Sustainable packaging solutions to improve resource efficiency in supply chains of perishable products

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Abstract

The production of high quality and safe foods has increased steadily in recent years. At the same time, a sustainable food production gains in importance. Sustainability aspects include several different aspects, such as for example the energy efficiency of production and cooling plants, the logistic concepts, animal welfare aspects or the energy supply concepts. Especially the reduction of waste along the entire supply chain is increasingly discussed in public. The application of innovative packaging strategies can deliver an important contribution to reduce the amount of food losses and ensure sustainable food production. Different studies have shown that the losses can be reduced by the implementation of intelligent and active packaging strategies.

Keywords: sustainability, packaging, perishable products, food loss

Introduction

Due to the continuing globalization, the variety of fresh products in each time of the year has increased progressively. At the same time, food chains increase in complexity, transport routes become longer and the quality and safety requirements from the retailer and consumer side are rising steadily. Furthermore, sustainability aspects and especially the reduction of food waste gain in importance. These are particular challenges for the food processing-, logistic companies, the wholesaler and retailers. Precisely, those products that have short shelf-life and thereby shortened sellable periods are those that exhibit accelerated spoilage and are often discarded prior to sale or consumption [1], [2]. This is a problem for environmental, food security and economic reasons. Food and drink represent 20–30% of the environmental impact of all consumed products in Europe like clothing, communication, transportation and so on. Within the food products sector, meat and meat products cause the greatest environmental impact followed by dairy products [3]. Fresh meat belongs to the food category with a relatively short shelf-life and consequently, to the most wasteful products. Within the German poultry meat chain, for example, the rate of wasted fresh poultry meat is assumed to be 15.5% from the point of production to consumption. This percentage equates an amount of around 48 million kg/a of meat (calculation is based on the sales volume of fresh poultry at the retailer stage of 326,442,000 kg/a, 2015) [2]. In meat supply chains, the amount of food waste increases with each link in the chain until the consumer stage [4], [5], [6], [7]. The highest amount of food waste (6%) occurs at the consumer stage, followed by the retailer (5%). For the production of this amount of waste, approximately 52,629,070 animals have to be bred and fattened. The products themselves are lost as well as huge amounts of primary energy and other resources such as feed for breeding and fattening, water and packaging material for the processing of the meat [2], [4], [7], [8], [9]. This also results in unnecessary high volumes of greenhouse gases. Thus, for a sustainable food production the reduction of food waste at all stages of the meat supply chain is of vital importance.

There are several different causes for wasting meat products, such as wrong handling, so that the product is spoiled before the use-by-date is reached or a lack of effective monitoring technologies to determine the real quality and safety of a product. This leads to the fact that several food products are wasted at the retailer stage before the best-before- or use-by-date is reached, even if the products are stil

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in good condition since retailers are aware of critical food safety and quality parameters. Also, several products are thrown away because they are not sold during the short selling time, which means the length of shelf-life of the products has a significant impact on the amount of food waste.

The rate of spoilage depends on several different factors, like the product characteristic and ingredients, hygienic conditions during production and processing, the logistic structures, and especially the temperature and packaging conditions in the chain [1], [2]. The application of innovative packaging strategies can deliver an important contribution to reduce the amount of food losses and ensure sustainable food production. Different studies have shown that the losses can be reduced by the implementation of intelligent and active packaging strategies [1], [7], [10], [11], [12]. This review is focused on previous and recent innovations in the field of active and intelligent packaging solutions. The most promising developments are highlighted in the context of practical implementation and future requirements for packaging of chilled products.

Packaging strategies for chilled products

Intelligent packaging is defined as food contact materials which monitor the condition of packaged food or the environment surrounding the food [13]. Thus, intelligent packaging strategies can deliver information about the real quality status, the safety, the shelf life, and the history of the product. By improving the monitoring process on-line, the handling of the product is improved and thus also the shelf life. The technologies focus, for example, on the control of temperature or ethylene conditions, the detection of pathogenic bacteria or metabolic components produced by bacteria. Based on their area application, intelligent packaging solutions comprise gas sensors, biosensors, temperature indicators, freshness indicators and several more [13], [14], [15].

Various intelligent packaging solutions have been developed, but one of the first and promising systems of intelligent packaging is the so called Time-Temperature Indicator (TTI). Time-Temperature Indicators (TTIs) are smart devices or labels monitoring the full time temperature history of their closest surroundings. The temperature history of the product is displayed by an easy-to-read colour change. The colour changes of the labels are induced directly or indirectly by specific reactions that show strong dependencies on time and temperature. Typical reactions are enzymatic, chemical, mechanical, electrochemical, photochromic or microbiological. A basic requirement is the accurate adaptation of the TTI to the monitored product, meaning that the product kinetics should be similar to the label kinetics. With a precise match between TTI discolouration and the spoilage process of the food, the TTI gives information about the current status of the product. Thus, the label can be used as a freshness indicator; delivering information about the remaining shelf life of the product [16]. During the last years, several systems have been developed and are available or ready for the market, like the OnVu™ (Freshpoint BASF, CH; DE); Monitor Mark (3M, DE); Check Point (Vitsab, S); eO® (Cryolog, F); Freshcode (Varcode Ltd.) and Fresh Check (TempTime, USA) [15]. Specialised to the particular needs of their area of application, these labels are covering several reaction systems, different kinetics and display methods. Besides explicit visual changes of colour, also barcodes systems are used. They are based on fading inks which disappear after interruptions of the cold chain. The process of activation of the labels is conducted, e.g., via UV light or the removal of barrier layers between reacting compartments. Reactant compartments can be based on ink, metal compounds, such as aluminium and jellylike or fluid media. The differences in the handling before activation, the process of activation and the materials used have great influence on the price and applicability of the TTI. Printable labels, with a fast activation process and low price, are easier to include into the package production line and can be used on a single item base. In contrast, sophisticated systems come into consideration for more expensive products or on a higher packaging scale. Hence, each of the TTI systems has its own characteristics and advantages or disadvantages and must be chosen well-considered with regard to their usability, flexibility, costs and the specific needs of the food chain.

Although the concept of time-temperature indicators had slipped into the background, recent observation has shown that the quantity of indicators being developed as well as those already on the market is growing significantly. Besides the increase in the technologies, there is a flare up of discussions about the application of TTIs in the food industry and also on the political level. The discussion on the application of TTIs in cold chain management focuses on several subjects, such as the application as a Safety Monitoring and Assurance System (SMAS) at the industry level of the chain [17]. Furthermore, aspects of consumer acceptance, traceability and transparency within the supply chain as well as matters of legislation and liability issues are part of the discussion. One major potential of TTIs gained in importance during the last years: their contribution in reducing food waste in cold supply chains [7].

Different studies are confirming the positive effect of the application of intelligent labels to a more sustainable food production [1], [7], [10], [11], [12] by controlling the compliance of the cold chain, the quality and safety status of a product or other important environmental factors over the entire chain. Furthermore, the additional information delivered by the intelligent labels allows the participant of the chain to decide if the product can still be used after the ‘best before’ date and thereby leads to a reduction of waste in the cold chain especially at the retailer and consumer levels. But up to now, a broad application of such labels in the meat chain is still missing.

Another packaging strategy to prolong the shelf life of fresh meat products is active packaging. Active packaging strategies are based on an integration of devices or antimicrobial components in the package, which interact with the product itself or the internal gaseous atmosphere between the package and the food system [18]. These reactions are leading to an increase of food quality, safety and shelf life or to the improvement of sensory properties [19], [20], [21], [22], [23].

The first developments in this field took place in the 1970s. During the last years, several different active packaging solutions have been developed and are now available in the market. Different examples of active packaging materials have appeared in the market in Japan and in the U.S., whereas in Europe these packaging solutions are not widespread. Active packaging technologies need to be approved by regulatory authorities in countries and have to comply with specific regulations in each country [24], [25].

Up to now, less active packaging solutions for perishable products are available on market. Commercially important active food packaging for perishable foods are oxygen scavengers/absorbers and moisture absorbers/regulators, carbon dioxide emitters/generators and antimicrobials integrated in packaging materials.

O_2 scavengers/absorbers bind the residual oxygen within the packaging to prevent oxidation of food constituents. O_2 scavengers reduce and actively control the levels of oxygen, in some cases to <0.01% oxygen [19]. Therefore, the growth of aerobic bacteria such as *Pseudomonas* spp. could be reduced for example in ground chicken meat [26]. Oxygen scavenging systems for example also inhibit the discoloration of sausages. Most systems are based on an enclosing of reactive compounds such as iron powder within porous sachets. Other systems are based on ascorbic acid oxidation catechol oxidation, photosensitive dye oxidation, or enzymatic oxidation [27]. The first commercially developed oxygen scavenging sachets under the trade name Ageless® by Mitsubishi Gas Chemical Limited in Japan contained ferrous iron oxide which oxidizes to the ferric state [28], [29].

Moisture absorbers control the moisture in the packaging and removal the tissue fluid by packaged fresh meat, poultry or fish or condense water by packaged fresh fruits. Thereby the microbial growth in the liquids can be reduced [19]. These systems basically consist of a superabsorbent polymer located between two layers. These systems are placed under the food and comprise in principle a superabsorbent polymer which is incorporated between two layers [23].

An example for a release effect is the carbon dioxide emitters/ generators, which include additives to produce a steady stream of carbon dioxide inside the package. The production of CO_2 can be based on different chemical reactions, for example the reaction of sodium bicarbonate and citric acid with the moisture of the packaged food [30], [31]. The moisture can be absorbed for example in a cellulose pad containing the additives. CO_2 pads can be used in fresh meat, poultry and fish packages to increase the shelf life [30], [31], [32].

Especially in recent years, several scientific papers have been published in the field of antimicrobial packaging material and the contribution to the reduction of waste in the chilled food chains by prolonging the shelf life [1], [10], [11], [12]. Such an approach of packaging can decrease the spoilage rate by directly inhibiting the microbial growth or killing the microorganisms. Reduction of initial bacterial count of fresh meat by one $\log_{10}$ unit due to antimicrobial packaging material can result in prolonging the shelf life by several days.

Most of these antimicrobial materials are based on surface release strategies, meaning that a migration of antimicrobial agents into the food product and environment is required. Antimicrobial active agents can be integrated, for example, in soaker pads, trays, or films. In recent years, a variety of migrating antimicrobial agents have been investigated and developed for the application in packaging material. Typical agents are organic acids, bactericides, plant extracts, nano-silver as well as complexes of metals, used as single substance or in combination [2], [21], [25], [33], [34]. Antimicrobial metals are the most common migrating antimicrobial additives in food packaging due to their temperature and mechanical stability. However, it has to be considered that the release process and thus the activity of different agents are often reduced at cool temperature conditions, which are typical in meat and fish chains [35], [36], [37], [38], [39], [40], [41]. Furthermore, migrating antimicrobial agents like nano-silver may be enterec into the environment.

Another technology is the contact-killing based system for example by cationic polymers such as chitosan. The antimicrobial property of the polymer is possible due to the interaction between the positively charged chitosan molecules and the negatively charged microbial cell components resulting in the leakage of intracellular constituents and its work as chelating agents of essential minerals [42], [43], [44], [45], [46], [47], [48].

In contrast to migrating agents, they are intrinsic contact antimicrobials due to their chemical structure. SAM polymers for example are a new class of contact antimicrobials. The antimicrobial activity of these polymers is based on the three dimensional helical structure with a high concentration of protonated functional amino groups [49]. The protonation of the functional amino groups leads to electrostatic interactions between the positively charged polymer and the negatively charged surface of bacteria. The cytoplasmic membrane is depolarized resulting finally in cell death [50]. The relatively new polymer Poly(TBAMS), for example, can be compounded with different standard polymers on normal polymer production machines like extrusion and can be developed further into packaging solutions such as films and pads. The different kinds of packaging show a high antimicrobial activity against a wide range of typical spoilage organisms present in meat as well as pathogenic organisms [2], [51], [52], [53].

There is broad interest from industry to implement antimicrobial packaging material to prolong shelf life, but up to now there is nearly no material available, which leads to a significant increase in the shelf life of especially fresh meat.

Sustainable food production

The contribution of intelligent and active packaging strategies to a more sustainable food production is described in several papers. Conversely, the use of packaging material is more and more critically discussed at the consumer level. Consumers are skeptical about the contribution of packaging to more sustainable food production. They are especially critical about the huge amounts of packaging material, for example more than 600 Million packages per year are needed for the fresh poultry, which are sold in German retail shops, and about the use of natural resources and the emission of carbon dioxid to dispose these materials [2].

To reduce the amount of natural resources for the production and to reduce the high volumes of greenhouse gases for the disposal of these materials, the application of bio plastic strategies is more and more discussed during the last years. Bio plastics, and bio polymers, respectively, are fully or partly produced from natural or organic ingredients, biodegradable, or both such as starch blends or polylactid acid [54], [55], [56].

However, the properties of the materials like gas barriers or mechanical stability, which are necessary to ensure quality, safety and long shelf life times of perishable foods such as fresh meat products, are often not comparable to synthetic not biodegradable packaging materials [2].

Following the current discussion in the field of packaging and the contributions to a sustainable food production is sometimes contradicting.

Discussion and conclusion

The results of the different studies as well as the point of views are widely divergent. Another challenge is that the results of different studies in the field of innovative packaging strategies are often not transferable due to differences in product- and chain specific factors and economics aspects as well as cultural matters. Besides, it is still a challenge to evaluate in a standardised way the right balance between the application of packaging material (including use of natural resources for the production and recycling of the material) and the amount of food waste and the economic aspects. The main problem at this point is up to now that a standardised evaluation sheet is missing, which would allow assessment of the real contribution of new packaging strategies to a sustainable food production. In such a standard, it is important to consider the three pillars of sustainability: environmental aspects (life-cycle assessment and the reduction of food waste, …), social aspects (cultural aspects, acceptance of the food industry and consumer, …) and economic aspects (costs and legislation, …) [2].

Furthermore, to achieve the described positive effects of the new packaging strategies on food waste reduction, open communication between all actors within the food chain and packaging industry and the identification of causes for food waste in the different food chains is necessary. This means that for the development and implementation of new packaging strategies close cooperation with the packaging-, chemical-, transport, food-, recycling and reuses industries and the consumer is important. Thereby, product and chain specific requirements have to be considered. By taking the different aspects into account, different active, intelligent and bio plastic packaging solutions can deliver an important contribution to a sustainable food production.

But it has to be kept in mind that it will never be one single packaging solution for a specific chilled product group which will achieve the overall and the highest level of sustainability in all aspects. Case to case decision is necessary under consideration of the above mentioned aspects. Thus, future research will focus on application scenarios and Decision Support Tools for the particular product and chain needs. Besides further developments of the innovative tools, a comprehensive approach for implementation in praxis is needed.

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