DELIVERABLE 3.5

FOOD MICRO SYSTEMS

SYNTHESIS REPORT ON THE NEEDS AND CONSTRAINTS FOR IMPLEMENTING MICROSYSTEMS IN THE FOOD INDUSTRY

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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, the French network of food technology institutes. More information on the project can be found at http://www.foodmicrosystems.eu.

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Executive summary

The Food sector is an important pillar in the European economy, as one of the most successful and dynamic business sectors. With more than 270.000 companies, it represents a significant market for developers of microsystems solutions.

The sector is facing several simultaneous challenges that require innovation and new technological solutions. The objective of the FP7 project FoodMicroSystems is to improve the competitiveness in the food industry by stimulating the implementation of microsystems. Microsystem can provide a wide range of technological solutions to make food safer and of better quality, and can contribute to convenience, shelf life and freshness.

This report analyses four aspects that can influence the demands for microsystems in the food sector: the needs and constraints from the food industry, the regulatory context, the perception of the consumers and the ethical aspects. Recommendations on how to support the future demand are provided at the end.

The analysis reveals that the main demands for application concerns:

- The assessment of quality and safety of food products;
- The monitoring processes in food industry and an improved control of the end quality of the product
- Food packaging applications
- Technologies to develop new food products.

Regulations and food law can also constitute an opportunity for developers of microsystems solutions

Despite this interesting potential, only a few microsystems applications have been developed so far. Public action is needed to support the demand for microsystems in the food sector.

Introduction

Micro Systems Technology (MST) can provide a wide range of technological solutions to the food industry. Microsystem devices and smart miniaturised systems often use micro-sensors, electronics, signal processing, micro-actuators and microfluidics. In the food industry, they are mainly used in systems that provide information on the food products, but could also be used to improve the process, and change or preserve the properties of the products. They can measure efficiency with in situ, non-invasive, faster and automatic sensors using less sample and/or reagents, but also less energy. Despite this interesting potential, only a few microsystems applications have been developed so far. The objective of the FP7 project *FoodMicroSystems* is to improve this situation by stimulating the implementation of microsystems in the food industry.

Innovations often occur at the boundaries of different technology areas. The up-take of innovations based on technologies that originate from another area than the application sector depends to a great extent on the demand expressed by the users and on the solutions offered by the technology providers. These two aspects are often reflected in the concepts of "*Technology push*" and "*Demand Pull*".

This report looks at the demand side. It considers four aspects that can influence the demands for microsystems in the food sector: the needs and constraints from the food industry, the regulatory context, the perception of the consumers and the ethical aspects. These four aspects have been analysed in five *FoodMicroSystems* reports: (1) D3.1.2: *Report on industrial needs, demand and constraints*, (2) D3.2.1 and D3.2.2 *Report on consumer perception and acceptance*, (3) D3.3 *Report on Ethical issues* and (4) D3.4 *Report on the EU regulatory situation*. These reports are available at www.foodmicrosystems.eu/library.

The first chapter provides an overview of the main findings from the previous reports: the results are presented in 25 key points that build on the executive summaries of the other reports. The second chapter provides a synthesis of the four perspectives and chapter three discusses the main factors that could influence the future demand for microsystems in the food sector. The conclusion provides recommendations on how to support the future demand for microsystems in the food sector.

1 Key findings from previous reports: summary in 25 points

1.1 Industry needs and demand

1) One of the key drivers for implementing microsystems in the food sector is **food safety**: the food industry is always looking for opportunities to further improve the safety of food products for the consumers. In general the solutions should be as close to the production line as possible; fast; cheap; accurate and simple. More precisely there is a demand for in-line solutions (continuous measurement) as well as for **portable, cheap and easy-to-use devices**.

2) 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.

3) Overall, there is a strong demand for **process control applications.** In-line, on-line and at-line measurement solutions will help the industry 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).

4) Solutions to optimise the **water and energy consumption** are needed to improve the sustainability of the sector, 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.

5) 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 and adulteration**.

6) **Intelligent packaging** that can monitor the deterioration of food products, increase their shelf-life and provide information to the consumer on the quality of the product inside are also interesting innovations.

1.2 Industry constraints

7) The main technological constraints are related to:
   (i) The robustness of the devices
   (ii) The reliability of the measurements
   (iii) The compatibility with food processes
   (iv) The time to process information and provide results
   (v) Cost per measurement
   (vi) The sampling strategy (how many measures, when, where etc.).
   (vii) Sample (pre)treatment
   (viii) Cleanability

8) 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. It is therefore preferable to develop applications of microsystems in food in partnerships in which also the end-users (the food industry) are represented.

1.3 Current regulations

9) The most relevant regulation regarding microsystems implementations in the food sector is the **legislation on food contact materials** (EC regulation no. 1935/2004 and 2023/2006, plus the legislation on specific materials). This regulation applies to microsystems directly in contact with food: for example in the case of a polymer-packaged sensor used for in-line monitoring of processes, the system has to comply with the regulation on plastic materials, which means that the components and additives of the polymer should be authorised and migration limits of the material should be respected.

10) Another relevant regulation is the no. 450/2009 **on active and intelligent materials and articles intended to come into contact with food**. This regulation applies when the use of microsystems is intended in packaging. In that case of intelligent packaging application, a dossier for safety evaluation will have to be submitted to EFSA to comply with the regulation 450/2009.

11) In some specific cases, the **regulation on Novel Foods** 258/97 may apply: in the specific case of micro-devices that enable new product and/or process innovation (for example micro-emulsification devices), the product will need to be evaluated by EFSA.

12) **In conclusion microsystems should be evaluated case by case** according to the nature of the microsystem materials in contact with food and their intended use. Other aspects such as **end of life and waste management of microsystems** should also be considered.

1.4 Consumer perception

13) Regarding the use of food microsystems, consumers show a **relatively neutral opinion**. This implies that at this moment in time there will be **little worry** about introducing food microsystems systems, but that it is also **unlikely consumers will be willing to pay any price premium** for products produced with or incorporating food microsystems in the product or package.

14) Some issues are identified where concern of consumers may occur. If communication of food microsystems is about the technology at large or very limited in scope, this may create **concern about control of the technology**, and uncertainty about future consequences. On the other hand products created and communicated as further developments of existing microelectronics, rather than a completely new technology (such as nanotechnology) may make it possible for consumers to link food microsystems in their minds to existing, reasonable trusted, technologies such as electronics. This may reduce likelihood of unexpected concern.

15) **Some health concerns are voiced** related to possible contamination of food products as a consequence of microsystems in the production process. Consumers in particular imagine toxicological (chemical) contamination (by transmission of e.g., metals from production line or packaging involving microsystems into food) or physical contamination as a consequence of parts of the microsystems breaking up, and ending up in the final product. **Thorough control of finished products on foreign particles and chemical contamination** might take away these concerns.

16) Some worries were voiced in relation to consequences outside the immediate food production chain. Consumers voiced worries that high tech microsystems would **benefit larger companies over smaller**, more highly educated consumers over lower educated people. **Environmental damages** as a consequence of microsystems embedded in packaging ending up in the environment were foreseen as a potential problem. **Malicious use to track consumers after purchase** (privacy violation) was also considered a possible negative consequence.

17) Benefits of relevance to the end user were seen in after-purchase safety control of the cold chain. In the shop, however, food safety is considered the task of the retailer, so no end-user benefit was seen in relation to in-shop safety. **Product level allergen detection** was considered a potential benefit for allergic people, as well as product level ingredient declaration accessible through modern ICT means (e.g. smart phones).

18) To implement food microsystems as an official quality control mechanism, consumers show **limited trust towards the food chain**. Consumers would prefer some kind of oversight on the application of food microsystems in the food chain for example by the microelectronics providers, a certification body or a governmental agency.

1.5 Ethical weighing of interests

19) To guarantee a responsible implementation of food microsystems into food production, the different stages in the production process can be reviewed on the **ethical deliberation into effects on different stakeholders**. The main stakeholders include: microsystem developers, food processors, consumers, the environment and future generations.

20) For a fair, responsible and ethical implementation of food microsystems changes in autonomy, justice, non-malfeasance and benefits for stakeholders should be considered, and compared against the current status quo. As a general principle, changes in any production stage (mainly processing and packaging) should result in no worse end-results for any stakeholder compared to the current status quo.

21) The interests of microsystem developers and food processors lie in autonomy to choose between different (relevant) systems, the responsibility to apply these responsibly, and the possibility to reap the benefits in improved production. They require however, **a clear regulatory frame concerning allowable safety issues** (safety of workers).

22) Consumer interest should be weighed against consumer autonomy to choose, which can be facilitated by **transparency about the application of microsystems**, and having access to risk information, and reap relevant end-user benefits. If food microsystems are applied to the packaging stage, additional weighing of consumer interests is required, in particular in relation to autonomy through communication about the presence of such systems in the packaging, and non-malfeasance by looking at privacy risk.

23) The environment and future generations should not be worsened by introduction of microsystems: potential risks to the environment and future generations should be mapped into detail, and regulations should weigh these risks against benefits compared to current practice, ensuring that the replacement of current practice does not result in additional risks without sufficient benefits for the environment and future generations.

24) For the environment the effects of product **waste and disposal into nature should be considered** and weighed against the current situation. For future generations and long term effects, **bio accumulation of particles** could require consideration.

25) In the case of microsystem used in packaging, the additional factor of **consumer disposal of packages** comes into play beyond the previous issues.

2 Synthesis on the main demands for microsystems

To reflect the different perspectives that can influence the demand (industry, regulation, consumers and ethics), four main application areas are considered in this section: (1) microsystems for assessing the quality and safety of food products; (2) microsystems to monitor processes in food industry and allow better control of the end quality of the product; (3) microsystems in food packaging applications; and (4) microsystems for new food products.

2.1 Microsystems for quality and safety assessment of food products

Food has never been as safe as it is now, at least in industrialized countries. Food industry constantly is improving on hygiene in the production systems and the presence of pathogens or contaminants in raw materials and products. However, every year a substantial number of consumers suffer from a foodborne problem and many hospitalizations take place. The bottom line is that there is always room for improvement.

Food almost invariably is a biological product which quickly deteriorates without appropriate measures. In the past sterilization, salting, application of alcohol and more recently cooling and freezing were used to maintain the quality of the products. In the current western societies these methods to maintain the quality are often not regarded acceptable anymore. We want our foods fresh or only mildly conserved. The compromise between freshness and safety is a very delicate one. The industry, recognizing the trend for freshness in society, is constantly looking for ways to maintain the freshness *and* safety. Microsystems can offer new opportunities in this area. Not only can they sieve out bacteria from liquid food products like milk, effectively pasteurizing them without having to heat them, they can provide devices that allow testing for pathogens and monitoring for microbial activity in a cost effective way in more places along the different production chains. Low cost, easy to use but especially fast tests to determine the presence of pathogens and/or contaminants or measure the amount of spoilage organisms that is a good predictor of shelf life (together with storage temperature) is an important demand to further improve on the safety of food products.

The safety of food products is highly regulated all over the world. Industry has to do specific tests to be able to prove that products were safe when they were delivered to the customer. Because of the responsibilities food companies regularly test for microbial activity or contaminants in the raw materials and they constantly monitor the products in various stages of production on these aspects. It requires an extensive laboratory, high-end equipment and well educated personnel to maintain the highest quality and safety standards. The biggest problem in this respect is that especially the pathogen tests often take days before the results are available. This is obviously a problem in fresh products that need to get to consumers as quickly as possible. Microsystem based devices can test much faster and if necessary can provide results within the hour. Unfortunately these tests are not allowed in the governmental regulations on food safety. The solution is to use the micro-devices for screening, eliminating batches of materials and products that are possibly compromised and doing the prescribed official tests on the products that are delivered to the next element in the production chain.

From a consumer perspective the benefits are obvious. Not only does it improve the safety of food products, it also addresses the clear demand in society for fresher yet safe products. From an ethical point of view there is the concern of disposal. These tests are often one-time-use tests and create a substantial amount of waste. The tests are usually made up of two parts: a disposable part and a read-out unit that is used many times. The disposable part has little to no micro-electronics in it but does use small amounts of chemicals and reagents. It is important when developing these devices to minimize the environmental impact and, if necessary to develop a recycling system in conjunction.

2.2 Microsystems for controlling food products and food processes

Technological solutions that allow a better control of the food products and of food processes are the main demand from the food industry. For this, there is a need for systems that allow the continuous and simultaneous measurement of several parameters and for portable devices allowing in-situ measurements.

Microsystem devices can provide such systems but the new detection and measurement solutions are not a need per se: the results of the measurements should trigger actions that should be cost-effective (for example optimise the use of inputs or of processes parameters to reduce costs, reduce the amount of non-conformity to decrease losses etc.). The new solutions should thus be designed with the food industry so that they can be easily integrated in existing management systems.

The analysis of consumer perception reveals little concerns for the utilisation of microsystems in such applications. There is a clear recognition of the benefits that microsystems can have on the quality of food products. The main concern is about health risks because of the possible contamination of food products by (components of) microsystem devices. In the EU there is already a regulation into force to prevent such contaminations: the EC Regulation 1935/2004 and 2023/2006 (completed by the legislation on specific materials) applies to any materials in contact with food. In practice, it means that any surface material in contact with the food products should contain only authorised substances (for example polymers and its additives in the case of a plastic) and that migration limit of the food contact material should be respected.

Taking into account the limited trust from the consumer towards the food industry, MST based solutions should mainly be used for internal quality control systems or in applications that present a clear and obvious benefit to the consumer. If the new devices are intended for a use in official controls on food (for example in the frame of the EC Regulation No 882/2004 on official controls performed to ensure the verification of compliance with food law), then the consumers would support the implementation of a supervision systems by a governmental agency or a certification body.

From an ethical perspective, the main concern is about the effects of product waste and disposal into nature of the devices after their utilisation. The end-of-life effects of the microsystem devices should thus be considered by developers of microsystems and the regulatory aspects related to the waste management should be taken into account at an early stage of the design of the new equipment and applications.

2.3 Microsystems in food packaging applications

The food industry also recognises a demand for solutions in packaging applications. Microsystems could be used to develop intelligent or active packaging solutions (packaging that provides information on the food products or increase the shelf-life of the food products). There is a clear interest from the consumer to use such systems to obtain information (through smart phones or other systems) on the food products. A particular interest is for the alerting the presence of allergens. Retail organisation have reservations towards these kinds of applications since they fear that customers will select fresher products and leave them with more products that can't be sold anymore because of their expiry date.

Compared to the microsystems intended for controlling food products and food processes, the implementation in packaging application raises more concerns by consumers. The concern on health is more important because of the possibility of potential migration of harmful compounds from the packaging. This concern is already taken into account in the EU legislation: in the case of active and intelligent packaging, the regulation on food contact materials applies and in addition, the packaging will also have to comply with the EC Regulation 450/2009. In practice, it means that a dossier evaluating the safety of the packaging will be submitted to the European Food Safety Authority (EFSA) and that an authorisation will be delivered prior to its commercialisation.

Another consumer concern is about privacy and the control of the technology: in the case of intelligent packaging able to communicate data to ICT devices (smart phones or other), the malicious use to track consumers after purchase has been identified as a possible negative consequence. This calls for the development of agreements about privacy protection and about the control of the technology.

There are also some reserves regarding the potential impact on the environment. Similar to microsystems used by the industry for product or process control, the end-of-life of the devices is a concern, but the disposal of packages is an additional complication. Obviously when a substantial part of all food packages is equipped with microsystems to monitor the quality of the product the number of devices that end up in the garbage is much higher than when individual systems are used in food production processes. This calls for the design of microsystems with negligible environmental impact, even when discarded in nature. This constitutes an important challenge for developers of microsystems technologies.

Finally, the last difficulty concerns the price of the active and intelligent packaging: the study on consumer views reveals that consumers are not willing to pay any extra price for the utilisation of microsystems by the food industry unless there is a very clear and obvious direct benefit.

2.4 Microsystems for new food products

The third application area is the utilisation of microsystem technology to design equipment that allows the creation of new food products. The main application is the use of micro filtration membranes to sieve out bacteria or valuable compounds from e.g. milk, and similar membranes or microfluidic devices for emulsification. Emulsions play an important role in food products and in the industry for the preparation of ingredients or final products. They are used in many processed foods such as ice-cream, coffee creamer, yoghurt, margarines, whipped products, dressings, sauces, etc. This emulsion technology usually uses a silicon nitride membrane or micro channels manufactured in a cleanroom environment with semi-conductor technology. The advantage of emulsions produced with microsystems is the fact that the droplet formation process is controlled to a very high extend, not only producing very mono-disperse emulsions that have better stability, but also the opportunities to develop new food products with improved and/or innovative characteristics like double emulsions. An additional advantage is that these processes require much less energy input, not only making the processes more sustainable, but also offering opportunities to use sensitive components that in the traditional processes would not survive the preparation of the product.

This third type of application is very different than the first two as it is a "passive microsystem device": microsystem technology is only used to fabricate the device, the device itself (the micro-filtration membrane) does not contain any micro-electronic components. Concerns from the consumers focuses on the food product rather than on the technology. The EU regulation relevant to such applications is the EC Regulation 258/97on Novel Foods.

3 Conclusions

With more than 287.000 companies and annual turnover of around 1 trillion euros, the food sector represents a significant market for microsystems solutions. Microsystem technologies can help the food sector to address its key challenges (safety, quality, authenticity and resource efficiency) and there is a strong demand for technological innovation. Also from the consumer side there is a clear demand for information on the quality, safety, composition and origin of the food products.

The analysis reveals that the main demands are for food product quality and safety assessment and food process control. These areas of applications combine favourable indicators in all the dimensions of the study: there is a strong demand expressed from the industry, consumers recognise the benefits and are ready to accept the implementation of such systems, and legislative provisions are already in place to regulate the utilisation of microsystems in such applications. For a successful implementation of such systems, the innovative solutions should be easily implemented in the current management practices of the food industry taking low cost solutions into account, the economic benefit of their use should be clearly demonstrated and sufficient considerations should be given to limit the impact on the environment at the time of the disposal of the device. Development of such systems by technology providers should be done in close collaboration with food industry partners to ensure compatibility with food processes and hygienic procedures.

There is a demand for microsystems in active and intelligent packaging but there are more constraints than for product and process control: consumers are not inclined to pay extra costs for the package, the legislative framework is more constraining (the innovative packaging needs to be approved by the EFSA) and there are concerns about the environmental impact linked to the disposal of the packaging, especially if it ends up in nature.

Finally, there are opportunities to use microsystem devices to improve specific processes in the industry, allowing the preparation of new or improved food products (mainly passive microsystem devices pasteurisation and for emulsion) with superior characteristics. However, for the time being this corresponds to a niche market application.

It is expected that the industry demand will be reinforced in the coming years, in particular for the control of food products and processes. Food safety will continue to be a priority of the food sector and the need for control of authenticity is increasing under the pressure of recent food scandals and growing global food chains. The input prices (raw materials but also water and energy) are expected to increase in the coming years and the EU food industry will need solutions to optimise the use of resources. In this context, the demand for more sustainable processes and sensing systems allowing to better control of processes, including cleaning operations is likely to increase in the coming years.

Regulations and food law can also constitute an opportunity for developers of microsystems solutions. This report mainly looks at the compliance of new technologies with existing regulations. But regulation can also act as an incentive for developer of control systems: if new technologies allow to easily and efficiently implement assessment of the quality and/or safety of food products, the legislators may decide to implement new provisions for testing of microbial activity, authenticity, chemical contaminants or spoilage.

Regarding consumer perception, the current reserves regarding the utilisation of technologies in packaging application may evolve positively. The observed trend towards convenience, health and quality could be served by packaging technologies although it is not clear whether the trend towards "authenticity and natural foods" is at odds with the benefits delivered by these high tech solutions. For example, there indications in the literature that consumers perceive plastic wrapped cucumbers as less natural and less sustainable in spite of the fact that the reduced spoilage compensates for the little amount of plastic needed. Thus the specific perceptions and relation to trends of high-tech packaging approaches deserves considerable attention.

These findings confirm that there are definitive opportunities for applications of microsystems in the food sector offering benefits to consumers, the society and both the food industry and the technology providers. Microsystems can contribute to make our food safer, of better quality, and provide solutions that can contribute to convenience, shelf life and freshness. They can make the sector more sustainable, provide opportunities for product innovations and improve the competitiveness.

There are a number of remaining barriers to take up MST in food applications related for example to the compatibility of the new solutions with food processes, the robustness of the devices, time to process information and provide results or the sampling strategy (how many measures, when, where etc.). Research projects where the food industry plays a major role can help to address these barriers.

Several types of future projects are needed to boost the implementation of MST in the food sector: in the short-term innovative projects focused on process control are recommended while in the long-term perspective basic research on emerging areas such as battery-less and biodegradable electronics are needed to support the development of application for food packaging. For applications in intelligent packaging, it is indeed important to underline that the innovations should not add to electronics waste and instead must be fully recyclable or biodegradable. These conditions should be met before implementing active and intelligent labels in food packaging.

Ethical aspects considered in the FoodMicroSystems project revealed that the main concerns are related to safety issues and environmental issues. A clear regulatory frame concerning allowable safety issues is needed, transparency about the application of microsystems should be facilitated and the effects of product waste and disposal into nature should be considered with great attention.

Public action is needed to support the demand for microsystems in the food sector: the food industry and developers of microsystems come from two remote areas and there is a need to stimulate collaboration and the exchange of information between the microsystem solution providers and the food sector. Without adequate support programmes, it is unlikely that the demand from the food industry will be translated into requirements understood and adopted by the microsystems developers.

There is also a need for an ambitious support to innovation. The adoption of microsystem devices by the food industry depends to a great extent on prices: as the cost also depends on the quantity produced, there is a "chicken and egg situation" (price depends on quantity and quantity depends on price). The implementation of adequate programmes to boost the commercialisation of successful applications will help to tackle this difficulty and will demonstrate the interest of microsystems in the food sector through real business cases.

The findings from this report should be complemented by additional work on the offer from the technology providers, possibly in the form of technological roadmaps. The *FoodMicroSystems* project has followed this approach with the preparation of four technological roadmaps reports (roadmap for the implementation of microsystems in the dairy industry, in the meat industry, in the beverage industry and synthesis roadmap). These reports looks at both the demand from the food sector and the offer from the technology providers as they provide detailed plans for the development of the most promising microsystems applications for the food sector.

The project encourages the preparation of additional roadmaps in the future. Roadmaps are a useful tool to help designing future research programmes (for public bodies) or to programme future developments (for companies). The results of this study on the needs and constraints from the food industry provide useful guidance for the elaboration of such roadmaps.