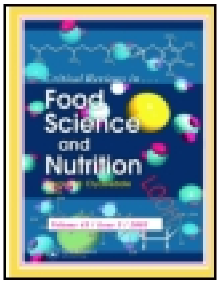

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Monitoring the qualityof perishable foods: opportunities forintelligent packaging

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Monitoring the qualityof perishable foods: opportunities forintelligent packaging

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Abstract

This review paper discusses opportunities forintelligent packaging ~~in the context of~~for monitoringdirectly or indirectly quality attributes of perishable packaged foods. ~~It is discussed~~The possible roles of ~~how~~ intelligent packaging ~~can be used~~ as a tool in supply chain management ~~to deliver high quality food products to consumers~~are discussed as well as the barriers to implement this kind of technology in commercial applications.Cases on pasteurized milk and fresh cod fillets illustrate the application of different intelligent packaging concepts to monitor and estimate quality attributes.Conditions influencing quality (e.g. temperature-time) can be monitored to predict the quality of perishable products when the initial quality is knownand rather constant (e.g. pasteurized milk). Products with a highly variable~~tion in~~ initial quality (e.g. fresh fish) require sensors monitoring compounds correlated with quality.

Keywords

Intelligent packaging, food quality, perishable foods, sensors, indicators, supply chain management

Introduction

The basic functions of a food package are containment, protection, convenience and communication (Robertson, 1993). Thecommunication function of packagescan be greatly extended in the future:Packagescan inform consumers about allergy, nutritional preferences or discounts; the package of a ready-to-eat meal can control the microwave; and the freshness of a perishable product can be read-out from the package. This article reviews the state of the art of intelligent packages that give information about the quality of the packaged food within the supply chain. The possible application of intelligent packaging for perishable foods is further illustrated for two cases: pasteurized milk and fresh cod fillets.Suggestions are given to select the type of intelligent packaging for different types of foods.

Denomination

Intelligent packaging (IP) can be defined in many ways.Yam et al. (2005) defined it as "a packaging system that is capable of carrying out intelligent functions (like detecting, sensing, recording, tracing, communicating, and applying scientific logic) to facilitate decision making, to extend shelf life, enhance safety, improve quality, provide information, and warn about possible problems".~~Smart packaging is used often interchangeably with IP, but is also used for active packaging(packaging that contains a component that actively protects the food by changing conditions, e.g.,scavenging of oxygen).We propose to use the term smart packaging for the combination of intelligent and active packaging (AP).~~In this article IP is considered as packaging that monitors conditions of food during its life cycle to communicateinformation related to the quality of the product.

IPcontains sensors or indicators to estimate and communicate quality of a food product to users. The terms sensors and indicators are often used interchangeably, but we make a distinction: A sensor only measures certain aspects, whilst an indicator integratesmeasurement and display. Sensors have to be connected to a separate device to transduce the sensor signal to an observable response, while an indicator directly provides qualitative or semi-quantitative information about quality by a visible change. For example, a pH electrode is considered a sensor and pH indicator paper is considered an indicator.

Product quality can be described as "meeting or exceeding customers' expectations" (Luning et al., 2002). Product quality can be described by quality attributes. Product attributes are turned into quality attributes by the perception of a consumer.Intrinsic attributes are directly related to the physical product properties and involve (for consumers) safety, nutritional value, shelf life and sensory properties, convenience and product reliability(Luning et al., 2002).

Intelligent packaging types

Several authors have described developments in IPfor foods and their principles of operation(Han et al., 2005; Yam et al., 2005; Kerry et al., 2006) and about the legislation (Dainelli et al., 2008). In short there are three types of indicators and sensors used for IP:

Environmental conditions: This type monitors conditions that influence the kinetics of changes in quality attributes of the food, e.g. time-temperature indicators,gas leakageindicators, and relative humidity sensors. These devices might be attached inside or outside the package, depending on the condition monitored. Information on the conditions can be translated with mathematical models to predict quality of foods inthe supply chain. However, these predictions can only be reliable when the initial quality (defined as: quality status of the food on the moment right after packaging at the manufacturer) is known and rather constant.

Quality attributes or quality indicator compounds: The second type of devices ~~are placed inside the package andthese~~monitors quality indicator compounds of the product itself that change due to changes in the product. Direct quality sensors, e.g. biosensors and freshness sensors and indicators, measure quality-related compounds formed in the product (or micro-organisms in/ on the product) and are good direct indicators of food quality attributes.These devices are usually placed inside the package but some could also monitor certain properties indirectly from the outside e.g. by an optical system.

Data carriers: The third type of devices are data carriers and other information devices that are used to increase the efficiency of information flow and effective communication between the product and the consumer. Devices include barcode labels and radio frequency identification (RFID) tags and other product traceability, anti-theft, anti-counterfeiting and tamperproof devices belong to this group (Yam et al., 2005).

Figure 1 illustrates IP concepts containing sensors or indicators from the first and second type, whichmonitor environmental conditions, or quality attributes of the product related with overall food quality change.

Figure 1

IP monitoring quality attributes

Many intrinsic product attributes of foods can be checked during processing and remain constant in most products during the whole supply chain until consumption (e.g. mineral content). Some intrinsic attributes of highly perishable foods always change after processing. This can result in an increase in the quality performance (e.g. ripening of fruits improves sensory properties up to a certain level), or a decrease in the quality performance (e.g. microbial spoilage). These product attributes are often difficult to estimate by consumers. Besides, the reaction rate of the changes is influenced by several factors (Van Boekel, 2009). Other quality changes only ~~do not~~occur with a low frequency ~~always~~ (e.g. food safety issues), ~~but~~ theyare the result of occasional defects in product composition, packaging or environmental conditions. Consumers implicitly expect certain quality attributes, like product safety or packaging integrity, to be obvious(Luning et al., 2002).~~,therefore t~~These product attributes usually cannot be ~~estimated~~ perceivedby consumers~~(Luning et al., 2002)~~. When changes happen after processing the quality attributes will normally not be monitored in the supply chain. Consumers or retailers have difficulties in estimating quality, since they cannot estimate certain quality attributes while the food is in the package. IP can be used to give consumers and retailers a tool to estimate quality attributes that are difficult to estimate and thereby IP can assist in assuring~~e consumers of~~good product qualityto consumers (Figure 2).

Figure 2

Role of intelligent packaging in supply chain management

The quality of food productsduring their life cycle changes since foods are perishable by nature. Product properties and the related intrinsic quality attributes of food products are susceptible to various deterioration processes andquality defects may be due to different mechanisms and depend on the type of food product, the package and the conditions in the supply chain. Moreover, agricultural products are often heterogeneous with respect to various quality parameters, since variation is caused by many variables like seasonal and local differences. On the other hand, consumers are demanding for more convenient, less processed and fresh, constanthigh quality food products. This complexity necessitates quality control of food products during and after processing. IP can be used as such a tool in supply chain management to monitorthe established quality requirements and inform and provide confidence to the next customers in the supply chain and consumers at the end.If IP can be combined with AP ina smart packaging, new possibilities arise to extend the shelf life and improve the quality of foods. Figure 3 shows how the package can be used for adaptive quality control: the quality can be monitored by the IP and corrective actions can be taken automatically by the active packaging component (e.g. IP monitored gas composition and AP absorbs/emits gas to maintain optimal gas composition in respiring fruits).

Figure 3

For perishable foods the quality changes fast along the supply chain. QACCP (Quality Analysis Critical Control Points) is a novel tool to support supply chain management to take technological actions in a food chain to realize a desired quality performance(Verkerk et al., 2007). IP can complement quality assurance systems to support managerial decisions along the supply chain. QACCP can be used to identify processes that strongly affect the quality attributes and to efficiently improve the final food quality. Mathematical models can describe and predict changes in quality along the chain by modeling the relationship between environmental conditions and quality attributes (Van Boekel, 2009). These models require input data to make predictions. This is where IP can help quality assurance: IP monitors environmental conditions, or quality attributes of the product related with overall food quality change in the supply chain.

An advantage of IP as a tool in quality assurance is that environmental conditions can be monitored close to the product and the history can be seen directly from the product. Monitoring quality attributes directly has the great advantage of being able to incorporate variation, which is inherent in many foods since raw materials vary in their composition and many environmental conditions change over time. Sensors that measure external conditions, like Time Temperature Indicators(or Integrators) (TTI), have the advantage that they can be applied on many products. TTI are cheap and reliable IP concepts that can be adapted to the temperature sensitivity of the quality changes of specific food products(Shimoni et al., 2001). However, measuring environmental conditions is only related to the change of quality attributes and therefore, if the initial quality of the product is not known and constant this information is of limited value. This is not always described correctly, because temperature indicators are sometimes described as quality indicators, without mentioning the necessary analysis of initial quality.

Mathematical modeling is important in the development of IP concepts to translate the sensor signal in prediction of the quality or the remaining shelf life of the food product. Knowledge of kinetics of reactions that influence the quality of food is necessary to model the relation between sensor data and food quality status. Figure 4displays the approach that is needed to predict the quality of food, dependent on the type of sensor.

Figure 4

Despite the potential roles of IP in supply chain management the implementation of the IP in commercial applications is still limited. Although initial concepts are available in Japan from 1970's, commercial uptake in the USA and Europe only started in the mid 1990's. The market for was estimated at $ 1.4 billion in 2008 and is expected to grow to $ 2.3 billion in 2013 (Restuccia et al., 2010). The commercial uptake of IP in the EU was described to be limited due to cost aspects and industry and consumer acceptance of this technology. Especially consumers do not perceive strongbenefits of IP and are not prepared to pay extra for this feature (Dainelli et al., 2008). In Table 1 an overview is given of intelligent packaging applications for quality control (adapted from Ahvenainen, 2003).

Application of intelligent packagingtohighly perishable food products

IP might be used as a tool in supply chain management. Since foods are complex products, it should be considered per product type whether IP can be worthwhile or not.IP will increase packaging costs (Dainelli et al., 2008), thereforeit will be profitable if the income from increased sales and/or reduced wastage will be higher than the increased costs of the package.This makes the price and the shelf life of the food important criteria for applying IP. In Figure 2we already concluded that products with relatively stable intrinsic quality attributes and long shelf life will hardly take advantage of IP. Examples of suchproducts are soft drinks, canned products and sweets.

Foods that will benefit the most from IP are expensive, highly perishable foods, especially if consumers cannot estimate their essential quality attributes.Dada and Thiesse(2008) studied the impact of novel sensor-based policies on product quality in the supply chain of perishables. They found that the classical 'First-In-First-Out' (FIFO) policy is not the best policy for perishables. In most cases the Lowest Quality First Out (LQFO) showed to be the best policy with the lowest percentage of unsold items.Policies that rely on automatically collected expiry dates and product quality bear the potential to improve the quality of items in stores (Dada and Thiesse, 2008).

In the next section we will discuss the application of IPto monitor quality of highly perishable foods.To illustrate thisfor two very different products in terms of price and control of initial quality p~~P~~asteurized milk and chilled fresh fish will be taken as case studies. First the product specific quality development and factors influencing quality development are described.Subsequently considerations whether to measure quality attributes or external conditions are given and possible sensors for monitoring quality developmentare discussed.

We will not discussIPthat monitors food safety. Safety is an essential quality attribute, but consumers demand safe food and will not negotiate with food producers about this quality attribute (Botta, 1995). We will focus on IP monitoring freshness of foods.Freshness is an essential quality attribute of perishable foods andthis quality attribute of perishable foods always changes after processingas is discussed in the cases.

Case 1: Pasteurized milk

Changes in intrinsic quality attributes

The quality ofpasteurized milk can be controlled quite well by processing conditions. Pasteurization is used to increase shelf life by destroyingenzymes and micro-organisms, but heat resistant spores and recontaminationmake pasteurized milk still highly perishable. The cold storage of pasteurized milk may result in defects and off-flavors caused by psychrotrophic micro-organisms after some time. Without contamination, pasteurized milk is generally spoiled by enzymes from*Bacillus* species (Ternström et al., 1993). If the milk is recontaminated after pasteurization, deterioration is generally faster and caused by the formation of bitter peptides and rancidity from enzymes produced by *Pseudomonas* spp. (Ternström et al., 1993). Uncooled recontaminated milk often becomes sour from the production of lactic acid by lactic acid bacteria.

The keeping quality of pasteurized milk is determined by raw milk quality, pasteurization conditions, extent of recontamination, storage temperature, and effect of light. The shelf life of pasteurized milk varies greatly between different countries (Antonelli et al., 2002), but if machinery is working properly and microbial growth and enzymatic action in raw milk is controlled, it can be assumed that the quality of pasteurized milk from the same factory is uniform, due to mixing large amounts of raw milk, standardization and pasteurization. By sampling batches of pasteurized milk this initial quality can be quantified.

Approaches for intelligent packaging for pasteurized milk

Temperature sensors and indicators

Increasing the temperature increases the growth-rate of micro-organisms and reduces shelf life of milk, as is the case for most perishable products. In general, every 2 °C increase of storage temperature, reduces the shelf life of pasteurized milk by 50% (Rysstad and Kolstad, 2006). The actual cold chain varies considerably between countries and regions, but also within different steps in the supply chain (Rysstad and Kolstad, 2006). Usually estimates of a weighted average temperature or a worst case temperature exposure are taken for shelf life estimations. Deviations from these estimated temperaturescan result in food products with unacceptable quality before the end of shelf life (in case of temperature abuse), or discard of foods of good quality (if too conservative temperature estimateswere used). The prediction of quality status and remaining shelf life becomes more accurate ifthe rate of quality deterioration is estimated from a monitored temperature history of the food during the supply chain. This can be done with temperature-sensitive food quality sensors and indicators. TTI are small tags or labels attached onto a package that show a readable, time- and temperature-dependent irreversible change that reflects the full or partial temperature history of a food product or package from the point of manufacture to the end-consumer(Taoukis and Labuza, 1989).Full history TTI give a continuous temperature-dependent integrating response throughout a product's history and can be used to predict the freshness of food, especially when microbial growth is the major deterioration mode of the food (Shimoni et al., 2001).However, a TTI can only predict a quality or freshness status if the initial quality is known, otherwise only prediction of the quality change is possible, as described earlier in Figure 4, but this is the case for pasteurized milk. TTI provide visual indications by a colorchange, diffusion of a dye along a straight reference line or mechanical deformation. The mechanisms of TTIcan be based on a polymerization, diffusion-based or enzymaticreaction(Kerry et al., 2006). The change of the TTI must be irreversible and correlate well tothe quality deterioration rate of the food(Taoukis and Labuza, 1989), i.e.the temperature dependencyof the TTI and the deterioration reaction should besimilar.Fu et al. (1991) studied the application of TTI for monitoring spoilage of dairy products, including milk, and concluded that the application of TTI for dairy products is feasible.

Freshness sensors and indicators

Ideally, a quality indicator for packaged food indicates direct spoilage or freshness by measuring compounds that are produced or consumed in reactions that determine the quality of the food. These freshness sensors and indicators have the advantage that a constant initial quality is no longer a requirement for accurate estimation of the quality (de Jong et al., 2005).

Winquist et al. (1998) described an electronic tongue on the basis of voltammetry for monitoring the freshness of milk. The electronic tongue contains 5 electrode wires of different metals that have different selectivity for the target components in milk. The output pattern of the 5 different sensors needs to be analyzed with pattern-recognition software to give an analysis of all relevant components, for practical application of this sensor the software needs to be integrated with the package. This device was used to follow the deterioration processes in quality caused by microbial growth in milk at room temperature. Voltammetry can be used, because electroactive species are both consumed and generated during these processes and the pH of the solution will also change(Winquist et al., 1998). Sim et al. (2003)also described a disposable taste sensor based on screen-printed disposable lipid membrane strips. With PCA (Principle Component Analysis) plots based on the sensor signals different stages of the ageing process of milk can be distinguished.Also electronic nose technology can be used for measuring the freshness of milk, by monitoring volatile compounds,direct contact with food not beingnecessary (Labreche et al., 2005).

Milkcan become sour from produced lactic acid or by the formation of free fatty acids by lipolytic enzymes. This souring can be indicated by a pH sensitive indicator dye.pH is a better quality indicator for raw milk than for pasteurized milk, it is however not a very sensitive signal due to the buffering capacity of the milk (Antonelli et al., 2002).

Biosensor

A biosensor is a device that is used to analyzethe concentration of a specific target component with a biological sensing element. A biosensor converts a biologically induced recognition event (e.g. based on anantibody, enzyme or microorganism) into a detectable signal, via a transducer and a processor(Terry et al., 2005). A disadvantage of biosensors in IPis that they oftencannot continuously monitor the quality of the food. Advantages of using biosensors are their specificity and sensitivity, however some reactions will be induced only at the surface of food in contact with the sensors, which reduces the sensitivity in solid foods.

A disposable microbial based potentiometric biosensor for determination of urea levels is described for quality control in milk (Verma and Singh, 2003). An immobilized microbe, that produces urease in the presence of urea which hydrolyzes urea to ammonium, is coupled to an ammonium selective electrode (Verma and Singh, 2003). Recently, several biosensors for determining the concentration of lactose in milk are described in literature, most based on (multiple) enzymes and electrodes(e.g. Stoica et al., 2006; Marrakchi et al., 2008).However, changes in urea and/or lactose do not reflect quality attributes that influence consumer acceptabilityof a pasteurized milk product. Both types of biosensors are more interesting for monitoring quality during processing and for management purposes than for application in IP.

Schmidt et al. (1996)described abiosensor for milk based on an oxygen electrode that measures oxygen consumption by respiratory activity of the immobilized micro-organism *Arthrobacternicotianae* that degrades short chain fatty acids ($C_{4:0}$-$C_{12:0}$) that are produced by lipolysis of milk fat and can be used as a quality index of milk (Antonelliet al., 2002).

Many immunosensors containingspecific antibodies against pathogens are developed for food safety applications (Ricci et al., 2007).Examples, applied on milk, are immunosensors to detect*Listeria monocytogenes*(Crowley et al., 1999),*Salmonella typhimurium*(Lakshmanan et al., 2007) and*Staphylococcus aureus* ssp. (Huang et al., 2008).Since this review focuses on food quality rather than safety these biosensors are not discussed further.

Case 2: Fresh cod fillets

Changes in intrinsic quality attributes

Freshness is an essential quality attribute of fresh fish (Ólafsdóttir et al., 1997). The major changes in the eating quality of iced cod (0 °C) are initially due to thedegradation of adenosine triphosphate (ATP)through the following pathway(Venugopal, 2002):

ATP → ADP → AMP → IMP → inosine → hypoxanthine → xanthine → uric acid

The formation of inosine is a fast process caused by endogenous enzymes present in the fish muscle (Huss, 1995). The oxidation of hypoxanthine to xanthine and to uric acid proceeds much slower and is catalyzed bybacterial enzymes(Venugopal, 2002).A strong correlation exists between the nucleotide loss andfreshness, since IMP is responsible for the characteristic fresh fish flavor(Huss, 1995).

After a period of neutral flavor, off-flavors and softer flesh from bacterial activity determine the eating quality of fish (Herbert et al., 1971; Huss, 1995).The initial number of microorganisms varies greatly; A normal range of 10^2-10^7 cfu/cm^2 on the skin surface and between 10^3 and 10^9cfu/g on both the gills and the intestines have been reported(Huss, 1995).Not all micro-organisms initially present on the fish contribute to the spoilage.The specific spoilage organisms (SSO) are the micro-organisms that produce the spoilage metabolites that cause the sensorial rejection of the fish(Dalgaard, 1995). *Shewanella putrefaciens*is the SSO of aerobically stored cod at 0 °Cand*Photobacteriumphosphoreum* is the SSO of MAP cod stored at 0 °C(Dalgaard, 1995;Gram and Huss, 1996; Gram and Dalgaard, 2002). Above 5°C *Aeromonas spp*. becomes important for spoilage for fish packed under normal or modified atmosphere.The most important spoilage compounds produced by the SSO are volatile basic nitrogen compounds (TVB-N), sulphur containing compounds, hypoxanthine, aldehydes and ketones(Fraser and Sumar, 1998). Absence of these components indicates freshness. The end of shelf life of fresh cod is usually reached when spoilage related sensory attributes such as trimethylamineand rotten odor from microbial origin lead to rejection of the fish (Huss, 1995,Gram and Huss, 1996).

Approaches for intelligent packaging for fresh cod fillets

Temperature sensors and indicators

Proper chilling is important to delay autolytic and microbial activity that deteriorate fish freshness and quality. An increase in the temperature from 0 to 3 °C doubles the spoilage of chilled fish, and an increase to 10 °C accelerates the spoilage by a factor of 5-6 (Venugopal, 2002). Taoukis et al. (1999) and Giannakourou et al. (2005) studied application of TTI for fresh tropical fish. Modeling of the temperature dependence of the shelf life was done by describing the effect of temperature on growth of the SSO *Pseudomonas* spp. and *S. putrefaciens* and by correlating the bacterial count to the organoleptic quality(Taoukis et al., 1999).A kind of TTI based on the enzymatic conversion of hypoxanthine that closely matches the kinetics for loss of freshness has been developed (Watanabe et al., 2005).

The initial quality of fish, however, is highly variable(Venugopal, 2002). The quality of packed cod leaving the factory will therefore be variable and uncertain. This makes it difficult to predict the spoilage of individual fish products accurately with an indirect quality sensor as the TTI.

A temperature sensor might be used to predict the remaining shelf life if the initial quality of individual packages with cod is known and can be incorporated in the prediction. Seafood Spoilage and Safety Predictor (SSSP) (www.dfu.min.dk/micro.sssp/) is software that contains relative rate of spoilage (RRS) models based on the growth of SSO to predict shelf life at different storage temperatures. The software enables combining temperature profiles from electronic data loggers and analysis of the initial quality attributes from sensory or instrumental methods to predict remaining shelf life(Dalgaard et al., 2002).Variables like CO_2 concentration, initial SSO concentration and T are used by models to describe the effect of storage conditions on the growth of SSO.

A TTI/RFID tag that uses a micro-chip to sense and integrate temperature over time (Yam et al., 2005) gives the potential to access the data remotely and makes optimization of supply chain management and connecting temperature data to initial quality determination more easily. Electronic temperature loggers allow for more flexible translation of the temperature profile into

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quality by software instead of (bio)chemical reactions of TTI. TTI for fish would only be applicable if the initial quality of the fresh fish can be better controlled.~~, for example in the case of farmed fish.~~

Freshness indicators and sensors

Sensors or indicators for estimating the freshness of fish that are based on volatile compounds are promising. In the post-mortem muscle, the TVB-N level increases in time and off-flavors are responsible for decreasing sensorial quality of fish. Ammonia (NH_3),dimethylamine(DMA) and especiallytrimethylamine (TMA) contributes most to the TVB-N level. TMA is formed from the bacterial reduction of the odorless compound trimethylamine oxide (TMAO) found in the fish muscle of many marine fish species, including cod (Gram and Huss, 1996; Gram and Dalgaard, 2002).TMAis a good indicator for the spoilage of fish, since this compound is related to the microbial spoilage and related to the sensory quality of fish since the compound is responsible forthe characteristic ‘fishy’ off-flavor.The correlation between TMA and eating quality has been reported to be excellent (Huss, 1995). The TMA yield of *P. Phosphoreum* is 30x higher compared to *S. Putrefaciens*, so a smaller bacterial count can obtain higher TMA values and cause spoilage in MAP-packed fish at lower bacterial counts compared to aerobically stored fish(Dalgaard, 1995). When stored aerobically 10^8-10^9cfu/g of *S. Putrefaciens* are required to cause spoilage of iced fish, in CO_2-packed fish 10^7*P. Phosphoreum*are required (Dalgaard, 1995; Debevere and Boskou, 1996).

Pacquit et al. (2007) developed an in-package pH color indicator that monitors spoilage of fish. The indicator color changesby a pH increase caused by the release of volatile amines, which correlatedat room temperature with the changes in total viable count and *Pseudomonas* spp. in cod (Pacquit et al., 2007). However, the indicator changes color when the fish is spoiled, therefore it cannot be used to predict the remaining shelf life.

The sensory quality of fish largely determinesrejection of fish by consumers. Sensory properties can be determined with panels and sensory analysis. Quality Index Method (QIM) is a scoring system for freshness and quality estimation of fishery products (Bonilla et al., 2007). Electronic noses aim to imitate the sensory analyses by simulating the sense smell. (Olafsdottir, 2005) studied the use of electronic nose as a rapid technique to detect volatile compounds like CO, H_2S, NO, SO_2 and NH_3 related to quality changes during chilled storage of different fish species, including cod. The complex data-analysis needs to be integrated with the sensor on the package to enable practical applications.

Biosensors

The development of biosensors for fish quality was reviewed by (Venugopal, 2002). However, these biosensors use extracts of a fish sample, therefore the required non-destructive analysis inside a package is not possible.

Gas indicator

Modified atmosphere packaging (MAP) is often used to extend the shelf life of fish(Sivertsviket al., 2002). Gas indicators in the form of a label or printed on packaging films can monitor changes in the gas composition to indicate integrity or to assure O_2 scavengers function properly(Mills, 2005). Most indicators are based on color change as a result of a chemical or enzymatic reaction (de Jong et al., 2005), like CO_2-sensitive indicator strips. The color changes only when the CO_2 is below a thresh-hold. A problem using a CO_2 indicator for a leakage in MAP is that microbial growth can compensate for the CO_2leakage (Smolander et al., 1997). In future, gas indicators can be integrated with RFID tags to allow distant monitoring (Yam et al., 2005).

Conclusion and future research

The ~~To optimize supply chain management,~~ dynamic information about the quality status of foods supplied by IPcan~~is~~ contribute substantially to the optimization of supply chain management.~~vital.~~ Expensive, highly perishable foods are the most important target group for IP, because the intrinsic quality attributes of highly perishable foods change fast after processing and cause important economic losses. IP will only be profitable if the income from increased sales and/or reduced wastage exceeds the increased costs of the package. Quality deterioration is specific for each product type, therefore IP concepts have to be tailored to different perishable foods. IP concepts that monitor environmental conditions like temperature are most suitable for foods that have a known and constant initial quality. Foods with variable initial quality require IP monitoring quality attributes or compounds correlated with quality attributes. The decision tree for choosing IP is illustrated in Figure 5.

Figure 5

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For the application of IP in the cases discussed (pasteurized milk and fresh cod), the overall quality and freshness is influenced most by temperature. TTI can give reliable predictions of freshness of pasteurized milk because the quality of the product at the moment of packaging is relatively constant. The kinetics of the TTI should ideally be similar to the kinetics of the main deterioration reactions influencing the eating quality of the milk, which is microbiological activity. An advantage of the use of TTI is that they are relatively cheap. The initial quality of fresh cod fillets,on the other hand, is highly variable at the moment of packaging. Therefore this fish product requires sensors monitoring compounds correlated with quality. Sensors monitoring volatile compounds, like TMA, can be used to predict the spoilage of individual fish products.

Indirect quality indicators, like TTI, can give more reliable estimation of the quality of a food if several IP concepts are combined. A multi-sensor can give more information about complex spoilage changes than sensors or indicators based on monitoring one single quality indicator compound.If IPiscombined with AP, further improvements for maintaining high quality of perishable foods could be realized. IP devices could monitor the quality or the conditions of the food and take decisions for corrective actions of the AP device.

Further research is necessary to develop low cost indicators and micro-sensors. Food specificmathematical models need to be developed for translating themeasured informationwith the quality perception of the consumer.

When these issues have been tackled intelligent packaging offers an enormous potential for commercial applications to improve supply chain management and guarantees for product quality for consumers.

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Tables

Table 1: Overview of intelligent packaging concepts for quality control (adapted from Ahvenainen, 2003)

Indicator	Principle	Information	Application
TTI (external)	Mechanical Chemical Enzymatic	Storage conditions	Chilled and frozen foods
Oxygen (internal)	Dyes (redox, pH) Enzymatic	Storage conditions Leakage	MAP packed foods
CO_2 (internal)	Chemical	Storage conditions Leakage	MAP packed Foods
Microbial growth (internal/external)	Dyes (pH or reacting with volatile or non-volatile	Spoilage	Meat, fish, poultry, etc.

	metabolites		
Pathogens	(Immuno) Chemical methods	Pathogenic safety	Meat, fish, poultry, etc.

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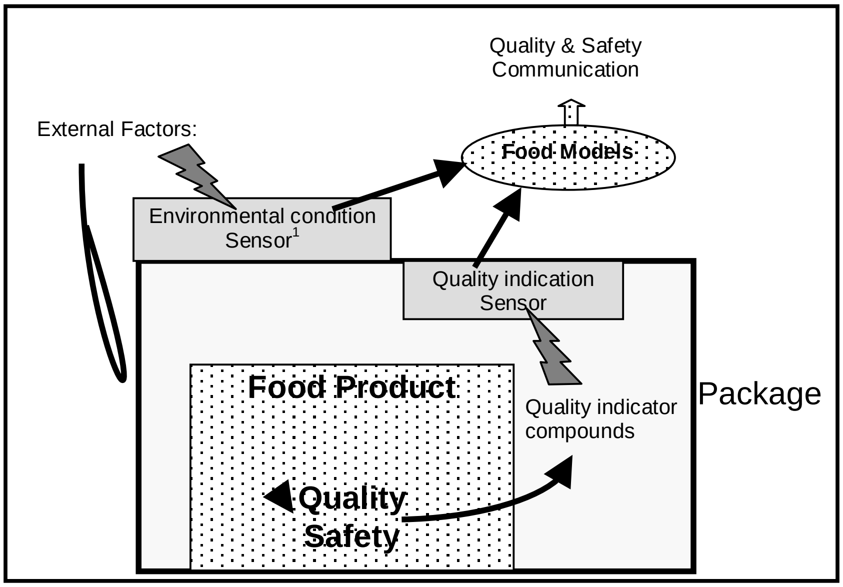

Figure 1: Schematic illustration of IP with sensors that monitor environmental conditions, or quality attributes of the product related with overall food quality change.

Note 1: Environmental condition sensor can also be placed inside the package, depending on the measured condition.

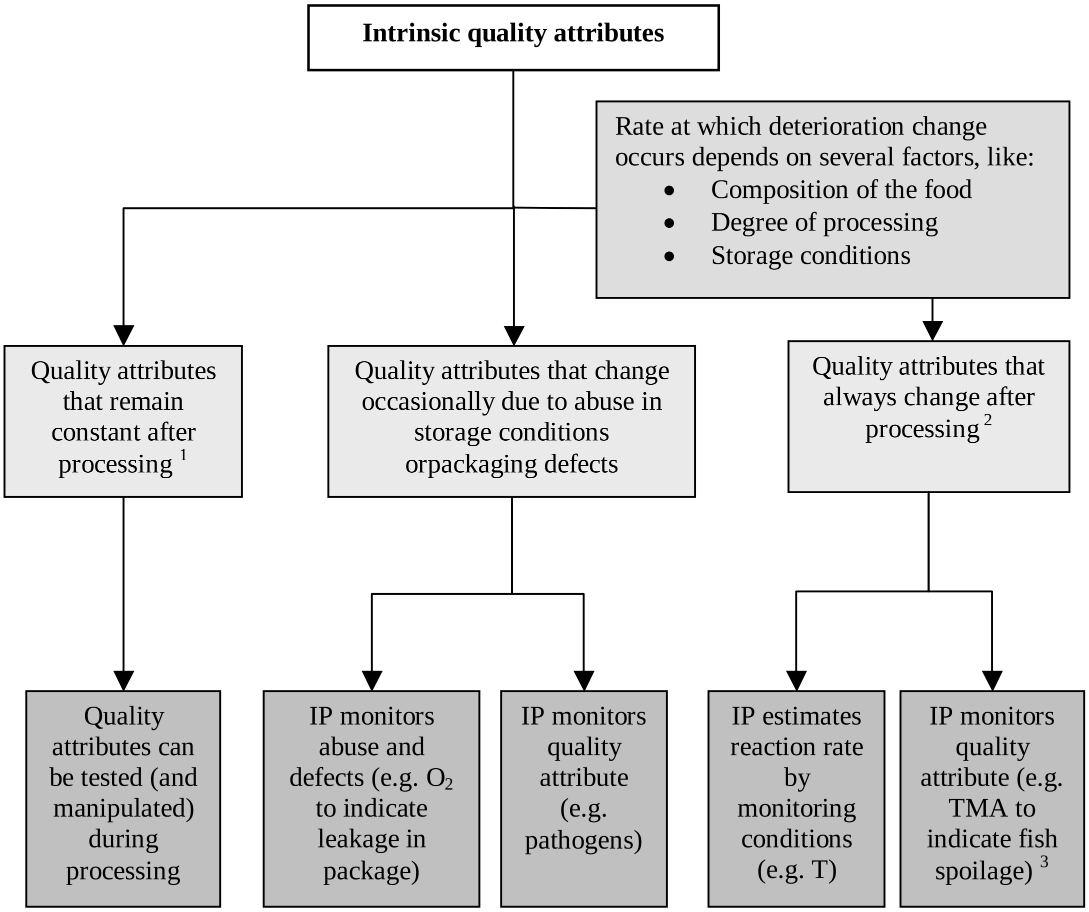

Figure 2: Overview of use of Intelligent Packaging to communicate about quality attributes.

Note 1: Whether a quality attribute changes after processing or not, depends on the food type and the shelf life. For example, the quality attribute ‘nutritional value’ of fresh fish will not change much during it’s life cycle, since the sensory changes happen much faster and are rate limiting for the shelf life of the product. Therefore nutritional value is considered stable in fresh fish, although lipid oxidation can become important (rate-limiting) in fish with longer shelf life.

Note 2: Some quality attributes can be estimated well by consumer, e.g. color of banana indicates ripeness, in this case there is no need to monitor this quality attribute by an intelligent package.

Note 3: To monitor a quality attribute, product properties that can be measured in a non-destructive way in the package must give a good indication of the quality attribute.

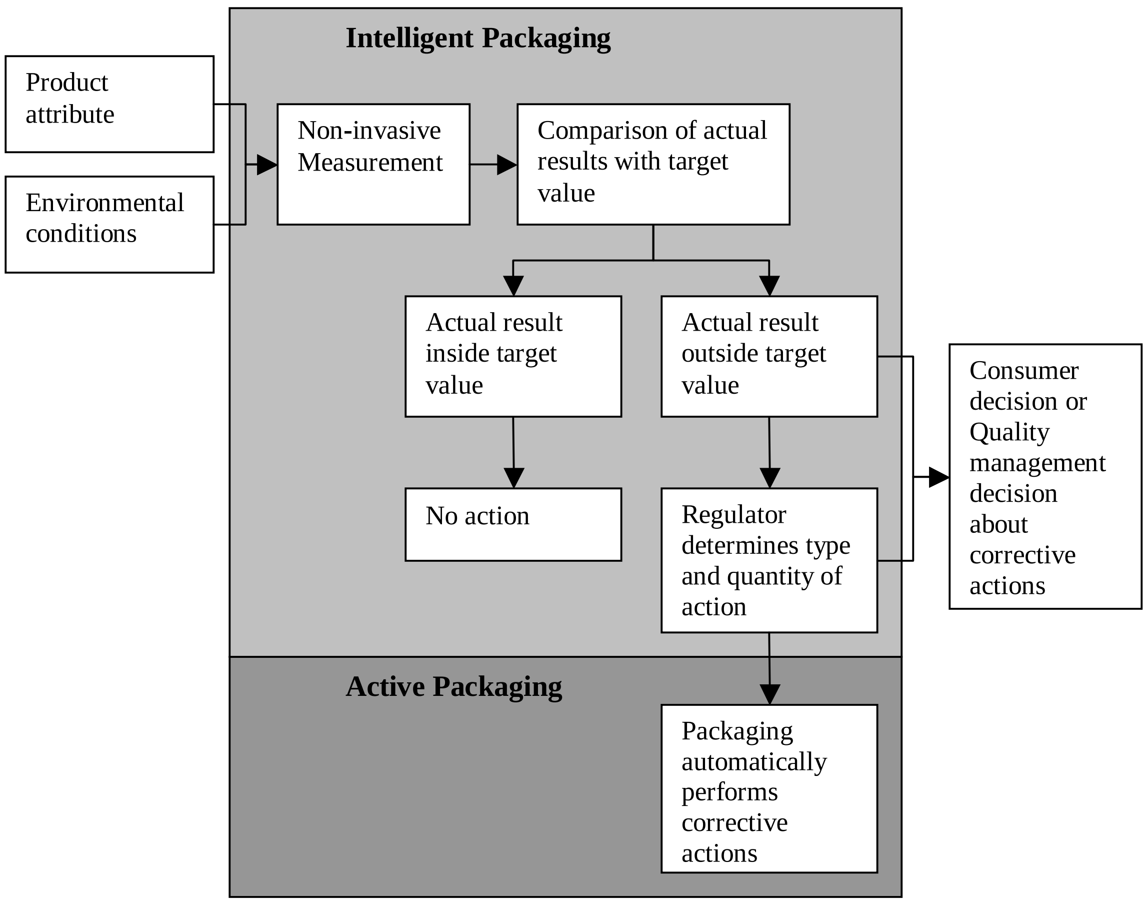

Figure 3: Role of intelligent packaging and active packaging in quality control of food products after processing.

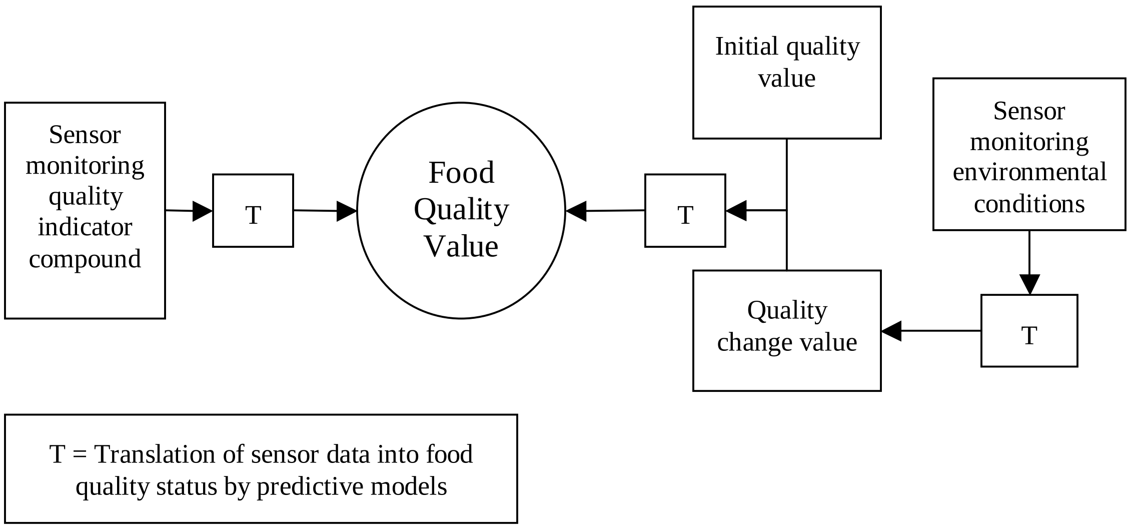

Figure 4: Approaches to predict quality, dependent on sensor type.

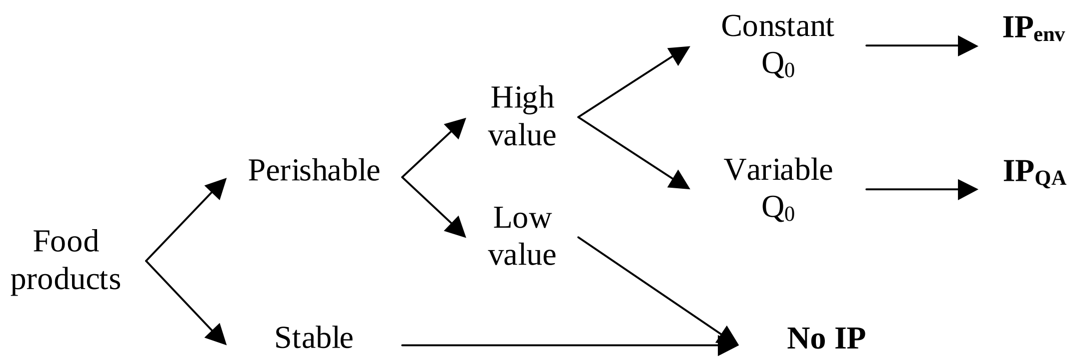

Figure 5: Decision-tree for choice of IP. Q_0 = initial quality, IP_{env} = IP monitoring environmental conditions, IP_{QA} = IP monitoring quality attributes