DELIVERABLE 3.1.2

FOOD MICRO SYSTEMS

FINAL REPORT OF INDUSTRIALS' NEEDS, DEMANDS AND CONSTRAINTS

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SEVENTH FRAMEWORK PROGRAMME

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FoodMicroSystems aims at initiating the implementation of microsystems & smart miniaturised systems in the food sector by improving cooperation between suppliers and users of microsystems for food/beverage quality and safety.

The project runs from September 2011 to November 2013, it involves nine partners and is coordinated by ACTIA (Association de Coordination Technique pour l'Industrie Agro-Alimentaire, France). More information on the project can be found at http://www.foodmicrosystems.eu.

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Content

Executive summary: key findings from the report

1) With more than 270.000 companies, the food sector represents **a significant market** for developers of microsystems solutions. It includes a limited number of large companies controlling many production sites and a high number of small producers supplied by a very large number of farmers (e.g. 1 million farms delivering milk to 5000 processors in the EU).
2) One of the key drivers for implementing microsystems in the food sector is **food safety**: the food industry needs solutions that guarantee that the food is safe for the consumers. There is a demand for in-line solutions (continuous measurement) as well as for portable and easy-to-use devices.
3) Another key driver is related to **food quality**: a better monitoring of the quality parameters of the raw materials, of materials during processing and of the final products is needed to optimise the processes. The demand is mostly for solutions allowing continuous and simultaneous measurements of several parameters. Portable devices for in-situ measurements are also in demand.
4) The recent "horse meat" crisis also reveals that there is a market for solutions allowing **authentication** (solutions to detect the origin of the food products), traceability and detection of fraud.
5) Solutions to **optimise the water and energy consumption** are needed to decrease the impact of the industry on the environment and to reduce the production costs. Tools allowing the **optimisation of cleaning operations** are particularly in demand.
6) **Intelligent packaging** that can monitor the deterioration of food products and increase their shelf-life are also interesting innovations.
7) Overall, there is a strong demand from the industry for **in-line, on-line and at-line measurement solutions** that help to address the four key challenges of the sector (safety, quality, sustainability and efficiency). These solutions should be embedded in the process management systems of the industry to allow actions (measurement is not enough, they need to be utilised).
8) The **main technological constraints** are related to (i) the robustness of the devices (ii) the reliability of the measures and (iii) the compatibility with food processes. The sampling strategy (how many measures, when, where etc.) can also be a challenge.
9) There are important **organisational constraints** for developers of microsystems solutions interested to enter the food industry market. A very good knowledge of the sector and of its practices is needed from the conception phases so that the solutions proposed are properly embedded in the management practices of the food producers. New detection and measurement solutions are not a need per se: the results of the measurements should trigger actions that should be cost-effective (e.g. optimise the use of inputs or of processes parameters to reduce costs, reduce the amount of non-conformity to decrease losses etc.).

1 Introduction

This *FoodMicroSystem* report describes the food industry demand for microsystems. It is designed for companies and research organisations developing microsystems with the view to help them to better understand how the food industry can represent an attractive market for future microsystems applications. It gathers the views expressed by the food industry in a study implemented in 2012 and 2013 in several EU countries: the report provides information on the needs from the food sector and discusses the constraints for implementing microsystems in the food industry.

The food industry is the largest European manufacturing sector with more than 270.000 companies providing employments to more than 4 million persons and an annual turnover of 956 billion Euro[1].

The food industry is characterised by large volumes and small profit margins. Depending on the specific type of food chain, the market can be very concentrated with a few dominant players (for example in the dairy sector, the top 5 players represents 30% of the market share) or scattered in a very high number of small players like in the wine sector. Besides the powerful major players like *Unilever, Nestlé, Kraft Foods or Danone* who have specialists for different tasks, the food sector also comprises many small and medium enterprises (SME), including many family businesses, often comprising of only a few employees responsible for all tasks in a company, including production, quality control, innovation and finances. If needed these smaller firms outsource parts of their operations to external companies: for example many food quality and safety controls can be sub-contracted to external laboratories. Both large and small companies relies on a great extent on specialised companies for the design and the construction of their productions chains. SMEs providing equipment also play a major role by supplying sensors, measurement devices or process control systems.

The food market includes many traditional processes involved in authentic and traditional production, but also includes highly industrialised automatized production. Food production includes many chemical and biological products and productions steps that may introduce pollutions, contamination or spoilage into the process. This means that cleaning, sterilising of production and equipment are essential steps in food production and process equipment should be able to withstand rough treatment and abrasive cleaning.

Food industry itself however is not a single industry but is composed of many different production systems that have only partial overlap.

[1] http://www.fooddrinkeurope.eu/uploads/publications_documents/temp_file_Summary_FDE_datatrends_page_par_page1.pdf

Issues of importance for dairy such as continuous flow, short shelf life, fermentation, extraction of high value proteins are of less importance for meat production, where hygiene, foreign bodies like bone fragments, cross contamination and bacterial contamination present important challenge.

Other products like wine or beer, have relatively higher added value and may gain even higher value with aging- high investment in time and resources that cannot be afforded to be lost, but require high level quality of control, or lose a whole batch.

Fruits and vegetables which continue to ripen and spoil after production and shelving; the optimum quality is reached after packaging. Logistics in moving about vulnerable product over large distances is particularly tricky for fruits and vegetables.

Finally packaging industry is an important industry in all food products, but has its own typicalities. Packaging is important to enhance shelf life and product quality, protect products during transport and for presenting information to the consumer and chain actors. Packaging however, as a food contact material requires very strict quality control in and out of itself.

Together dairy, meat, fruits and vegetables and beverages (wine) represent a fairly comprehensive overview of both the food industry in volume and the scope of problems and issues encountered in the production process. The report provides a detailed analysis of the needs and constraints for implementing microsystems in these four sectors.

2 Methodology

The potential applications of microsystems in the selected food chains presented in this report have been identified through (1) preparatory work, (2) workshops and interviews with food companies, (3) web-consultation with other companies. The analysis is carried out in five representatives EU countries: Estonia, France, Germany, the Netherlands and Spain.

The methodology of the preparatory work has analogies with a HACCP methodology. HACCP (Hazard Analysis at Critical Control Points) is a methodology utilised in the food sector to guarantee food safety: it evaluates the danger (hazard) that can possibly occur during the production, identifies the steps at which these dangers can appear (critical points) and establishes measures to control these hazards. It is based on a detailed analysis of each “operation unit” of the production. A similar approach has been used but, instead of hazards, the critical points identified are points for which application of microsystems is interesting and can significantly improve the current situation.

The preparatory work consisted of establishing, for each food chain, diagrams of the production processes. For each food chain selected, one or several tables have been prepared indicating the critical points identified as relevant for a potential solution or improvement with the contribution of microsystems.

As an example, for the dairy sector the following table has been set up identifying the critical points where Microsystems can provide a solution (Contribution of ACTILAIT).

<table>
<tr><td colspan="5">Synthesis table of technological needs for Microsystems development in the different activity of the dairy sector:</td></tr>
<tr><th>Dairy sector activities</th><th>Milk collection, transport, storage</th><th>Treatment of milk</th><th>Transformation</th><th>Conditioning</th></tr>
<tr><td rowspan="9">Thematics or Technologies</td><td></td><td>Process optimization
Ability indicator of milk to the growth of lactic acid bacteria</td><td>Process optimization
Ability indicator of milk to the clotting
Control online of pH kinetic (acidification during cheesemaking, deacidification during ripening)
Control online of the drainage in curd and cheeses
Control online of clotting properties (firmness, rate of firming)
Control of the maturity of cheeses during the ripening
Control of the opening characteristics (hard cheeses)</td><td>Intelligent packaging
Leak indicator (ripening under film, vacuum packaging)
Cold logistics: Time/Temperature indicator</td></tr>
<tr><td colspan="4">Analyzing</td></tr>
<tr><td colspan="4">Online indicative measurement of microbiological quality of products (Pathogens, Total Flora, Bacteriophage)</td></tr>
<tr><td colspan="2">Measure/evaluation of the lipolysis in milk</td><td></td><td></td></tr>
<tr><td>Control of residual antibiotics on the farm</td><td>Measure of whey proteins denatured</td><td>Measure/evaluation of the fermentation activities (lactates, volatile fatty acids)
Measure/evaluation of the mineralization (soluble and colloidal calcium)
Measure of the rate of salt and its distribution
Measure/evaluation of the proteolysis in cheese</td><td></td></tr>
<tr><td colspan="4">Cleaning
Online indicative measurement of cleaning and/or disinfection efficiency
Online indicative measurement of the presence of biofilms</td></tr>
<tr><td colspan="4">Traceability</td></tr>
<tr><td colspan="4">Miniaturized systems for products tracking along the production lines (Ex : RFID chips)</td></tr>
<tr><td colspan="2">Miniaturized systems for tracking the thermal history of milk</td><td></td><td></td></tr>
</table>

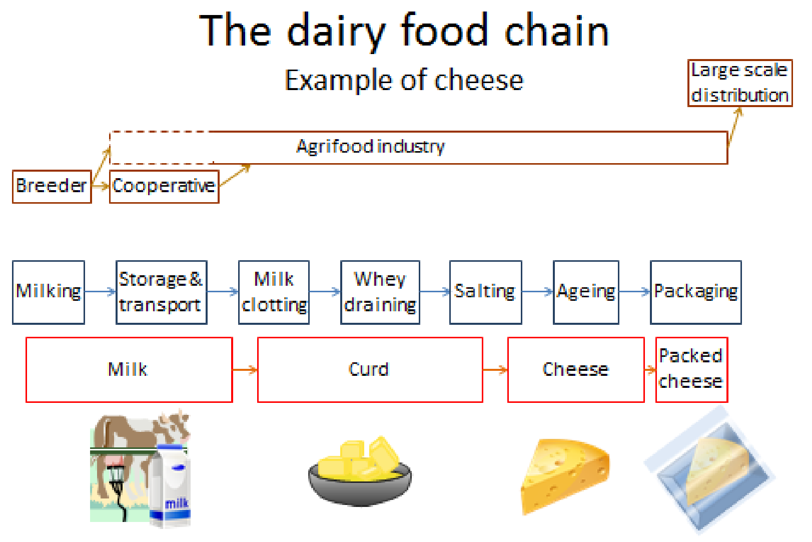
Seven workshops linking the food chain related demands and possible micro and nanotechnology systems were organised. Two kinds of programmes have been used. Either the demands were presented in plenary cessions and next subgroups were formed to discuss a demand (demands not linked, large audience); or the demands were presented one after the other and discussions were held after each presentation with all the participants (related demands, small audience). Findings from the workshops have been complemented by interviews of food and equipment companies. In total, around 100 food companies from Estonia, France, Germany, Spain and the Netherlands have been consulted.

3 Results

3.1 Dairy sector

The dairy sector is one of the most important food market in Europe: milk is the first agricultural product in the EU in terms of value at approximately 15 % of the total agricultural output. The EU is a major player in the world dairy market, it represents around 20% of the world wide milk production and account for 25% of the world dairy trade. The main producers are Germany, France, the United Kingdom, the Netherlands, Italy and Poland: they represent more than 70% of the EU production.

The dairy sector is characterised by a high level of concentration: the first five key players (*Danone, Unilever, Friesland Campina, Nestlé, Arla*) represent more than 30% of the European dairy market. Most of the dairy companies collect, process and commercialis milk products. They engage with long-terms partnerships with dairy farms. In the EU-27, there are more than one million farmers supplying annually close to 150 million tonnes of milk to around 5.000 dairy processors (55% of which are SMEs)[2].



3.1.1 Needs and demands

3.1.1.1 Safety and hygien

Dairy industrials are looking for advanced **contamination detection methods** as tools to detect and assess more **quickly** any contamination incidents or threats. To protect even more products from the risk of contamination, improvement in **cleaning operations** can be made thanks to microsystems applications.

[2] http://ec.europa.eu/agriculture/eval/reports/dairy/

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a. Fast microbiological analysis

Under some signs of quality, the specification indicates that the maximum time between the oldest collected milking and renneting is 24 hours (protected designation of origin Mont d'Or, Morbier, Comté). This short time does not currently allow having the results of microbiological detection of pathogenic bacteria (e.g. Listeria, Salmonella) before the processing of milk.

The main need for these traditional industries is thus to have a means of **detecting** various pathogens (Listeria, Salmonella, STEC) that can deliver an answer within a **short time** (less than 12 hours). Dairy industries are also interested to have tools for **rapid or online detection** of bacteriophages in milk and whey. **Control online** of the milk could also be very interesting.

b. Portable devices

Portable device for in-situ and quick **diagnostic and identification** tools for the **animal diseases** is an important demand. Microsystems could provide quick solutions in case of outbreak of a new disease or a new strand.
Detection of animal diseases in e.g. faeces, in-line monitoring of micro-organisms with the use of microsieves (Innosieve), are of interest for the sector. Farmers do not have PCR equipment. They need a more user friendly test tool, which can be easily used on farms (like the at-home-pregnancy test) such as a specific transportable PCR system.

Microsystems could also **distinguish the type of organism** which is causing the disease to know which specific antibiotic must be used. Detection of specific compounds in the milk can also be of interest for the sector. For instance to distinguish between "Weidemelk" (a Dutch word meaning milk from cows that eat grass in a pasture) and ordinary milk from cows in a barn fed with hay and concentrate.

c. Cleaning operations

Performance monitoring and optimization of units of Cleaning in Place (CIP) would allow a significant gain in productivity. Presently, the length of cleaning cycles is based on empirical means. Dairy companies need to have a **reliable means of monitoring the effectiveness of their cleaning** so they can finely control cleaning operations and with full knowledge of the facts in keeping with microbiological hazards.

Currently, checks are performed to monitor the effectiveness of cleaning: upstream controls to check the good application of instructions for use of detergents to bring a good efficiency to cleaning products (detergent concentration, exposure time and temperature). All these tests give an idea of the fouling and of the level of bio-contamination at a given time but they are not sufficient to control the process of cleaning and disinfections. This evaluation is only possible through the use of online sensors related to the automation which drives the cleaning station. **Fouling problems** in microchips have been sold; it would be interesting to now convert this solution to large scale installations currently used in the food industry. Surface modification could provide solutions, but the question is if these modifications are stable under treatments necessary to e.g. clean the machines.

Alongside the cleaning efficiency, a need for **controls on the persistence of cleaning products** has been identified. Indeed they can pollute the raw material and cause problems in the lactic fermentation necessary for the fabrication of many dairy products.

3.1.1.2 Quality control

The dairy industry always looks for possibility to improve its productivity. For this purpose, industrials needs to better **control specific processing steps** of cheese making such as milk clotting, dry matter, whey protein and denaturation rate or the opening characteristics of cheeses. For this, non-intrusive, cheap and fast sensors measuring new parameters are needed.

a. Milk clotting

To achieve a maximum yield of cheese and the best quality of cheese, the cheesemaker is looking for a precise determination in **continuous of the firmness of the coagulum** for optimal cutting. Moreover, changes in equipment (closed tanks) and labour legislation (safety), the increase of the size of the cheese plant and the increasing importance of automation explain the need of an **objective instrumental method online and in real-time** for the **monitoring of clotting characteristics**.

b. Dry matter

There is no method to measure the **draining of whey in vat**. However this parameter is critical to determine the time of moulding the curd. As for clotting characteristics, changes in equipment and the increasing importance of automation make the need for a measure of dry matter online and in real time even more relevant.

c. Whey protein and denaturation rate

To increase yields, dairy industries apply to milk important heat treatments to denature the whey proteins which can thus be recovered in the curd and better valued. The **monitoring of the denaturation rate** would improve regularity of yields and decrease the standard deviations of weight. This will allow a lower average weight of the cheese with an increase in profitability.

d. Opening characteristics

An objective method to determine the **openings characteristics of cheeses** would allow better management of ripening cycles (e.g. out of hot room, temperature, humidity, etc.).

3.1.1.3 Other issues

a. Surface status and monitoring of materials ageing

On this topic, three themes were identified: Qualification and quantification of **interactions between materials and cleaning products; sensitivity of surfaces to the development of biofilms**; and **monitoring of the mechanical properties of a material** (for example the porosity of mould and the capacity to evacuate the whey).

b. New production device - micro sieves

Actual micro sieves deliver a log 7 reduction, which is inferior to sterilisation, but better than pasteurisation. Therefore, there is a great opportunity for improvement and development for these microsystems by increasing the log reduction. With this treatment, milk can be stored uncooled, which is a relevant advantage for the consumer. Added value for the consumers must be transparent, because if they see a benefit, the industry will invest. **Replacing sterilisation** will avoid heat treatment that influences certain constituents of the product which could change the flavour for example. Nanomembranes could be a new way to **fractionate whey proteins**, to add value to the whey (lactoferrin) and to separate certain components (specific proteins) from the main stream. These ones could add value to high end products (energy and sport products, medical food, healthy products, etc.).

3.1.2 Constraints for implementing microsystems

Dairy industry is a sector of small margins and the **costs of microsystems** can represent a barrier to their implementation. To decrease the costs, the numbers of devices (e.g. microsieves) must be high but one major difficulty is to scale up the device at commercial level.

Dairy industrials need to critically evaluate the financial impact of the new technology compared with the one currently used (capex/opex). Energy (=cost) saving could trigger the use of new technologies. Calculations for these cases show that a technology has a financial margin to fit in of 0,03 ct/l. In general, dairy industries are ready to invest if the return on investment is less than 3 years.

On a technical point of view, some devices still require specific equipments (like PCR), so they first need to be **more user-friendly or automatic** before being available for farmers to test their milk. For applications of milk sterilisation with microsieves, a better log reduction is necessary to remove all active bacterias.

For the adoption of microfluidic methods it is necessary to create new products that can only be made through these methods or to realize significant improvements of existing methods (reduction of emulsifiers = E-numbers).

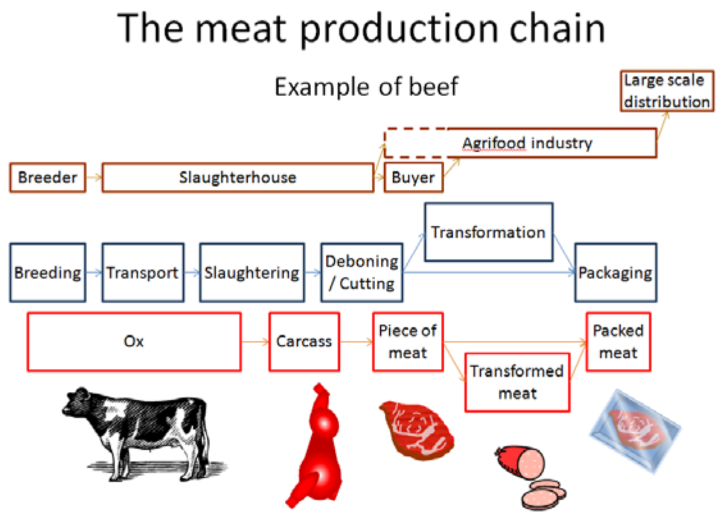
Overall, systems must be food grade (they need to be safe, materials in contact with the food must be authorised, breakage or leakage need to be prevented), integrated into the process and able communicate with automatisms in order to control the process.

For many technologists, one important constraint to meet concerns **cleaning issues**. Technologies must be fixed and easily compatible with the cleaning techniques used. This concept is important because it is unthinkable for the dairy industry to integrate a system too fragile to withstand cleaning procedures or that can be a potential point of contamination in the process. It is important to look at fouling of the devices and how they can be cleaned in an industrial setting. Finally the possibility of disassembling a device, such as a sensor, before cleaning is rejected for reasons of practicality and cost in staff time.

3.2 Meat sector

With an annual output above 100 billion euros, the animal production is the largest agricultural production in the EU. Pig is the largest market (50% of the EU meat production) followed by poultry (25%), beef (15%) and sheep and goats (2%)[3]. Europe accounts for 20% of the world pig-meat production, the main producers being Germany, Spain, France and Poland followed by Denmark, Italy and the Netherlands (85% of the EU production). For beef, France, the UK and Germany are the most important market (45% of the total EU production). The main producers of poultry meat are France, the UK, Germany, Spain, Poland and Italy (70% of the production) while the sheep and goat production is concentrated in the UK, Spain and Greece (also 70% of the production).

The meat sector is less concentrated than the dairy sector but it is still a concentrated market: the top 15 producers represent around 35% of the production[4] and the top 100 producers represent around 55% of the total EU production. The largest players are *VION* (NL), *Danish Crown* (Denmark), *Tönnies* (Germany) and *Bigard Group* (France): their combined turnover reached 23 billion euros in 2010. The supply chain includes farmers who breed animal, slaughterhouses (transport, slaughter and deboning operations), traders and processors. Many players engage with long term partnership with farmers and integrate the slaughter, deboning and transformation operations.



[3] http://ec.europa.eu/agriculture/statistics/factsheets/pdf/eu_en.pdf
[4] http://ec.europa.eu/dgs/health_consumer/information_sources/docs/ahw/pres_24102012_opening_4_richard_brown_en.pdf

3.2.1 Needs and demands

3.2.1.1 Safety and hygien

Meat sector needs tools to detect chemical residues (e.g. veterinary drugs), microbiological contamination (e.g. salmonella) and to control **online microbiological quality** of products (pathogens and/or total flora). Rapid and simple methods to **measure the formation of compounds** resulting from transformation processing or their migration related to the interaction between the container and the product are also a crucial need.

3.2.1.2 Quality control

The meat industry needs fast and reliable quality information **throughout the whole production process (slaughtering, deboning/cutting, transformation)**, which would ultimately provide a quick and guaranteed classification of the raw material for the production of the adequate products (among others, cooked or cured hams). The main demand of the industry for that subject is to measure the instant **meat tenderness** and track its development to predict time of maturation and optimum of tenderness.

a. Slaughtering

The first need is to measure, verify or **control animal stress** from the cattle farming sites up to the slaughtering places with automatic sensors. It could be also helpful to have a measure of the **stunning efficiency** to verify that the animals are unconscious before “bleeding” operations. Another demand is to be able to **monitor the changes in the product** temperature and pH, during the cooling phase of meat carcasses.

b. Deboning/Cutting

Online measurement and evaluation of the **meat tenderness and meat maturation** is a demand that microsystems could answer **without being invasive**. They could also help measuring the pH of meat, which is a crucial indicator of the process for the conservation.
Microsystems could be a solution to **understand** oxidation process of meat after deboning, **and** to **anticipate oxidation** by creating new indicators.

c. Processing

Measure of drying surfaces evolution (to avoid the creation of a too dried layer at the surface) is an important demand. Microsystems could also **measure mechanical energy** (kneading, friction, etc.) transmitted to the muscles during the churning operation for the production of ham.

During the cooking of ham, fluorescence spectroscopy measurements to **predict the cooking output** (loss of meat juice) and predict the **stability of the emulsion** would be of interest; as well as the **measure of volatiles particles** to control the smell of ham, of roasted products and to monitor the maturation of the meat. Tools do verify **mixing homogeneity** of ingredients and minerals in sauces, or minced meats are missing.

Finally, industrials need smaller sensors to monitor temperature and pH to respectively control cooking or sterilization phases and **the acidification kinetic** at the centre of the meat

3.2.1.3 Other issues

Further topics of interest include:

- Traceability: miniaturized systems to track animals, products and containers along the production lines more cost-effective than the RFID chips already used.
- Content of GMO in soya feed.
- Animal welfare: air control in the stable by gas sensors.
- Implementation of MST in the automation of technical processes.
- Sustainability, organic food, regional food, carbon foot print and food chain management in general…

3.2.2 Constraints for implementing microsystems

Nearly all the needs listed require non-invasive and non-destructive methods of measurements. This could be an advantage for the microsystems and the smart sensors but it still implies **more constraints** for their implementation.

Processed meat products generally present a high heterogeneity: disparity of structure and tenderness inside a muscle, disparity of treatment inside a dryer due to the differences between meat pieces. A major constraint is thus the **representativity and validity of the measure**. Indeed, the smaller is the sample, the better it is to avoid waste, and the microsystems are good devices to do that provided they are **accurate** both in terms of positioning and measurement. They also have to be **adapted to the current equipment** of the industry, including the IT and automation systems.

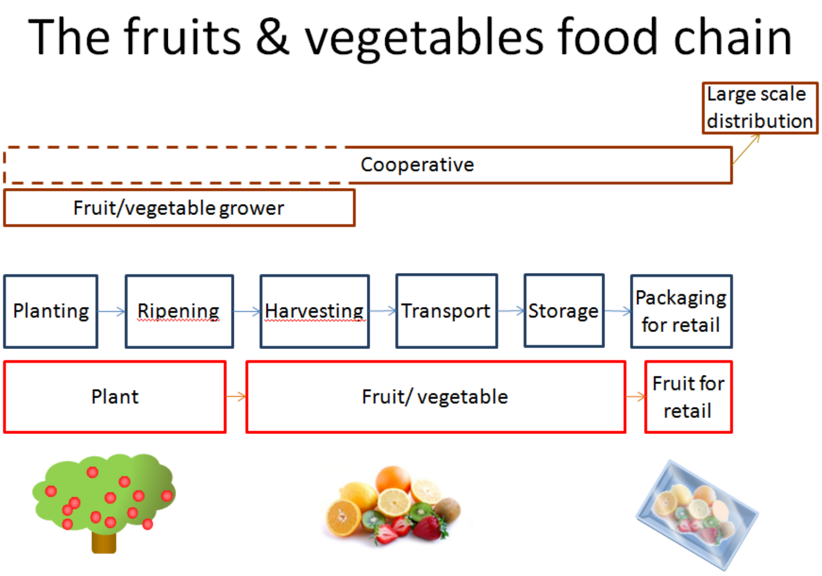
In order to have continuous measurements during a long period of time, devices have to be implemented online. Wireless sensors embedded in food products can also provide interesting measurements. This implies that they have to be **autonomous, to support cleaning and not to add contamination problems**. Special attention should be given to the **hygienic aspects** of these devices: it must be easy to clean (also with strong detergents) and not a contamination source on its own. A lot of solutions have already been found but they are only available at laboratory scale.

Overall, devices have to be **small, robust and cheap** to be adopted by the meat industry. Another problem is related to the confidentiality of the data collected thanks to new sensing systems, considering the possible reluctance of the food chain operators to share data related to their products.

3.3 The fruits and vegetable sector

In 2010 the EU fruit and vegetable sector accounted for 17% of the value of the EU agricultural production. The combined turnover of the fruit and vegetables supply chain was estimated at more than 120 billion euro, with around 550 000 employees and 1.4 million farms holdings[5]. In 2005, there were 10.000 companies processing fruits and vegetable, 42.500 specialized wholesalers and 76.000 specialized retailers in the EU-27[6].

A large majority of the fruits (90%) and of the vegetables (80%) are consumed as fresh products. Other types of consumption include cans (8% for the vegetables, 4% for the fruits), frozen (6 and 1%) and fresh-cut (4 and 1%)[7]. The production of fruit and vegetable is very regionalized and concentrated in a few countries. For example oranges are mainly produced in Italy and Spain (80% of the EU production) while onions are mostly grown in Spain, the Netherlands and Poland (80%). The sector is less concentrated than the milk or the meat sector. Large companies include *Pomona, Dole, Bonduelle, Agrial, Bakkavör, Salico, Hessing Supervers, Vezet, or Natures Way Foods.*



3.3.1 Needs and demands

3.3.1.1 Safety and hygien

Assuring consumer security and **satisfying regulatory constraints** are the main demands of the fruits & vegetables sector:

- Microbiological quality: three kinds of organisms, presenting a risk for human health, are likely transported by fruits and vegetables: viruses (hepatitis A), bacteria (Salmonella, E. coli…), in most case, and parasites.

[5] http://www.gis-fruits.org/Documentation/Bibliotheque/European-Fruit-Sector
[6] http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-08-060/EN/KS-SF-08-060-EN.PDF
[7] http://www.freshconveniencecongress.com/resources/documents/1308561709cindyvanrijswick.pdf

- Phytosanitary quality: maximum residue levels (MRL) are established by considering the consumption habits and fixed for each combination (fruit or vegetable/approved pesticide).

In most cases, products are sold before the results of the analyses are known, so **rapid methods for the detection and quantification of contaminants** with a sanitary risk for the consumers are needed.

3.3.1.2 Quality control

Improving the global quality of the offer is always a need. Microsystems could provide a system that enables the correlation between physicochemical properties (colour, texture, volatile compounds) and organoleptic quality. There are several demands from the industry, related to the **key points of the production** of fruits and vegetables. Transversal needs such as the independence from expert laboratories also emerged.

a. Fast phytosanitary analyses

Fertilization is necessary both for open ground and soil less. During production, preventive treatments with phytosanitary products are generally applied to avoid diseases linked to a plant contamination by viruses or parasites which could lead to production losses up to 30% of the harvest. Therefore, **rapid methods** to **detect and quantify** residues of phytosanitary products are a demand of the industry. To reduce the variation in treatment, a **quick method to detect contaminants** representing a risk for the crops will be helpful.

b. Ripening and harvesting period

For fruits and vegetables, firmness and colour are the main parameters used **to evaluate the ripening**. To avoid or at least limit harvest losses, microsystems could provide new kinds of measurements.

3.3.1.3 Other issues

a. Storage

Regulate temperature and hygrometry is essential to control breathing and sweating (which can lead to modifications of the aspect or the texture) but also to limit post-harvest losses due to the growth of microorganisms in storage platforms. So a **system for the storage management** (for products with a long storage period such as potatoes or apples) is a need.

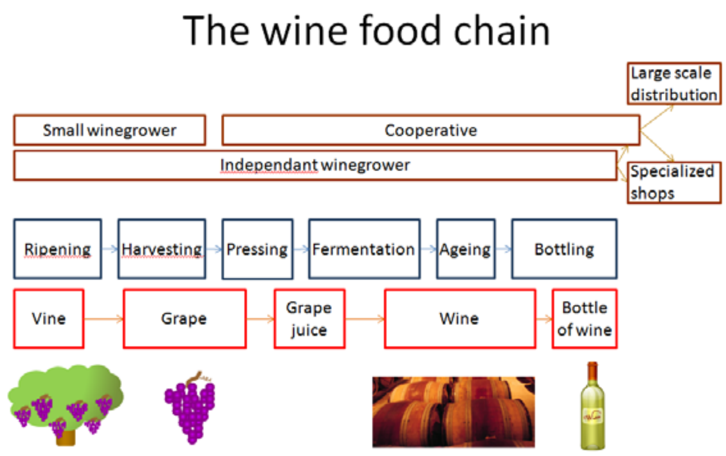
3.3.2 Constraints for implementing microsystems

As in other food sector, the **investment margin is low**. This is especially important as the fruit sector has lengthy production cycles resulting in delayed return on investment. Therefore efficiencies to ensure productivity, profitability and safety must be continuously implemented to be competitive. Innovations have to be **easy-to-use** and designed as a decision support tool.

3.4 Wine sector

The structure of the wine sector is very different than the one of the meat or dairy industry due to the importance of small businesses. Two types of business models coexist: independent wine growers who cultivate their grapes, produce and commercialize their wine and larger companies (often cooperatives) that collect the grapes from vine growers and transform it into wines. In the EU there are around 600.000 wine growers producing quality wines and more than 1.75 million of farmers involved in the production of "other wines". The production is concentrated in a few countries: France, Spain and Italy accounts for 80% of the EU wine production. Other producing countries are Portugal, Greece, Hungary, Romania, Bulgaria and Cyprus[8].

The wine market is very dynamic and exports play a major role in the development of the sector: the demand for wine is expected to increase by 10% between 2012 and 2016, due to a spectacular increase of the consumption in Asia (+40% in China)[9].



3.4.1 Needs and demands

3.4.1.1 Safety and hygien

Although quality is the main driver of the wine sector, safety improvement is also a demand of the producers. They need fast analysis methods for different parameters in the laboratory: in-situ at the reception of the raw materials and on-line detection systems that could lead to 'intelligent tanks', 'intelligent corks' and 'intelligent labels'. They also require instruments to measure safety parameters such as: detection of foreign bodies in the bottles, multiresidues in the wine, ochratoxin, fumonisin, aflatoxin, biogenic amines, heavy metals, histamine, lactic bacteria, prevention of volatile phenols.

[8] http://ec.europa.eu/agriculture/evaluation/market-and-income-reports/2012/wine-sector/full_text_fr.pdf
[9] http://www.viti-net.com/actualite/international/article/de-plus-en-plus-de-vin-consomme-au-niveau-mondial-mais-pas-en-france-12-86201.html

Cleaning issues could be addressed by microsystems with the **on-line control of cleaning** and therefore allow saving water in the process.

3.4.1.2 Quality and process control

Overall, wine producers require continuous, more frequent and precise measurements to better control the quality from the **grape production to the wine elaboration**. Transversal needs such as the independence from expert laboratories also emerged.

a. Grape production

To ensure the quality of the wine, microsystems could help the precision viticulture, and **measure upstream parameters** such as grape classification (quality/state) on entry to the cellar and assessment of the filtration and the clarification.

b. Process and elaboration

The **oxygen rate and activity control** throughout the winemaking process is today a major objective in wineries. Control Quality (monitoring committees, results of international wine challenges ...) showed that, for the wines detected as faulty, a high issue frequency of problems is related to oxygen management (oxidation, reduction).. The monitoring of other **crucial parameters** (gluconic acid in grapes, fermentation with alcoholic content, automatic measurement of density, sugar on-line, faster total sugars, ensure fermentation in the bottle) , **chemical reactants** (sulphide/mercaptans, free SO_2, NH_4^+) and **quality parameters** (organoleptic objectivity, monitoring indicators of the authenticity of the wine) could be addressed by Microsystems. Smilarly, the **assessment of physical or chemical parameters** (control of the pressure in the bottle, potential redox in the bottles) and the **counting of viable yeast cells** would be of interest for the sector.

3.4.1.3 Other issues

The other issues concern:

a. Traceability

To guarantee traceability depending on knowledge of the environmental conditions, sensors integrated into the label can measure temperature, light and humidity.

b. Packaging

Microsystems could improve the bottling operations and facilitate measurements of interests such as the presence of trichloroanisol (TCA) in corks.

3.4.2 Constraints for implementing microsystems

In the wine sector, while cost is the first concern of the producers, experts rather prioritised reliability. The wine industry is not against innovation, but they require that the microsystems satisfy certain criteria. **Time, cost and reliability** of the measurements are the most important factors that must be considered for the implementation of microsystems. These ones have, of course to be **user friendly, robust** and their maintenance must remain simple.

3.5 Packaging sector

The packaging plays a major role in the innovation of the food industry: it preserves foods, guarantees their safety and it is closely linked to the image of the food products. Marketing plays an important role together with technological and environmental aspects. Research is mostly focusing on new materials (more environmentally friendly, often produced from bio-based resources and easily recyclable), on active packaging (packaging that interacts with the food product e.g. to maintain its quality or extend its shelf-life) and on intelligent packaging (packaging that has the ability to provide information e.g. on the quality of its content or storage conditions).

The food industry is rarely involved in the production of packaging, they rely usually on specialised suppliers. The market is divided into plastic, glass and metal and paper-based packaging.

3.5.1 Needs and demands

3.5.1.1 Food preservation

Depending on the requirements of packed foods, the application of appropriate active packaging systems can significantly **reduce food quality deterioration**. Food packaging conditions play an important role in the shelf-life of food, include physiological processes (e.g. respiration of fresh fruits and vegetables), chemical reactions (e.g. lipid oxidation), physical processes (e.g. dehydration) and microbiological aspects (e.g. spoilage by microorganisms).

Oxygen scavengers are the best known applications used in active packaging. Besides the oxygen scavengers, antimicrobial agents, moisture absorbers, ethylene absorbers, ethanol and carbon dioxide emitters can be used as active features in order to address the weak points in the shelf-life of packed goods and need to be developed.

3.5.1.2 Quality control

Monitoring the quality of food is also a need expressed by the food manufacturers and developments are requested for **intelligent packaging**, such as time-temperature indicators (TTIs), freshness indicators and tracking services to enable (i) to track with respect of the cold chain, (ii) directly detect product quality of the packed food (e.g. detection of volatile and non-volatile compounds, detection of the presence of microbiological metabolites), (iii) take the right decisions in terms of logistics (delivery, storage) in order to avoid product spoilage.

3.5.1.3 Other issues

a. Packaging materials properties

To meet consumer expectations and environmental challenges, packaging manufacturers are now seeking to develop packaging which is more light-weight according to the prevention of packaging waste and materials from bio-resources. However, the materials developed do not have suitable properties to meet the requirements of the applications. Industrials need **materials to improve gas transfer properties, mechanical properties and stability.**

In addition, the development of materials with **surface properties to reduce microbial adhesions** is also a need to avoid microbial contamination from packaging to food product.

b. Shelf-life of packaging materials and traceability

Depending on their nature and conditions of storage, packaging materials are able to age faster or slower. To assess their ageing and their shelf-life, it would be useful to resort to the **inclusion of tracers** in the packaging materials. Similarly, the insertion of matrix tracer would facilitate the recovery and recycling of packaging waste after consumption. Another aim of the indicators is be to avoid counterfeits.

c. Packaging & Cold chain management

Microsystems could provide non invasive methods to co**ntrol the leaks of conditioning gas**. They can also be a solution for the **monitoring of the cold chain** in terms of time and temperature such as RFID combined with WSN / Intelligent container for storage and transport.

3.5.2 Constraints for implementing microsystems

The introduction of new packaging is subject to compliance with regulatory requirements. Regulation EC 1935/2004 on materials and articles intended to come into contact with foodstuffs specifies: “*Food contact materials shall not transfer constituents to food which could endanger human health, bring about an unacceptable change in the composition and bring about deterioration in organoleptic characteristics*” and regulation EC 450/2009 on active and intelligent materials intended to come into contact with foodstuffs states : “*Substances should undergo a safety assessment by EFSA before they are authorized for use” and “Intelligent systems that are on the non-food contact surface of the package have to be separated from the foodstuff by a functional barrier, i.e. a barrier to any migration*”.

Another aspect to take into account concerns the **acceptance** of micro-systems by the consumer and the **environmental impact** of the use of micro-systems on the recyclability of packaging.

Finally, as in all the sectors, the **additional cost** associated with the use of innovative products with respect to margins generated in the food industry has to be taken into consideration.

4 Synthesis

4.1 A significant market for microsystems

The food sector represents a significant market for developers of microsystems solutions. In the EU, there are more than more than 270.000 food processing companies and 3.7 million of farms above 5 hectares (12 million of farms in total). These numbers do not take into account the suppliers of the food industry (packaging, equipment, laboratories), the transporters, wholesalers or retailers.

Some production like the dairy of the meat food chains are very concentrated and dominated by multinationals while other food chains like the wine or the fruits & vegetable are more regional with many small producers. There are a limited number of multinational companies with a global position: 14 companies have an annual turnover above 20 billion usd as illustrated below.

Rank	Company	Food Sales ($ millions)	Year Ending
1	Nestlé	99,733	Dec. 10
2	PepsiCo, Inc.	57,838	Dec. 10
3	Kraft Foods	49,207	Dec. 10
4	Anheuser-Busch InBev	36,297	Dec. 10
5	The Coca-Cola Company	35,119	Dec. 10
6	JBS	31,285	Dec. 10
7	Archer Daniels Midland Company	31,000	Jun. 10
8	Unilever	30,160	Dec. 10
9	Mars	30,000	Dec. 08
10	Tyson Foods	28,430	Sep. 10
11	SABMiller	28,311	Mar. 11
12	Cargill	26,000	May 10
13	Danone	22,530	Dec. 10
14	Heineken	21,370	Dec. 10
15	Kirin Brewery Co.	19,545	Dec. 10

Source: Global Food Markets (GFM), Leatherhead Food Research.

If the key drivers that may determine the implementation of microsystems are similar from one food chain to another, there are important differences in terms of structure of the supply chain, type of actors involved and there are important "cultural differences". These differences may represent a barrier for companies interested to supply the food industry with new microsystems devices: the food industry does not represent a unique market, it is actually constituted of several different markets (dairy, meat, fruits and vegetable, beverage etc.).

4.2 The demand expressed by the food industry

The food sector is facing several simultaneous challenges:

- To guarantee food safety,
- To improve the quality of the food products,
- To decrease its impact on the environment,
- To provide affordable food supply to a growing population.

New technologies can contribute to address these challenges. For this reason, it can be considered that **safety, quality, sustainability and efficiency represent the main drivers** for the implementation of microsystems in the food sector.

The need for microsystems is geared by these drivers: in this study, the industry consulted in the five different areas (dairy, meat, wine, fruits & vegetables and packaging) expressed a strong demand for solutions that help to ensure food safety and food quality. Solutions that can improve the sustainability of the food production and reduce costs are also a demand, in particular for the optimisation of water and energy consumption.

The consultation of the food industry reveals that there is a **strong demand for sensors** in all the sectors examined of the agri-food industry. Microsystems can actually match two of the most important concerns of this industry: guaranty the safety and improve the quality of the food products.

To ensure the food safety, it is important to obtain fast and accurate microbiological analysis, to be able to give margin to time dependant Critical Control Points by detecting pathogens. Detection of compounds is another need: contents of neo-formed compounds could be followed during the cooking to better understand their formation. Micro-organisms metabolites could be track to measure spoilage and contamination. Intelligent packaging which could monitor the deterioration of the product and increase the shelf life could also include microsystems. Hygiene could also be improved by non-fouling surfaces thanks to surface treatments.

To improve product quality, microsystems could help optimising the processes or designing new ones, and help controlling them continuously. They could allow fine monitoring of kinetics of pH or microorganisms for fermented products like cured meat or cheese. The detection of compounds specific to the quality of the produced food is also relevant: ethanol and gas detection could allow monitoring fruit and vegetable metabolism, the measurement of volatiles compounds could help control the cooking of meat etc.

For water and energy, sensors allowing to monitor and optimise their consumption are needed. For the dairy and the wine production, solutions for optimising the cleaning operations are particularly in demand.

Microsystems could also help to tackle **horizontal issues** such as intelligent packaging and traceability. The recent "horse meat" crisis reveals a demand for solutions allowing authentication and detection of fraud.

There is a demand for two main types of sensors: portable devices for fast and easy-to-use in situ measurements and sensors integrated in the production lines.

For **portable devices** the concept is similar to the Point-Of-Care Testing (POCT) used in medicine: the idea is to allow in-situ measurement for a rapid measurement. Such device are usually handheld and they must be easy-to-use and sufficiently robust to resist to rough conditions. Examples of applications include handheld devices for animal health and welfare testing (detection of) or devices for testing the quality of the raw materials (evaluation of the ripening of fruits and vegetables in the fields to determine the time of harvesting, quality assessment of the grapes at the reception of wineries).

Sensing systems embedded in the production lines can be on-line, in-line or at-line. The main need is to obtain continuous measurements of simultaneous parameters relevant to food safety and food quality. Rapid, multi-parameters and continuous measurements are asked by all the sectors. Sensors which do not need any sample preparation and which are non-invasive are also a needed.

10) Off-line measurements are realised in a laboratory (environmentally controlled location) by technically trained personal.
11) At-line measurements are realised in the production area and is performed by an operator
12) On-line and in-line measurements are fully automatized systems realised into the process stream. Usually, in-line means that the measure is realised into the main process steam and on-line means that the measure is made in a bypass of the main stream.

The application can concern an evaluation of the raw and in-process materials as well as the monitoring of food processes. In process foods, they can allow real-time monitoring of key parameters which in turn will help to understand the influence the raw materials and of the process parameters on the quality of the final products. Such systems could actually bring considerable innovation as the possibility to acquire long series of data will give access to knowledge currently not available.

These solutions should be embedded in the process management systems of the industry to allow actions that optimise the production. They can be integrated in Decision Support Systems or part of a Process Analytical Technology (PAT) system by providing continuous measurements of the Critical Process Parameters (CPP) which affect Critical Quality Attributes (CQA).

Microsystems could also lead to intelligent systems: sensors coupled to controllers could optimise to change the atmosphere of the room for fruit storage, sensors which could correlate the sensorial parameters to physicochemical analysis. For wine, intelligent tank could follow and regulate fermentation, intelligent corks which could regulate the exchange with the environment etc.

4.3 The constraints for implementing microsystems in the food industry

The microsystems need to be cheap, to have a good return on investment and to have a low operating budget with easy maintenance. Then they must be robust and resistant to cleaning without decreasing the cleaning efficiency of the plant. The sensors have to be reliable and precise. Another constraint mentioned is the ease of use of the technology.

Economical constraint

The first constraint highlighted by the industry is the cost and the return on investment. It means that new detection and measurement solutions are not a need per se: the results of the measurements should trigger actions that should be cost-effective. They can for example help to optimise the use of inputs or the parameters of a process and help to reduce costs by reducing the quantity of raw materials or the consumption of water or energy. An improved monitoring of the production can also avoid waste by reducing the amount of non-conformity of the products. These aspects have to be taken into account at an early stage of the design of the innovative solutions based on microsystems.

Technical constraint

The evolution of Microsystems for food applications will depend on the ability to provide solutions to the following technical points:

- The reliability and sensitivity must be better than actual methods or at least equivalent;
- The compatibility with a food process: it must be grade food.
- The integration into the process and the communication with automatisms must be facilitated
- The surface must be easy to clean and resists to severe cleaning procedures cleaning process to avoid any risk of contamination

Practical constraint

The innovation developed mustn't bring complexity. The system must remain easy to use to be adopted by the industry.

Commercial/market constraint

For a successful uptake of innovations by the food industry, it is necessary to demonstrate the added value of the new product. In the case of measurement solutions, it is of primary importance to anticipate how the industry can benefit from the results of the measure. This has to be taken into account at a very early stage of the development of the new solutions and for this, a very good knowledge of the practices of the food producers is needed. Partnerships with companies supplying equipment to the food industry can represent a good strategy to overcome these constraints.

5 Conclusion

This report provides a synthesis of the views expressed by the industry regarding the needs and constraints for implementing microsystems in the food sector. More than 100 food companies from Estonia, France, Germany, Spain and the Netherlands have been consulted in workshops and interviews during the preparation of this study.

It reveals that there is a strong demand for solutions that help to address the four main challenges of the sector: safety, quality, sustainability and efficiency. Microsystems can bring considerable progress for the control of food products, the monitoring of food processes and they can help the industry to optimise its operations. Besides the price and the necessity to provide reliable and robust solutions, the main constraint for implementing microsystems in the food sector is of an organisational nature. It is very unlikely that a single solution will fit the requirements of all food chains. Supplying the food industry with new equipment also requires a very good knowledge of the food sector targeted.

These constraints can be overcome. The prices of microsystems can drop if they are produce in large quantities. With more than 270.000 food companies and 3.7 millions of farms in Europe, the size of the market is very significant. To overcome the difficulty to enter the market, partnership with equipment providers of the food industry can be an effective strategy .

This report will be used in *FoodMicroSystems* for the construction of three technological roadmaps. These reports will provide a more detailed framework to guide researchers and entrepreneurs of microsystems solutions in the development of applications for the food sector. For more information, please visit www.foodmicrosystems.eu.