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Granting society with LOw environmental impact innovative PACKaging

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Position Paper on Barriers of market introduction of Active and Intelligent Packaging

2021

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CONTENTS

INTRODUCTION

The GLOPACK (Granting society with LOw environmental impact innovative PACKaging) project is investigating food packaging with no environmental footprint and the ability to extend the shelf life of food products. Project funded by the European Union's Horizon 2020 research programme under grant agreement No. 773375.

The project is focusing on three food packaging areas:

- biodegradable materials made from agro-food residues
- active packaging to improve food preservation and shelf life without additives
- RFID enabled wireless food spoilage indicators linked to food date labels

Active and intelligent packaging is a new and exciting area of technology, the potential of which has received much attention from the food business operators, retailers and consumers alike. Consumer demand for natural products and increasingly extended and diverse supply chains required to feed the growing global population mean that traditional packaging is becoming less capable of meeting the functional demands. The use of active and intelligent packaging is not exclusive to food manufacturing as many solutions, in particular elements of the intelligent feature have been adapted from the logistics industry while other technologies are shared for instance, with the pharmaceutical, medical device and health care industry.

Consumers don't purchase packaging; they purchase food products that must have some sort of packaging built into the product offering. To help to ensure the commercial success of the proposed packaging technologies, a thorough understanding of consumers attitudes toward them is required. Understanding the factors that affect consumer acceptance and market penetration will help to adapt packaging development to meet consumer preferences and food safety needs and ensure that communication about the technologies answers consumer concerns and informs them on the benefits.

This Position Paper aims to oversee the barriers identified for the rapid market introduction of active and intelligent packaging and to offer recommendations on lifting these barriers. The examples brought forward in this Position Paper are based on the results and experiences from the GLOPACK project as well as relevant publications, guides and experience collected from industry practice.

This Position Paper is intended to all food chain stakeholders, from manufacturers to the retail, who intend to introduce biodegradable, active and/or intelligent packaging for their food products.

CURRENT MARKET AND APPLICATIONS OF ACTIVE AND INTELLIGENT PACKAGING

Packaging has become an essential technology in the food chain to ensure safety, avoid undesired reactions, satisfy consumer expectations, and increase food shelf life. There are many potential applications for active packaging in areas where traditional packaging no longer has been able to meet customers' and retailers' expectations. For intelligent packaging, a great potential exists in industry segments where JIT (Just-In-Time) delivery, stretch shelf life and associated complex traceability are issues, such as the high added value chilled food and beverage industry. Next to these, most smart packaging solutions were developed and targeted toward the food supply chain (including storage and transport) to reduce food loss and waste.

According to the Food and Agriculture Organization of the United Nations, one-third of all food produced globally for human consumption – 1.3 billion tons – is lost or wasted, causing financial losses and depletion of natural resources (FAO, 2019). While many food industries have already embraced loss reduction initiatives and have optimised their internal and external supply chain, the prevalence of retail and household waste suggests that the improved packaging's ability in reducing spoilage and extending shelf life can play a large role in addressing this problem.

Many technologies exist today that can either track or test (but usually not both) agri-food products for contamination as they travel through the supply chain. However, these techniques are cost prohibitive, and testing slows down the supply chain since qualification, and quantification tests for randomised samples are often performed through external technical and certified laboratories. Also, it is currently difficult to get the data related to testing and tracking to the end-user because of gaps or breaks in the data stream or an inability to share the information with the consumer. Thus, the industry still needs technologies that can seamlessly track, test, and share data about agri-food products throughout the supply chain without requiring any significant change to the existing infrastructure. There is, for example, great interest in the industry in creating an effective detection and monitoring system that can provide data about any exceptions to certain sets of target markers, such as chemical, physical, or biological indicators for organic and inorganic volatile compounds and pathogens. This data could be used in mathematical models to generate predictions about product quality and shelf life.

Food packaging represents about half of all packaging area in developed countries, with a reported market size of USD 305 billion in 2019 that is projected to reach USD 464 billion by 2027, growing at an annual rate of 5.9%, while 'smart' packaging is expected to grow at 8.3% during the same period, starting from USD 6.87 Bn in 2018, most of it coming from active packaging (Precedence Research, 2020).

The increasing demand for fresh and quality packaged food, consumer convenience and manufacturers' concern for longer shelf-life of the food products are driving the market for global active and intelligent packaging technology for food and beverage market. These technologies offer tremendous potential to fulfil the growing demand for food safety in various applications, including dairy products, meat and poultry, ready-to-eat meal segment, etc. Advantages over their conventional counterparts include reduced counterfeiting, increased shelf-life, improved safety, and easy implementation (Sohail, M et al., 2018).

Although many of these features have been considered unnecessary, the development of technology that allows the low-cost production of electronics and sensors and the elimination of specialised electronic readers in favour of smartphones will allow them to enter into this tendency.

Furthermore, developments in printing practices are providing their added functionality for the potential development of intelligent packaging and smart labels, associated with the use of RFID technology and printed electronics (Mordor Intelligence, 2021) (Liao et al.).

One example of such a system might be a label-like technology applied to food packaging or a container and provides tracking and sensing. The data from the label would be uploaded on the Internet without any human intervention for information sharing and analysis. For example, smart RFID tags could be integrated with a sensing element to detect any changes in the food that might indicate spoilage. This information would then be read by smart RFID tag readers, allowing the company to track the location of the food and its quality. Although RFID infrastructure is well-developed and has gained significant momentum over the last decade, high research and development cost still hampers the market's growth. Currently, only a few commercially available smart packaging systems use RFID tags to track and record food quality.

LEGAL REGULATIONS ON ACTIVE AND INTELLIGENT PACKAGING

Ancestors of the active packaging have been with the mankind for over two millenea when it was discovered that the use of certain packaging also contributes to better keeping properties; the best examples probably being the antioxidant property of tanned leather hoses for storing and carrying edible oils in the Middle East or the use of copper and silver cookware to delay food spoilage owing to the antimicrobial properties of these metals. Some other, more recent uses of non-inert packaging materials have since been overruled, a notable example the biphenyl (preservative E230) infused wrappers in the preservation of citrus fruits during transportation which is no longer approved as a food additive in the European Union.

The food industry has seen great advances in the packaging sector, with most active and intelligent innovations occurring during the past decades as consumer demand and shelf-life expectation for pre-packed foods has grown. The same led to the development of chemical indicators and later, electronic sensors to be incorporated into intelligent packaging solutions. As the packaging material was no longer considered 'inert' this called for the review of the relevant legislation. Before 2004, there was no regulation on these packaging at EU level. In 2004, the European Framework Regulation (EC) 1935/2004 for all food contact materials was published, allowing the introduction of active and intelligent packaging on the European market.

This Framework Regulation states that active and intelligent materials and articles shall not transfer constituents to food in quantities, which could endanger human health, bring about an unacceptable change in the composition and bring about deterioration in organoleptic characteristics thereof (Article 3).

The Framework Regulation describes specific requirements for active and intelligent materials and articles (Article 4), the main provisions are the following:

- Active materials and articles may bring about changes in the composition or organoleptic characteristics of food on the condition that the changes comply with the food legislation.
- Substances deliberately incorporated into active materials and articles to be released into the food or the environment surrounding the food shall be authorised and used in accordance with the relevant EU provisions applicable to food.
- Active materials and articles shall not bring about changes in the composition or organoleptic characteristics of food, for instance by masking the spoilage of food, which could mislead consumers.
- Intelligent materials and articles shall not give information about the condition of the food which could mislead consumers.
- Active and intelligent materials and articles already brought into contact with food shall be adequately labelled to allow identification by the consumer of non-edible parts.
- Active and intelligent materials and articles shall be adequately labelled to indicate that the materials or articles are active and/or intelligent.

Regulation (EC) 1935/2004 was amended by Regulation (EU) 2019/1381 on the transparency and sustainability of the EU risk assessment in the food chain amended with effect from 27 March 2021.

In 2006, the Framework Regulation was supported by European Regulation 2023/2006 on Good Manufacturing Practice for materials and articles intended to come into contact with food: this GMP states, that business operator shall establish, implement, and maintain

- an effective and documented quality assurance system,
- an effective quality control system,
- appropriate documentation with respect to specifications, manufacturing formulae and processing.

In 2009, European Regulation (EC) 450/2009 on Active and Intelligent Materials was declared, which is the specific measure under the Framework Regulation that regulates active and intelligent materials and articles. Definitions of active and intelligent materials and articles used for food in the context of this regulation are the following (Article 3):

- "active materials and articles' means materials and articles that are intended to extend the shelf-life or to maintain or improve the condition of packaged food; they are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food;
- "intelligent materials and articles' mean materials and articles which monitor the condition of packaged food or the environment surrounding the food.

This regulation sets down specific requirements on the use and authorisation of active and intelligent materials and articles intended to come into contact with food:

- they must be suitable and effective for the intended purpose of use;
- must not release into the food any components in sufficient quantity as to endanger human health or to bring about an unacceptable change in the composition, taste or smell of food;
- must not mislead consumers through their labelling, presentation or advertising material.

The regulation also establishes a "Community list' of authorised substances that can be used in the manufacture of these materials: substances may only be added to the list once their safety has been evaluated for safety by EFSA (European Food Safety Authority). Exemptions in components of active and intelligent materials and articles without being included in the list exist for:

- released active substances, added or incorporated by techniques such as grafting or immobilisation which are used in full compliance with the relevant EU and national rules;
- substances used in the components which are not in direct contact with food or the environment surrounding the food; and are separated from the food by a functional barrier, and if they are not mutagenic, carcinogenic, or toxic to reproduction or substances produced deliberately in a particle size that exhibits chemical and physical properties that significantly differ from those at a larger scale.

Inedible parts must be made recognisable to the consumer, therefore additional labelling requirements are laid down by the European Regulation (EC) 450/2009. Article 11 states that active and intelligent materials and articles or parts thereof shall be labelled, whenever they are perceived as edible.

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FACTORS AND BARRIERS OF ADAPTATION

PERCEPTIONS OF VALUE OF USING ACTIVE AND INTELLIGENT PACKAGING

CONSUMER MOTIVES FOR USING ACTIVE PACKAGING

The majority of active packaging technologies are focused on enhancing the product's functional protective value, thereby maintaining food safety and quality at a higher level over a longer period of time. In a study (Young E, 2020), functional value was the most significant value perceived by consumers, motivating purchase intent. The functional benefits of active and intelligent packaging were easy to understand and could be seen clearly. Consumers perceived a number of benefits associated with active and intelligent packaging, including functional benefits such as improving food safety and quality by minimising deteriorative food reactions. The desirability of shelf-life extension as a functional benefit of active packaging suggested consumers wanted a longer shelf life, which offered additional flexibility in consumption timings reducing food waste and therefore increasing convenience but at the cost of perceived naturalness, freshness and healthiness. Active packaging's protective function to extend a product's shelf life can also be viewed as the provision of safer and higher quality food but not an increase in longevity of mediocre products (Wilson et al., 2018).

CONSUMER MOTIVES FOR USING INTELLIGENT PACKAGING

In addition to the standard information printed on the packaging (e.g., brand, ingredients, date coding, and weights), intelligent packaging provides more dynamic information about the product's history and/or quality (Robertson, 2013). This review suggests that the epistemic value provided by the communication function of packaging is an important attribute involved in consumer's purchase decisions and that intelligent packaging was a useful enhancement of that functionality. Several types of intelligent packaging technologies were discussed in the studies, including time-temperature indicators, traceability indicators, freshness indicators, pack integrity indicators to show leaking or tampering, and headspace gas composition.

The benefits cited included a belief that they confer a form of quality guarantee and their perception, resulting in safer higher quality products and enhanced supply chain and retailer reliability. Intelligent packaging can also assist with within the home monitoring of storage temperature and/or product quality. Perishable products (chilled and frozen), modified atmosphere, and vacuum-packed products were all identified as ones that would benefit most from intelligent packaging and the increased provision of information about the product's condition (Pennanen et al., 2015). More highly processed products were also considered to benefit from traceability provisions proving authenticity, particularly in light of food adulteration, and counterfeiting scandals (Spence et al., 2018). The ability to monitor, then adjust food planning and to consume products prior to "going bad" via intelligent packaging links to a growing food awareness amongst consumers for decreasing food (and packaging) waste (Barska and Wyrwa, 2016).

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BARRIERS OF ADAPTATION FOR ACTIVE AND INTELLIGENT PACKAGING

CONSUMER FUNCTIONAL AND PERCEPTION BARRIERS

As with the motives for purchasing food packaged in active or intelligent packaging, consumer perception barriers against purchase were also varied by a study (Young E, 2020): a hurdle to take is the conservative consumer attitude in Europe towards active packaging. Resistance to innovative packaging is a functional barrier which may be a usage barrier or a value barrier.

Usage barrier was defined as an incompatibility with existing practices or habits, including practical difficulties and challenges. Examples include concerns about downloading traceability apps to scan codes and having data coverage and availability to connect and download the information when codes are scanned. Confusion using time-temperature indicators was also a significant barrier for participants in a study (Pennanen et al., 2015) if the indicator contradicts a printed expiry date and what transitory colours mean.

There were concerns also raised about risks to consumers and society, such as whether or not it would work as advertised (Aday and Jenner, 2015), if it contained components that were harmful to health (O'Callaghan and Kerry, 2016), or would cause more food waste (Pennanen et al., 2015). Consumers in Europe have no affinity with this type of technology. The perception is that although active packaging is increasing the shelf-life, it decreases the quality and freshness. Consumers were also concerned about access to technologies, for example colour based indicators being unable to be used by colour blind consumers (Pennanen et al., 2015) and also the magnitude of change they needed to make in their purchasing habits (Lindqvist et al., 2012). Barriers to purchasing products enhanced with active and intelligent packaging technologies were more varied and included concerns about the additional cost for food items incorporating active or intelligent packaging (Greehy et al., 2011); (Aday and Jenner, 2015); (Spence et al., 2018).

Another functional barrier is cost, or the value proposition in terms of performance to price compared with alternatives solutions. If there is no improvement in the value proposition, there is no motive to change (Ram and Sheth, 1989). (Aday and Jenner, 2015), (Barska and Wyrwa, 2016), (Greehy et al., 2011), (Spence et al., 2018), (Schnettler et al., 2014) and (Pennanen et al., 2015) all discussed the trade-off between additional benefits provided by active and intelligent packaging and the assumed increased costs to consumers to implement. (Pennanen et al., 2015) also confirmed that customers chose active and intelligent technologies when the price was approximately the same, whereas (O'Callaghan and Kerry, 2016) confirmed the concern that shelf life benefits could not justify an increased cost where the food product was already expensive. (Nosálová et al., 2018) suggested that consumers want economical packaging that uses a reasonable quality of resources without an enormous price increase to gain the additional value from active and intelligent packaging. However, (Schnettler et al., 2014) identified a group of consumers that associated higher price with better quality, meaning that cost was less of a barrier.

These findings are in agreement with the conclusions of GLOPACK WP1, Deliverable 1.3 "Report on the mapping and analysis of stakeholders' preferences, acceptances and expectations" (GLOPACK, 2020):

- Lack of knowledge and information of consumers and experts is an important barrier to remove. First, if consumers do not understand the real advantage of active packaging and how and why it acts, they could be suspicious and may not readily adopt it. In the same way, experts must be more informed about and involved in the development of active packaging.
- End-of-life fate of the active packaging remain an environmental issue to market uptake.
- Consumers question the usefulness and relevance of the intelligent packaging technology for their own benefit rather than that for retailers or manufacturers. They have the feeling that using intelligent packaging technology will make the to stop using their senses and common sense to choose the products. This point of view is shared by the experts, who worry that consumers rely on intelligent system only to the detriment of their own judgment and think that the intelligent packaging will not replace the best-before date.
- The high costs of all components are an issue for both experts and consumers, who are concerned that the cost of the final product will increase as it is technological innovation.

INDUSTRIAL AND [CIRCULAR] ECONOMICAL BARRIERS

What currently stands in the way of closed-loop recycling of food packaging is that materials (foils, additives, coatings, inks) and intelligent devices (sensors, RFID tags, indicators) are not designed or selected with closed-loop recyclability in mind. Today, packaging materials must be as cheap as possible, limiting certain design aspects and often leading to multilayer composites or laminates that are difficult or impossible to reuse or recycle. The lack of foresight in packaging design and the extensive use of many different materials inevitably results in complex and expensive recycling processes, reduced performance and attractiveness of recycled packaging, and downcycling of packaging materials (Vanderroost et al., 2014).

To gradually introduce the C2C design approach in the packaging industry, the GLOPACK project has established a closed-loop system for all packaging.

ACTIVE PACKAGING

Innovative packaging solutions, especially active MAP, where active compounds are emitted from packaging toward headspace, creating a modified atmosphere that limits microbial spoilage, are good examples of eco-packaging solutions. However, these solutions remain challenging to adapt and up-scale because they need to be fitted to the specific needs of the food, such as the O_2 and CO_2 permeability property of the film must be adapted to the size and type of the product. There is a high risk of failure if empirical trial-and-error approach is used to adjust the film permeability, the gaseous atmosphere composition or the quantity of active compound to obtain the expected effect on food quality and safety preservation. Currently, no well-established food requirement driven approach is commercially used or available to help the industry to use active packaging.

Moreover, regulatory constraints regarding solutions that imply solutes or volatiles migration (such technologies have to comply with both food and packaging regulation) create additional cost and delay before market uptake. In addition, there is a general consumers' widespread suspicion on sachets and emitters due to their possible interaction with the food product and misunderstanding of their role.

As regards the usage benefit, the reduction of food waste and losses achieved by using well-dimensioned packaging solutions, especially active packaging solutions, still need to be quantified and disseminated to all stakeholders in an informative and easy-to-understand manner, especially to consumers to increase their awareness and acceptance of such packaging as sustainable food packaging solutions.

INTELLIGENT PACKAGING

Based on the literature, the following main difficulties and hurdles have been identified regarding the introduction of intelligent technology:

Cost: The cost of RFID technology is higher than of using traditional solutions for product identification such as UPC barcode. Therefore, the introduction is more widespread in the case of high-value products, e.g. in the fashion industry (Abdelnour, 2018); (Bibi et al., 2017); (Tanner, 2016); (Weis, 2012).

Data management/ data inflow / event filtering: The use of RFID technology enables besides the identification of the storing or in certain cases the recording of data, such as location (tracking applications) or even product parameters (temperature, volatile compounds) in case of sensor tags. This additional data inflow must be handled preferably by an integrated information management system (Kumar et al., 2018); (Meng and Li, 2016).

Non-uniform standards: The spreading of the application of RFID resulted in an increasing need for the global harmonisation of the technology through standardisation. There are several RFID standards available describing different aspects of RFID systems as format, the protocols, the contents of the electronic product code (EPC), the operating frequencies used but a lack of standards is available concerning RFID readers (Bibi et al., 2017).

Integration of the RFID sensor tags in the packaging and integration of sensors on RFID tags: In the case of food packaging application, the sensing capability of the tags is a huge advantage considering the perishability and sensitivity of most food materials; however the integration of the sensing element is a technical challenge and should also be examined as a food safety concern (Bibi et al., 2017).

Waste: One of the open questions regarding RFID technology in food packaging is its environmental impact. During the design of packaging and in the concept of product life-cycle management the handling of RFID tags or RFID sensor tags (and probably the collection after their use) has to be considered since adhesives, chips, pieces of metal from the antenna and conductive inks can affect the recycling process of paper, plastic, and metal (Bibi et al., 2017).

The sensitivity of tag readability to environmental conditions and influence of food composition: Differences in the reading range of UHF RFID tags are influenced by tag orientation, chemical composition, and temperature of the food product. The changes in readability due to environmental conditions must be taken into account in food packaging applications.

According to Barge (2019), these problems can be overcome by changing tag orientation. (Barge et al., 2019); (Bibi et al., 2017) (Meng and Li, 2016); (Mohebi and Marquez, 2015).

Interference caused by other wireless systems, or unknown sources and interference among different readers: The adoption of technology in new areas such as the food industry has its requirements in terms of experience and know-how. The introduction of the system, installation, configuration, and management needs professional knowledge. The technical issues of deployment related to the interference can be handled only with the help of extensive practical experiences (Bibi et al., 2017); (Meng and Li, 2016); (Weis, 2012).

Safety concerns (forgery, eavesdropping, privacy): Related to the deployment of RFID technology, several safety concerns arise. However, they are rather typical in the case of healthcare and medical applications or the case of "smart home" applications of RFID systems for the elderly, the technology enables access to the stored data on the RFID tag and the localisation of the tag leading to potential privacy concerns of the end-user. The more sensitive data are stored the more serious privacy concern could arise. Another question in connection with safety is the forgery, the imitation of tags to readers. For example, it is a potential threat in the case of anti-counterfeiting devices or access control (Meng and Li, 2016); (Tanner, 2016); (Weis, 2012).

RECOMMENDATIONS

In spite of the promise of active and intelligent packaging, several challenges lie in the way of it being more broadly adopted. To mitigate the barriers and to facilitate adoption, these areas are to be considered as the easiest to implement and to be acted upon with priority:

Develop a solid business case: As most active and intelligent packaging products are still in the early stage of development, there are no long-term proven successes, making it difficult to develop a solid and robust commercial business model for the product. Moreover, there is no sense of the total cost of ownership for smart packaging, nor is there any comprehensive estimate about the costs that the technology could take out of the supply chain or the value it could provide. The industry needs a comprehensive end-to-end value chain study that would include the final cost of the packaging solutions, where these solutions can be deployed, key customers most willing to adopt new packaging solutions, and where the technology has the maximum potential to provide a significant impact.

Need for new manufacturing techniques: Manufacturers will need to develop techniques for fabricating such sensors and indicators compatible with current packaging standards. Printing is one manufacturing technique that has received significant attention from the research and manufacturing community. GLOPACK has identified such methods for fabricating intelligent packaging to directly deposit electronics (sensors and RFID tags) on flexible substrates in an efficient, scalable, and cost-effective manner.

Sustainability: Some components of the intelligent packaging are not completely sustainable by nature of the sensing and RFID tag element, which are challenging to separate and recycle and do not snugly fit into the environmentally friendly expectations of consumers. It is essential to understand, measure and communicate the environmental impact of active and intelligent packaging components and their long-term viability. Solutions might include the use of easily detachable electronics that can be collected and recycled separately.

Reduce cost: Active and intelligent packaging solutions are not cheap, especially compared to more traditional packaging solutions such as fossil-based plastics, whose abundant thickness may compensate some of the barrier property requirements.

Privacy Issues: Security and data privacy issues are also top concerns for all communication systems that have remote read capabilities. This information must be protected against unauthorised use. Cryptography systems and blockchain are among the leading potential solutions to resolve these issues by storing information so that it cannot be read by anyone except the intended recipient and by making it difficult to tamper with its unique identifier.

Legislation: In particular, intelligent packaging's complex composition also creates legal complexity. Because it is made up of many different components, it may be subject to further regulations and legislation, e.g. extension of the WEEE Directive (European Community Directive 2012/19/EU on Waste Electrical and Electronic Equipment) once they become a common consumer good. On one hand, the legislation frameworks need to be flexible and easily updated to support and keep up with this highly innovative and fast-moving sector; also manufacturers need to adopt environmentally friendly

construction materials and manufacturing methods such as electrically conductive organic materials instead of metals, in sensors and antennae.

Proactively engaging with government agencies and regulators assists in building trust through carefully considered regulation to ensure physical risks are minimised, in addition acceptance can be provisional on comprehensive labelling. Communication methods may include commercials, advertising, media and social media. On the other hand, managing the precautionary principle by avoiding mandatory labelling and balancing the disclosure of the risks with the benefits may be necessary to avoid that risks and labelling be interpreted as a potential danger, which will consequently reduce willingness to purchase.

Consumer education and communication:

Consumer acceptance of active and intelligent packaging is not a well-researched area so there are many areas to investigate more deeply, such as a covering a broader geographical spread, understanding if the hierarchy of food needs explains the heterogeneous results relative to socio-demographic control variables, or understanding the diffusion of innovation theory explains the influence of curiosity and attitudes to innovation reflected in the acceptance of active and intelligent packaging.

If familiarity is low, education must play a significant part in the communication message. To target particular desired consumer groups, tools can be addressed by communication from regulatory bodies as well as manufacturers themselves and will influence consumers to a greater or lesser effect. Phrasing of communication needs to be carefully considered, as different phrasing can have significant impact on acceptance e.g., bacteria being perceived as bad even if prefaced with a "good" word like "protective", and this should be taken into account when developing communication strategies.

SUMMARY

A bright future may be anticipated for active and intelligent packaging. EU regulations have presented a new basis for the general requirements and specific safety and marketing issues related to active and intelligent packaging.

Consumers have detailed and complicated relationships with food, and primarily, their trust must be won, which improves attitude and reduces risk, particularly for consumers that have little knowledge or interest in the technology. Despite the hurdles that have to be overcome in the future, there is a strong view that active and intelligent packaging will be a marketing tool with high potential. Intelligent packaging technology will offer substantial potential as a marketing tool and the establishment of brand protection. Recognition of the advantages of active packaging technology by the brand owners, developing economically viable packaging systems, and increased consumer acceptance open new horizons and will become more commercially viable and commonplace in the coming years.

Over the last years, much progress has been achieved in improving the conversion yield, processability and end-user behaviour of bioplastics. These novel packaging will open new frontiers and opportunities for preserving the quality of food products and monitoring the status of product quality, saving fossil resources through biomass that regenerates and provides the unique potential for carbon neutrality. The biodegradability of the active and intelligent PHA/PHBV based bioplastic products developed within GLOPACK also offers the potential solution for controlling food waste and preventing fossil plastic leaking into the environment.

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