Technology options for feeding 10 billion people

Options for sustainable food processing

Summary

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This document is the layman's summary of the STOA state of the art report 'Technology options for feeding 10 billion people - Options for sustainable food processing'.
The full report related to the topic is available on the STOA website.

Abstract of the report

Innovations in food processing techniques can significantly contribute to meeting the needs of the future 10 billion world inhabitants with respect to quality, quantity and sustainability of their food intake. The present study provides an expert judgment for the potential of new and emerging technologies to enhance sustainability in the food processing sector. It includes the following technologies: sensor technology, sustainable packaging and refrigeration climate control, non-thermal pasteurisation and sterilisation, nano- and micro technology, innovative processes for utilisation of by-products, alternative processes requiring less energy or water, plant-based meat alternatives and information and knowledge transfer.

For each technology the direct impact (reduced losses, energy and water use) as well as the indirect impact (food losses, suboptimal utilisation and unnecessary quality decay within the supply chain) are described, as well as their contribution to the areas of improvement of the European food processing industry (new and better food products, resource efficient manufacturing processes, integrated and transparent supply chains and enhanced innovation capacity).

INTRODUCTION

Within the system of food supply, food processing focuses on the conversion of agro-raw materials into (packed) food products with the desired quality and functional properties. Industrial food production started in the 18th and 19th century, when traditional and artisanal production methods were slowly substituted by more science-based and reproducible techniques. Modern food processing techniques have the following three major aims:

1. To make a sufficiently stable food product that is safe for human consumption (microbiologically and chemically).
2. To give the product the required intrinsic quality aspects, e.g. digestibility, nutrient content, flavour, colour and texture.
3. To add value to the product on other aspects, e.g. convenience, lifestyle and marketing.

Innovations in food processing techniques can significantly contribute to meeting the needs of the future 10 billion world inhabitants with respect to quality, quantity and sustainability of their food intake. The present study provides an expert judgment for the potential of new and emerging technologies to enhance sustainability in the food processing sector. More specifically, technology options have been identified that also support the competitiveness of the European food processing industry on the following areas:

1. ***New and better food products*** to meet the growing food demand, alleviate the food security gap, account for demographic changes as well as changing consumer demands and prevent lifestyle-related diseases.
2. ***Resource efficient manufacturing processes*** that minimize the dependency on high-value crops, consume less water and energy and preserve local balances, prevent the generation of waste, produce high quality and high functionality products with an extended and predictable shelf life and allow for diversification with respect to specific consumer demands.
3. ***Integrated and transparent supply chains*** that provide global food security, connect the globalizing food industry and retail to local food production and demand, increase the consumer trust through transparency, traceability and objective information, generate less losses and waste and operate in a synergistic way with other sectors of the upcoming bioeconomy.
4. ***Enhanced innovation capacity*** of the industry itself to realize a faster translation of scientific results into industrial implementations as well to utilize scientific advances from other disciplines (e.g., nanotechnology and ICT), despite its highly fragmented character (EU: 287.000 companies, of which 285.000 are SME's).

Table 1 summarizes the technologies that are included in this study and their linkages to the areas of improvement, thereby identifying the opportunities for innovation in the food processing industry.

Table 1. *Summary of sustainable technology options and their linkage to the areas of improvement for the EU food and drink industry*

TECHNOLOGY OPTIONS	**OBJECTIVES FOR INNOVATION**			
	New and better food products	**Resource efficient manufacturing**	**Integrated and transparent chain**	**Increased innovation power**
sensor technology	increase control on quality & safety issues	reduce product losses: decision making based on measured product properties	advanced management and control of food quality & safety	increased product quality control and differentiation
sustainable packaging and refrigeration climate control	high quality semi-prepared convenient food	reduce food losses through increased shelf life; work on sustainable packages	smart packaging	
non thermal pasteurisation and sterilisation	shelf-stable (semi-)fresh products	reduce losses through increased shelf life		new processing technologies result in products with improved properties
nano- and micro technology	advanced product development	reduction of energy use; detection of contaminants and spoilage micro-flora		new processing technologies result in products with improved properties
innovative processes for utilisation of rest and by-products	generate natural and health-beneficial ingredients from by-products	generation of food ingredients from by-products; valuable application instead of waste		alternative thinking results in new concepts and products; continuous improvement related to avoidance of waste
alternative processes requiring less energy or water	less intensive processing for less refined products	reduction of energy and water use	less refined food ingredients: more specific relation between ingredient supplier and food producer	exploration of new routes for alternative food processing chain design
product development: plant-based meat alternatives	develop more attractive meat replacers	production efficiency of plant-based is higher than animal-based		broader spectrum of raw materials speeds up product innovation process
information and knowledge transfer	improve quality control along the chain	improve production planning based on shared information along the chain	improve knowledge sharing along the chain; make chain transparent for consumer.	faster translations of R&D results into industrial implementations

SENSOR TECHNOLOGY

Sensor technology is a crucial element for assessing the quality evolution and traceability of raw materials, intermediates and final products throughout the entire food production-to-consumption chain. Within the area of food processing, sensors are used for the design, control and optimization of the manufacturing processes (including logistics and storage). Technology developments in this area are focused on new sensors and analytical technologies for direct measurement of key quality parameters, ICT to obtain *real-time* information from the process (enabling faster feed-forward and feedback loops) and the application of quality models to enable predictive control. Improved process control contributes to food chain sustainability through optimization of product quality, including reduction of quality losses and defects, as well as reduced consumption of water, energy and high-value ingredients.

Smart sensors can also contribute to the efficient use of resources in other parts of the food supply system. Adaptive storage conditions based on the simultaneous measurement of oxygen, carbon dioxide and ethanol during storage allow for long term stability of perishable fruits like apples and pears. With the application of monitoring devices (equipped with the required sensors) viable information can be obtained about the actual conditions under which products have been stored and shipped. Unique identification of each product is possible through combining such monitoring devices with radio frequency identification (RFID) tags. Tags containing a microcontroller enable on-chip interpretation of the environmental data. Upon reading the chip the actual status of the goods is immediately available, while the expected future status can be described by quality models using the experienced environmental conditions an input. This technology enables the use of guaranteed quality statements, the supply of consumption-ready products to the supermarket as well as the application of logistical concepts such as FEFO (First Expired First Out).

SUSTAINABLE PACKAGING AND REFRIGERATION CLIMATE CONTROL

The causes of food losses and waste in developed countries are mainly due to consumer behaviour and lack of coordination within the (increasingly complex) supply chain. Quality decay of vegetables and fruits involves a number of biochemical and physiological changes which depend on the experienced conditions. An integrated chain approach is required to achieve optimal product quality and extension of shelf life, and includes control strategies like (controlled atmosphere) packaging, control of temperature, relative humidity and ethylene as well as phyto-sanitary and anti-mould treatments.

Developments in packaging technology include skin (vacuum) packaging, cardboard based barrier trays allowing for packaging under modified atmosphere, material (weight) reductions, the application of biobased packaging materials (like PLA and PEF) and packaging made of recycled materials (mainly PET).

Temperature control and a well-designed cold chain is by far the most important strategy to maintain the desired quality of the products. Due to its high energy demand, cooling is a less sustainable technology. This energy use, however, should be put into perspective by the fact that refrigeration avoids huge amounts of products to be wasted. Nevertheless, significant savings in energy consumption (up to 65% less CO_2 emission) are feasible through smart control of the compressor and the internal air circulation in refrigerated container units.

NON-THERMAL PASTEURIZATION AND STERILISATION

Traditional preservation technologies like heat pasteurization or sterilization, enhance food safety and shelf life, but often negatively affect product quality attributes such as taste, color, texture and nutrients. Mild processing technologies can therefore be an interesting option for both chilled and ambient stable products, thereby meeting consumers' growing demand for fresh-like and nutritious foods that are safe and shelf-stable.

High pressure, microwave heating, ohmic heating and radio frequency heating are currently used in the food industry, mainly for pasteurization of food products. Other technologies are still under development, like high pressure sterilization of packed food products, pulsed electric field processing for pasteurization of liquid food and cold plasma treatment for decontamination of surfaces.

In addition to an improved product quality, novel processing technologies also contribute to improving the sustainability of food processing. As mild processing technologies can be applied at much lower temperatures compared to conventional processing, less energy is necessary for heating and cooling of the product. Furthermore, these technologies enable the production of ready-to-eat meals with the quality of fresh chilled meals, but without the need for chilled or frozen storage. Extension of the shelf life of fresh products also contributes to the avoidance of food waste in the supply chain. Finally, products treated with high pressure, microwave or radio frequency processing are packed in the consumer package before processing. This avoids the risk on recontamination of the product and significantly reduces the volume of packaging material as repacking is not necessary.

NANO- AND MICRO-TECHNOLOGY

Nano/microtechnology is considered a key future technology in food and nutrition, enabling the development of targeted production and delivery systems (encapsulation/emulsification), new sensors for detection of pathogens and toxins (enabling advanced process control and quality monitoring) as well as advanced packaging materials with unique barrier or microbial growth inhibiting properties. Furthermore, nano/microtechnology offers many options for the development of advanced food processing tools and equipment for mixing and homogenisation, separation, fractionation and structure forming. As most of the mechanisms for structure formation in foods take place at micrometer scale, such new process technologies are intrinsically more energy efficient, and make better use of available raw materials. For emulsification and fractionation the feasibility of this approach has already been demonstrated in practice. Other applications are still under development.

PROCESSES FOR UTILISATION OF REST- AND BY-PRODUCTS

Within the European context, food manufacturing on average accounts for about 5% of the total food losses that are generated. Nevertheless, in food processing relatively large streams of by-products are generated. Direct utilising of these streams for food would require alternative (and generally technically more complex) processing; a large part of these side streams is, therefore, only poorly valorised. In their efforts to maximise (economic) production value, especially large-scale industries have made major steps in the valorisation of by-products. For example, by-products from dairy and meat processing made a transition from relatively elementary feed applications to high-value food ingredients. With increasing food prices and with on-going consolidation/scaling up of food various food processing industries, this practice is expected to be followed in other sectors as well (e.g., by-products from fisheries and fruit and vegetable processing). Next to technological developments (e.g., separation, extraction, conversion, stabilisation and drying technology) this also requires new quality standards for ingredients and intermediate products, sustainability assessment protocols as well as practical demonstrations of the potential of by-products.

ALTERNATIVE PROCESSES REQUIRING LESS ENERGY AND WATER

The most energy-consuming processes in the food industry are: process heating (evaporation, pasteurisation, boiling, drying), process cooling/refrigeration, processing machinery (e.g., fans, pumps, ventilation, compressed air) and transport. The use of residual heat, process intensification and alternative chain layout (e.g., including a mild preservation step) are strategies to lower the energy requirements for process heating. Refrigerated storage is highly relevant for sustainable food supply since it contributes to the reduction of food losses. Further enhancement of sustainability can be realised through further development of refrigeration technology (new refrigerants, equipment with higher energetic efficiency and lower greenhouse emissions), advanced control systems (e.g., applied in refrigerated container transport) and the application of mild technologies that enable storage of fresh products at ambient temperature.

Water use is mostly related to washing, dilution and separation processes. Dry fractionation methods (replacing wet fractionation) could significantly reduce the use of water and energy in food processing as it avoids the common practice in ingredient production of adding water, drying and subsequent re-wetting during the mixing/formulation step. Dry fractionation will result in less purified components, but in many food applications high purity of the ingredients is not fundamentally necessary (although in the current system of commodity ingredients often preferred by the food industry).

PRODUCT DEVELOPMENT: PLANT-BASED MEAT ALTERNATIVES

The development of new products can help to reduce the environmental impact of our diet. In many cases technological innovations are required to give these products the desired properties. As an example, the development of so called 3rd generation plant-based meat alternatives required improvement of existing processing technologies to better meet consumer demands with respect to e.g. texture and juiciness. Shear-induced structuring technologies which are now under development are aimed at better mimicking the fibrous nature of meat.

The next breakthrough in meat-replacing products can be realised by the development of new, sustainable sources of proteins. Examples of such sources are insects, duckweed and algae. The exploitation of new protein sources requires the development of new, mild processing technologies for disentanglement and extraction of the protein. The implementation of the biorefinery concept (i.e., maximum valorisation of sub-fractions into food and non-food applications) will strongly support the commercialization of these sources. A limiting factor may be formed by the present regulation and legislation concerning the use of novel protein sources.

INFORMATION AND KNOWLEDGE TRANSFER

The weak innovation power is one of the main reasons for the decreasing share of the European food and drink industry in the global markets. The excellence scientific research that is conducted in the field of food and nutrition is insufficiently translated into industrial implementations of either new technologies or new food products (*the European innovation paradox*). To stimulate knowledge transfer within the food industry a spectrum of tools and instruments is available, including financial incentives, the formation of networks and sharing of best-practices. Although many systems and instruments have been developed and tested in practice, a widely applicable *best practice* for knowledge transfer in the food processing industry has not been identified yet. The highly fragmented character of this industrial sector, including the large amount of SME's, may be the most plausible explanation for this. Nevertheless, ICT solutions like the Food Technology Innovation Portal (Food TIP, developed in the Network of Excellence HighTech Europe) can help to improve the knowledge transfer from academia to companies.

Furthermore, regulatory bodies can also play an active role in promoting innovation in the food sector. Similar to the pharmaceutical industry, a one-sided focus on excluding food safety risks will lead to a standstill in innovation. With the implementation of modern risk-management concepts as well as more science-based manufacturing the right balance between ensuring product safety on the one hand and stimulating innovation on the other hand should be found. A promising route for this may be to allow food processing industry more regulatory freedom, e.g., in the implementation of new technologies or the use of side streams in food applications, provided sufficient understanding of their manufacturing processes can be demonstrated ("science-based manufacturing").

CONCLUSIONS AND RECOMMENDATIONS

Technology development can contribute to eco-efficient processing in the food industry through *direct* savings, mainly in energy and water use, and the reduction of waste. This will also lead to cost reductions and reduced vulnerability to future scarcity and price increases. Examples include:

- More sustainable refrigeration technologies combined with more effective climate control strategies, insight into steering options for product quality and innovative packaging will reduce the energy use of refrigeration/cooling;
- Dry processing as alternative to wet processing routes will reduce the energy costs of drying processes;

- Innovative food microsystems will reduce the required energy in fractionation processes and in the production of advanced food structures like emulsions;
- Advanced process control to manage variation in the process.

An even larger impact on sustainability can be expected from improvements in resource valorisation (*indirect effects*). The main inefficiencies within the food processing sector are food losses, suboptimal utilisation of by-products/processing residues and unnecessary quality decay within the supply chain. Technology development to reduce such inefficiencies include:

- Cooling, stabilisation / preservation processes and packaging technologies contribute to increasing the shelf life of products, thereby reducing losses in the chain. Technological advances with respect to innovative sensor technologies and packaging solutions support these developments.
- Creation of more added value through higher value applications of by-products. Successful examples are available where industries are generating new food ingredients from former waste streams or low-value by-products.
- The application of smart sensors and RFID tags allow for quality control over the entire supply chain. Application of such sensors enables the use of guaranteed quality statements, the supply of consumption-ready products to the supermarket as well as logistical concepts such as FEFO (first expired first out).
- The implementation of novel technologies for mild preservation, e.g. non-thermal pasteurization or sterilization techniques. Application of such technologies could help to reduce food losses over the supply chain by prolonging the shelf life of the (semi-) fresh products.
- Mild separation technologies for the creation of functional fractions (instead of pure ingredients): next to maintaining the nutritional value of the original plant material, the application of functional fractions could lead to significant savings in water and energy consumption, especially when drying and subsequent rehydration steps in the manufacturing process could be omitted.
- The development of plant-based meat alternatives: technological developments initiated by the food processing industry can help to increase the consumer acceptance of such products.

Policy recommendations to support the implementation of sustainable process technologies are:

- Stimulate the implementation of novel preservation technologies that are ready for use (e.g. high pressure pasteurization, advanced heating) via knowledge transfer and feasibility studies, specifically aimed at SME’s.
- Stimulate the knowledge basis for technologies that are currently not ready for application, like cold plasma processing.
- Stimulate the development of industrial equipment for technologies that are proven to be interesting but for which industrial equipment is not yet available, like high pressure sterilization and pulsed electric field processing (as equipment manufacturers are hesitating to invest in the development of novel equipment).

- Support the publication of eco-efficiency manuals to help companies to identify areas of improvement, e.g., through providing benchmark data on water and energy use or sharing best practices.
- Active promotion of operational excellence programmes like Lean Manufacturing or Six Sigma as modern methods for Quality Risk Management. These programmes have already proven their success in other sectors of the industry and could potentially lead to reductions of 80% in the costs of poor quality.
- The further deployment of Industrial Symbiosis programmes to stimulate new partnerships between suppliers and potential users of side- and waste-streams.