4

Packaging

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4.1

Introduction

People are very selective about the food that they eat. Evolution has taught us that contamination and spoilage are serious threats to consumer health, as well as food quality. Food must therefore be fresh and clean. Packaging is potentially an important way to deliver these requirements. Packaging has been used for centuries to contain foods, and to keep foods free of undesired contaminants. Food needs to be digestible by a biological organism, and so is by its very nature a perishable product. This means that food quality deteriorates over time to a level that consumers reject it. Again, packaging can help prevent or slow down deterioration of foods.

With the advent of nanotechnologies, innovative applications in the area of packaging are being developed, providing new opportunities to improve on the sometimes already very sophisticated packaging concepts that have been developed to fulfill the demands of the modern consumer. Improved packaging can deliver improved convenience and, at the same time, improve sustainability and reduce waste [1].

4.2

Reasons to Package Food Products

Apart from the obvious need to contain certain food products, such as beverages or powdery materials, to avoid contamination by dirt, and to keep foods free of rodents and other pests, the most important reason for packaging foods is to maintain the quality of the product for as long as possible. Quality deterioration of food products can be caused by various processes. Physical processes like drying or wetting can potentially change the texture of the product to a level that consumers reject it. Bread becomes hard because moisture evaporates; biscuits or potato chips become soft because they take up water from the atmosphere. Although the

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nutritional quality is not necessarily affected, consumers tend to throw the product away or, at best, feed it to animals.

The influence of light can cause color changes that often are interpreted as quality deterioration, also causing the consumer to discard products that are still perfectly suitable for human consumption. Chemical processes can occur between food components, or between one or more components of the product and external substances like water or oxygen. Sometimes these processes are desirable – like the aging of wine or the ripening of fruits – but mostly they result in negative changes in taste and/or texture. Although they usually do not affect the safety of the product, these changes provide reasons for consumers to dispose of the product.

The most important processes for quality deterioration are of biological origin. Apart from the threats that rodents and insects constitute for the product, most food spoilage in industrialized countries originates at the microbial and fungal levels. For products that have been sterilized, the packaging has to prevent recontamination occurring, which necessitates the use of strong materials like metals for canned foods, thick plastics, and so on. Mildly processed or unprocessed foods still contain bacteria or fungi or the spores thereof. In those cases, it is important to prevent the rapid development of these organisms. Cooling/freezing or chemical additives like salt can be used in many cases, but for certain products "modified-atmosphere packaging" is more appropriate. In modified-atmosphere packaging the product is kept in an atmosphere in which a certain gas, necessary for the growth of the micro-organisms, usually oxygen, is absent. The concept relies on the packaging to maintain the modified atmosphere for as long as possible to extend the shelf-life of the product.

4.3
Physical Properties of Packaging Materials

In many food packaging applications, certain physical properties of the packaging materials are important. These physical properties enable the packaging concept to work and sometimes are the cause of the failure of the packaging to deliver. At this point, it is relevant to review the contributions that micro- and nanotechnologies can make to improve the physical properties of packaging materials.

4.3.1
Strength

In order that products are effectively contained, food packaging materials are required that have sufficient strength to withstand the pressure or the forces that the product exerts on the containment, or forces from outside that can occur under circumstances arising from normal use. The material from which a bottle is made should be strong enough to prevent the bottle from tearing, even when the pressure inside is raised under the influence of temperature or processes occurring within the product. For example, champagne bottles need to be extra-strong to withstand the pressure of the carbon dioxide that is generated in the champagne. Even the closure needs to be strengthened with iron wire to prevent the cork popping prematurely.

The strength of a material usually needs to be traded off against other properties like weight and transparency. Consumer preferences for convenience have resulted in food packaging being “multifunctional”, insomuch as increasingly strong materials also need to fulfill other requirements like transparency, light weight, and so on. The rapid introduction and acceptance of polyethylene terephthalate (PET) bottles is an example of this trend. The PET bottle combines strength with reduced weight and reduced vulnerability to breakage. On the one hand, the PET bottle offers a lot of advantages, although, on the other, there is a disadvantage to PET bottles that will be discussed later in this chapter.

The ability to modify materials at the nanolevel to provide new functionality has already delivered one material that is extremely strong: carbon nanotubes. The remarkable properties of carbon nanotubes were one of the drivers for the “hype” associated with nanotechnology, when scientists, researchers, and developers started to realize that these remarkable properties were examples of what could be developed at the nanolevel. Carbon nanotubes per unit weight are much stronger than steel [2]. Indeed, multiwalled carbon nanotubes are the strongest material currently known to humanity. For this reason, they are used in the manufacture of sports equipment to improve the strength-to-weight ratio, and to enhance stiffness [3].

4.3.2
Barrier Properties

Packaging forms a barrier against contamination of the product from external elements. The properties of the packaging materials have to agree with the requirements of the packaging purpose under normal storage conditions. For example, if a product is sensitive to moisture, and usually stored in the open air, the packaging material should be water-tight. There is very little that nanotechnologies can add regarding improved waterproofing. However, when packaging is required to be gas-tight, nanotechnologies can make important contributions.

If a fizzy drink bottle is left open for some time, the carbon dioxide (CO_2) that was dissolved in the product evaporates and the properties of the drink are changed to such an extent that most people do not want to consume it, although other aspects of quality and taste are unaffected. Such products must therefore be packaged in containers that are impervious to CO_2 to prevent evaporation from occurring during storage. Glass, metal, and polymer materials like PET are suitable for this purpose.

In other cases, products are vulnerable to gases or vapours permeating the package. Potato chips (crisps) represent an example of a product where water diffusing through the polymer packaging material has, in the past, limited the shelf-life of these products. Prior to the advent of nanotechnology, the problem was solved through application of a very thin metal layer on top of the polymer. The disadvantage of this solution is that the consumer cannot see through the packaging in order to inspect the contents. Arguably this does not represent a very big problem for processed products like potato chips. However, when buying fresh produce, consumers prefer to see the product in order to be able to make a visual assessment of food quality.

In another example, certain products are vulnerable to oxidation. These products must be packaged in such a way that oxygen (O_2) is kept out of the package for as long as possible. Beer is an example of such a product. Unfortunately, because the O_2 molecule is smaller than the CO_2 molecule, it is much more difficult to keep oxygen from diffusing in through the packaging material than to keep CO_2 from diffusing out. Oxygen can diffuse through PET material and, before the use of nanotechnologies in packaging, it was not possible to package beer in a PET bottle and to maintain its quality for sufficiently long.

In the application of nanocomposites, nanoparticles are used to enhance the barrier properties of these materials. The advantage of nanocomposites is that the particles used to achieve the required functionality are too small to scatter visible light, which enables the development of clear transparent food packaging materials. The application of nanotechnologies is also a good way to improve the properties of more environmentally friendly biopolymers [4]. However, these materials are less suitable for packaging purposes because usually they are not transparent and can degrade over time.

A nanocomposite typically is a polymer matrix in which nanoparticles have been embedded to improve existing barrier properties. These nanoparticles can be of natural origin. For instance, several manufacturers use a special kind of clay, montmorillonite, or other silicates as an additive to different kinds of polymer materials.[1] These clays are mined in Africa and typically are made up of larger particles of stacked platelets. In a special process, these particles are exfoliated, which results in individual clay platelets that are relatively large in two dimensions, but have a thickness in the order of nanometers (Figure 4.1). Gases cannot penetrate the platelets. By adding them to the polymer, a material is formed that forces the gas molecules to diffuse around the platelets, substantially elongating the path of the molecules (see Figure 4.1) and therefore increasing the time needed for the molecule to pass through the wall of the container. The platelets also improve the mechanical properties of the material such as the tensile strength and the elasticity.

In some cases “oxygen scavengers” are added to the polymer matrix. These react with any oxygen molecules that do manage to diffuse into the material.

In the case of modified-atmosphere packaging concepts, the normal atmosphere is replaced by one or more gases that are inert to the product. These prevent or

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[1] Imperm and other products by Nanocor, http://www.nanocor.com; Aegis by Honeywell, http://www51.honeywell.com/sm/aegis/products.html; Cloisite and Nanofil from Southern Clay Products Inc., http://www.nanoclay.com; Durethan from Bayer, http://www.research.bayer.com/edition_15/15_polyamides.pdfx.

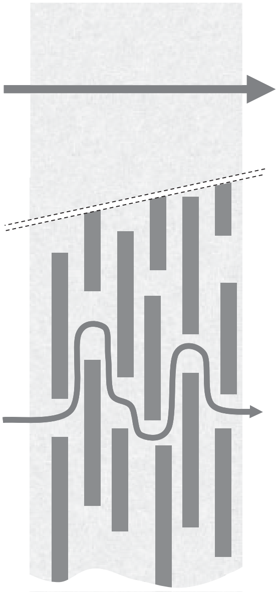

Figure 4.1 Clay platelets (rectangles) force gas molecules to follow a tortuous path, thus improving the barrier properties of the material.

reduce quality deterioration processes. Such applications can also benefit from the improved barrier properties of nanocomposite materials because they slow down the deterioration of the modified atmosphere caused by diffusion of atmospheric gases.

Nanocomposites or nanostructured materials can also be used as a film on top of other packaging materials to form multilayered materials in which the properties of the different layers combine to achieve the required overall specifications of the packaging material.

For example, recently, a new method of structuring polymer material into stacked layers of 20 nm thickness has been reported [5]. Polyethylene oxide is forced to crystallize in thin lamellae, or layers, which increase the gas permeability by two orders of magnitude, maintaining the modified atmosphere even longer.

4.3.3
Light Absorption

Certain food products are vulnerable to light irradiation. The products may change color, which potentially affects their appeal to the consumer. Chemical reactions, triggered by photons, can reduce the quality of the product. This is one of the reasons why beer used to be packaged in brown or green bottles. As is known from the use of certain nanoparticles in sunscreens, titanium oxide and zinc oxide nanoparticles are very effective in absorbing ultraviolet (UV) light. In sunscreen applications, the nano-sized particles are small enough not to scatter visible light, thus providing a clear fluid or cream that does not leave a white film on the skin, but still blocks the dangerous high-energy part of the solar spectrum.

These properties are also used in food packaging materials to provide a concept that is transparent, enabling consumer inspection of the contents, but which also locks out the UV radiation that can cause deterioration of certain quality aspects of the product.[2] In this application, the nanoparticles, mostly metal oxides, are embedded in the polymer matrix of the packaging material. As a consequence of their small size, they do not interfere with visible light, resulting in a clear package.

4.3.4
Structuring of Interior Surfaces

In specific cases, the product to be packaged is sticky and adheres to the inside of the package. For example, removing custard from packaging can be a time-consuming undertaking. Micro- and nanotechnology has been used to structure the surface of packaging materials in such a way that it mimics the water- and dirt-repellent effect of the lotus leaf [6, 7], which facilitates removal of the product from the package. With the lotus effect,[3] a micro- and a nanostructure are used to create a surface that is very hydrophobic [8], causing even very sticky substances to slide from the surface. The lotus effect can be implemented as a coating.[4] At the present time, these coatings are mostly used in non-packaging applications.[5] However, the potential for packaging material application is obvious.

It is also possible to modify the structure of the food packaging material to give it “self-cleaning properties”.[6] In other words, a reusable packaging can be reused without extensive cleaning, and chances of contamination after reuse are reduced. At the moment, self-cleaning materials are in the development stage, but they will ultimately be applied in food storage containers.

4.4
Antimicrobial Functionality

Micro-organisms are usually responsible for the spoilage of food products. People have traditionally applied high-temperature processing (pasteurization and sterilization) or chemical treatment (salt, sugar, alcohol, smoke, etc.) to kill the organisms that are always present on or in foods to prevent or slow down the spoilage processes. Packaging was frequently required to prevent recontamination of the product after heat or chemical treatment. There is, however, a trend toward consumer preferences for the application of mild preservation techniques and the wish for fresh or minimally processed and preservative-free products. In order to

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2) Light Stabilizer 210 by DuPont, http://www2.dupont.com/Titanium_Technologies/en_US/products/dls_210/dls_210_landing.html.

3) See http://www.lotus-effect.com.

4) Lotusan, http://www.stocorp.com/allweb.nsf/lotusanpage.

5) Mincor by BASF, http://www.basf.com/group/corporate/en/news-and-media-relations/science-around-us/mincor/index.

6) Lightmotif, http://www.lightmotif.nl.

achieve this, the need to slow down the development of micro-organisms near the product has increased. There are several options to achieve this, and nanotechnology can provide some of them [9].

It has long been known that silver has antimicrobial properties. Alexander the Great is reputed to have used large silver containers to ensure his personal supply of fresh water. Although the exact mechanism of these properties is not exactly known – experts dispute whether silver ions or metallic silver is the active species – it has been established that increased surface area of the silver enhances the antimicrobial activity [10]. Consequently, making silver particles smaller improves the antimicrobial properties, in the end resulting in silver nanoparticles as effective agents to contain microbial growth.

The antimicrobial effect of nano-silver is being exploited in several areas of application, including bandages for dressing wounds, and in textiles to inactivate the odor-producing bacteria on feet and in armpits. Nano-silver can also be used in food packaging. Food containers with nano-silver can be obtained commercially. Manufacturers claim substantially improved quality of food products even after extended storage. These containers are reusable, but the same effects can be achieved when nano-silver is incorporated into disposable food packaging materials.

Other antimicrobial concepts rely on the interaction of the microbe with cations in a polymer layer on top of the food packaging material, or a nanostructured agent. Based on delivery technology, a system has been developed that releases an antimicrobial chemical when the presence of a bacterium is detected through the chemicals it distributes in its direct environment.7) Although applications in food packaging of this specific system are not foreseen in the near future, there is potential for comparable developments to be applied specifically for this purpose. An advantage of such a development is that they can be made more specific to the types of bacteria causing deterioration in certain high-cost food products such as meat and fish.

4.5
Visual Indicators

One of the reasons that so much good food is thrown away in the industrialized world is consumer reliance on “sell-by dates” to safeguard the quality of food products. Unfortunately, sell-by dates are based on unsophisticated models of quality deterioration. Manufacturers, afraid of image damage if too many products have below-standard quality when they reach the consumer, build in a large safety margin. The result is that perfectly good products cannot be sold because of sell-by date expiration. Similarly, consumers may reject these products and discard them unnecessarily. Even under these conservative conditions, in exceptional circumstances (e.g., elevated storage temperatures), a product may deteriorate to unac-

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7) BioSwitch by TNO, http://www.tno.nl/content.cfm?context=markten&content=product&laag1=195&laag2=327&item_id=1126.

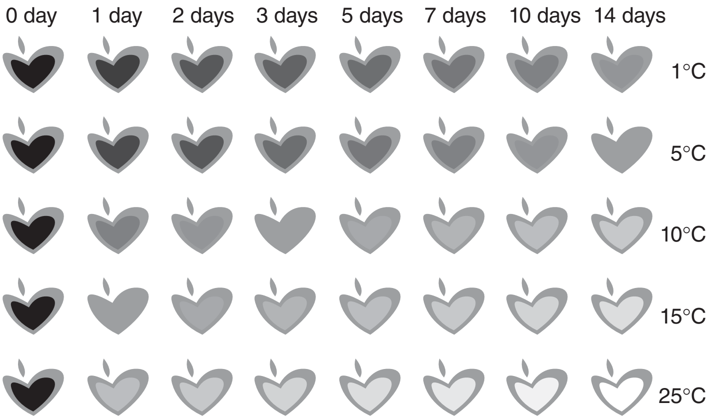

Figure 4.2 The OnVu system to check that a product has not been stored at elevated temperatures for too long.

ceptable levels before the sell-by date has expired. It would therefore be preferable to have some means to directly determine the quality of a food product in the package. Nanotechnology can provide applications that meet this need.

4.5.1
Quality Assessment

A concept that is based on the same principles as the sell-by date, but is more sophisticated, insomuch as environmental conditions are taken into account, indicates the product of temperature and time.[8] The indicator changes color more quickly if storage temperatures are higher (see Figure 4.2). This represents an improvement over the sell-by date system, in particular for fresh products. Although it is probably possible to tailor the change in color of the indicator to the specific spoilage behavior of the product under consideration – which would definitely increase the accuracy of the system – this could also reduce the economic viability of the concept for most food products.

However, an indicator still only represents an indirect measure of the quality of a food product. The main problem of these systems is that a certain storage period at a specific temperature might be perfectly all right for some products, while it may cause others to be totally spoiled. An accurate assessment of quality through the area below the storage temperature versus time graph requires intricate models of the product and models of the spoilage behavior. This, of course, can be incorporated into the system by calibrating it to different food products or classes of food product, but again that would make the system more expensive as it would require tailoring the indicators to different products. A better way to detect spoilage is through food safety indication.

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8) OnVu, http://www.onvu.com.

4.5.2
Food Safety Indication

The food industry is very conscience of quality, and also needs to ensure that optimal hygiene standards are applied in order to improve food safety. Even in industrialized countries, there is still substantial room for improvement. In developing countries, many deaths can be attributed to poor water and food quality. In the industrialized countries, the economic damage caused by hospitalization from food poisoning is substantial [11], as is the economic cost of a food recall or loss of consumer confidence in a brand. A useful innovation in food packaging would be a method of "warning" consumers about food products that are not fit for consumption.

If food safety is compromised, the cause is usually micro-organisms such as bacteria or fungi that develop in and on the food product. Certain types of micro-organisms, if present in sufficient quantities, can cause health problems by themselves, whereas others produce toxins. In fresh products like meat and vegetables, bacteria and/or spores of fungi will be present from the harvest stage onward. After harvest, they start to multiply. The traditional method to deal with this problem was to treat the product in such a way that these micro-organisms were killed. As mentioned before, heat, chemicals (salt/sugar) or smoke have all proven to be effective in killing organisms and preserving the product. Modified atmospheres, chilling, and freezing slow down or virtually stop the development of the organisms. Often, food packaging is required to maintain the sterile status of the product.

Modern consumers want their food to be not only fresh, but also convenient. This means that consumers prefer the application of mild conservation methods, if any – but then they buy precut and pre-prepared vegetables, fruits, and meats in order to maximize convenience. From the perspective of food quality and safety, these two types of consumer preferences represent a bad combination. Little to no conservation leaves micro-organisms alive, and the "wounds" inflicted on food by cutting provide them with a substrate on which to feast.

Food quality deterioration and spoilage processes produce different characteristic chemical by-products. If these molecules are small enough, they will be volatile, and can be detected in the atmosphere surrounding the product. With chemical detection, such as "Toxin Guard technology",[9] suitable molecules are deposited on the inside of the packaging. When they react with certain characteristic volatiles, a color change signals the presence of these substances and warns the consumer that certain organisms have developed on the food to such an extent that consumption of the product is no longer safe.

4.5.3
Product Properties

The production of by-products from ripening processes may represent an important signaling mechanism between plants and fruits. For example, ethene

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[9] See http://www.toxinalert.com.

(ethylene) is a plant hormone the production of which speeds up ripening in fruits. The amount of ethene in the package of a fruit is a measure of the state of ripeness of the fruit. Of course, ripeness does not necessarily represent a deterioration in quality, but can be a highly desirable aspect of the food product. The principle of ethene detection is employed in the "Ripesense" system[10] in which a color change in a suitably prepared dot on the inside of the package indicates the ripeness of the product in question.

4.6
Information and Communication Technology

Although visual indicators can be helpful in providing information to the individual consumer, they are less suitable for integration into logistical systems that can add value in the product chains. In our highly automated society, effective monitoring of safety, quality or product characteristics could be delivered to computer and information and communication technology (ICT) systems located remotely to enable automated electronic control of the logistic process. Storage systems could monitor certain product characteristics directly, and decisions could be made on how to optimize the value of the product. For example, products that approach quality or ripeness limits could be taken out of storage and sold in nearby markets; products that have sufficient shelf-life remaining could be shipped to more distant markets, where they bring more money. Systems such as these are dependent on effective communication between the sensors and the outside world.

4.6.1
Sensors

In packaged products, the amounts of by-products of deterioration can be substantial, and can be detected with suitable electronic devices. These devices are currently in development and often mimic the operation of a human nose. Different receptors, much like the ones that also are situated in the nose, are placed on a semiconductor device in such a way that, when a molecule of interest gets close enough, it "docks" onto the receptor, causing charges to shift in the receptor molecule. These charge shifts can influence conductance in the semiconductor material and, therefore, can result in an electronic signal that can be interpreted digitally. The presence of more molecules results in more docking events, and therefore increases the signal. These receptors usually are not very specific. By using more than one type of receptor, the device generates a pattern that will be able to specifically detect certain processes. This is also how the nose works: the human nose holds about 350 different receptors, and the brain has learned to interpret the signal pattern that results from food deterioration. Receptors can be

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[10] See http://www.ripesense.com.

developed that are more specific to the volatiles involved in the food quality deterioration processes. This would make the detection simpler yet more accurate.

At the moment, these systems are still in the development stage, rely on silicon-based microelectronics to do the sensing, the data analysis, and communication, and are very expensive. They are unlikely to be used in food packaging applications in the near future. However, progress is being made in other areas of nanotechnology that will result in “printable electronics” with which the electronic circuitry necessary to measure the parameters, analyze the signals, and communicate the outcome to external computer systems can be printed with conductive inks in combination with polymer components. This technology could be sufficiently mature, advanced, and cheap within 15–20 years. If the electronic nose can be developed using printable electronics, the application will be very cheap, and will certainly be adopted in order to assure the quality of food products.

Electronics require power to operate. The usual solution for this is batteries. Unfortunately, the combination of a food product and batteries is not very attractive. Moreover, batteries possibly run out of power before the product is out of storage. Alternatives are to scavenge power from external sources like the Sun, temperature differences, movement, etc. They all have their own drawbacks. However, radiofrequency identification technology may not only solve the power problem, but also provide the necessary communication channel to transmit sensor data to the outside world.

4.6.2
Radiofrequency Identification Technology

Being able to extract an electronic signal from a packaged product in itself is not sufficient. The signal still has to be communicated to computers in the outside world. To this end, radiofrequency identification (RFID) technology has been developed, which can identify individual objects without requiring a line of sight. RFID technology can be applied as an electronic version of the barcode, with the difference that it can be read without opening the box. Furthermore, RFID can be used to identify animals [12], for electronic access systems, to identify tools for professional workshops, and so forth.

Radiofrequency identification technology consists of two elements: the transponder attached to the object to be identified, and a reader that transmits an electromagnetic field to read the transponder. The transponder does not contain a power source of its own. It uses the electromagnetic field from the reader to temporarily power its electronics, and to communicate the predefined code back to the reader. A drawback of the technology is that the reading distance is dependent on the specifics of the electromagnetic field, and the range is typically in the order of 1 m. Regulations in most countries do not allow higher fields and/or different frequency bands that would allow larger reading distances.

Although developed for identification purposes, RFID technology is also used in combination with sensors. If measurements are also required when there is not a reader present, then there must be some sort of power source in the transponder.

For this purpose, limited storage of power to allow measurements in between reads has been demonstrated.

Radiofrequency identification is a high-frequency technology, and, as such, at the moment can only be implemented by application of silicon technology, which makes it expensive and less suitable for incorporation in food packaging materials. However, recent advances in other areas of nanotechnology have resulted in the first implementation of RFID transponders in polymer electronics.[11] Although these can already be produced very cheaply, it is generally expected that these will be used in food products when the electronics can be printed directly on the package.

4.7
Discussion

Although applications of nanotechnology in food packaging are less controversial than those where the nanotechnology is in the food product itself, and is thus consumed by the consumer, there are still some aspects that need careful consideration before large-scale introduction of some applications is warranted. Since the benefits of some of the systems are not equally distributed along the value chains, some stakeholders in the chain may be unenthusiastic about implementing them.

On paper, food quality indicators, for instance, seem a very good idea from a consumer perspective. The retail sector, however, is not that enthusiastic. Although sell-by dates also have this problem, if more detailed information on freshness is provided, retailers fear customers scavenging the shelves for the freshest products and the supermarket being left with more products that cannot be sold any more. Thus quality labels may not reduce the amount of food wastage, but could easily increase it. In addition, in systems such as these, the costs and the benefits are usually not spread evenly along the food chain. Very often they will increase the costs for those stakeholders involved at the earlier stages of the food chain, but the benefits will be accrued by stakeholders at the end of the chain.

4.7.1
Health Risks

Food is something that, following consumption, enters the body and cannot easily be removed if something is wrong with it. People are conscious about what they eat and prefer food to be natural and fresh (see also Chapters 12 and 14 in this volume). The food packaging materials that are used to maintain the quality of the food are usually not consumed. However, consumer concerns about contact between nanotechnology applied to packaging and foods may be an important issue. The

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[11] See http://www.polyic.com.

general public believes that nanoparticles, one of the more commonly known forms of nanotechnology, cannot be seen, can easily migrate from one matrix to another, and can even cross barriers in the body that cannot be crossed by non-nanoscale particles. Nanoparticles in packaging materials could therefore migrate to the food, be ingested, get into the body, and end up in parts of the human body where they could result in health problems. In the case of nano-silver, this scenario could be realistic. Nano-silver particles can get out of the packaging materials matrix and get into the food product. If they have antimicrobial properties in the packaging material, they will also be capable of damaging cells in the body.

Arguably, the health risks of the applications discussed in this chapter are very small. The amount of nanostructured materials used in applications like sensors and indicators is very limited. Even if some of the nanostructures can transfer to foodstuffs, consumer exposure will be very small. There are more nanoparticles involved in improved barrier properties and antimicrobial layers, but these nanomaterials are embedded in the matrix of the packaging material. The amount of nanoparticles released is also very low. However, this does need to be verified for each of the applications to be developed and brought to market. It can therefore safely be concluded that the health risks involved in applications of nanotechnologies in food packaging are less than those associated with the risks of contamination by nanoparticles, from wear of the machines, in conventional processes that are used to prepare the products.

4.7.2
Environmental Risks

One of the aspects of food packaging is that the materials used are usually discarded after consumption of the food. This means that, at least in some part, they will end up in the environment. If they include nanostructured materials, these will also end up the environment. At the moment, it is largely unclear what the effects of nanoparticles in the environment will be. Research into this problem lags behind research into health effects.

Nanoclays, which are basically natural materials, are nanostructured materials used to improve the barrier properties of packaging. They are embedded in the matrix of the polymer. When they are freed, for instance when the packaging material is incinerated, they will be no more harmful than other clays that are deposited by rivers and the sea. This is not true of silver nanoparticles. If they exist in the environment as individual particles with a large surface-to-volume ratio, they will be as effective in killing micro-organisms in the environment as they were in the initial application in food packaging. These particles could pose serious problems for wastewater treatment plants that rely on micro-organisms to break down certain chemical components in the wastewater. There could also be a negative impact on ecological systems and biodiversity.

If small amounts of nanoparticles were to get into the environment, it could also be argued that the amounts of free nanoparticles would be small, and exposure would therefore be limited, reducing the risk. However, persistent free nanoparticles – particles that do not dissolve and are not broken down by physical, chemical or biological processes – that entered the environment could accumulate in certain compartments and remain there for a long time. Moreover, it has been seen in the past that certain chemicals can accumulate in organisms that are high up in the food chain. This same effect can also play a role in the uptake of free nanoparticles. Before large-scale application of persistent nanoparticles in food packaging applications, more research is necessary to characterize these effects.

4.7.3
Consumer and Societal Acceptance

There are benefits that are likely to be achieved from the application of nanotechnologies to food packaging. Whether or not these benefits will be realized largely depends on the acceptance of the technology and its applications by individual consumers and society as a whole (see also Chapter 14 in this volume). The consumer will consider each application in the context of benefits to be gained for themselves in relation to the perceived personal (or personally relevant) risks that accompany the application. Societal concerns will focus on risks for specific population groups, future generations or environmental impacts. Perceived risks and negative effects may include ethical and psychological impacts. For instance, in the case of applications of radiofrequency identification technology, privacy may be an important issue. In order for nano-packaging technology to be successfully introduced and commercialized, the benefits for individual consumers, the environment, and society as a whole must be assessed. At the same time, research should be conducted to enable possible negative effects (e.g., risks to human and environmental health or negative socio-economic effects) to be assessed and communicated in an objective and honest way. Both the consumer and society need to feel that they are in control of these kinds of application before they will accept their large-scale implementation.

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