELIABLE INFORMATION ABOUT THE ENVIRONMENTAL PERFORMANCE OF THE PACKAGING? – TOTAL RESULTS

the role of other organizations external to the producer (authorities at various levels, including local authorities, non-governmental organizations and finally the certification bodies themselves) in the verification and, more generally, the promotion of knowledge and desirable patterns of behavior of buyers is crucial (Karwowska, Pawluk 2022).

The respondents considered the symbols of certificates issued by authorized institutions to be the most credible element of communication based on packaging compliant with the principles of environmental protection, i.e., the model considered by the authors of the study to be the most reliable. However, the high percentage of such answers raises serious doubts as to their credibility. On the one hand, such signs are rather not used in advertising, on the other hand, in subsequent questions, they were assessed as much less reliable than the manufacturer's own markings. Thus, a certain discrepancy can be noticed between the declarations of potential buyers and their practical implementation, which is probably primarily due to the lack of thorough knowledge and misinterpretation (Karwowska, Pawluk 2022).

In the case of a verbal description, a condensed description is more credible, and therefore more effective in influencing the buyer, than the extended version, more factual, but probably less understandable due to the accumulation of technical terms, especially for an older recipient. On the other hand, in relation to promotional slogans (i.e., shorter forms that do not require such a high level of involvement as a verbal description), the precise version was rated as more credible, and therefore also effective, and this regularity is particularly noticeable among the respondents from the younger groups. The analysis of the color issue confirmed the assumption that buyers pay special attention to this element. The green version of the same packaging considered to be the more credible version of the marketing message, but there were no clear differences broken down by demographic groups, so the regularity can be considered universal. Summing up the results of the analysis of the issue of certification marks and other occasional markings, the discrepancies between the theoretical declarations and the actual reactions of the respondents, probably due to insufficient knowledge, should be emphasized once again. It turns out that ultimately, manufacturers' own trademarks are more credible for a much larger percentage of respondents, which is particularly visible among younger respondents from the 25-34 age group (Karwowska, Pawluk 2022).

The main conclusion is therefore a significant discrepancy between the declarations of the surveyed people and their actual opinions and reactions in a situation of having to make a choice. In general, it should be stated that the current models of environmental marketing communication based on packaging are relatively effective in the areas of creating attitudes, but insufficient in the areas of conditioning specific purchasing behaviors. In the latter case, the element of lack of trust in enterprises is also crucial – to raise the level of efficiency, it seems necessary to involve external organizations and institutions of various types, which are both a source of knowledge and a guarantee for consumers (Karwowska, Pawluk 2022).

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ON THE SAFETY OF PACKAGING AND PACKAGED PRODUCT

The FoodFakty Workshop and Managerial Knowledge Forum, titled "Quality and Safety of Packaging and Packaged Product" and organized by the FoodFakty portal and the Institute of Fermentation Technology and Microbiology of Lodz University of Technology, took place on February 14-15th at the campus of the Lodz University of Technology.

After six years on the market, and dozens of online projects, FoodFakty is creating a unique space for managers to exchange knowledge and meet face-to-face – explains Janusz Olejnik, founder of the FoodFakty project. – *We are directing this initiative to managers of food safety, quality and packaging safety, managers of the packaging and all those who have a real impact on the selection and management of packaging and safety of packaged products. We are introducing a new, innovative formula based on knowledge and workshop activities with experts, combined with the opportunity for networking and one-on-one discussions.*

INNOVATIVE MEETING FORMULA

The event consisted of six plenary sessions and more than 20 substantive workshops with an interactive formula. The former covered topics such as packaging safety and sustainability, PPWR-related transformation, circular economy in packaging, and market challenges and trends. Partners of the managerial workshop were CDM Packaging (strategic partner), JS Hamilton, Lukasiewicz Lodz Institute of Technology, Institute of Fermentation Technology and Microbiology (main partners), as well as Avery Dennison, KGL, Knoell, SGS and Spectrometrics. Institutional partners were the following organizations: Polish Plastics Pact, Polish Chamber of Packaging, Natureef, Plastics Europe, Lodz University of

THE EVENT CONSISTED OF SIX PLENARY SESSIONS AND MORE THAN 20 SUBSTANTIVE WORKSHOPS WITH AN INTERACTIVE FORMULA. THE FORMER COVERED TOPICS SUCH AS PACKAGING SAFETY AND SUSTAINABILITY, PPWR-RELATED TRANSFORMATION, CIRCULAR ECONOMY IN PACKAGING, AND MARKET CHALLENGES AND TRENDS

Technology, Institute of Food Technology and Analysis, Faculty of Biotechnology and Food Science, Polish Association of Juice Producers, Polbisco and Association of Polish Diary Processors. Workshop sessions included the following topics: flexible packaging - technological and material requirements; methods of research and quality control of packaging; sensory safety of food packaging, environmental labelling of packaging; declarations of conformity; legislative requirements for food packaging in Poland and in the European Union; greenwashing in packaging; recycling of packaging; eco-design; requirements and considerations for labels in accordance with circular economy; packaging of the future; properties of polymeric packaging materials; biodegradation.

CDM PACKAGING, THE EVENT'S STRATEGIC PARTNER, ADDITIONALLY OFFERED THE OPPORTUNITY TO VISIT ITS PRODUCTION FACILITY LOCATED NEAR LODZ

VISITING CDM PACKAGING

CDM Packaging, the event's strategic partner, additionally offered the opportunity to visit its production facility located near Lodz. It is one of the largest suppliers of film and flexible packaging in Poland. It offers high-quality packaging for fresh produce such as lettuces, herbs and flowers, a wide range of food and industrial products, as well as for the pet and cosmetics industries, among others. Production uses state-of-the-art machinery for flexographic printing, lamination, laser processing, cutting, sealing and perforation. The company also offers state-of-the-art stand-up pouches and flat bottom pouch packaging, made of laminated film and/or paper, equipped with various types of closures, laser perforation, easy tear notches and window packaging. CDM Packaging is currently implementing innovative packaging with active features designed to extend product shelf life and ensure product safety. The production of PE and PP mono-material packaging is also being developed, as well as the innovative production of packaging made of weldable barrier paper with barrier functions appropriate to the packaged product. CDM also offers biodegradable packaging that is certified compostable. This year, the company was again a winner in the Forbes Diamonds ranking.

PARTNERS OF THE MANAGERIAL WORKSHOP WERE CDM PACKAGING (STRATEGIC PARTNER), JS HAMILTON, LUKASIEWICZ LODZ INSTITUTE OF TECHNOLOGY, INSTITUTE OF FERMENTATION TECHNOLOGY AND MICROBIOLOGY (MAIN PARTNERS), AS WELL AS AVERY DENNISON, KGL, KNOELL, SGS AND SPECTROMETRICS

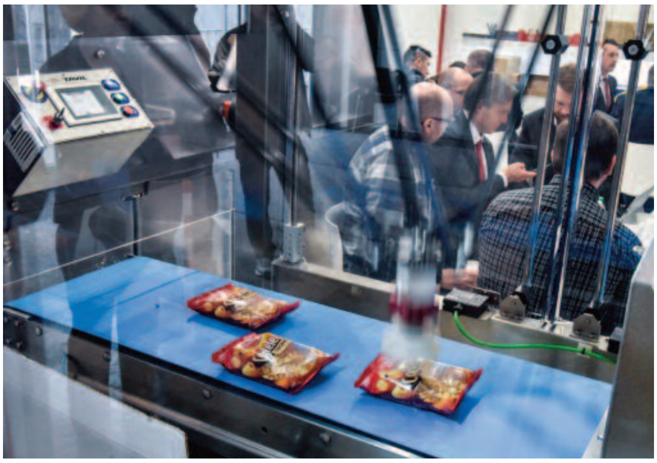
ANUGA FOODTEC: DIGITALISATION, SUSTAINABILITY AND INDIVIDUALISATION

Whether it is about complete production lines or individual process systems for milk products, cheese, beverages and viscous food – Best Practice technologies are currently called for that ensure both efficiency and product quality. At the same time, these systems must be scalable and flexible, in order to also be able to process new ingredients in future. In advance of Anuga FoodTec, which is taking place from 19 to 22 March 2024 in Cologne, it is becoming clear that the latest generation of process technology systems distinguishes itself through three important trends – digitalisation, sustainability and individualisation.

The goal of sustainably redesigning the food and beverage industries has never been as urgent as it is today. All the more important is it for producers to efficiently and flexibly use systems that are appropriate for this task. Not least, the consistently high quality of food and food safety is in the focus of developments. „Globally, we are seeing innovations of completely different kinds in process technology. This diversity is also reflected on the Cologne fair grounds at the stands of the exhibitors" – says Matthias Schlüter, director of Anuga FoodTec. More than a third of the around 1,350 exhibitors from Germany and abroad present solutions in the field of process technology. And these already start with mixing – a complex process that often takes place at the start of production.

EFFICIENT IN EVERY PRODUCTION STEP

Mixers are the workhorses of the food industry and are indispensable for the standardisation of product masses. Where a simple batch mixer was sufficient 15 years ago to process standard recipes with few ingredients, the situation has fundamentally transformed. The market is now more dynamic than ever before. Manufacturers change recipes several times per day in order to adapt their production to the changing wishes of consumers. A modern mixer must be able to master this complexity and be capable of mixing varied raw materials equally wet and dry, and that without making the process more difficult. At Anuga FoodTec, visitors will find a great variety of



models that can be adapted to the respective requirements. An example of this are trajectory mixers. They introduce the shear forces by way of the inertia of the mass through the use of programmable trajectories. The highlight: the product found in the process container processes itself gently with itself, entirely without stirring tools.

However, there is more than one process step behind the manufacture of food. The stirrers, kneaders, mixers, extruders, homogenisers and heat exchangers on the Cologne fair grounds are flanked by a large number of digital solutions that are specifically coordinated to the processes and network these to form a complete line. Recipe and batch management software makes it possible to plan and control fully-automated production. Thanks to central terminals, all functions, such as rotational speeds, vacuum values, exposure to gas or the speed of the conveyor systems, can be monitored and operated by one person. User-friendly designs ensure process-safe and intuitive operation and are also a response to the lack of skilled workers in the industry.

THE OPTIMISATION OF PRODUCTION PROCESSES OCCUPIES A LOT OF SPACE AT ANUGA FOODTEC. IT IS PRIMARILY THE DIGITAL TECHNOLOGIES THAT PROVIDE INSIGHTS INTO THE PROCESSES THAT WERE NOT SO AVAILABLE IN THE PAST

DIGITAL AND NETWORKED ALONG THE ENTIRE LINE

The optimisation of production processes occupies a lot of space at Anuga FoodTec. It is primarily the digital technologies that provide insights into the processes that were not so available in the past. Food manufacturers use this as the foundation for elevating their own production to the latest standard and to optimise the harmonisation of human being, machine and processes. With their portfolio, the exhibitors in Cologne begin at precisely this point – for example, with intelligent sensor and web-based process control systems that can also be retrofitted on existing systems. They enable comprehensive sustainability management at the central point of the plant control system.

This enables cross-process automation from the preparation of raw materials with mixing and reduction through processing with portioning, dispensing, molding or extrusion to options like gripping and insertion of the products into the packaging. Intelligent feeds and precise sorting then subsequently ensure that the products are finally packaged and ready for shipping. With such an integrated complete solution, the individual product components for ready-made meals pass without interruption through the weighing and filling stations and are subsequently filled cleanly into bowls and sealed.

GENTLE PROCESSING FOR HIGHER QUALITY

Food manufacturers face not only the challenge of continually improving the efficiency of their processes. They must at the same time ensure the durability and the quality of their products. Against this background, non-thermal preservation processes remain the trend. The solutions to be found in Cologne are bundled under the term „Minimal Processing". These include, for example, high pressure processing (HPP). This enables the gentle preservation of food at 6,000 bar, without heat or additives. The products are treated directly in the final packaging. Because high temperatures are unnecessary, the products remain fresh and of a high quality. That works as well for vacuum and modified atmosphere packaging (MAP) as it does with PET bottles.

New application areas in food processing are also always arising for pulsed electric fields (PEF). The technology is primarily used to date with vegetables and fruit. When producing French fries, PEF pretreatment has become the standard in the meantime. It results in a better cut appearance, reduced loss of raw material and starch losses for manufacturers. The process can be combined with conventional drying methods like hot air, freeze, vacuum, microwave or infrared drying and increases the attractiveness of the dried products – with reduced consumption of water and energy. The technology has recently promised great potential for the manufacture of wine or native olive oil. The principle of electroporation and the resulting discharge of cell sap is applied here to extract valuable ingredients.

THE FUTURE OF FOOD PRODUCTION

From 19 to 22 March 2024, Anuga FoodTec will show what levers food producers can apply to elevate their production processes to the next level of resource efficiency and product quality. The exhibition programme will be complemented by conferences with prominent guests, interactive forums, panel discussions and lectures, special events, guided tours as well as the presentation of the International FoodTec Award 2024. The Main Stage Responsibility (Hall 9, B080/C081) and the Innovation Stage (Hall 5.2, C100/D119) revolve around themes like automation, digitalisation, robotics, sustainability and process optimisation. „This overarching perspective of Anuga FoodTec on developments of the industry thereby helps with reaching investment decisions for new technologies", according to Matthias Schlüter. The Best Practice technologies shown at the trade fair offer trade visitors valuable stimuli in this regard.

Packaging Review

"PACKAGING REVIEW" REVIEWING PROCEDURE

"Packaging Review" quarterly magazine's reviewing procedure is multilevel in order to maintain high quality content and consists of the following steps:

- If Editor-in Chief decides that provided, scientific article fits the journal's scope, he appoints two Reviewers of recognized competence within the field of research, preferably with professor or postdoctoral degree. The reviewers are obliged to:
  - deliver an objective, independent opinion,
  - ensure that there is no conflict of interests – they should have no personal relationships or business relations with Authors,
  - keep any information regarding the content and opinion confidential.
- When the Reviewers are chosen, the Editor-in-Chief sends them a written offer with either a short description or an abstract of the article, defines the range of reviews and sets a deadline.
- If the Reviewers accept the offer, the Editorial Board provides them with a full version of the article and an obligatory peer review report.
- Reviewers' personal details are classified and they can be declassified only at the Author's request and with the reviewer's permission in case the review is negative or the article contains arguable elements. Once a year, the Editorial Board publishes in its journal the full list of the Reviewers cooperating with the journal.
- Once the review process is complete, the Reviewer delivers electronic version of the review by e-mail and the Editorial Board:
  - informs the Author that the review has been submitted to the journal (when the reviewer states that the article does not require corrections or it requires only minor editorial corrections),
  - forwards the review with critical comments to the Author, who is encouraged to make corrections suggested by the reviewer. If the Author disagrees with certain remarks, he/she is under obligation to prepare response letter substantiating his position.
  - sends the revised article to the Reviewer again, if the Reviewer finds it necessary.
- The Editorial Board makes the final decision about publishing the article based on analysis of the review and the revised version of the article that the Author has resubmitted.
- If one of the reviews is negative, the Editor-in-Chief makes decision about rejection of the article or invites an additional reviewer so as to get an extra opinion before making a decision. When both reviews are negative, the Editor-in-Chief rejects the article.
- The final version of the article is sent to the Author.
- Non-scientific articles do not need to be reviewed and they are accepted for publication by the Editor-in-Chief.

INFORMATION FOR THE AUTHORS

We kindly ask to submit to the editorial office author's application form available at www.packagingreview.eu with contact details, a title of the proposed article, number of pages, illustrations and tables as well as a brief abstract. After receiving information about the acceptance of the proposed article please submit the entire text prepared according to the editorial instructions as well as a complete declaration form.

Submitted articles are subjected to editorial assessment and receive a formal editorial identification number used in further stages of the editorial process. Every submitted article is reviewed. Publication is possible after receiving positive reviews.

GUIDELINES FOR PREPARING THE ARTICLES

- Articles for publication in „Packaging Review" should have scientific and research character and focus on innovations, trends and challenges of the industry.
- Articles must be original, not previously published (if the article is a part of another work i.e. PhD thesis, habilitation etc. the information about that should be placed in the reference section).
- The article should involve a narrow topic but treated thoroughly without repeating general knowledge information included in the widely known literature.
- If the problem is extensive, it should be it split into few articles for separate publications.
- Articles should be of a clear and logical structure: the material should be divided into parts with titles reflecting its content. The conclusions should be clearly stated at the end of the paper.
- The article should be adequately supplemented with illustrations, photographs, tables etc. however, their number should be limited to absolute necessity.
- The title of the article should be given in Polish and English as well as the abstract and key words.
- The article should not exceed 10 pages (1 page – 1 800 characters).
- The article should include post and e-mail addresses of the author (s).
- The article should be electronically submitted in *doc or *docx format and additionally PDF format. Equations should be written in the editors, with a clear distinction between 0 and O. If the equations exceed the width of column (8 cm) they must be moved, otherwise use double width column (16 cm).
- The editorial staff does not rewrite the texts or prepare illustrations. Apart from *.doc, *.docx formats it is recommended to submit the source files of illustrations (in *.eps, *.jpg or *.tif format).
- Drawings and graphs must be clear and fit A4 size of the column.
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