

Innovations in the Food Packaging Market – Intelligent Packaging – a Review

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Abstract

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The manufacturers have to provide modern and safe packaging due to the growing consumer interest in the consumption of fresh products with extended shelf-life and controlled quality. It is a challenge to the food packaging industry and it also acts as a driving force for the development of new and improved concepts of packaging technology. It is in order to meet these needs that intelligent packaging can be applied. This article presents a generation of packaging which allows maintaining and even improving the quality of the packaged product, which is an essential advantage particularly in the food industry. The most important advantage resulting from their use is a reduction in the loss of food products due to the extension of their shelf life.

Keywords: smart system; trends of packaging; food industry

Packaging production is a global industry which is characterised by its internal diversity and each of its sectors individually affects the situation in the market. The requirements for packaging and articles intended to come into contact with food are systematically growing. Due to the growing consumer interest in consumption of fresh products with extended shelf-life and controlled quality, manufacturers have to provide modern and safe packaging. It is a challenge to the food packaging industry and it also acts as a driving force for the development of new and improved concepts of packaging technology (FARMER 2013; CIERPISZEWSKI 2016; ZALEWSKI & SKAWIŃSKA 2016). Therefore, packaging producers are looking for solutions that allow improving the properties of packaging materials such as adequate barrier to gases, UV protection, extension of the storage period, transparency, and environmental performance (KUBIAK & BOROWY 2013).

This article presents a generation of packaging which allows maintaining and even improving the quality of the packaged product, which is an essential

advantage particularly in the food industry. It is to this end that the role and the application of intelligent packaging were discussed. The tasks of smart systems were analysed on an example of indicators monitoring the temperature at which the food was stored, indicators of freshness and the presence of oxygen (integrity of packaging) as well as tracers based on the RFID technology.

According to forecasts of experts, the emerging generations of intelligent packaging are the future of food packaging (PEREIRA *et al.* 2012; FARMER 2013; REALINI & MARCOS 2014; VANDERROOST *et al.* 2014; LEE *et al.* 2015; CIERPISZEWSKI 2016; GHAANI *et al.* 2016). It is estimated that the share of the so-called advanced packaging represents approximately 5% of the total value of the packaging market, of which 11% belongs to smart systems. Although the intelligent packaging has a small share in the value of the sales of all packaging, there are indications for a rapid growth of their sales in subsequent years. The interest in these solutions is reflected in the number of patent applications and granted patents.

These types of solutions were introduced in Japan and in the USA first and now they can be seen in Europe. The later introduction of these systems into the European market probably results from existing legal regulations which are much more restrictive in Europe (DAINELLI *et al.* 2008; CIERPISZEWSKI 2016). Intensification of interest in intelligent packaging in Europe is also reflected in the growing number of research projects related to their development (VANDERROOST *et al.* 2014).

Intelligent packaging

Intelligent packaging is a generation of packaging which monitors or provides information on a product and its quality, safety, or location during transport, storage, retail sales, and during use. UCHEREK (2011) defined intelligent packaging as “a control system inside packaging which is able to perform intelligent functions such as standby, detection, tracking, recording, and communicating in order to provide individual links in the packaging chain, i.e. producers, distributors, and sales representatives and consumers, with certain parameters”. Therefore, an intelligent packaging system is such a system that has functions enabling the observation of a product in the logistics chain or monitoring the internal and external environment of the packaging and allowing communication with a consumer. Intelligent packaging may monitor the quality and safety of a product but it may also provide a potential consumer or manufacturer with information on its condition. The appearance of intelligent packaging systems has contributed to a further significant change in the existing perception of packaging, because they transform traditional communication functions of packaging into intelligent communication (YAM *et al.* 2005).

The activity of intelligent packaging is mainly based on the use of interactive indicators which are most often colourful and enable assessment of the current quality of a product. Their functions may include control of the state of packaging, monitoring of ongoing temperature changes due to storage, control of oxygen concentration, activity of microflora, and leaks in the packaging (PŁACZEK & SZOSTEK 2009; CICHÓŃ & LESIÓW 2013; NOWACKA & FIJAŁKOWSKA 2014).

The main types of intelligent packaging are two systems (CICHÓŃ & LESIÓW 2013). The first is based on the measurement of conditions outside packaging,

whereas the second directly measures the quality of food products inside packaging and may get in direct contact with food, therefore additional safety and quality controls of the packed food are required (DAINELLI *et al.* 2008). Three types of intelligent packaging are most commonly available in the market (KUBIAK & BOROWY 2013; NOWACKA & FIJAŁKOWSKA 2014; DOBRUCKA *et al.* 2015): time temperature indicators, indicators of freshness, and indicators of leaks. Depending on their function, the indicators can be divided into three categories (KORZENIOWSKI *et al.* 2011; CIERPISZEWSKI 2016): critical temperature indicators – CTI, critical temperature/time integrators – CTTI, and time-temperature integrators or indicators – TTI.

Critical temperature indicators show only the fact that a product was exposed to a wrong temperature for a period of time sufficient to cause negative changes with respect to the safety or quality of the product. Indicators of this type may be used to protect products for which even a single exposure to a critical temperature causes irreversible changes in their properties: e.g. frozen products. While critical temperature/time integrators show whether the ambient temperature has exceeded a threshold temperature and a history of changes above the threshold temperature. Thus they indicate the amount of energy which was brought to the indicator, equivalent to the temperature exceeding the threshold temperature at which chemical reactions cause changes in the colour of the indicator and the time at which it was exceeded. Such indicators can be used to monitor storage conditions of the products which start to change their properties significantly after exceeding a certain temperature. These changes are most often due to an increase in the rate of chemical, enzymatic, and microbiological reactions.

Time and temperature indicators (TTI) are the most commonly used indicators in intelligent packaging. Two types of such indicators can be distinguished, i.e. temperature indicators and time temperature indicators (KUBIAK & BOROWY 2013; NOWACKA & FIJAŁKOWSKA 2014).

Temperature indicators are used to monitor the current temperature of a product continually. They react to thermal changes in the environment, may capture even a short-term increase or decrease in temperature beyond the limit for the safe product storage. When the temperature is exceeded, it is usually shown by a change in the colour of the packaging or its part. They are particularly important in the

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case of frozen and chilled food products. They enable to register transitional periods of food defrosting through a colour change. Similarly, in the case of chilled food products, when they are exposed to a higher temperature than that determined as optimal or when products are stored beyond a specified temperature range, it results in an irreversible discoloration of labels. It is extremely important information for a consumer, because it shows the poor quality of such products and the possibility of development of pathogenic microorganisms.

TTI show changes in the ambient temperature which occurred during food distribution and storage. Their action is based on physical, chemical, enzymatic, or microbiological changes under the influence of various temperature conditions. They are used to monitor the current temperature of a product and its environment as well as any derogation from the optimum temperature throughout distribution and simultaneous aggregation of its intensity and time of occurrence. In most cases, such indicators are placed on the outside of packaging and do not come in contact with food, which means that the temperature of the packaging surface is measured and not the temperature of the product itself.

Selected TTI indicators (KUSWANDI *et al.* 2011; FARMER 2013; REALINI & MARCOS 2014):

- CheckPoint label developed by the Swedish Vitsab Company, based on enzymatic changes;
- Monitor Mark produced by the American 3M Company, based on diffusion of a solution;
- FreshCheck (FreshPoint) developed by the American Lifelines Company, based on polymerisation;
- TRACEO produced by the French Cryolog Company, based on microbiological changes;
- OnVu™ brought to the market by BASE, based on a photochromic reaction.

The CheckPoint indicator is based on enzymatic hydrolysis of lipids, which results in a reduction in the pH value of the solution and, as a result, in the colour change. It is an indicator which provides full information on changes in and deviations from the optimal temperature conditions throughout the distribution. Before activation, the integrator consists of two mini-sachets. One of them contains a solution of a lipolytic enzyme and the other fat which is absorbed by powdered vinyl chloride and suspended in a water mixture of chemical compounds changing colour depending on the pH. The activation of the indicator is triggered by destroying the barrier between the two elements. It is as a result

of the reaction that decanoic acid is created, which causes a gradual colour change from dark green to light yellow. By using different combinations of enzymes, substrates, and their concentrations, indicators of various activity periods and active at different temperatures can be obtained. Indicators are available in two main configurations, differing in the number of points indicating changes – a CheckPoint with only one window and CheckPoint III with three points. Indicators with a single point are used to monitor the temperature of individual and bulk packaging while the three-point solutions are used in the wholesale and for the control of the temperature in the supply chain.

The Monitor Mark signals a change in the ownership of a product using the colour ring or belt sliding on a white background. This is a result of physical diffusion of a solution with a chemically changed colour. During storage in appropriate conditions, the indicator is white. After the product reaches a higher temperature than that recommended for maintaining its proper quality, a blue colour appears on the indicator. The degree of the tint determines the time of exposure to higher temperatures. Temperature ranges for the application of this indicator are different depending on the type of indicator, and the so-called threshold limits above which the diffusion appears are from -17°C to 48°C .

Fresh-Check is based on polymerisation reactions dependent on temperature, resulting in changes in the appearance of a label. This indicator has the shape of a small circle surrounded by another circle in a reference colour. When the packing is exposed to temperatures or its shelf life expires, the internal circle begins to darken. During the chemical reaction, the crystal structure of the monomer (starting substance) remains unchanged and the one-dimensional net does not change its optical properties. The change in the colour of the indicator is measured as a reduction in the coefficient of light reflection and the visible change of the colour from white to black. Comparison (e.g. by a consumer) of the shade of the internal part of the circle with the external part allows for determining (on a three-stage scale) the suitability of the product for consumption. If the centre of the circle has a lighter colour than the external part, the product is considered fresh. The same colour of the internal and external circle indicates that the product is still suitable for consumption but the shelf life has been significantly reduced due to negative effects of temperature. The freshness of the product is not

guaranteed when the internal circle is clearly darker than the external one.

The TRACEO indicator is a self-adhesive label in the form of a gel containing selected strains of lactic acid bacteria. The label may be affixed to packaging on the barcode of a product. Initially, the label is transparent, which means that the product is fresh and suitable for human consumption. When the product loses its suitability for human consumption due to expiration of its shelf life or interruption of the refrigeration chain during transport operations or storage, the label is stained and becomes opaque (intensively purple). The decrease in the transparency of the label causes problems in the correct reading of the barcode, which enables automatic detection of stale food. This indicator is prepared specially for selected food products in order to provide consumers and retailers with clear information about a possible deterioration of the product.

OnVu™ is an irreversible indicator, intended for monitoring the temperature history of food products in the refrigeration chain. Its operation is based on a photochromic reaction. Its colour changes from colourless to blue after exposure to ultraviolet light. The indicator has the shape of an apple with clearly marked edges which are a reference point when comparing the colours. After activation with UV radiation, the middle part of the drawing takes an intensive blue colour and with extending the time of exposure to the temperature, it returns to the initial state and the initial light beige colour. The end of the permissible period of the OnVu™ operation is defined as the point at which the blue colour on the label is identical to the reference colour printed on edges of the indicator. Manufacturers declare that OnVu™ labels are suitable for all perishable foodstuffs demanding storage at a low temperature.

The second group of intelligent packaging consists of indicators of freshness which differ from time temperature indicators above all in such a way that they react to changes in the composition of the atmosphere inside packaging or to changes on the surface of a product. Their operation is based on the detection of the presence of metabolites produced by microorganisms, i.e. carbon dioxide and sulphur, ammonia, hydrogen sulphide, amines, ethanol, organic acids, enzymes, and toxins (KORZENIOWSKI *et al.* 2011; KUSWANDI *et al.* 2012; NOWACKA & FIJAŁKOWSKA 2014).

Indicators of freshness show changes in the quality of a product directly after any change in the compo-

sition of the atmosphere inside packaging. An ideal indicator should show both the irregularities arising at the production phase and the loss of freshness of packaged products in further phases of distribution and use. The main element of the indicator is a substance which changes its colour in the presence of metabolites, e.g. as a result of the creation of colourful complexes, or changes its optical properties. Electronic detectors may also be used to identify changes. Work on designing effective indicators of freshness has been underway for a long time. However, only a few solutions found their application in the commercially available intelligent packaging. The Fresh Tag label and the Toxin Guard™ system belong to the best known indicators.

The Fresh Tag label is used to detect volatile amines. It consists of a plastic chip with a ring inside. The ring contains a patented chemical substance which is in contact with gases diffusing from packaging. The presence of volatile amines in the flowing gas causes a colourful reaction with the substance in the ring. With an increase in the concentration of amines, a bright yellow point is moved on the thermometric scale of the ring determining the actual quality of the food product. This indicator may be used for products requiring storage at refrigeration temperatures.

The Toxin Guard™ indicator enables the detection of pathogenic bacteria using immobilised lactic antibodies. It can be printed on paper or plastic foil which are then used for food packaging (PŁACZEK & SZOŁTYSEK 2009; KORZENIOWSKI *et al.* 2011; KUBIAK & BOROWY 2013).

Biosensors are an innovative type of indicators based on measurement of food quality, i.e. devices for detection and transmission of information on biological reactions occurring in a product. Their operation is based on reactions taking place between compounds of biological origin (enzymes, antibodies, nucleic acids) and microorganisms and/or products of their metabolism. Biosensors consist of a receptor which monitors the microbiological conditions of food and activity of enzymes and a transducer which converts biological signals into electrical ones and enables their reading. Detection of contamination with pathogens and/or their metabolites is generally illustrated using colorimetric methods (SINGH *et al.* 2008).

Indicators of leaks (opening). As a result of the interruption of packaging separating the outside and inside environment, it may come to a microbio-

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logical pollution, a change in the composition of the atmosphere in packaging with modified atmosphere and an exposure of the product to contact with oxygen. The presence of oxygen inside packaging may lead to accelerated deterioration of food, changes in taste and smell, autooxidation of fats, oxidation of colorants (vitamin E), darkening of fruits and vegetables, increase in the number of aerobic bacteria. To monitor the presence of oxygen inside packaging the following indicators are used (CIERPISZEWSKI 2016): based on the registration of physicochemical properties of the atmosphere in packaging, based on redox reactions, based on complexation reactions, luminescent indicators.

Many different solutions to oxygen indicators have been discussed in the literature: their construction, way of action, and possible applications. Their principle of operation is primarily based on a change of their colour as a result of chemical reaction or enzymatic activity. However, despite such a large number of reports, only a few solutions found their practical application; among them, the Ageless Eye of the Mitsubishi Gas Chemical Co. that is offered in the form of pills in the market. The mechanism of its operation is based on the oxidation reaction and reduction of methylene blue. The manufacturer declares that the pill is pink in anaerobic conditions and the presence of oxygen changes the colour to blue. The pink colour of the indicator is caused by adding a dye, which is intended to enable distinction between reduced and oxidised state. The speed of action of the indicator is higher and the change of the colour to blue occurs within a few minutes. The reduction reaction is much slower and 2 or 3 h are needed to return to the reduced state (CIERPISZEWSKI 2016).

RFID labels. A separate type of indicators used in packaging consists of RFID labels (radio frequency identification) (KITSOS & ZHANG 2008; KUSWANDI *et al.* 2011; CICHÓN & LESIÓW 2013; NOWACKA & FIJAŁKOWSKA 2014; VANDERROOST *et al.* 2014; LEE *et al.* 2015; CIERPISZEWSKI 2016). It is a modern system of product identification, often called the “radio barcode”. The RFID technology is used to transfer and store data in integrated electronic systems (transponders) via radio waves. Transponders, called tags or markers, take most commonly the form of adhesive labels with a flat thin electronic system. Every transponder is also equipped with an antenna integrated with the system for communicating with other elements of the radio identification system, i.e. readers. The reader emits low power radio waves

which are tuned to the frequency determined individually for each transponder enabling the wireless data transfer to a distance from a few centimetres to even several meters, depending on the wave frequency. The electromagnetic field produced by the reader is also used to power transponders which store energy in the built-in capacitors (SINGH *et al.* 2008).

CONCLUSION

Intelligent packaging is an excellent solution to a wide range of applications in the food industry. The most important advantage resulting from their use is a reduction in the loss of food products due to the extension of their shelf life and monitoring of the status of the packed food. Intelligent systems have tasks and they allow for monitoring of the quality of the packed food products and communicating emerging changes to a consumer.

Intelligent systems are the future direction for development of food packaging and their commercial success should be expected also in the coming years. It will undoubtedly result from constantly improved technologies of their production and from the knowledge of mechanisms of their functioning and the effectiveness of their operation in ensuring food safety accumulated by both producers and consumers over time.

The development and use of intelligent packaging will largely depend on the perception of the benefits of its implementation. Compared with traditional as well as active systems, this food packaging offers the ability to obtain, process, communicate, and also store information. Thus, the consumer learns about the presence of e.g. oxygen inside the package (that got there due to a leak or an undesired temperature to which the food was exposed) and of metabolites resulting from the transformation of microorganisms. These abilities of the packages aim to protect the consumer against consuming stale food that has been stored for too long or kept in unsuitable conditions. Intelligent packaging enables monitoring and providing information about the quality and safety of food products or their location during transportation, storage, retail sale, as well as during use. The most important benefit of smart packaging is extending the shelf life of food, enhanced control of its storage conditions, as well as favourable perception of the brand by consumers. It is worth noting that the introduction of new technologies into this area will

contribute to lowering manufacturing costs (such as use of print), which may lead to their broader application in the future.

Advantages of intelligent packaging are obvious; however, there are still issues that need to be resolved before packaging of this type becomes widespread. Both the hazards arising from traditional packaging and the new materials and technology may cause deterioration of the product quality and adversely affect the human health. The main risk in respect of active and intelligent materials is the excessive migration of chemical substances from packaging to food. Moreover, the improper marking is a significant risk for safety of consumers. There is a relatively small number of products packed in this way offered in the market in relation to the number of solutions presented in the literature. However, it is expected that these difficulties will be overcome and intelligent packaging will become commonly present.

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