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15, avenue de Ségur,
75007 Paris, France.
Tel (Fr) 01 45 51 26 07 - (Int.) +33 1 45 51 26 07
Fax (Fr) 01 45 51 26 32- (Int.) +33 1 45 51 26 32
E-mail: ijdst@europia.org
http://www.europia.org/ijdst

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Development of active packaging for agricultural food

Paola Garbagnoli*, **Lina Altomare****, **Luigi De Nardo***** and **Barbara Del Curto******
* Department "Giulio Natta", Politecnico di Milano, Italy. Email: paola.garbagnoli@polimi.it
** Department "Giulio Natta", Politecnico di Milano, Italy. Email: lina.altomare@polimi.it
*** Department "Giulio Natta", Politecnico di Milano, Italy. Email: luigi.denardo@polimi.it
**** Department "Giulio Natta", Politecnico di Milano, Italy. Email: barbara.delcurto@polimi.it

Conservation of perishable food is an open issue connected to several factors. In the scenario of active & intelligent packaging, the present work focuses on the problem of thermal maintenance of fresh food in the food supply chain. The research aims at the development of an active thermal insulation material for food packaging. The developed material was tested both in laboratory and in real conditions, as active material for secondary packaging. Results showed that active packaging are able to better maintain the thermal insulation of the content, compared with standard packaging. This opens the way to several possibilities of applications, products which are sensible at overheating, in order to extend the shelf life and to improve the quality and safety.

Keywords: *Food supply chain, active packaging, thermal maintenance, phase change materials*

1 Introduction: the evolution of packaging design

Food packaging is a complex object of everyday life: because of its complexity, it is object of study of many disciplines, such as communication design, product design, marketing, materials science, food science. It has the potentiality to guide consumers in new ways of food preservation or consumption.

After its introduction in the industrial context, at the end of the XIX century, packaging has received always more and more attention and it has widely extended its functionalities.

The history of packaging is a topic where various fields are involved. It refers to the evolution of materials, productive processes, communication, iconographic system, productive system, distribution system. These different fields have found in packaging an interesting meeting point [5]. Moreover, during its evolution, packaging has gained a recognized role in the industrial design. Most people judge the pack as a “multifunctional tool”: it is not only recognized as having the function of container, but also that of facilitating use and transportation, preservation of the product, as a means of information and creation of image, as well as an aesthetic tool of appeal.

From the advent of the industrial revolution, packaging has always been a tool used by the world of production and trade for preserving and moving all forms of goods in space and in time. This role, apparently simple on a theoretical level, in actual fact reveals all its complexity as soon as you start to pair up the huge range of products with the broad possibility of packaging solutions. Packaging has been and will be the solution for making consumption previously reserved for the few, accessible to many. But, above all, it has allowed to broaden the range of goods on offer today, even on a world scale, and this while respecting a principle very dear to enterprises: maximum efficiency at the lowest possible cost.

In the countries with the greatest industrial concentration, where there is a strong presence of packaging world, such as Italy, the deterioration of merchandise has been minimized and stands at around 2-3%, while in the developing countries even up to 50% of goods are lost, because of the poor or zero effectiveness of packs.

Hence, even packaging, simple packaging, defined according to the most critical as a necessary evil, generates great wealth. It guarantees to the consumer the certain of buying products that have been preserved in the best ways for the time needed, while bringing them to the place of sale or to home.

The 34% of empty packaging produced in Italy is used in the food products sector. Overall, the segment that moves the greatest quantity of packaging is that of fresh fruit, followed by wine, mineral water and tomato-based products.

Companies design and purchase packaging made by different materials that ensure given performance and that are made using the most varied techniques, according to the type of contents to be preserved, protected and transported.

It has to be considered that packaging has its present form by way of continuously following the evolutionary paths of the materials and packaging technologies. The materials have evolved considerably, modifying the possibility of use and broadening their own range of applications to new segments, inventing new solutions, stealing secrets from other sectors and thus transferring them from one material to another in a continuous shift of technological progress.

The technological evolution of materials has enabled the improvement and the devising of small details, innovative ideas, which now are taken for granted.

Materials technology, design solutions, products innovation have thus mutually become cause and effect of the changes [4] [9].

1.1 The emergent packaging: active and intelligent packaging

In recent years, several researches have been addressed to food packaging, in order to further enhance its functions, to improve products shelf life, and to better communicate food characteristics to the consumer.

Into this scenario, one of the main innovation is represented by active and intelligent packaging.

Unlike traditional packaging, which must be totally inert, active and intelligent packaging are designed to interact with the contents and/or the surrounding environment [17].

Definitions stated in Regulation 1935/2004/EC and in Regulation 450/2009/EC consider active materials and articles as “materials and articles that are intended to extend the shelf-life or to maintain or improve the condition of packaged food”. They are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food. On the other hand, intelligent materials and articles means “materials and articles which monitor the condition of packaged food or the environment surrounding the food”.

Accordingly the purpose of the active packaging is the extension of the shelf-life of the food and the maintenance or even improvement of its quality, while the purpose of intelligent packaging is to give an indication on, and to monitor, the freshness and quality of food. There are many different types of active and intelligent materials and articles. Substances responsible for the active or intelligent function can be contained in a separate container, such as in a small paper sachet, or directly incorporated in the packaging material. Hence, an important objective is to design functional materials that include the active agent in their structure where this active substance can act or be released in a controlled manner. Moreover, designing functional materials benefits packagers by simplifying handling, and improves consumer safety by eliminating the potential of accidentally consuming a sachet. Moreover, the active and intelligent materials and articles may be composed of one or more layers or parts of different types of materials, such as plastics, paper and board or coatings and varnishes. Considering active packaging, they include additives or “freshness enhancers” that can participate in a host of packaging applications enhancing the preservation function of the primary packaging system. Active packaging includes additives that are capable of scavenging or absorbing oxygen, carbon dioxide, ethylene, moisture and/or odour and flavour taints; releasing oxygen, carbon dioxide, moisture, ethanol, sorbates, antioxidants and/or other preservatives and antimicrobials. The wide diversity of active packaging devices have specific applications to individual food products for which the shelf-life can be extended substantially, so long as the food’s unique spoilage mechanisms are understood and controlled.

Intelligent packaging is packaging that in some way probes some properties of the food it encloses or the environment in which it is stored and is able to inform the manufacturer, retailer and consumer of the state of these properties. Intelligent packaging is an extension of the communication function of traditional packaging, and communicates information to the consumer based on its ability to sense, detect, or record external or internal changes in the product’s environment. Basically, there are two types of intelligent packaging: one based on measuring the condition of the package on the outside while the other measuring directly the quality of the food product, i.e. inside the packaging. In the latter case there is direct contact with the food or with the headspace and there is always the need for a marker indicative of the quality and/ or safety of the packed food. Examples include time–temperature indicators (TTI), gas leakage indicators, ripeness indicators, toxin indicators, biosensors, and radio frequency identification. Although distinctly different from the concept of active packaging, features of intelligent packaging can be used to check the effectiveness and integrity of active packaging systems.

Among emerging technologies nanocomposite packages are predicted to make up a significant portion of the food and beverage packaging market in the near future, although not yet widely widespread. Some of the applications associated with nanotechnology include improved taste, colour, flavour, texture and consistency of foodstuffs, increased absorption and bioavailability of food or food ingredients (nutrients), and the development of new food-packaging materials with improved mechanical, barrier and antimicrobial properties. Nanoscale technologies also are in development to improve traceability and monitoring of the condition of food during transport and storage. Improvements in fundamental characteristics of food-packaging materials such as strength, barrier properties, antimicrobial properties, and stability to heat and cold are in part being achieved using nanocomposite materials. Other applications include carbon nanotubes or nanosensors. The first are cylinders with nanoscale diameters that can be used in food packaging to improve its mechanical properties, although it was recently discovered that they may also exert powerful antimicrobial effects, while nanosensors could be used to detect chemicals, pathogens, and toxins in foods.

Over the past decade, active and intelligent packaging have experienced significant growth and change as new products and technologies have challenged the status quo of the traditional forms of food and beverage packaging. Firstly introduced in the market of Japan in the mid-1970s, active and intelligent packaging materials and articles, only in the mid-1990s raised the attention of the industry in Europe and in the USA.

The global market for food and beverages of active and intelligent packaging coupled with controlled/modified atmosphere packaging increased from 2005 to 2013 with a compound annual growth rate of about 6.9%.

Considering the diffusion of active and intelligent packaging in EU market, it should be mentioned that the issues of acceptance by user industries as well as the more conservative behaviour of European consumers regarding innovations in food, are key points that still need to be addressed. Low diffusion in EU countries of active and intelligent packaging has been related to two main reasons: the first is cost and the second is acceptance. Considering costs, it is obvious, that they will drastically be reduced with broader application and thus scaling-up of production. Discussions are ongoing as to whether consumers will be ready to pay the extra costs for the extra safety/quality tools. About acceptance, often consumers do not perceive active and intelligent materials as a strong benefit. In a study carried out by PIRA International, both brand owners and packaging converters identified as main resistance to the introduction of these materials in the market the fact that the existing materials were considered already adequate to the market needs. Food producer, consumer and retail acceptance will be needed to enable an introduction on a large scale. To this regard, consumers' attitudes were investigated in a number of European countries, showing that most consumers are open to innovations in this area provided the material is safe and the information is unambiguous for the user. Furthermore, consumers are demanding food-packaging materials that are more natural, disposable, potentially biodegradable, as well as, recyclable.

Anyway, despite the hurdles that have to be overcome in the near future, there is a strong view that active and intelligent packaging will be a technical tool in the market with a high potential, covering both more transparent communication to consumers and the need for the retail and food industry to better control the food production chain [18] [19].

Considering the contrast between the need of standardization and the request of diversification, today materials and technologies represent an opportunity for new structural and functional solutions, they have the power of suggestion for packaging designers. Along this direction, the approach is to experiment materials and technologies, maybe already used in other fields of application, and test them in packaging, in order to identify new promising solutions especially for active and intelligent packaging. Within this scenario, the environmental sustainability is a necessary value and a primary request that need attention in the project of all the new solutions [5].

1.2 Packaging for agricultural products: analysis of the open issues

Within the reference scenario, the present research focuses on the study of new materials and technologies with interesting properties for applications into the food supply chain, to support food quality and safety. The type of food supply chain chosen for the present research is the agricultural one (in details, vegetables and fruit) because of the unsolved problems related with perishability, the amount of food waste, and thanks to the increasing consumption of them for healthy diets. Moreover, most of the food packaging is used for agricultural products.

The production and distribution processes of agricultural food correspond to the cold chain. A cold chain is a temperature-controlled supply chain. An unbroken cold chain is an uninterrupted series of storage and distribution activities which maintain a given temperature range. It is used to help, extend, and ensure the shelf life of food products such as fresh agricultural produce, but also seafood, frozen food, chemicals and pharmaceutical drugs.

Depending on the type of vegetables or fruit, the optimal conservation conditions may vary. The right conservation is one of the main important factor in order to avoid the risk of food deterioration and the proliferation of microorganisms.

The supply chain practices of agricultural food products are currently under public scrutiny. This is the result of several factors, such as the national attention given to recent cases of fresh produce contamination, the changing attitudes of a more health conscious and better informed consumer who wants to have precise information about the farming, marketing, and distribution practices used to bring the agricultural products into the shelves of the neighbourhood supermarket. This scrutiny will undoubtedly translate into additional regulations and market driven standards that will affect the design and operation of an already complex supply chain. This complexity is particularly critical in the case of perishable agricultural commodities where the traversal time of the products through the supply chain and the opportunities to use inventory as a buffer against demand and transportation variability are severely limited.

Food safety is currently considered to be an important issue for all stakeholders in food production. Consumers and other stakeholders are increasingly concerned about the continuing sequence of food scandals and incidents. We only need to refer to the recent EHEC-bacteria outbreak in Germany in 2011 to illustrate this point. A novel strain of Escherichia coli O104:H4 bacteria caused a serious outbreak of foodborne illness focused in northern Germany in May through June 2011. In total, 3.950 people were affected while 53 died, 51 of which were in Germany. A handful cases were reported in several other countries including Switzerland, Poland, Netherlands, Sweden, Denmark, United Kingdom, Canada and United States of America. Essentially all affected people had been in Germany or France shortly before becoming ill.

Consumer perceptions thus show an increasing concern about food safety and about properties of the food they buy and eat. Although much information is available as a result of labelling conventions, this does not always translate into more confidence. It is of great importance to the food industry to protect brands in order to restore and maintain consumer confidence. It has been recognized that there is an increasing need for transparent information on the quality of the entire food chain, supported by modern tracking and tracing methods. High quality food, integrity and associated services and information should be guaranteed.

Over the past decade, quality assurance has become a cornerstone of food safety policy in the food industry. Much focus has been devoted on integral quality management systems. These systems include all steps in food production chains such as supply of raw materials, food manufacturing, packaging, transportation and logistics, research and development, maintenance of production equipment and training and education of staff. Increasingly, food quality is associated with a proactive policy and the creation of requirements to maintain safe food supply [3].

In order to assess quality and safety risks in food supply chain, a very critical need is the prediction of food degradation processes [12] [13] [20]. Typically, next to biological variations, food quality is determined by time and environmental conditions, which may be influenced by the type of packaging, way of loading, and the availability of temperature-controlled packages, vehicle and warehouses and generally by the all factors which mainly configure the supply chain.

The quality and nutritional characteristics of raw materials and food products may be altered along the food supply chain with respect to several physical factors of stress such as temperature, light, humidity, mechanical static and dynamic stresses [21].

The chemical deterioration of food is caused by adverse reactions (i.e. oxidation) that affect sensitive components such as polyphenols, fats, vitamins and flavourings, with negative consequences on the quality of food products [23]. In particular, temperature can significantly affect food products and their shelf life [22].

Another important open issue of agricultural products is related with food waste. The term food waste most commonly means food that was purchased but not consumed and ends up in the garbage. However this is by no means the only valid meaning because, along the whole food supply chain, there are various reasons why edible food products are discarded.

Most food waste can be found in the dairy industry and in the production and preserving of fruit and vegetables. The increase in demand for meat, fruits, vegetables, and other easily perishable products increases the risk of losses and waste.

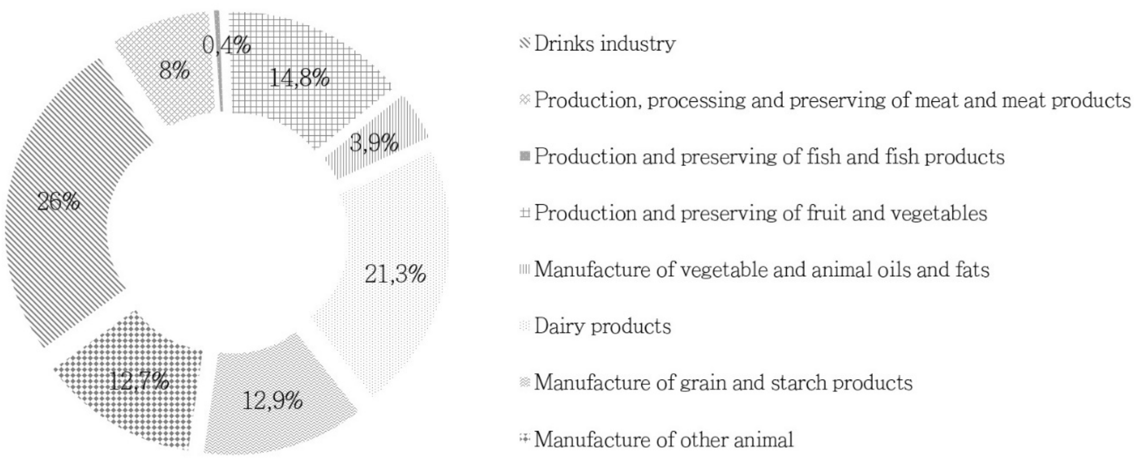

Figure 1 Percentage breakdown of waste in the food industry [2]

Analysing the data on fruits and vegetables, the food wasted directly by final consumers in developed countries amounts to 15-30% of the total, but quality standards set by distributors also cause high amounts of waste during distribution. In this stage, waste is generally the consequence of inappropriate ordering and incorrect projections of demand for food products, resulting in enormous quantities of merchandise which are not sold before the expiration date and/or natural deterioration (which is mainly a concern for fruits and vegetables).

Additional significant causes of food waste at this stage are represented by limits of the technology used to conserve products, particularly fresh products (cold chain).

Food losses and waste have negative environmental and economic impacts and their existence raises questions for society [2].

Every stage of the food supply chain is made up of different operations, both agricultural and industrial, within which different types of losses and waste occur. On a global level, the food chain is becoming longer and more complex. Elements such as the expectations by consumers for variety and convenience of choice, the growing portion of the population moving from the rural areas to cities, and the resulting increase in distance dividing production areas from consumption ones, have made the distribution structure and the food offer increasingly complex. At the same time, the increase in demand for meat, fruits, vegetables, and other easily perishable products increases the risk of losses and waste.

Today, these aspects and the open problems are object of interests of many companies, research institutions and society in general, because of several factors. The main factors are: the growing expectations of consumers in terms of quality and ethics, the upcoming Expo 2015, and the guidelines of Horizon 2020 which are in line with the issues presented above.

The research has been addressed to active thermal insulation property because it is a key factor to guarantee food quality and safety, as explained previously.

To date, materials used in food packaging still play a marginal role for the temperature control: in particular they are not able to control the undesirable accidental overheating during the distribution phase.

The warm temperature spikes have sometimes duration up to hours, which is high enough to cause product spoilage, and are generally correlated to a temporary uncontrolled exposition to incompatible temperatures or passages in unrefrigerated areas. As widely reported in literature, for example, the proper temperature for the storage of many fresh vegetables, such as lettuce, is in the range 0/+8°C with 0/+4°C as optimal range. Higher temperatures increase the rate of different degrading processes and also increase the presence of bacterial colonies [15]. An optimization of heat maintenance, during the transportation and distribution phases, is also important for energy savings.

By definition, an active packaging is able to absorb or release "something", depending on the external conditions, in order to improve the conservation of the contained food. Along this direction, the idea to develop an innovative packaging, able to absorb or release heat, was considered, in order to control the internal temperature. The focal point was the investigation of smart materials and technologies to select the right instruments to proceed.

This idea was dealt with an experimental scientific method, developed both in laboratory and in collaboration with a food company. After preliminary tests with different kind of agricultural products, the food selected for the experiments was ready-to-eat (shortly RTE) salad.

Figure 2 Typology of food used for preliminary tests: courgette flowers, RTE salad, nectarines and grapes, respectively

A RTE food item is any food which does not need cooking or has already been cooked. Deli meat, salad, sandwiches, cheese, dry cereal, nuts, and fruits and vegetables are a few of the many food items called RTE. Because of they do not need to be cooked in order be consumed, the risk of foodborne illness is high, and in order to prevent it, these products are subjected to several safety controls. These products receive some degree of minimal technological processing before commercial distribution. Processing, in most cases, is inadequate in ensuring sterility or even microbiological stability [7].

The research considered, as case study, RTE salad, because of its high sensibility to thermal variations, and because it presents an additional value, in terms of costs, compared to fresh vegetables not transformed. The company involved in tests (San Lidano, Societa'Cooperativa Agricola s.r.l.) produces ready-to-eat salads.

1.3 Research question

The analysis of the context permitted to identify problematic and interesting points where focus the research, and consequently, the main research question was elaborated: how can design research improve food quality and safety, through packaging, playing with material and technologies?

From the research question, consideration about the role of design emerges: nowadays, design is not only the discipline that guide the project of a new packaging in terms of shape, material, structure. On the contrary, design research has a multidisciplinary role: it identifies problematic points, selects the instruments to intervene (in the present work they are materials and technologies), and connects different disciplines in order to obtain good design, considering functionality, industrialization, sustainability, appeal, communication, etc.

Within the research question, as mentioned, the work focuses on the study of new materials and technologies with interesting properties for applications in food packaging, in order to improve food quality and safety.

The work is based on experimental method: an innovative packaging was developed and tested in laboratory and into the food supply chain. The work is focused on the functionality, industrialization and sustainability of the product. Future steps will be addressed to the other design aspects such as communication and appeal.

2 Experimental work: materials and methods

The aim of this research is the study of innovative active packaging able to control the overheating of the content products at a specific temperature. The work includes an experimental phase, conducted in laboratory, where a composite material was developed to achieve smart thermal insulation properties; after that, the characterization of the composite material was done in order to compare mechanical and thermal properties, in static conditions, with the ones of traditional materials employed in food packaging. Finally, the composite material was used to realize a sampling of packaging, which was tested in laboratory and in real conditions, in order to evaluate the thermal property of the material in dynamic conditions, when external temperature increases and decreases. Following each phase of the research is described.

2.1 Development of the composite material

Smart materials and conventional materials for food packaging were investigated. The idea to work on the secondary packaging was supported by the possibility to have a wider selection of materials available. Indeed, materials forming the secondary packaging are not subjected to strong restrictions, thanks to the fact that they are not directly in contact with food.

Existing and currently used packaging was analysed. Secondary packaging for ready-to-eat salads typically consists in corrugated cardboard boxes, made of secondary row materials. Cardboard is the most common material used for wholesale packaging (38% share in food packaging industry) [6].

Reported below, considerations about the material and the productive process involved.

Cellulose materials present good thermal insulation properties in static conditions (thermal conductivity: λ=0,06 W/ (mK)).

Approximately 22% of the total waste mass is made of cellulose materials: the reclaim of wastepaper for the production of recycled paper is a well consolidated industrial process that brings proven economic and environmental advantages. However, the current collection and production of recycled paper is marked by an offer excess, which is difficult to be absorbed from materials and products currently made [6].

The idea to develop a composite material, based on cellulose fibres, with the addition of a smart material in order to confer special properties to the composite, can be an approach in order to extend the application fields. The present work is based on this idea.

Composite materials are made by combining two or more materials which have different properties such as mechanical, thermal or electrical behaviour. The different materials work together giving unique properties to the composite. Materials remain physically separate and distinct at the macroscopic or microscopic scale within the finished structure. The great advantage obtainable by the use of a composite material is related with the capability to combine different properties and characteristics that a single material does not allow to have [1].

The first part of the work focuses on the realization of a composite material that combines the structural properties required for secondary packaging with an active heat control as innovative point. This material can be based on a cellulose matrix, obtained from recycled paper, conveniently loaded with a smart material to convey the required functionality.

One possible solution to control thermal insulation and to maintain a desired temperature, for a limited period of time, is represented by thermal energy storage approach. Along this direction, large quantity of thermal storage/recovery can be achieved in the form of melting/freezing latent heat by using phase change materials (shortly PCM).

PCMs are materials that undergo a phase change, for example from solid to liquid state, at a specific temperature (or in a narrow range of temperature) near envisaged application. In such systems, energy is stored during melting and recovered during freezing. The latent heat is the thermal energy absorbed or released when PCMs change phase which are hence capable to store or release large amounts of energy.

Because of their great capacity to absorb and slowly release the latent heat, it is easy to imagine that if a PCM is added to the interior of packaging, it increases the thermal energy storage capacity of the container, representing the most ideal solution for temperature peaks modulation. The use of PCM allows to obtain little or no change in temperature during transition processes: heat storage and delivery, in facts, occur over a fairly narrow temperature range (the transition zone). A container exposed to hot temperatures, hence, slowly increases its temperature in a process governed by sensible heat: when it approaches the phase-change temperature, the content is held at a nearly constant temperature, due to the latent heat adsorbed by PCM. Once the material has changed phase, the container temperature finally increases up the ambient temperature.

Currently, more than 50 PCMs are commercially available. Most commercial PCMs are based on material classes of the salt hydrates, paraffin, and eutectic water-salt solutions. Commercial PCMs cover a temperature range from -40°C to +120°C.

In most cases, the PCM needs to be encapsulated. The two main reasons are to hold the liquid phase of the PCM, and to avoid contact of the PCM with the environment, which might harm the environment or change the composition of the PCM. Further on, the surface of the encapsulation acts as heat transfer surface. Encapsulations are usually classified by their size into macro- and microencapsulation. For the aim of this work, which is to use PCM in order to build a composite material, only microcapsules will be considered.

Microencapsulation of PCM is technically feasible today only for organic materials. Commercial products seems to use exclusively paraffin. The typical capsule diameter is in the 2-20 micrometres range [14]. PCMs selected for the present project are microcapsules of paraffin characterized by a melting temperature of about +6°C.

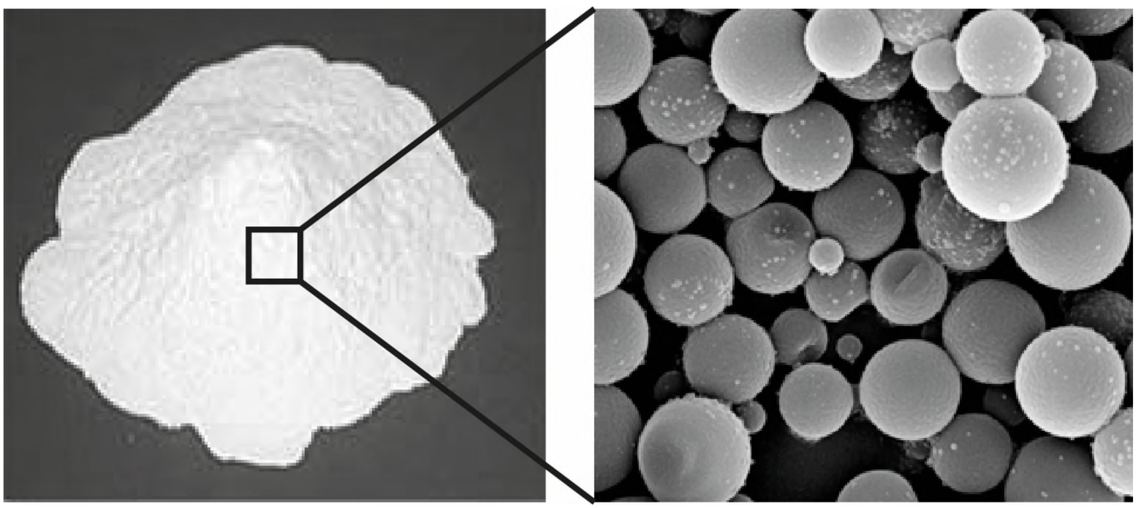

Figure 3 PCM microcapsules by Rubitherm Technologies GmbH, and related optical micrograph.

Figure 4 Realization of cellulose pulp into the pulper, starting from cardboard scraps

A set of different composite materials using paraffin as PCM, has been developed and commercialized by Rubitherm Technologies GmbH. The compound is a shape stabilized PCM and consists of paraffin as PCM embedded in a polymer structure. The integration of PCMs in other materials has not been investigated yet.

Here, a simple method for the stable incorporation of PCM microcapsules in paper matrix is proposed, in order to realize PCM cellulose composite as novel active packaging material.

The composite material developed in laboratory is made by 50% cellulose fibres and 50% Phase Change Materials (Microtech) (w/w) ratios. PCMs were integrated into the cellulose matrix during the recycling process, using a pulper (Adirondack Machine, Formax 450h High Consistency Laboratory Pulper) while adding water [10] [15]. The obtained suspension of water, cellulose, and PCMs is called pulp.

The possibility to select the PCM activation temperature allows to have composite materials with different activation temperature, depending on the final application. In this work, the object of study is the secondary packaging for ready-to-eat salad bags. This product has to be conserved under +8°C. Consequently, the melting point of the PCM used was +6°C, which correspond to the PCM activation point.

2.2 Laboratory characterization

The composite material was characterized in terms of mechanical properties and insulation thermal properties in static conditions.

Mechanical properties were evaluated through flexural strength tests. The results obtained demonstrate that the composite material presents flexural strength value of about ∂=1MPa. This value does not result adequate for the considered application, consequently the material was coupled forming a multilayer structure to improve mechanical performances.

Thermal insulation was evaluated using a thermo-fluximeter (Heat-Flow-Method) under static conditions. This method is generally used to calculate the thermal conductivity of a non-homogeneous material. Tests were elaborated through the software SUBB. The results showed that the composite material is characterized by a thermal conductivity value of λ=0,06 W/(mK), the same as cellulose material.

2.3 Realization of active packaging

The composite material developed was used to realize active packaging. The composite pulp was worked in order to obtain a suitable semi-finished product to realize packaging. The composite pulp was spread on a filter membrane placed on a stainless steel grid, and pressed in order to remove the water and obtaining a dry plate panel with constant thickness of 3 mm, as shown in Figure 5. The panel was coupled between corrugated cardboard (1 mm thickness, Ghelfi Ondulati) and kraft paper (Ghelfi Ondulati) obtaining a sandwich panel with a final thickness of about 5 mm. The sandwich structure was manufactured in order to confer to the material the suitability to be used for packaging, in terms of appropriate mechanical properties and possibility to place it in contact with food products.

The semi-finished product was used to realize active packaging. They were realized with the same shape and size as standard packaging, using a cutting plotter (Zund), in order to compare their thermal maintenance behaviour. A sampling of 20 active packaging was realized for testing. Tests were performed both in laboratory and in real conditions, in a real food supply chain.

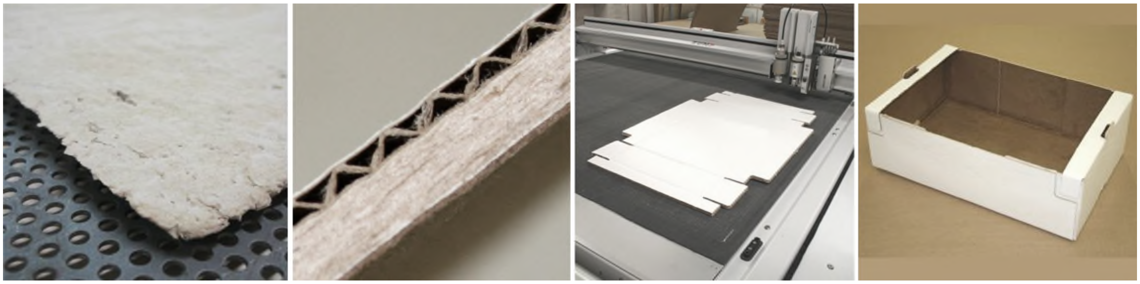

Figure 5 From the panel to the final packaging: panel in composite pulp, multilayer panel, cutting and final active packaging, respectively

2.4 Test performed in a real food supply chain

Thermal insulation properties of the realized active packaging were compared with the ones of standard packaging commonly used for the transportation of ready-to-eat salad bags. A sample of 20 active packaging was used in a real food supply chain in collaboration with the company San Lidano.

The temperature variations were recorded inside each active packaging as well as inside each standard packaging. Starting from the packaging phase, when salad bags are placed inside secondary packaging, temperature variations were monitored using a data temperature recorder (RYAN-SENITECH, mod ETZ) arranged into each packaging, as shown in Figure 6.

Figure 6 Data temperature recorder arranged into each packaging

2.5 Test performed in laboratory

The functionality of the active packaging was also been tested in laboratory and compared with standard packaging.

Each packaging, active and standard, was filled with bags of salad, placed for 24 hours in an industrial refrigerator (EPTA) set at +3°C, and then pulled out at room temperature (+20°C). Temperature variations were recorded during all over the process.

The aim of laboratory tests was to monitor temperature variations inside each packaging during the storage phase in the refrigerator, and also verify the duration of thermal insulation when packaging were pulled out from the refrigerator.

A system of thermocouples (National Instrument system acquisition NI cDAQ 9172) was set in order to record temperature variations. It was used to monitor temperature inside each packaging as well as temperature inside the refrigerator. The system of thermocouples allowed to obtain very precise data (over tenth celsius degree), observed every 10 minutes. Tests were repeated 3 times.

3 Results and conclusions

First of all, the development of a composite material based on cellulose, opens the way to several possibilities of applications. The application considered here, food packaging for fresh products, can take advantages from the composite material thanks to its properties of active thermal insulation.

The work done, permitted to carry out a comparison between the developed active packaging and the traditional ones.

The comparison was done considering both the properties in static conditions (thermal and mechanical properties) and in dynamic conditions, when temperature variations are relevant. Results of each research stage are described below.

3.1 Development of the composite material

Figure 7 shows optical micrographs of the homogeneous integration of the PCMs into the cellulose fibres.

The particles of PCMs result well fixed into the net formed by cellulose fibres. Their presence confer to the material active thermal insulation properties thanks to their great capacity to absorb and slowly release the latent heat. The composite material realized, results suitable for the application in packaging industry, as explained in the next paragraph.

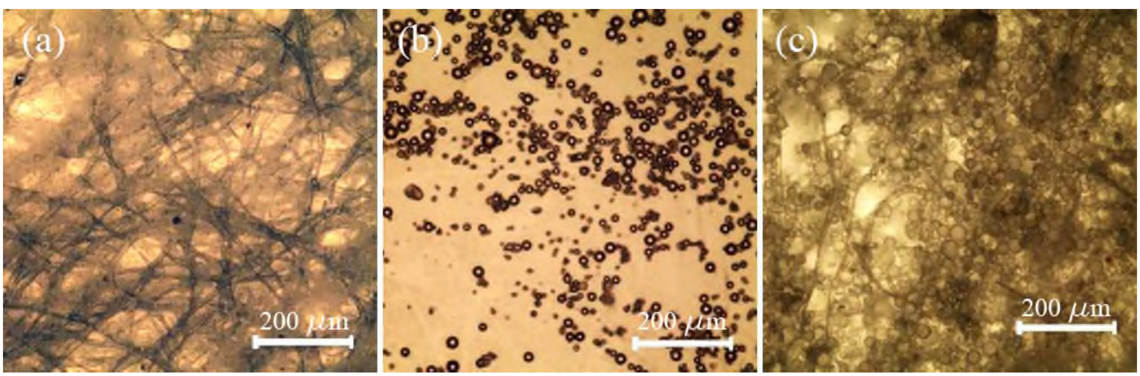

Figure 7 Optical micrographs of (a) PCM microcapsules as received; (b) cellulose fibres; (c) composite material

3.2 Laboratory characterization

Laboratory characterization demonstrated that the developed composite material does not present adequate mechanical properties (flexural strength) to be applied in food packaging. In order to solve this problem, panels were coupled to arrange a multilayer structure that results even more strong and resistant than traditional packaging.

Thermal properties under static conditions are comparable to the ones of cellulose material that means that the developed material does not present disadvantages considering static thermal insulation. The advantages of the composite, in terms of thermal performances, emerge under dynamic conditions.

3.3 Realization of the active packaging

Figure 8(a) shows the composite material used for the development of the active packaging. PCMs are equally distributed into the cellulose fibres creating a composite material. The working processes carried out on this pulp allowed to obtain a multilayer panel, represented in Figure 8(b), presenting the required mechanical properties, suitable to be used for the selected packaging. Moreover, the sandwich structure can guarantee the possibility to use the panels for food applications, indeed the external layers, kraft paper and corrugated cardboard, are commonly used as material for secondary food packaging.

Using the sandwich panels, a sampling of 20 active packaging, with the same shape and size as the standard, was realized (Figure 8(c)).

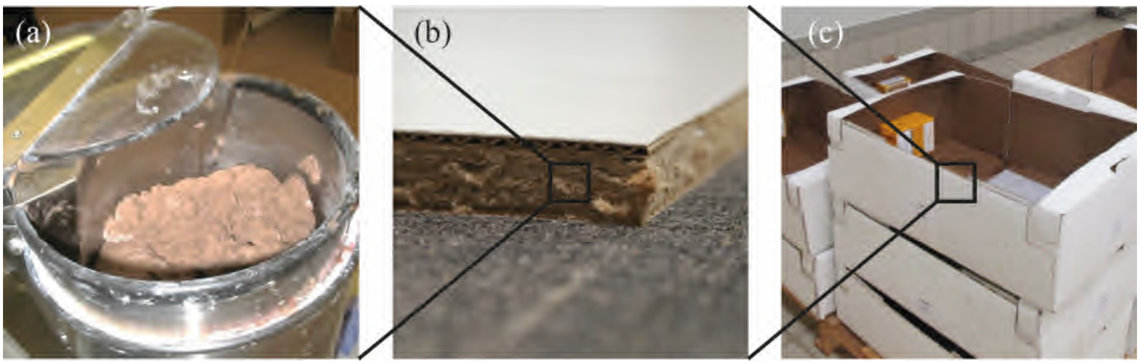

Figure 8 (a) Composite pulp; (b) Sandwich structure of the panel; (c) Sample of active packaging

3.4 Tests performed in a real food supply chain

The Figure 9 summarizes results obtained during tests in real conditions. Temperature variations recorded during all over the tests (20 hours) are reported. Precisely, Figure 9(a) reports the average temperature of the thermal cycles observed inside each standard packaging, as well as the curve reported in Figure 9(b) represents active packaging behaviour.

The recorded thermal cycles permit to observe that, during the food supply chain, ready-to-eat salad is not always kept into the adequate range of temperature for a good and healthy conservation. This issue is related with many reasons like the packaging transfer from a storehouse to the truck or vice versa, the malfunctioning of the truck refrigerator system, the contact with warmer products, or others. This incorrect conservation causes food waste and can also increase significantly the spreading of bacteria.

Figure 9(c) shows the average temperature of the thermal cycles of standard packaging compared with the one of active packaging. Interesting results are observable during the first 9 hours: when the temperature started to increase, due to the external causes, active packaging demonstrated to be able to delay the rise of temperature. In particular, active packaging delay the reaching of the critical point of +8°C, for more than 1 hour.

Similar results can be observed also at the end of the thermal cycle, after 17 hours, but at that time salad bags were removed from secondary packaging at the supermarket, consequently results may be meaningless.

Results are highlighted in Figure 9(d): during the first part of the distribution, products are subjected to overheating. Here, when the temperature increase up to +8°C, +9°C and +10°C, as shown by the 3 different dashed lines, the active packaging delay the rise of temperature for a range of time between 1 and 2 hours, which is a significant time for the good maintenance of salad.

Results of tests in real conditions showed that it is possible to use active thermal insulation packaging to improve the conservation of food.

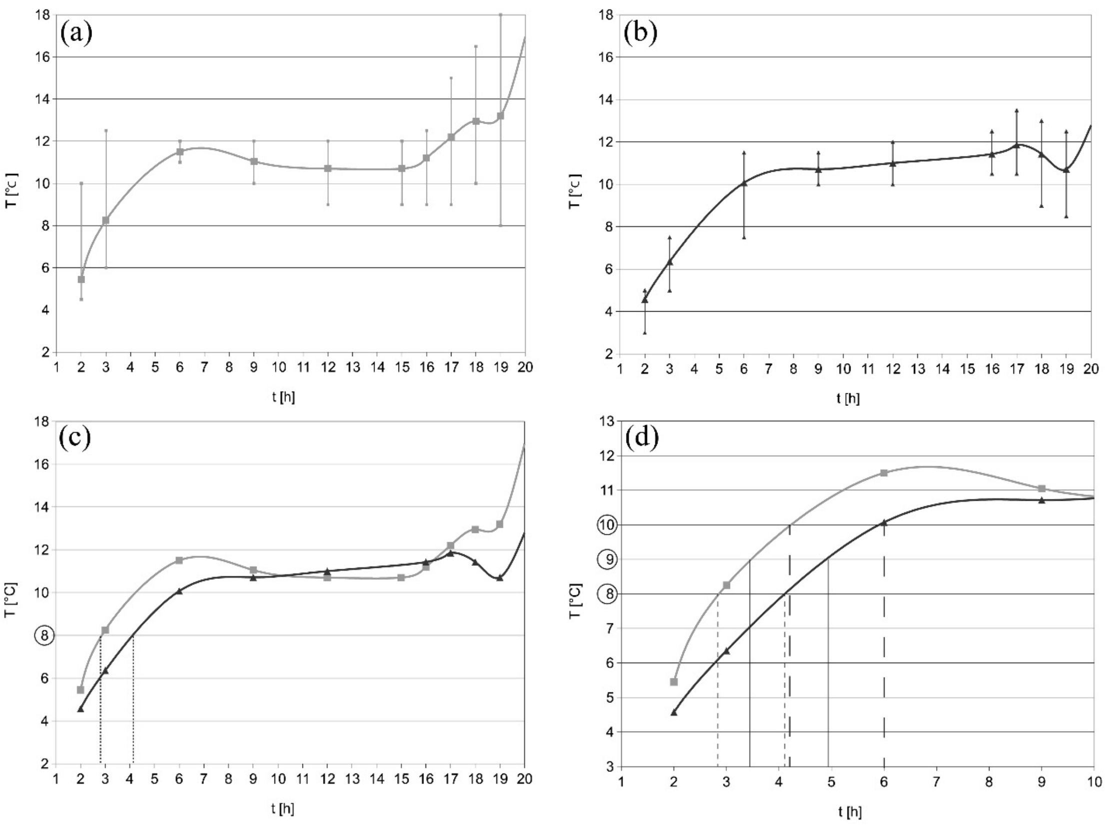

Figure 9 (a) Average temperatures recorded inside standard packaging; (b) Average temperatures recorded inside active packaging; (c) Comparison between standard packaging and active packaging; (d) Focus on the first hours of the distribution

3.5 Tests performed in laboratory

Laboratory experiments allowed to study and analyse the maintenance conditions of the food, during the storage inside the refrigerator. They also verified the results obtained in real conditions.

Figure 10 reports results of laboratory tests: it shows the average temperature of the thermal cycles recorded inside the refrigerator, into the standard packaging and into the active packaging, respectively. The first consideration is that the temperature inside the refrigerator, set at +3°C, is not constant, but it is subject of several peaks. The reason is related to the duty cycle operation of the machine. A duty cycle is the percent of time that an entity spends in an active state as a fraction of the total time under consideration. Electrical motors, such as the refrigerator, typically use less than a 100% duty cycle. For example, if a motor runs for one out of 100 seconds, or 1/100 of the time, then, its duty cycle is 1/100, or 1 percent. The best estimate of the duty cycle for all properly working refrigerators seems to be 50%.

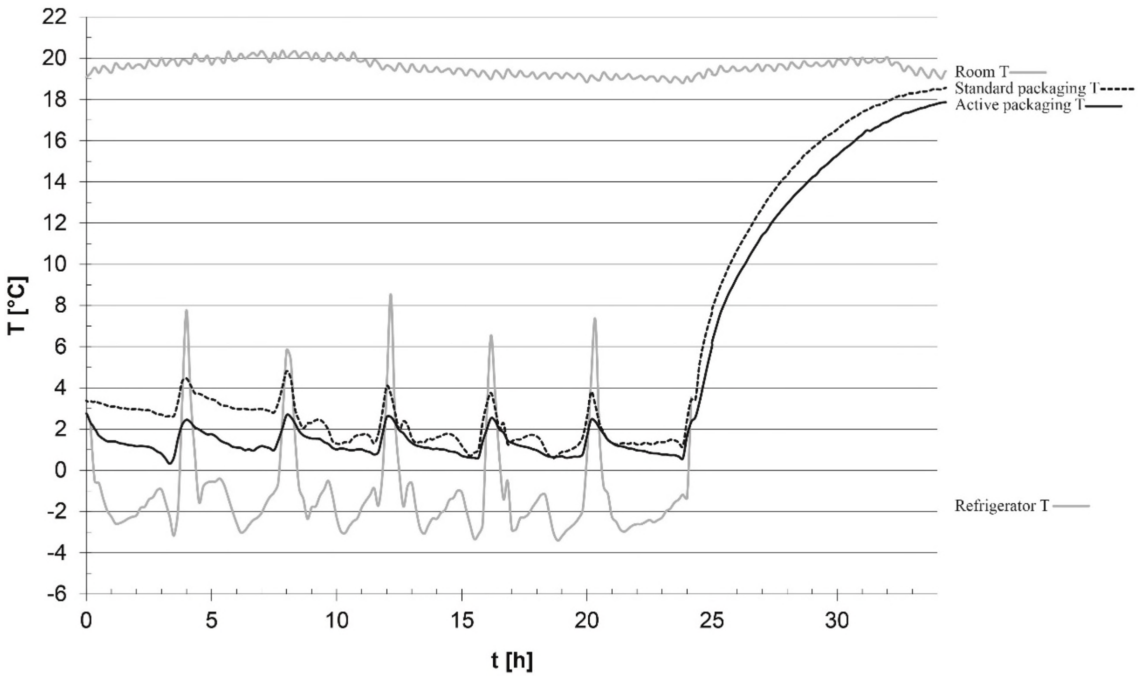

Figure 10 Results of laboratory tests

Duty cycle affects the temperature conditions into the refrigerator, and consequently, the maintenance of the products stored inside. As shown by the diagram, peaks reach +9°C as well as -3°C every few hours. This typology of thermic profile hastens the degradation of fresh food and let to understand that also during the storage in the refrigerator, many factors can affect the quality of food conservation. Observing the diagram, it is possible to notice a double role for the active packaging. The first one takes place when products are stored in the refrigerator: here active packaging are able to better modulate the duty cycle peaks compared to standard packaging. This fact could have implications also in terms of energy saving; indeed refrigerator systems represent the first source of energy consumption in a supermarket (30% of the total amount of the energy employed, European Commission Directorate-General for Energy and Transport). Using active thermal insulation packaging it is possible to suppose a reduction of the use of refrigerator systems, keeping the same quality of conservation. This promising aspect will not be investigated in this research project, but could be an interesting starting point for other works.

The other important result clearly shown by the diagram is the confirmation of the results obtained during tests in real conditions. After 24 hours, when all the packaging were pulled out from refrigerator at room temperature, active packaging demonstrated to be able to delay the rise of temperature, over +10°C, of at least 1 hour [10] [11].

3.6 Conclusions

In the scenario of active packaging, most of the researches conducted and reported in literature are focused on the active control of the atmosphere composition, absorbing or releasing some substances. For example, oxygen or ethylene absorbers, or carbon dioxide regulators.

In terms of temperature control, there are several materials, used in packaging applications, characterized by good thermal insulation properties (low thermal conductivity value), such as polystyrene. However, this kind of materials are passive insulator; indeed, they are not active at a specific critical temperature, but they tend to thermally insulate in general. Thermal maintenance is a critical point for the conservation of perishable products but, in literature, examples of active packaging addressed to solve this problem are not widespread.

This is the explanation why the first objective of the present work was focalized on this open issue.

The study and development of an innovative hybrid material was conducted and, using it, an active packaging was realized.

The developed active thermal insulation packaging demonstrated to be able to delay the overheating at a specific temperature, selectable depending on the application. Good results were obtained thanks to the operation of PCM.

This innovative packaging guarantees better conditions of storage, and consequently better quality of fresh food and less food waste compared to standard packaging. Moreover, when food is stored inside the refrigerator, and suffers the inconstant thermal cycle caused by the duty cycle of the machine, the active thermal insulation packaging modulates temperature peaks, preserving the food.

The benefits generated by the active thermal insulation packaging can be considered in terms of social impacts, economic impacts and environmental impacts. Social impacts are related with the reduction of food waste and the improvements of food quality and safety. This last point, the impact of active thermal insulation packaging in food safety, has been later enhanced and verified in another research, not here reported.

All social impacts present effects in economic area. The reduction of food waste means saving the economic value of the food not wasted, and saving the value of resources employed for the production of food (plantation, harvesting, transport, transformation, storage, etc.). Environmental impacts are identifiable in the reduction of food waste and use of refrigerator system. Considering the ability of active packaging in controlling the peaks during the storage in the refrigerator, it is possible to suppose that the combination of active packaging and refrigerator permits to reduce the use of refrigerator of few Celsius degrees, which is, for a huge storage like supermarkets, a large economic and environmental impact. Indeed, it is evaluated that about 30% of the energy consumption of a supermarket is attributable to refrigerator systems [8]. A reduction of their use means energy saving and money saving.

The research open the way to several applications for the composite material: not only for smart packaging, but also in other fields where thermal insulation is request, the developed material could be experimented and optimized to obtain an active insulation. Examples of applications could be insulating panels for building industry, insulating containers for shops and markets, or again insulating panels for transport lines. In all these cases, the active thermal insulation materials could reduce the use of air conditioning.

Considering in detail packaging field, the active thermal insulation packaging was realized and tested for RTE salads, but it can be used for several other perishable products, such as chocolate, bakery, ice cream, otherwise non-food products like cosmetics, drugs, vaccines, etc. which are sensible to temperature variations.

Depending on the optimal temperature range of conservation of the content, adequate PCM (with their own transition temperature) can be selected and used.

4. Future prospects and potential applications

Packaging, as most physical objects of everyday life, is becoming a smart packaging into the smart world of “Internet of Things” where everything is connected and things can communicate and interact each other, with the environment and with users. Active packaging, as example of innovative smart object, is proceeding along this evolution: it increasingly interacts with the environment, changing some properties to improve its functionality [16].

The work done followed this evolution of design: products are becoming dynamic, smart, interactive, and emotional. The project is focused on the functionality of packaging and future steps will be addressed to the communication and emotional aspects of the developed packaging.

An in-depth analysis of the possible applications will direct the development of the communication aspects. Considering the results obtained, the identified applications can vary from packaging for take away food, fresh food, frozen food, to packaging for cosmetics, drugs, vaccines, organs and blood sack.

The use of the developed active packaging will guarantee a better conservation of the content and a reduction of products waste. After their use, packaging can be recovered and re-used, also in everyday life as refrigerator box or food box.

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