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ACTIVE AND INTELLIGENT PACKAGING TECHNIQUES IN FOOD PRODUCTION CHAINS

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INTRODUCTION

A significant worldwide trend is the change of customers' expectations regarding food quality: gradual conversion to lighter food, and growing customer concerns are experienced regarding additives, microbial contamination and nutrient deterioration due to processing, storage or transportation conditions. As a consequence, customers now turn towards fresh food with little intervention in its raw materials. While such food has a lengthy record of cultural tradition in countries like Japan, it is now also becoming appealing in regions so far dominated by processed food.

In addition to changing production practices, the supply chain requires adaptation as well, owing to the sensitivity of fresh food to spoilage. Without such adaptation, losses would occur due to adverse ambient conditions, or inappropriate handling policies of goods due to a lack of process transparency [11],[13]. Improvement can be effected by both making the conditions of supply chains more suitable for fresh food, and by employing special packaging that presents a better match for the conditions and requirements of the supply chain [4].

Presently, specific conditions of the European market, technological and legal backgrounds can still hamper direct adoption of fresh food handling practice established in other regions of the world, and coordinated action is needed to improve the situation. The paper presents AIP-CORNET, a European R&D project dedicated to facing these challenges, by giving a brief overview of the problem domain, the potential of active and intelligent packaging and track-and-trace solutions, and characterizing the current European situation within which the actions of the AIP-CORNET project take place.

CHALLENGES IN THE FOOD SUPPLY CHAIN

The handling of fresh food may require notable adaptation in all stages of the supply chain. Here, typical stages are briefly examined, and extended by an after-sales step of the product life cycle.

Production—In the adaptation of this stage, the production processes themselves receive most attention, i.e., the transformation of raw material into the desired product. However, accompanying processes as packaging may also call for changes [4]: advanced packaging may need special activation or initialization steps, and process transparency may require more thorough reporting, in addition to the food traceability measures already required by today's legislation [6].

Transportation—As perishables proceed through the supply chain, undesired or dangerous degradation of the product must be prevented. For transportation, this implies: *i)* reducing transportation time and ensuring suitable handling conditions (possibly requiring more advanced transportation assets), and *ii)* providing information about the shipping process itself to grant transparency and enable better dispatching and handling decisions [13] (at the cost of additional information sharing infrastructure).

Warehousing—Regarding time lags and handling conditions, warehousing shares many problems with transportation. Additional challenges are introduced by the re-organization of shipment units typical for distribution hubs, joining different goods with varying handling tolerances [11]. Also, responsible decisions must be taken when goods of the same type but different remaining shelf life are present, and goods must be reliably located [8] before unnoticed spoilage presents safety threats or induces further losses. In addition to granting the proper ambient conditions, meeting these challenges mainly requires an improved information infrastructure.

Sales—Points of sale inherit several requirements generally applying to the entire food supply chain (those related to handling conditions and transparency), while they present a most heterogeneous selection (from high-tech supermarkets to small, low-end shops) regarding their technological background and attitude to additional investment [3]. This is also the stage where the consumer enters the processes and represents a totally different perspective with small-scale and often bounded-rational decisions [9]. Due to the latter fact, points-of-sale may need to bridge conflicting expectations, especially regarding transparency, and may have to introduce several solutions and policies in parallel.

After-sales issues—While points-of-sale are generally considered the end of the food supply chain, it is still important to examine the phase of storage with the consumer prior to consumption. This is recommended for two reasons: *i)* consumer confidence also depends on the persistence and transparency of product quality after its sale, and *ii)* it is important to keep the consumer shielded from health risks posed by food that is contaminated or spoiled without making the latter noticeable to the consumer [6]. It should be emphasized that the home of the typical consumer is possibly the most "low-tech" point in the entire chain. An average home may have limited means for granting optimal ambient conditions, and without reading or measurement devices, a mere visual check may be the only option to assess the freshness of an unopened package.

TECHNOLOGICAL BACKGROUND OF SOLUTIONS

While solutions to the above challenges rely on a wide range of theoretical advances and technologies, the present survey is restricted to some selected areas within the scope of the AIP-CORNET project, namely, active and intelligent packaging, and tracking services. The main focus of the paper is centered around information technologies; however, related domains of the project's scope will be mentioned as well to complete the picture.

Advanced packaging technologies—The term *active packaging* refers to solutions actively interfering with deterioration processes to prolong shelf life without altering the composition of the product itself. Two fundamental classes are recognized here: *i)* those that absorb chemical agents allowing or accelerating spoilage (most commonly oxygen [12] or moisture), and *ii)* those that inhibit the growth of microbes effecting spoilage (antimicrobial packaging [2]). Active packaging accompanies the product through the entire supply chain and can meet challenges present in all stages the product passes, however, it may require specific technological steps for initial activation.

Various *intelligent packaging* solutions facilitate the assessment of an estimated shelf life or supply information on actual freshness [4],[5]. A commonly practiced method of shelf life estimation is the use of a simplified indicator—either an electronically implemented mathematical model, or any physical or chemical process that runs in parallel to actual food degradation but can be measured more easily, serving either as *time indicators* or *time-temperature indicators*. *Freshness indicators*, on the other hand, directly monitor food quality by detecting compounds that are characteristic products of spoilage processes and are, therefore, not restricted to the detection of conditions on or near the packaging surface. These may be based on chemical or physical processes effecting visible changes of an indicator, but conversion to electrically measurable signals (in the fashion of an "electronic nose") is also possible. Indicators can reduce losses by allowing flexible product handling policies or narrowing down the amount to be actually discarded due to spoilage.

Integrating electronic solutions into the packaging has become technically feasible due to the development of low-power devices that are either battery-powered, or are tapping electromagnetic waves. Sensor-equipped RFID tags and wireless sensor networks are often considered for food surveillance applications [1], however, the choice of a particular solution depends much on key application constraints regarding measurement and data transfer timing, reading equipment available along the supply chain, and data processing capacities [10]. Electronic solutions, especially RFID, are considered the most efficient way of entering data into an information sharing network, however, at the cost of major initial investment and exclusion of low-tech participants from direct food quality detection. The latter are better served by optically readable indicators due to their low cost, and their easy observation and interpretation (mostly intuitive even for first-time consumers) [11]. Nevertheless, such solutions do not serve large-throughput supply chains too well owing to their more labor-intensive and visually constrained reading procedure.

Tracking in the supply chain—Counteracting and indicating spoilage with advanced packaging are only one way of reducing losses in fresh food supply chains. In parallel to these efforts, it is also possible to improve the throughput and efficiency of supply chains as material streams. Both surveys and practical experience suggest that much supply chain efficiency is lost due to sub-optimal decisions taken without proper knowledge of the materials handled. This, again, is the result of imperfect transparency of the processes involved, and a major step of remedy can be taken by introducing tracking services providing reliable data without much time lag.

According to [11], selected properties (most commonly physical location) of the material can be tracked (kept track of and maintained in a database) if *i) unique identification* of material units is made possible, and *ii) information services* must be established to record and retrieve tracking data. Unique identification can be practically implemented with one or more forms of automatic identification (AutoID) with the particular choice depending on desired material throughput and availability of various enterprise resources (work force, reading equipment, finances for additional investment, etc.). It can be advantageous to combine AutoID solutions with data acquisition from intelligent packaging units (e.g., sensor-equipped RFID), as this facilitates the seamless inclusion of product status information in tracking services [1],[11]. Since complex supply chains usually cross company borders, the infrastructure for sharing tracking data must address the key issues of security and access control, as well as interpretability by all parties involved [11].

THE EUROPEAN SITUATION—CONDITIONS AND CHALLENGES

European food supply chains and local regulations differ from those in regions where active and intelligent packaging are massively deployed (notably Japan and North America). The following issues prevent AIP technologies (and partly also today's mainstream tracking solutions) from being directly adopted in European fresh food supply chains:

Business heterogeneity—As opposed to relatively few large companies, both production and replenishment of food is dominated by SMEs in Europe. The practices of large-volume supply chains of other regions may prove unsuitable as SMEs have limited resources to invest in new technologies and have sporadic access to expertise needed for their adoption. The heterogeneity of SMEs presents special challenges for tracking infrastructures as well.

Legislative obstacles—European regulations are not well-prepared for direct adoption of packaging techniques used in other regions [7]. Some solutions, such as separate sachets with agents, are currently not permitted in food packaging, requiring either the elaboration of suitable technologies or the reassessment and modification of corresponding regulations.

Consumer attitude—A significant part of European consumers is very critical towards certain technologies employed in large-scale food supply chains, the more so as local trade of fresh food often remains a popular—and reasonable—alternative. Especially in Western Europe, consumers are growing conscious about products with less health risks and no excessive environmental threat (see, e.g., the almost unanimous rejection of genetically modified crops forced into production without proper testing). Environmental and health issues [5],[6] will surface in the case of packaging, and they must be addressed before a large-scale roll-out. Tracking services may prove more appealing: they can reduce environmental impact, and transparency may improve consumer confidence. Most consumers in Eastern Europe present another challenge by being extremely price-sensitive due to their poor financial situation. Chances are that this will limit the Eastern European market of packaged fresh food to a narrow range of premium products for a considerable time.

MEETING THE CHALLENGES WITH AIP-CORNET

Started September 2009, the two-year European R&D project AIP-CORNET (Active and Intelligent Packaging (AIP) Competence Platform, http://www.activepackaging.eu/) aims to overcome the aforementioned burdens by two types of efforts exerted in parallel: *i)* the channeling of vital information especially to technological stock holders, prospective users and standardization or legislative bodies, and *ii)* elaboration of new technologies that better suit the European conditions of application. The consortium of AIP-CORNET joins a wide range of expertise, as it includes stock holders from the packaging and food industry, R&D partners in chemical/biochemical research, as well as members with IT expertise and SME-friendly tracking resources at hand. Although the brief duration of the project limits the observation of long-term impact, ongoing and frequent consultation with targeted user groups will ensure that the identification, evaluation and integration of suitable solutions meets the European needs, especially of small-scale members of perishable supply chains. Figure 1 summarizes the addressed problems and targeted solutions in a systematic view. Here, the IT-relevant tasks will be presented in detail.

Channeling of knowledge—Collecting and presenting knowledge is a highlighted challenge due to the nature of a major part of the targeted audience: SMEs that may not even have a rough picture of the given scientific and technological domain and are thus left without any initial orientation. This calls for a systematic organization of knowledge resources for both fast and directed search (to specific criteria), as well as browsing that guides the inexperienced user through the structures of the domain and gives a good first impression of "where to locate" a given answer. Most suitable for this purpose are topic maps that can place a structured conceptual index on a pool of information resources. As the project has limited time and resources for establishing such a structure, a “lightweight” implementation of the topic map concept with somewhat restricted flexibility will be built. This is still easy to handle for those populating the repository as well as those using it.

AutoID and machine readability—It is well-understood by the consortium that RFID, despite all efforts of pushing it into practical use, will experience limited penetration in supply chain applications of the next years. Therefore, AIP-CORNET is seeking possible alternatives in the optically readable domain. This includes two parallel branches of progress: i) developing optical indicators that work reliably enough for automatic acquisition and processing, and ii) development of suitable methods and technologies (protocols, selected devices, etc.) for automated acquisition and interpretation of optical indicator readings.

Tailoring of tracking services—Within the AIP-CORNET consortium, considerable expertise is present regarding tracking services with small-scale members of high variability [13]. An already implemented solution platform presents a solid basis for mastering specific tasks of fresh food supply chains with the inclusion of small-scale or occasional users as SMEs. As the identity-based tracking platform is independent of the particular choice of physical ID carrier, it can also serve as a test bed for assessing a variety of prospective labeling and identification technologies.

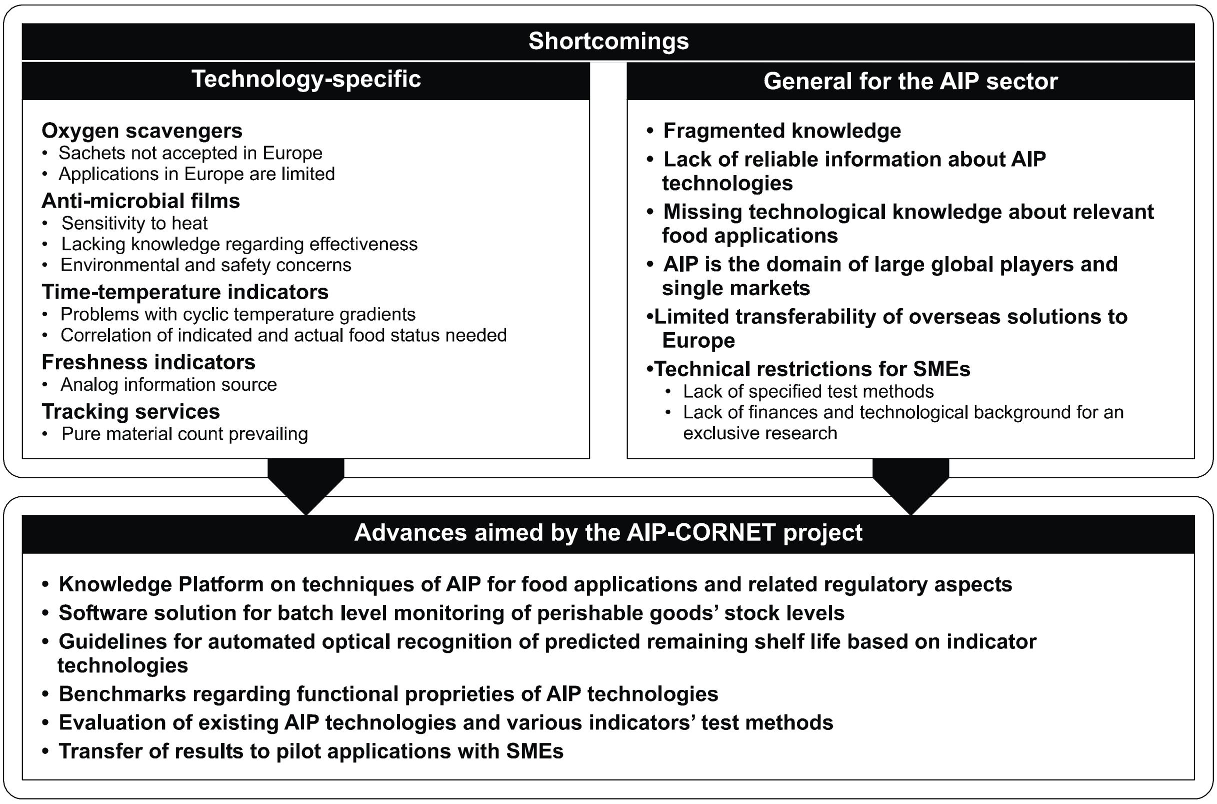

Figure 1. Problems addressed and goals pursued by the AIP-CORNET project

CONCLUSIONS

The paper presented the key challenges of supply chains conveying fresh food products over an extended range. Active and intelligent packaging, as well as tracking services were named as feasible solutions for attaining longer shelf life, more precise information about current product quality, and improved information transparency in dispatching and replenishment processes. The paper pointed out that these solutions, although commonly used in other regions of the world, can meet obstacles in Europe due to a different legislative framework, a different composition of market players and critical user expectations. Finally, the paper summarized steps to be taken by the recently started project AIP-CORNET to overcome these obstacles by channeling of expert knowledge and developing technological alternatives that are better suited for a roll-out in Europe.

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