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# THE FUTURE OF ACTIVE AND INTELLIGENT PACKAGING INDUSTRY

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**ABSTRACT. Background:** Innovation in food and beverage packaging is mostly driven by consumer needs and demands influenced by changing global trends, such as increased life expectancy, fewer organizations investing in food production and distribution. Food industry has seen great advances in the packaging sector since its inception in the 18th century with most active and intelligent innovations occurring during the past century. These advances have led to improved food quality and safety. Active and intelligent packaging is new and exciting area of technology which efficient contemporary consumer response.

**Materials and methods:** On the basis of broad review of the current state of the art in world literature, the market active and intelligent packaging is discussed.

**Results:** This paper shows present innovation in the market active and intelligent packaging.

**Conclusion:** Research and development in the field of active and intelligent packaging materials is very dynamic and develops in relation with the search for environment friendly packaging solutions. Besides, active and intelligent packaging is becoming more and more widely used for food products. The future of this type of packaging system seems to be very interesting..

**Key words:** active packaging, intelligent packaging.

## PACKAGING INDUSTRY

Increased awareness of health and environmental consumer undoubtedly contributed to the growing requirements for used packaging. New food packaging technologies are developing as a response to consumer demands or industrial production trends towards mildly preserved, fresh, tasty and convenient food products with prolonged shelf-life and controlled quality. In addition, changes in retailing practices (such as market globalization resulting in longer distribution of food), or consumers way of life (resulting in less time spent shopping fresh food at the market and cooking), present major challenges to the food packaging industry and act as driving forces for the development of new and improved packaging concepts that extend shelf-life while maintaining and monitoring food safety and quality [Dainelli et al. 2008, Bilska 2011]. Innovations in packaging were up to now limited mainly to a small number of commodity materials such as barrier materials (new polymers, complex and multilayer materials) with new designs, for marketing purposes. However, food packaging has no longer just a passive role in protecting and marketing a food product. New concepts of active and intelligent packaging are due to play an increasingly important role by offering numerous and innovative solutions for extending the shelf-life or maintain, improve or monitor food quality and safety [Gontard 2006]. Food quality and shelf-life extension (e.g. for delicatessen, cooked meats etc.) Next to these, numerous others concepts such as ethanol emitters (e.g. for bakery products),


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ethylene absorbers (e.g. for climacteric fruits), carbon dioxide emitters/ absorbers, time/temperature and oxygen indicators etc. have been developed. In a general way, the field has been extended largely as a series of niche markets owing to the current approach of packaging industries looking at it in terms of new market opportunities [Rooney 2005].

Introduction of active and intelligent packaging can extend the shelf life of food or to improve its organoleptic properties and thus prevent food losses. According to the FDA report of 2011, every year is thrown away about 1.3 billion tons of food. Every year only in Europe, 89 tons of wasted food (European Commission, 2011), and the average European household rubbish thrown on 20-30% of food purchased. New packaging solutions allow to improve the economic aspect. Each year is grows interest in active and intelligent packaging. This is evidenced by the fact that the global market for food and beverages of active and intelligent coupled with controlled/modified atmosphere packaging (CAP/MAP) increased from $15.5 billion in 2005 to $16.9 billion by the end of 2008 and it should reach $23.6 billion by 2013 with a compound annual growth rate of 6.9%. The global market is broken down into different technology applications of active, controlled and intelligent packaging; of these, CAP/MAP has the largest share of the market estimated to comprise 45.4% in 2008, probably decreasing slightly to approximately 40.5% in 2013. Also, active packaging will comprise approximately 27% of the global market in 2008 but will decrease slightly to 26.9% by 2013. This segment will be worth an estimated $4.6 billion in 2008 and should reach $6.4 billion by 2013. Intelligent packaging represented a $1.4 billion segment in 2008, increasing to $2.3 billion by 2013 [D. Restuccia et al. 2010].

## ACTIVE PACKAGING SYSTEMS

In contrast to traditional packaging, active and intelligent packaging may change the composition and organoleptic characteristics of food, provided that the changes are consistent with the provisions for food. Besides the released substances will be allowed to add to food. The principles behind active packaging are based either on the intrinsic properties of the polymer used as packaging material itself or on the introduction (inclusion, entrapment etc.) of specific substances inside the polymer [Gontard 2000]. Besides, active packaging refers to the incorporation of certain additives into packaging systems (whether loose within the pack, attached to the inside of packaging materials or incorporated within the packaging materials themselves) with the aim of maintaining or extending product quality and shelf-life. Packaging may be termed active when it performs some desired role in food preservation other than providing an inert barrier to external conditions [Hutton 2003]. On the other hand, active packaging has been defined as packaging, which 'changes the condition of the packed food to extend shelf-life or to improve safety or sensory properties, while maintaining the quality of packaged food' [Ahvenainen 2003]. The development of a whole range of active packaging systems, some of which may have applications in both new and existing food products, is fairly new. Active packaging includes additives or 'freshness enhancers' that can participate in a host of packaging applications and by so doing, enhance the preservation function of the primary packaging system. Table 1 lists some of the food applications that have benefited from active packaging technology.

Oxygen scavengers are by far the most commercially important sub-categories of active packaging and the market has been growing steadily for the last several years. The development of oxygen scavenging systems was first based on self-adhesive labels, others adhesive devices or loose sachets to be included in the packaging with the food. A second concept, developed later, was based on the design of active substances for being included in the packaging material itself, using monolayer or multilayer materials or reactive closures liners for bottles and jars [Rooney 2005]. Oxygen scavengers can be used alone or in combination with MAP. Their use alone eliminates the need for MAP machinery and can increase packaging speeds. However, it is usually more common commercially to remove most of the atmospheric oxygen by MAP and then use a relatively small and inexpensive scavenger to mop up the residual oxygen remaining within the food package [Day, 2003;

Robertson 2006. Non-metallic oxygen scavengers have also been developed to alleviate the potential for metallic taints being imparted to food products. The problem of inadvertently setting off in-line metal detectors is also alleviated even though some modern detectors can now be tuned to phase out the scavenger signal whilst retaining high sensitivity for ferrous and non-ferrous metallic contaminants. Non-metallic scavengers include those that use organic reducing agents such as ascorbic acid, ascorbate salts or catechol. They also include enzymic oxygen scavenger systems using either glucose oxidase or ethanol oxidase, which could be incorporated into sachets, adhesive labels or immobilised onto packaging film surfaces [Day, 2003].

Table 1. Selected examples of active packaging systems [Day, 2003]
Table 1. Wybrane przykłady systemów aktywnych [Day, 2003]

| **Active packaging system** | **Mechanisms** | **Food applications** |
|---|---|---|
| Oxygen scavengers | iron based<br>metal/acid<br>metal (e.g. platinum) catalyst<br>ascorbate/metallic salts<br>enzyme based | bread, cakes, cooked rice, biscuits, pizza, pasta, cheese, cured meats and fish, coffee,<br>snack foods, dried foods and beverages |
| Carbon dioxide scavengers/emitters | iron oxide/calcium hydroxide<br>ferrous carbonate/metal halide<br>calcium oxide/activated charcoal<br>ascorbate/sodium bicarbonate | coffee, fresh meats and fish, nuts and other snack food products and sponge cakes |
| Ethylene scavengers | potassium permanganate activated carbon<br>activated clays/zeolites | fruit, vegetables and other horticultural products |
| Preservative releasers | organic acids<br>silver zeolite<br>spice and herb extracts<br>BHA/BHT antioxidants<br>vitamin E antioxidant<br>volatile chlorine dioxide/ sulphur dioxide | cereals, meats, fish, bread, cheese, snack foods, fruit and vegetables |
| Ethanol emitters | alcohol spray<br>encapsulated etanol | pizza crusts, cakes, bread, biscuits, fish and bakery products |
| Moisture absorbers | PVA blanket<br>activated clays and minerals<br>silica gel | fish, meats, poultry, snack foods, cereals, dried foods, sandwiches, fruit and vegetables |
| Flavour/odour adsorbers | cellulose triacetate<br>acetylated paper<br>citric acid<br>ferrous salt/ascorbate<br>activated carbon/clays/zeolites | fruit juices, fried snack foods, fish, cereals, poultry, dairy products and fruit |
| Temperature control packaging | non-woven plastics<br>double walled containers<br>hydrofluorocarbon gas<br>Lime/water<br>ammonium nitrate/water | ready meals, meats, fish, poultry and beverages |

Another popular group of active packaging systems are moisture absorbers. Several companies manufacture moisture absorbers in the form of sachets, pads, sheets or blankets. For packaged dried food applications, desiccants such as silica gel, calcium oxide and activated clays and minerals are typically tear-resistant permeable plastic sachets. For dual-action purposes, these sachets may also contain activated carbon for odour adsorption or iron powder for oxygen scavenging [Rice 1994; Rooney 1995]. Interesting solution is the use a carbon dioxide scavenger or a dual-action oxygen and carbon dioxide scavenger system. A mixture of calcium oxide and activated charcoal has been used in polyethylene coffee pouches to scavenge carbon dioxide but dual-action oxygen and carbon dioxide scavenger sachets and labels are more common and are commercially used for canned and foil pouched coffees in Japan and the USA [Day 1989; Anon 1995; Rooney 1995].

The development of unpleasant flavors as a consequence of food processing can be the result of thermal degradation of components, such as proteins, or of reaction such as the Maillard reaction. In 1979 Cahndler and Johnson showed that substantial quantities of limonin could be removed by acetylated paper, following earlier work involving cellulose acetate gel beads [Chandler 1968]. Franzetti et al., 2001 presented that unpleasant smelling volatile amines, such as trimethylamine, associated with fish protein breakdown are alkaline and can be neutralised by various acidic compounds.

Packaging containing natural preservatives and antioxidants undoubtedly has a high potential. Using antimicrobial or antioxidant agents in active food packaging is relatively recent, and causes consumer concerns regarding their safety due to their possible migration into foods [Vermaeiner et al. 1999, Han 2003]. For this reason, there is growing consumer preference for natural agents which have been isolated from microbiological, plant, and animal sources [Nicolson, 1998]. Active substances of biological origin have a powerful wide-spectrum activity with low toxicity, and are expected to be used for food preservation as a means of active packaging [Han, 2003]. Vojdani and Torees [Vojdani 1989a, Vojdani 1990] have examined the diffusion barrier properties of a variety of polysaccharide-based films and they have found that methyl cellulose offers the greatest potential as a substrate for the antimicrobial agent potassium sorbate. Further work established that creating multi-layer films of methyl and hydroxypropyl methyl cellulose would allow slower, thus more effective, diffusion of potassium sorbate into a potential food product. The addition of fatty acids such as lauric, palmitic, stearic and arachidic acids were also found to be effective for lowering the diffusion of potassium sorbate in cellulose-based films. To group natural antimicrobial agents belongs nisin- bacteriocin produced by Lactococcus lactis. Fang, T.J. and Lin in 1994, used nisin in combination with modified-atmosphere packaging in a study involving cooked pork which was inoculated with Pseduomonas fragi and Listeria monocytogenes. Both microorganisms were effectively reduced in number by the modified-atmosphere/ nisin combination during refrigerated storage of the cooked pork [ Fang 1994].

## INTELLIGENT PACKAGING SYSTEMS

Intelligent food packaging is an innovative technology which is developing in recent years [Bilska, 2008]. Intelligent packaging (also more loosely described as smart packaging) is packaging that in some way senses some properties of the food it encloses or the environment in which it is kept and which is able to inform the manufacturer, retailer and consumer of the state of these properties. Although distinctly different from the concept of active packaging, features of intelligent packaging can be used to check the effectiveness and integrity of active packaging systems [Hutton 2003]. Intelligent packaging devices are capable of sensing and providing information about the function and properties of packaged food and can provide assurances of pack integrity, tamper evidence, product safety and quality, and are being utilized in applications such as product authenticity, anti-theft and product traceability [Summers 1992; Day 2001]. Intelligent packaging devices include time-temperature indicators, gas sensing dyes, microbial growth indicators, physical shock indicators, and numerous examples of tamper proof, anti-counterfeiting and anti-theft technologies. Information on intelligent packaging technology can be obtained from other reference sources [Summers 1992; Day, 1994, 2001].

Besides, intelligent packaging systems attached as labels, incorporated into, or printed onto a food packaging material offer enhanced possibilities to monitor product quality, trace the critical points, and give more detailed information throughout the supply chain [Han, Ho, & Rodrigues, 2005]. Intelligent tags such as electronic labelling, designed with ink technology in a printed circuit and built-in battery radio- frequency identity tags, all placed outside the primary packaging, are being developed in order to increase the efficiency of the flow of information and to offer innovative communicative functions. Diagnostic indicators were first designed to provide information on the food storage conditions, such as temperature, time, oxygen or carbon dioxide content, and thus, indirectly, information on food quality, as an interesting complement to end-use dates [D. Dainelli et al. 2008]. Indicators are called smart or interactive because they interact with compounds in the food. Microwave heating enhancers, such as susceptors and other temperature regulation methods, are sometimes regarded as intelligent methods as well. Table 2 depicts examples of external and internal indicators.

Time-temperature indicators or integrators (TTIs) are defined as simple, cost-effective and user-friendly devices to monitor, record, and cumulatively indicate the overall influence of temperature history on the food product quality from the point of manufacture up to the consumer [Taoukis and Labuza 1989; Giannakourou et al. 2005]. Temperature indicators show whether products have been heated above or cooled below a reference (critical) temperature, warning consumers about the potential survival of pathogenic micro-organisms and protein denaturation during, for example, freezing or defrosting processes [Fault 1995].

Table 2. Examples of external and internal indicators and their working principles used in intelligent packaging [Ohlsson & Bengtsson, 2002]
Tabela 2. Przykłady zewnętrznych i wewnętrznych wskaźników i zasada ich działania w opakowaniach inteligentnych [Ohlsson & Bengtsson, 2002]

| Indicator | Principle/reagents | Information given | Application |
|---|---|---|---|
| Time-temperature indicators (external) | Mechanical, chemical,enzymatic | Storage conditions | Foods stored underchilled and frozen conditions |
| Oxygen indicators (internal) | Redox dyes, pH dyes, enzymes | Storage conditions Package leak | Foods stored in packages with reduced oxygen concentration |
| Carbon dioxide indicator (internal) | Chemical | Storage conditions Package leak | Modified or controlled atmosphere food packaging |
| Microbial growth indicators (internal/ external) and freshness indicators | pH dyes, all dyes reacting with certain metabolites | Microbial quality of food (i.e. spoilage) | Perishable foods such as meat, fish and poultry |
| Pathogen indicators (internal) | Various chemical and immunochemical methods reacting with toxins | Specific pathogenic bacteria such as *Escherichia coli* 0157 | Perishable foods such as meat, fish and poultry |

Besides, time table indicators display a continuous temperature-dependent response of the food product. The response is made to chemical, enzymatic or microbiological changes that should be visible and irreversible, and is temperature dependent [Rodrigues et al. 2003].

Oxygen and carbon dioxide indicators can also be used to monitor food quality. They can be used as a leakage indicator or to verify the efficiency of, for example, an oxygen scavenger. Most of these indicators are based on colour change as a result of a chemical or enzymatic reaction. These indicators have to be in contact with the gaseous environment inside the package and hence are in direct contact with the food [De Jong et al. 2010]. Conventional oxygen indicators are known to use methylene blue (methyl thionine chloride) MB, a dye that reversibly changes its color upon oxidation and reduction [Sumitani et al. 2004]. One of the latest is indicator based on fluorescence. The reaction is based on the phosphor layout has been extinguished when in contact with molecular oxygen. Luminescent compounds are placed in the gas permeable and impermeable to ions materials such as silicone rubber or polymers (e.g. PVC). This allows the creation of indicators in the form of thin films [Mills and Thomas 1997]. One of most popular is tris(4,7-diphenyl-1,10-

phenanthroline) ruthenium(II) perchlorate, i.e. [Ru(dpp)3](ClO4)2, where dpp is the complexing ligand, 4,7-diphenyl-1,10-phenanthroline. The most commonly-employed leak indicator used in food packaging is a colorimetric redox dye-based indicator [Mills 2005].

Changes in the concentration of organic acids such as nbutyrate, L-lactic acid, D lactate and acetic acid during storage offer potential as indicator metabolites for a number of meat products [Shu et al. 1993]. Colour based pH indicators offer potential for use as indicators of these microbial metabolites. Another example of microbial indicators is system based on immunochemical reactions that occur in the barcode [Goldsmith 1994], and the barcode will become unreadable when a particular microorganism is present [Rodrigues et al. 2003]. Ethanol, like lactic acid and acetic acid, is an important indicator of fermentative metabolism of lactic acid bacteria. Randell et al. [1995] reported an increase in the ethanol concentration of anaerobically MA packaged marinated chicken as a function of storage time.

## SUMMARY

Changes in consumer preferences have led to innovations and developments in new packaging technologies. Research and development in the field of active and intelligent packaging materials is very dynamic and develops in relation with the search for environment friendly packaging solutions. Active and intelligent packaging is becoming more and more widely used for food products. Application of this type of solution contributes to improve the quality of consumer life, undoubtedly the consumer. Besides, innovation systems will improve the product quality, enhance the safety and security of foods, and consequently decrease the number of retailer and consumer complaints.

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## PRZYSZŁOŚĆ PRZEMYSŁU OPAKOWAŃ AKTYWNYCH I INTELIGENTNYCH

**STRESZCZENIE**. **Wstęp:** Innowacje w opakowaniach żywności i napojów związane są głównie z potrzebami i wymagania konsumentów pod wpływem zmieniających się globalnych trendów, takich jak wzrost długości życia, czy mniejszą liczbą organizacji inwestujących w produkcję i dystrybucję żywności. Przemysł spożywczy zrobił olbrzymie postępy w sektorze opakowaniowym od momentu jego powstania w XVIII wieku, czego dowodem jest pojawieniem się opakowań aktywnych i inteligentnych w minionym wieku. Ten rodzaj opakowań przyczynił się do poprawy jakości i bezpieczeństwa żywności. Aktywne i inteligentne opakowania są niewątpliwie nowym i ekscytującym obszarem technologii, który wychodzi na przeciw wymogom współczesnego konsumenta.
**Materiał i metody:** Na podstawie na podstawie obszernego przeglądu stanu badań w bieżącej światowej literaturze przedstawiono rynek opakowań aktywnych i inteligentnych.
**Wyniki:** Niniejsza praca przedstawia istniejące innowacje na rynku opakowań aktywnych i inteligentnych.
**Wnioski:** Badania i rozwój w obszarze opakowań aktywnych i inteligentnych są bardzo dynamicznie i rozwijają się w związku z poszukiwaniem opakowań przyjaznych środowisku. Poza tym opakowania aktywne i inteligentne są coraz częściej stosowane do produktów spożywczych. Przyszłość tego rodzaju opakowań wydaje się więc bardzo interesująca.

**Słowa kluczowe:** opakowania aktywne, opakowania inteligentne

## DIE ZUKUNFT AKTIVE UND INTELLIGENTE VERPACKUNGEN INDUSTRIE

**ZUSAMMENFASSUNG. Einleitung:** Unter dem Einfluss der sich verändernden globalen Trends, wie Zuwachs der Lebensdauer oder die verhältnismäßig kleine Anzahl der in die Herstellung und die Nahrungsmittelverteilung investierenden Organisationen, gehen die Innovationen hauptsächlich im Bereich der Verpackungen für Lebensmittel und Getränke mit Bedürfnissen der Konsumenten einher. Die Lebensmittelindustrie hat teilweise einen riesengroßen Fortschritt seit ihrer Entstehung im 18. Jahrhundert notiert, was seine Folgen im Auftreten von aktiven und intelligenten Verpackungen schon in dem vergangen Jahrhundert hatte. Verpackungen dieser Art haben zur Verbesserung der Lebensmittel-Qualität, -Tauglichkeit und -Lebensdauer beigetragen. Die aktiven und intelligenten Verpackungen stellen zweifellos neue und spannende Technologie-Herausforderungen dar, die den Anforderungen des modernen Konsumenten entgegenzutreten vermögen.
**Material und Methoden:** Die Analyse der heutzutage auf dem Markt bestehenden aktiven und intelligenten Verpackungen wurde anhand eines Überblicks über die zu diesem Phänomen veröffentlichten Gegenstandsliteratur vorgenommen.
**Ergebnisse:** Der Beitrag stellt die gegenwärtig vorhandenen Innovationen auf dem Markt der aktiven und intelligenten Verpackungen dar.
**Fazit:** Die Forschung und Entwicklung im Bereich der aktiven und intelligenten Verpackungen wächst rasant und ist bei der Suche nach umweltfreundlichen Verpackungen. Darüber hinaus werden die aktiven und intelligenten Verpackungen zunehmend im Bereich der Nahrungsmittel verwendet. Die Zukunft dieser Verpackungsart scheint sehr interessant zu sein.

**Codewörter:** "intelligente Verpackung", "aktive Verpackung"

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