National Research Council of Italy

Science & Technology Foresight
from research to market

AREA SciencePark

Converging technologies for Sustainable and Healthy Food

F2F Workshop: Diversified Adaptable Food

6th-8th May, 2015

La Borghesiana - Rome

We seek: to define key principles on which a stable, sustainable Diversified Adaptable Food Supply can be based and further developed; to identify possible obstacles; to indicate to national and international authorities and stakeholders priorities for funding research projects, and for channeling investments.

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In collaboration with:

ISGP Institute on Science for Global Policy

National Research Council of Italy

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"Converging technologies for Sustainable and Healthy Food"
La Borghesiana Romana - Via della Capanna Murata, 120 - Roma

F2F Workshop: Diversified Adaptable Food 06.05.15 – 08.05.15 - PROGRAM

Wednesday 6th of May

Opening

18:00 **Ezio ANDRETA.** Coordinator of the International S&T Foresight Group
18:10 **Luigi Nicolais.** President of CNR
18:20 **Adriano De Maio.** President of Area Science Park.
18:30 **Giorgio EINAUDI**
Approach and goals of the workshop
18:50 – 19:20 **George ATKINSON**
"Lecture on Interdisciplinarity" *
20:00 *Dinner*

Thursday 7th of May

Session 1

9:00 **Topic 1**
Yoav LIVNEY
Nutrient Delivery Systems: Fortified food against dietary deficiencies
Mitsutoshi NAKAJIMA
Emulsification: an innovative process allowing the formulation of healthier food
9:20 Moderator: **Ralf GREINER**
Questions and Answers
10:30 *Break*
10:50 Parallel Group Discussions Topic 1
12:00 **Antje GROBE**
Nanotechnology and Society: Towards an Integration and Responsible Approach to Innovation.
12:15 Moderator: **Stephen TAYLOR**
Questions and Answers
13:00 *Lunch*
14:30 Moderator: **Ralf GREINER**
Report Group Discussion Topic 1

Session 2

15:30 **Topic 2**
Leonardo FRACETO
Nanotechnology in Agriculture
Ron JOHNSTON
Management of Agricultural Waste
15:50 Moderator: **Richard CANADY**
Questions and Answers
17:00 *Break*
17:20 – 18:30 Parallel Group Discussions Topic 2
19:30 *Dinner*

Friday 8th May

Session 3

9:00 Moderator: **Richard CANADY**
Report Group Discussion Topic 2
10:00 **Topic 3**
Vincenzo FOGLIANO
Diversified adaptable proteins: meat replacement from plant, insect or single cell
Andrew D. MAYNARD
Risk and Benefits of the Application of Sophisticated Materials to the Food Sector
10:20 *Break*
10:40 Moderator: **David CARLANDER**
Questions and Answers
11:50 Parallel Group Discussions Topic 3
13:00 *Lunch*
14:00 **TBD**
Innovation technologies: Opportunities and Challenges for Developed and Developing Countries.*
14:15 Moderator: **Stephen TAYLOR**
Questions and Answers
15:00 Moderator: **David CARLANDER**
Report Group Discussions Topic 3
16:00 *Break*
16:15 – 18:00 Plenary Discussion Closing remarks

***the titles of these presentations may slightly change | In collaboration with:** ISGP Institute on Science for Global Policy

Converging technologies for Sustainable and Healthy Food

Cecilia Bartolucci, November 2014

1st Face to Face Workshop *(6th- 8th May 2015)*: Diversified Adaptable Food

We seek: to define key principles on which a stable, sustainable Diversified Adaptable Food Supply can be based and further developed; to identify possible obstacles; to indicate to national and international authorities and stakeholders priorities for funding research projects, and for channeling investments.

Scientific Committee: Richard Canady, David Carlander, Ralf Greiner

Introduction

The National Research Council (CNR) and the Trieste Area Science Park Consortium (AREA), with the support of the Ministry of Education, University and Research (MIUR), launched the ***Science and Technology Foresight Project (STFP)*** to strengthen the development of new technologies in the medium to long term to deal with important problems related to health, food, environment, energy, transportation, safety and security (http://foresight.cnr.it). This initiative is motivated by the need to develop new strategic directions.

A key aspect of the project is the involvement of scientists and experts from academia, government and the private sector. A series of “face-to-face” (f2f) workshops, each of them with its own focus on different, but correlated, sub-topics are being organized. Using a highly interdisciplinary approach, participants in the workshops will be able to share knowledge, to identify gaps in knowledge, to point out obstacles, to identify needs for more and better education as well as for more funding, and to outline market potential and social acceptability for activities and products.

In December 2013 the Foresight Group held the first event, the “Foundation Seminar” in the topic Food. The experts present were:

Karin Aschberger (Institute of Health and Consumer Protection, Nanobiosciences Unit, JRC, Italy)
David Carlander (Director of Advocacy, Nanotechnology Industries Association, Belgium)
Ralf Greiner (Head of the Department of Food Technology and Bioprocess Engineering, MRI Federal Research Institute of Nutrition and Food, Germany)
Mélanie Kah (Department of Environmental Geoscience, University of Vienna, Austria)
Doris Marko (Head of the Institute of Food Chemistry and Toxicology, University of Vienna, Austria)
Domenico Rossetti (Principal Administrator for Social Sciences and Humanities at the EC, DG for Research and Innovation, Belgium)
Clara Silvestre (Institute of Chemistry and Technology of Polymers, CNR, Italy)
Nicola Trevisan (General Director, Veneto Nanotech, Italy)

At the end of the seminar we agreed that even though we may want to stress nano, all **converging technologies** should be taken into account. **Synergistic or competing technologies** should be considered as well.

We further agreed that a concerted effort addressing both **health** and **sustainability** is necessary if longlasting results are to be achieved. A healthier society is part of a common vision and a priority for all, but this goal is not achieved through the application of one single, specific strategy. **Food** and **health** are closely related and several paths, adapted to different situations, need to be developed for a successful outcome. The different situations may be due to geographic habitats, climatic niches, ethnicity, religious or social status, age, gender, or, at a more specific level, due to hereditary or sporadic disease, occupation etc. To envisage sustainable and socially acceptable solutions, knowledge of the specific starting conditions as well as the diverse needs and goals is necessary. Each problem could be addressed individually, developing specific technological solutions but this is time-consuming and not always efficient.

Proposal

An intriguing alternative is the identification of **one technological approach**, which would allow more control over the composition of food and hence adapt it to needs, providing a **Diversified Adaptable Food**. Applications should start at the farm with the raw materials and run through the whole food chain to the fork and beyond to the disposal of food waste in the environment. Some of the issues that could be addressed in **agriculture** are: detection of needs of major and minor crops according to different growth conditions and climate; targeted or triggered delivery of inputs; “protection” of nutrients in raw materials and better bioavailability. Innovation in **processing** should pick up at the raw materials provided by smart agriculture, further supporting protection of nutrients and bioavailability, while ensuring safety and sustainability of its procedures. In this context **food contact materials,** and their application in a broader sector rather than just packaging, should also be considered.

This kind of approach would encourage the exploration and exploitation of a wider variety of food, greatly supporting biodiversity while appraising quantitatively small but qualitatively high value productions. It would also address the challenges posed by climate change, stressing the necessity for adaptability, and it would provide one tool with dual use, applicable in opposite situations as well (e.g. more or less nutritious food for developing versus industrialized countries; crops growth in extreme, variable climatic conditions).

All issues mentioned above can be addressed by converging technologies. These can greatly contribute to providing the diversification and adaptability needed for the sustainable production of healthier and safer food. Knowledge transfer from the experience acquired in other sectors is essential. An example is the application of nanotechnology and nanomaterials in medicine, which paves the way both in terms of innovation and social acceptance.

Diversified Adaptable Food is a concept that, if properly introduced, can be understood and accepted by consumers, whose sense of belonging to at least one of the many groups addressed, will make them feel involved. Considering the increasingly important role of consumers in influencing the market, this aspect should not be underestimated. The identification of different needs, the acknowledgment of the existence of many different geographic and socio-economic realities and the search for an appropriate approach would support and justify the development and application of innovative technologies. Furthermore, if the essential question “When we put something in food, what impact does it have on our health?” is addressed openly, consumers would be more inclined to recognize a real benefit in the application of innovative technology to the food sector, beyond a simple market strategy and be more open to a constructive discussion.

For the development of **Diversified Adaptable Food** the specific areas of intervention would be **agriculture** and **processing** but the strong link between each step in the food chain should be considered. A holistic approach is an integral part of the concept of **Diversified Adaptable Food**. We do not want to address the single sectors individually but rather to encourage the identification of functionalities that could be developed through the application of converging technologies, also in combination with other technologies, and which could provide actual benefits.

It is of primary importance that we develop an approach that considers the whole food chain, **a food chain approach**, which stimulates us to evaluate every time how the introduction of a new application at a specific step is going to affect the rest of the chain. Gathering experts with specific disciplinary skills in a highly multidisciplinary context chosen to promote the transfer of knowledge across situations, should encourage the food chain approach, allowing us to deal with specific issues, while keeping a broad view. During the workshop we will ask eight scientific experts to propose and introduce one specific case, dealing with either a local or a more global reality and identifying a challenge concerning e.g. a climatic issue, a defined target group or an economic problem. Within one main topic, two aspects of particular relevance for the developed or developing economies will be addressed by two experts. It will be important to project how converging technologies, and the **Diversified Adaptable Food** produced through their exploitation, can impact the challenges addressed in each case. Furthermore it will be key to assess if the acquired technological knowledge can be transferred to different situations.

Outcome

By the end of the workshop we want to be able to propose key principles on which a **Diversified Adaptable Food** supply can be based and point out to the technological development that could best support such innovation. Indications for the focus of the 2nd f2f workshop should also emerge from the workshop. The combined approach applying both broad and multidisciplinary as well as specific knowledge should allow us to propose a scenario in which Diversified Adaptable Food plays a key role to solve future social challenges. Evaluation of this scenario will eventually support the submission of a report to the scientific and governmental authorities as well as to other stakeholders, pointing out priorities for research funding, investments, regulatory and social adaptation.

Position papers

TOPIC 1: Personalized nutrition: Disease prevention/control

Nutrient Delivery Systems: Fortified food against dietary deficiencies - Yoav D. Livney

Emulsification: an innovative process allowing the formulation of healthier food - Mitsutoshi NAKAJIMA

TOPIC 2: Improved quality/quantity ratio

Nanotechnology in Agriculture - Leonardo FRACETO

Management of Agricultural Waste - Ron JOHNSTON

TOPIC 3: Sustainable food production

Diversified adaptable proteins: meat replacement from plant, insect or single cell - Vincenzo FOGLIANO

Risk and Benefits of the Application of Sophisticated Materials to the Food Sector - Andrew D. MAYNARD

Nutrient Delivery Systems: Fortified food against dietary deficiencies

Yoav D. Livney, livney@technion.ac.il
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1. Summary

An important component in the strategy for addressing global health problems, like the metabolic syndrome and cancer, is the effective fortification of staple foods and popular beverages with micronutrients, including vitamins missing in our diets (e.g. vitamin D and omega-3 fatty acids), and nutraceuticals of established health benefits (like EGCG and curcumin). Novel food nanotechnologies are being developed, which enable effective food fortification with these sensitive bioactives, without compromising product sensory quality, and while protecting the bioactives from degradation during processing, shelf life and digestion, and improving their bioavailability and health impact. Re-assembled casein micelles (rCM) are an example we have introduced as a mean for delivering hydrophobic nutraceuticals, like vitamin D (VD), by fortifying milk products, using only natural milk components. A clinical human trial demonstrated excellent bioavailability of VD in rCM. Similarly, it is imperative that more such technologies would be developed, and evaluated in all aspects, in particular, safety and efficacy. The results obtained by in vivo studies would facilitate regulatory approval. The technologies must be commercially viable, ideally, improving product taste, not just its label. Another important challenge is to educate people of the relationship between nutrition and health, and on the benefits and safety of food nanotechnology, achieved through concerted efforts of scientists, regulators, nutritionists and the food industry. Longer range and greater challenges are posed by the personalized nutrition revolution initialized by deciphering the human genome.

2. Case study (2-5 years)

About 1 billion people worldwide are VD deficient or insufficient[1], mainly due to avoiding sun exposure to prevent melanoma and to low dietary intake[2]. Proper VD levels can be maintained by vitamin supplementation or food fortification[1]. Milk products are the most appropriate foods for VD fortification, mainly because they are widely available, palatable and rich in calcium and phosphorus, but naturally poor in VD. Their low VD content intensifies by losses during thermal processing and fat removal[3]. In Canada, all milk is fortified to provide 44% of the recommended daily intake (of 400 IU) per 250-mL serving[4]. However, most fortified foods and beverages are under-fortified. VD fortification is challenging due to vitamin insolubility in aqueous systems, posing a problem for incorporating the vitamin in nonfat products; vitamin sensitivity to light, air and high temperature[5] and low pH, e.g. in yoghurt, and during gastric digestion[6]; risk of poisoning due to uneven distribution of the added vitamin; consumer demand for the use of all-natural ingredients, which calls for avoiding synthetic emulsifiers such as Tween-80 (Polysorbate-80). We have previously introduced the potential of rCM as natural nanovehicles for hydrophobic nutraceuticals, e.g. VD[7], and shown the good solubilization and protection conferred to the vitamin against heating, UV exposure[7] and during shelf life[8]. The main question we then wished to answer was whether VD_3 encapsulated in rCM is still bioavailable. To answer this question we performed a clinical trial and evaluated the serum levels of 25-hydroxy VD, the accepted VD status indicator, following a single-dose of 50,000 international-units (IU) VD_3 encapsulated in rCM, in 1% fat milk, in a double blinded placebo controlled clinical study with 87 human volunteers. We found that VD bioavailability in rCM was at least as high as that of an aqueous Tween-80-emulsified VD_3 supplement (considered to be highly bioavailable, and prescribed by physicians to VD deficient patients). We found that VD_3 encapsulated in rCM is highly bioavailable[8]. Taken together with our other results showing the much better protection (compared to Tween 80) conferred by rCM to VD during heating, and shelf life[8], and the fact rCM are inexpensive to produce and are made of natural ingredients only, we conclude that rCM prove to be a preferable nanovehicle for VD fortification in milk products.

3. Extrapolation to other realities (5-10 years)

There are many other micronutrient deficiencies worldwide, even in modern countries, and among people of all economic and education levels. While poor populations tend to suffer malnutrition due to insufficient food or to relying on high energy staple food for survival (without sufficient vegetables and fruit in the diet), middle class and wealthy people often develop certain micronutrient deficiencies due to lack of awareness for the importance of a diverse balanced diet, and to routine selection of indulging foods lacking essential nutritional elements.

Many innovative nanotechnologies have been developed over the last decade, which may enable the enrichment of staple food and popular beverages with important micronutrients that are lacking in today's nutrition of wide populations, and are safe to be used in food fortification (like vitamin D, and omega-3 oil; As a counter example, vitamin A, which becomes toxic if given in excess above the recommended daily amounts should not be used for wide fortification). These nanovehicles may solubilize water insoluble micronutrients, protect sensitive nutraceuticals form degradation during production, shelf-life and digestion, mask undesired sensory attributes and enable their programmable release and improved bioavailability, for safe and enhanced health benefit materialization. This strategy may provide one of the key elements in the societal program for combating the pandemic problems of metabolic syndrome (obesity, cardiovascular diseases and diabetes), cancer, neurodegenerative diseases and more. In the longer run, more advanced strategies, such as personalized nutrition, are likely to become widely applied, but there is much to be done in the intermediate time, using theses simpler approaches, to make the foods we eat more health-promoting, without relying on dramatic changes in life style, that are difficult to implement even for the more educated and affluent people.

4. Identification of gaps and obstacles

The main gaps and obstacles are a few: Many of the new nanotechnologies for food fortification still need to undergo important in-vivo and clinical safety and efficacy examinations, and the results obtained need to be assessed by the regulatory agencies for commercial implementation approval. Moreover, the technologies must be commercially viable, not increasing the price for the consumer (who is unfortunately yet not willing to pay significantly more for a more health-promoting product). Ideally, outstanding success would be achieved whenever the more health-promoting product would win over the alternative also in taste, not just in label information. Another important challenge is to communicate and to educate the population: on the one hand of the relationship between proper nutrition and health, and the need for preventive nutrition, as part of a healthy life style; and on the other hand- on the benefits and safety of food nanotechnology, achieved through concerted efforts of scientists, regulators and the food industry. Positive signs of rising consumer acceptance for nanotechnology are being reported[9]. There is work to be done by nutritionists in defining best suiting micronutrients for enrichment, and the proper dosing in various fortified foods, taking into account also the improved bioavailability provided by the new nanotechnologies.

In the longer term, larger challenges exist toward personalized nutrition. These include bridging the huge knowledge gap between knowing the genome sequence of a person, and matching the most suitable diet for that person, and revolutionizing food production and distribution to provide personalized products, available on demand.

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Emulsification: an innovative process allowing the formulation of healthier food

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1. Summary

Emulsification is an important, innovative process for formulation of healthier food. In emulsion science food functionality and their structure need to be studied, to improve industrial emulsification processes, and to understand gastro-intestinal tract process in the human body by more qualitative/quantitative investigation. More collaboration between scientific, engineering, and medical fields should be encouraged. In addition to research and development, education of food and nutrition is considered to extend health life expectancy.

2. Introduction

In the last 50 years Japan has experienced rapid extension of the average life expectancy, and present average life expectancy is 80 for men and 85 y for women and the average healthy life expectancy is 75 and 80 y respectively. The extension of life expectancy was mainly due to improvement in public health, medical treatment, health insurance system, reduction of the infant mortality rate and school lunch program for children. Since 1970, however, overeating and lack of exercise have caused the increase of obesity and lifestyle-related diseases (diabetes, hypertension). Under these circumstances, Japanese government formulated the Shokuiku Basic Act in 2005, and various programs have been planned. “Shokuiku” can be translated to “Education of eating, including gratitude to food and traditional food culture”. In the World Food Summit of 1996 held in Rome, it was declared by international consensus, that “adequate nutrition is a human right”. “Shokuiku” aims to foster mental and physical health, as well as individual humanity, throughout lifetime. In our busy daily lives, we may forget the importance of diet for basic health. Diet related problems such as unbalanced and irregular diets, increase obesity and lifestyle-related diseases. Because our knowledge on food and nutrition is limited, we should learn more about appropriate diet, and pay more attention to the food to control obesity and other diet-related health problems.

Emulsification is one of the food processes for homogenized milk, mayonnaise, chocolate, low fat spread and so on. Emulsification is also one of the encapsulation methods of formulation of healthier food components. If healthier components are hydrophobic, they are incorporated into oil, and dispersed in water (O/W emulsion). If healthier components are hydrophilic, they are dissolved in water, and dispersed in oil (W/O emulsion) for higher stability, and W/O emulsions are dispersed into water again, obtained as W/O/W emulsions. Depending on the conditions employed, solid fat can be used instead of liquid oil, and properties of water phase can be also changed by adding gelling agents, such as gelatin and agar, getting hydrogel.

There are three basic functions attributable to food. One of them, the most important, is the nutrient function (primary function), followed by the taste and sensory function (secondary function), and the biological regulation function, that is involved in the maintenance and improvement of health (tertiary function). The so called “functional health food component” is related to the tertiary function. Most of the functional components, such as polyphenols and carotenoids are water-insoluble, leading to low bioavailability in the body. The properties of functional components in foods can be controlled by their micro/nano-scale structure. Conventional preparation for functional foods are generally formulated by applying large-scale processing. Therefore, it is difficult to control precisely the structure of the products. Recently micro/nano engineering has been developed, and applied to functional foods. Conventional mechanical emulsification equipment, such as high-pressure homogenizer, is used to produce emulsions. However, the obtained emulsions were polydispersed, with droplet diameter of 0.1-10 µm. We have developed precisely-microfabricated microchannel (MC) arrays to produce emulsions. MC emulsification is capable of producing monodisperse emulsions, formulating the monosized microparticles and emulsions. A nanochannel (NC) emulsification device has also been developed, in order to produce monodispersed sub-micron emulsions.

3. Case study (2-5 years)

Emulsification is used for formulation of healthier foods in the food industry. In the human body, emulsification also takes place. Oils are hydrophobic, and less soluble in aqueous digestive tract. Lipase can work at the oil/water interface, and oil hydrolysis takes place. The digestion is enhanced by emulsification with bile containing bile salts and phospholipids. Peristaltic movement in the body also affects the digestion process. After digestion, micelles are formed with fatty acids, mono-glycerides, bile salts and phospholipids. Micelles are much smaller than emulsions, and can be transported to the surface of the enterocyte where they can be absorbed. Micelles contain lipophilic functional components.

We need to understand the relationship between the functionality and the structure of the components in foods both during processing as well as in the body. Qualitative investigations of human digestion have been carried out, however, there are only a few quantitative investigations. Both qualitative and quantitative investigations will be needed in order to transfer the knowledge about the emulsification systems in the body to the industrial processes.

Bioassay tests using caco2 cells are effective to model the intestine environments, and the effect of functional components in the emulsions can thus be analyzed. Bioassay, animal and human tests will be done by food and medical scientists in order to get evidence of functional components in foods with the help of engineers to design and carefully formulate functional foods.

Attentive discussions on appropriate foods between the scientists of different fields including medical doctors are needed. Appropriate foods may change depending on the age of the consumers and their local food production, and may differ between countries.

4. Extrapolation to other realities (5-10 years)

In addition to the R&D of food processing technologies, understanding the phenomena occurring in the gastro-intestinal tract, as well as getting reliable evidence-based information on functional components, is very important. For instance, many old people suffer from arthritis and osteoporosis. Uptake of vitamin D, polyphenols such as quercetin, and branched amino acids would be beneficial; and emulsion formulations would be a good approach. Food fiber-based or resistant starch-based emulsion uptake could also be a valid approach to addressing the problem of obesity by over-nutrition.

More information on functional components with actual evidence should be obtained. This may reduce huge cost for medical care, and increase healthy life expectancy. More sophisticated, and innovative industrial emulsification processes may be developed based on understanding the gastro-intestinal tract processes. Currently health supplements depend mainly on their functional components, from a chemical point of view. However, supplements should be formulated not only from a chemical, but also form a physical and biological point of view.

In society, people are very concerned about their health, however, their knowledge on food and nutrition is quite limited even in advanced countries. Better education about food and nutrition will be required. Qualitative and quantitative understanding of food and nutrition in primary school, high school and university will be important for promoting a healthy life.

5. Identification of gaps and obstacles to be overcome

Knowledge of food and nutrition between countries is not well shared. Most people are concerned about their health, but their knowledge of food and nutrition is very limited. Medical doctors know about their patients and have some idea of the relationship between the patients' diet and disease. However these data are not available to the public. This expert knowledge should be collected and analyzed. In order to develop the innovative, optimum emulsification for functional foods, more collaboration among scientists of different fields is needed. Furthermore, more collaboration between countries is required to establish international standards for the formulation and regulation of products.

Diversified Adaptable Food: Nanotechnology in Agriculture

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1. Summary

In recent decades, there have been major advances in the area of nanotechnology applied to agriculture. Nonetheless, many issues remain to be addressed in order that this technology may make a significant contribution to increased agricultural productivity (which will be needed due to the predicted increase in the global population), while at the same time reducing adverse impacts on the environment and human health. The aim of the present paper is to describe the main advances and difficulties expected in this area in the near future (2 to 5 years), and to suggest future scenarios for the use of nanotechnology in agriculture.

2. Current and future trends

There is a wide range of potential applications of nanotechnology in agriculture, and research into novel techniques is increasing in both the academic and commercial spheres. Some of the main applications are Systems for increased productivity where these include methodologies based on the use of capsules and metallic, polymeric, and lipid nanoparticles, notably the following techniques: i) Intelligent systems for the release of nutrients; ii) Systems for the control of pests and diseases.

In relation to the systems for the control of pests and diseases, nanotechnology can be used to improve the properties of an active agent in several ways: i) increasing solubility, ii) providing controlled release to target organisms, iii) protecting against hydrolysis and photodecomposition, and iv) increasing toxicity towards the target organism, as well as, novel particles can be developed as active agents to combat pathogens. As example, Atrazine (6-chloro-N2-ethyl-N4-isopropyl-1,3,5-triazine-2,4-diamine), which is a member of the triazine class of herbicides, is used in many cultivations for pre- and post-emergent control of weeds. Its mechanism of action is by inhibition of photosynthesis. Bioaccumulation and contamination of the soil with atrazine residues can affect non-target plants in cultivations, reducing productivity, while contamination of aquatic systems can have impacts on many species. European Union bans the use of atrazine because of ubiqitous and unpreventable water contamination.

However, the nanoencapsulation of this herbicide has been showed: i) reduction in cytoxicity and genotoxicity; ii) increasing in the effectiveness of atrazine to target organisms (such as mustard plants); iii) the fate in soil of atrazine encapsulated presents no differences in relation to the atrazine (initial studies). By the way, even the first results showed that the nanoencapsulation could reduces the environmental impacts, more studies need to be done in order to really develop a system that can helps the weed control in agriculture with no harmful impacts to the humans and to the environment. In this way, despite considerable advances in terms of identifying possible applications atrazine nanoencapsulated, there are many issues that remain to be resolved in the near future (within a timeframe of around five years) in order that this technology might make significant contributions to the area of agriculture. Some of the main aspects that require further attention are:

- Development of hybrid carrier systems for different active agents in order to maximize efficiency and reduce the number of separate applications required. In the case of atrazine, is possible to associate with other herbicides in order to reduce the plant resistance to this formulation. The development and synthesis of such systems should be based on the principles of green chemistry and environmental sustainability;
- Development of processes that can be used at an industrial scale, given that few studies have addressed this issue, with the nanotechnology techniques developed often showing promise, but not being commercially viable. For atrazine, the production of nanocapsules nowadays is restrict to small amount and in this way, new technologies are need to increase the production in order to be used on the field.
- The need for field studies to compare the effects of nanoformulations/nanosystems with those of existing commercial products, in order to demonstrate real practical advantages in the field. Some efforts were done in this direction; however, a critical study is need to certify that this technology really can increase the atrazine effectiveness and reduces the environmental impacts.

- Aspects involving environmental interactions and toxicity of encapsulated atrazine. Some studies showed some evidences of the reduction of the environmental problems related to the use of this herbicide in agriculture. However, some points need to be improved in order to give a real scenario of the use of nanopesticides in agriculture, as example:
  - Development of knowledge in the area of risk assessment of nanomaterials;
  - Development of knowledge in the area of the fate of nanopesticides and evaluation of associated risks;
  - Development of knowledge for evaluation of the safety of this technology when used by agriculturalists;
  - Assessment of the impacts on non-target organisms: soil microbiota, bees, birds, etc.
  - Investigation of the phytotoxic effects of nanosystems on non-target organisms;
- Advances in terms of regulation of the use of nanopesticides. In short, the progress made in the use of nanopesticides (such as atrazine) in agriculture has led to a need for studies designed to propose parameters for the prediction of the behavior of nanomaterials in the environment. It is necessary to understand the mechanisms of interaction of atrazine nanopesticide system with both target (such as mustard) and non-target organisms (corn), as well as to obtain the information required to ensure the safety of workers and the consumers of foods produced using nanomaterials (Figure 1). This should lead to a positive perception by society of the use of nanotechnology.

3. Other applications

It is anticipated that advances in the area of nanotechnology in agriculture will lead to the development of intelligent systems for the monitoring of conditions in the field, based on sensors able to detect parameters such as humidity, pH, fertility conditions, pathogens, and weeds, in order to assist decision-making by agriculturalists. Such systems could be integrated in platforms employing wireless signals, enabling adjustment of the inputs of fertilizers and pesticides during the course of cultivations, avoiding waste and improving productivity. The use of integrated systems could make it possible to control pests at critical locations within the plantation, hence reducing costs and minimizing impacts on the environment and human health. Depending on the type of cultivation and the ease of access to particular areas of the field, the application of nanofertilizers or pesticides could be achieved using devices such as drones.

It is anticipated that the use of technologies based on multichannel nanosensors could help in the measurement of different parameters in the field, as well as enable the controlled use of irrigation water, avoiding excess and reducing the loss of

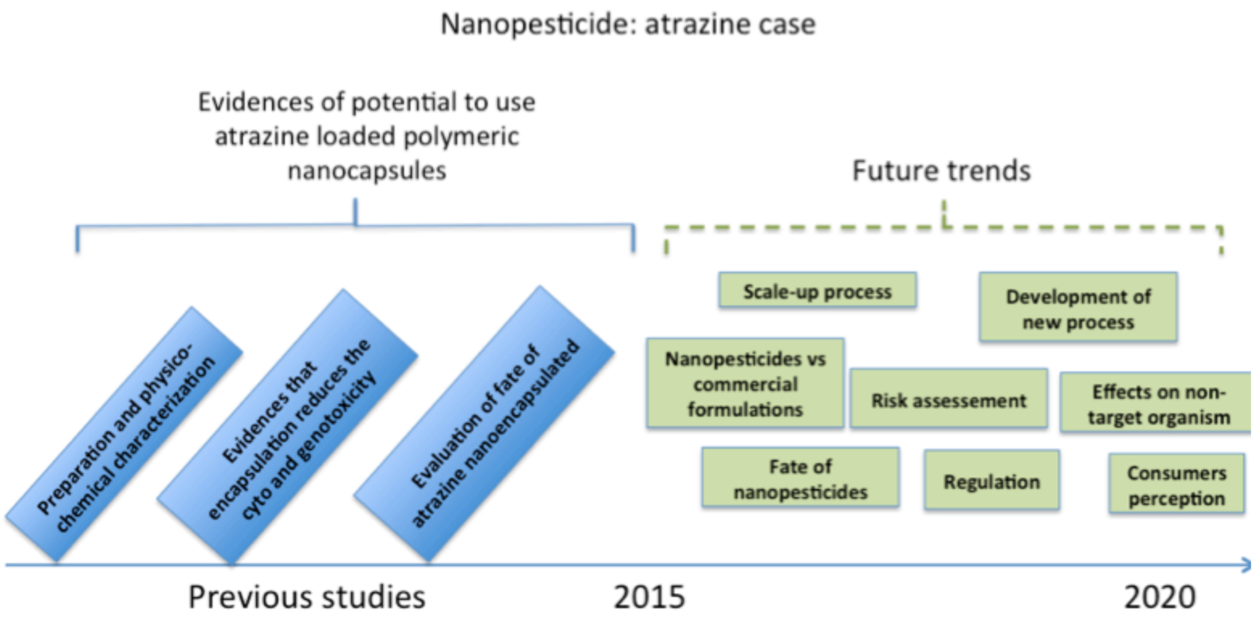

Figure 1: Timescale for developments in atrazine nanopesticide.

nutrients due to leaching processes. However, it should also be pointed out that the application of nanotechnology in agriculture could have undesirable economic impacts, due to the need for qualified personnel. Furthermore, the use of this technology (as observed previously in the case of the advent of mechanization) could lead to unemployment among less qualified workers, due to the need for fewer employees per hectare.

It is essential that future nanotechnology systems should be as efficient as possible, for example using the smallest quantity of an active agent required to have the desired effect on a target organism, while ensuring minimal or no effect on non-target organisms. In this context, the development of nanotechnology systems based on secondary metabolites of plants could help to optimize the development and productivity of cultivations. The use of pest control systems based on botanical insecticides could provide environmental benefits and protect the health of workers and the final consumers and probably this research subject will increase a lot in next years.

4. Identification of gaps and obstacles

The implementation of nanotechnology in agriculture has led to an urgent need to develop techniques capable of quantifying nanoparticles at the concentrations present in different environmental compartments. The methods currently available are not sufficiently sensitive for the generation of reliable data that would enable understanding of the dynamics of nanomaterials in the environment, or the interactions of these nanosystems with target and non-target organisms. Furthermore, the development of reliable methods for the detection of nanomaterials would assist in studies of their fates, and contribute to the development of predictive models able to determine the concentrations of nanopesticides in different environmental compartments such as soil, water, sediments, and the atmosphere.

With the advent of methodologies capable of quantifying nanomaterials in the environment, it will be possible to implement studies designed to understand the effects of these materials along the trophic chain, as well as to investigate the possible development of resistance to nanomaterials by target organisms.

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Management of Agricultural Waste

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"Globally, 140 billion metric tons of biomass is generated every year from agriculture. This volume of biomass can be converted to an enormous amount of energy and raw materials. Equivalent to approximately 50 billion tons of oil, agricultural biomass waste converted to energy can substantially displace fossil fuel, reduce emissions of greenhouse gases and provide renewable energy to some 1.6 billion people in developing countries, which still lack access to electricity. As raw materials, biomass wastes have attractive potentials for large-scale industries and community-level enterprises." [1]

Summary

The sustainability of food production to feed the global population requires, among other changes, a dramatic decline in the wastage associated with agricultural and food production and consumption. Currently emerging technologies such as the biorefinery offer the prospect of capturing substantial value by converting waste to valuable product, and in moving agriculture towards a 'leaner' mode of operation. There is potential for newer emerging or converging technologies to support further advances. However, given the highly distributed structure of agricultural production, and the subsistence model on which so much of it is based, technologies to facilitate learning, access to information, and communication of good practice may well be the greatest contributors to change.

Introduction

In addressing the issue of reducing agricultural and food waste in developing countries, it is widely recognised that the greatest levels of economic and social development are likely to result from the widespread application of existing technologies (eg improved storage, pest management transport and low-level processing)[2] and through social innovation, such as changed patterns of cultivation, crop or animal selection, food storage and treatment, and cooking and eating practices

Case Study – Biorefinery Technology

There has been substantial progress in the conversion of agricultural waste into energy and/or usable material resources via the emerging technology of the biorefinery - a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals. A key application of biorefinery technology is focussed on the waste from sugarcane production, known as bagasse. The biorefinery process requires pre-treatment of the bagasse in a reactor at moderate temperatures and pressures, followed by hydrolysis using enzymes to produce fermentable sugars which can be fermented into target chemical products, such as ethanol or lactic acid3.

The potential impact of the application of biorefinery technology to sugar waste is enormous. Sugarcane is widely grown in the tropical regions of the world, primarily as a source of sugar. It is the world's largest crop by production quantity. In 2012, the UN FAO estimates it was cultivated on about 26.0 million hectares, in more than 90 countries, with a worldwide harvest of 1.83 billion tons. Furthermore, as sugarcane rapidly perishes once cut, its cultivation and processing is necessarily regionally based, and hence it is a direct generator of local employment and development.

Alternatively, thermochemical conversion processes can be used in a biorefinery for gasification of biomass feedstocks to produce direct heat, electricity and fuels. Techniques currently emerging from the pilot plant stage include pyrolysis and gasification, whereas bio-oil and bio-chemical applications are mostly still at the R&D stage4.

Biorefinery technology is currently emerging from its demonstration and proving stage, and has the potential for widespread diffusion to dramatically shift the treatment, and realisation of the value, of agricultural waste in both developed and developing countries over the next 5-10 years.

New Approaches to Treating Agricultural Waste – the 10-20 Year Time Horizon

THE UK Report on the Future of Food and Farming states the broad challenges clearly:

"Substantial changes will be required throughout the different elements of the food system and beyond if food security is to be provided for a predicted nine billion people. Action has to occur on all of the following four fronts simultaneously:

- More food must be produced sustainably through the spread and implementation of existing knowledge, technology and best practice, and by investment in new science and innovation and the social infrastructure that

enables food producers to benefit from all of these.
- Demand for the most resource-intensive types of food must be contained.
- Waste in all areas of the food system must be minimised.
- The political and economic governance of the food system must be improved to increase food system productivity and sustainability."[5]

Approaches to reducing waste include:
- Use of modern scientific advances to produce crops that are less susceptible to pests and spoilage;
- The use of ICT (mobile phones in particular) could help improve market information and allow producers to make better decisions about timely supply to markets.
- The development and use of cheap, mass-produced sensor technology that can detect spoilage in certain perishable foods.

A number of opportunities based on nanotechnology have been identified. These include:
- When cotton is processed into fabric or garment, some of the cellulose or the fibres are discarded as waste or used for low-value products such as cotton balls, yarns and cotton batting. With the use of newly-developed solvents and a technique called electrospinning, scientists produce 100 nanometer-diameter fibres that can be used as a fertilizer or pesticide absorbent.
- Nanotechnology can enhance the performance of enzymes used in the conversion of cellulose into ethanol. Scientists are working on nano-engineered enzymes that will allow simple and cost-effective conversion of cellulose from waste plant parts into ethanol.
- Rice husk, a rice-milling by-product can be used as a source of renewable energy. When rice husk is burned into thermal energy or biofuel, a large amount of high-quality nanosilica is produced which can be further utilized in making other materials such as glass and concrete.

Challenges for the Future

In the developing world, the opportunities for reducing agricultural waste in order to provide a more sustainable food supply sufficient to feed all are less likely to be found in the development and application of new agricultural technologies, than in the effective application and adaptation of existing technologies. This suggests the focus of technology development to address this issue should be focused on education, access to appropriate information, and enhanced learning. The greatest advances may well come from information and communication services able to facilitate the pursuit and sharing of learning.

1. UNEP, 'Converting Waste Agricultural Biomass into a Resource (2009), p.6.

2. "It has been estimated that the application of existing knowledge and technology could increase average yields two- to threefold in many parts of Africa, and twofold in the Russian Federation. Similarly, global productivity in aquaculture could, with limited changes to inputs, be raised by around 40%." Foresight. The Future of Food and Farming Executive Summary. The Government Office for Science, London, (2011), p. 16.

3. O'Hara, I. M. et al, Prospects For The Development Of Sugarcane Biorefineries, in In Hogarth, D.M. (Ed.) Proceedings of the 28th International Society of Sugar Cane Technologists Conference, Sao Paulo, Brazil (2013).

4. UNEP, op cit, p. 15.

5. Foresight, op. cit. p. 12.

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Diversified adaptable proteins: meat replacement from plant, insect or single cell

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1. Summary

The expected increase of population to 9 billion in 2050 will parallel an increase of meat consumption. Sustainability pressure will gradually increase the price of the meat (particularly beef and pig) opening new possibility for meat replacer not limited only to vegetarians but also to the expanding categories of "reducetarians", environmental/health conscious people that are willing to reduce the consumption of animal products. A successful introduction on the market of alternative to animal protein food should follow the five principle of the so called SHARP diet – Sustainable – Healthy – Affordable – Reliable – Palatable. In the short term the available alternative are primarily from plant: first of all legumes and cereals. Other possibilities are coming up: fungi based protein food (Quorn), and insect based products are already on the market. Microalgae as well as other single cell biomasses (yeast or in vitro meat) have an extremely interest perspective in the medium term. In 5-10 years the availability of environmental friendly sustainable protein-rich ingredients having well characterized techno-functional and nutritional properties has the potentiality to bring a deep innovation in the field of proteins-rich products and meat replacers. Beside the cultural acceptance, which are particularly relevant for insects, the main barriers for all these protein-rich ingredients are their technological functionality, palatability, and the construction of a production chain leading to affordable price. Last but not least regulatory issues should be tackle to free this enormous potentiality which has been tapped up to now.

2. Case study (2-5 years)

The expected increase of population to 9 billion in 2050 will parallel an increase of meat consumption. In developing countries the possibility to eat more animal proteins is considered a symbol of progress exactly as it was in the EU Western countries during the second half of the 20th century. This is rapidly leading to a not sustainable situation due to the overutilization of natural resources related to cattle breeding.

The food industry is well aware of this perspective and in the last few years the focus on products sustainability increased exponentially. The search of alternative solution for the protein-rich food should follow the five principle of the so called SHARP diet – Sustainable – Healthy – Affordable – Reliable - Palatable. Unfortunately, the possibilities available up to now fail to satisfy one or more of these principles. In the tables below the existing versus future possibilities are listed

Traditional Food	% protein (dry matter)
Meat & fish	67
Eggs	47
Skim Milk	43
Soybean	42
Peanuts	37
Wheat	12
Corn	11
Rice	8

Innovative Food	% protein (dry matter)
Insects	40-75%
Microalgae	25-70%
Yeast	65-70%
Quorn (mycoproteins)	40-50%
In vitro meat	??

From the technological perspective the replacement of animal proteins in formulated foods having many ingredients can be efficiently solved in most of the case using plant proteins (soybean, lentils, lupins, etc..). Using appropriate processing it is possible to obtain formulated foods without dairy or egg proteins having physical and sensory properties that are acceptable by most of the consumers.

On one hand, if we narrow down the view to meat replacement products it is not possible to have the same physical and sensory properties of a T-bone steak using alternative protein source and this will likely remain a dream in the long term future too. On the other, moving to reconstituted meat products (from sausages to all bread-coated meat products) soybean proteins has been efficiently used in the last 20 years to create texturized preparations resembling meat products. The large majority of users is happy with vegetable meat replacers mainly because of the prior cultural decision (vegetarians or vegans) and not because of a sensory preference. However, in developed countries the number of sustainable conscious people is increasing thus boosting the number of those who are willing to reduce the consumption of meat without becoming strictly vegetarians. This people are named "reducetarians", they are usually health and environmental sensitive, and their number is expected to increase in the future. The alternative protein sources for this new consumers' need are again primarily from plant, first of all legumes and cereals. We could foresee a scenario similar to that of the vegetable alternatives to milk, that has got about 10% of the market and is growing fast. Also other alternatives are coming up: fungi-based protein-rich food (Quorn), and insect-based products are now on the market. Insects are marketed primarily as a snacks and this is pretty much the same what happen in the countries (Africa and South-East Asia) where their consumption is traditionally widespread. Microalgae, as well as other single cell biomasses (yeast or in vitro meat), have an extremely interesting future perspective, however at this stage the production capability in very limited, costs are relatively high and therefore their consumption remained confined in a small niche of the market as nutraceuticals or medicinal foods.

3. Extrapolation to other realities (5-10 years)

Sustainability pressure will gradually increase the price of the meat (particularly beef and pig) opening new possibility for meat replacers, not limited also to vegetarians. Protein-rich products, which has become already very trendy in the last two years, will increase their market share to fill the gap and provide the necessary amount of proteins.

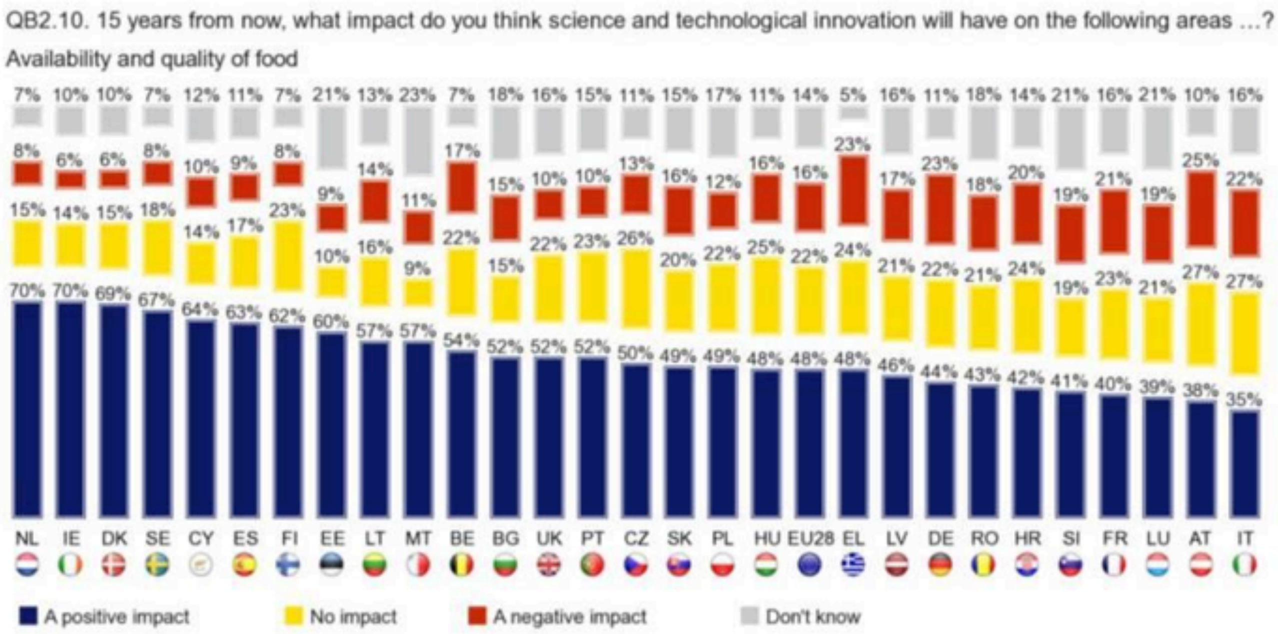
Fractionation technologies, particularly dry fractionation, will increase the availability of convenient protein rich ingredients from sustainable resources such as vegetable biomasses (mainly agro-food by-products), insects and microalgae. The availability of sustainable protein-rich ingredients, having well characterized techno-functional and nutritional properties, has the potentiality to bring a deep innovation in the proteins-rich products. These ingredients can be easily combined and integrated into the different consumption style. According to the target of consumption they can either be used to perfectly mimic the "conventional" products or they can prompt the design of new foods following the new societal needs. The huge variety of insects and microalgae will be exploited, giving the possibility to industries and final consumers to play with many more instruments to tailor their food products and their specific needs.

4. Identification of gaps and obstacles

The very first obstacle to innovation in food is still that a significant part of the population is very conservative and they are in principle against any new development in food sector. Below the result of this 2013 EU survey

So in the long term we should assume that more than people willingness there will be strong external sustainability constrains (such as an increasing of the meat products price) that will somehow force consumers to be more open to the possibility to get proteins from alternative sources.

As far as the insect consumption the main barrier is the instinctive repulsion most of the people have for them as a food. For this reason entomophagy per se will remain also in the future only a niche of occasional consumption. On the other hand, most of the cultural barriers disappear when we move to insect-based ingredients: simply grinding dry insect and using an insect flour where no legs, eyes and antennas are visible, drastically increases



consumer acceptance. Beside the cultural acceptance for all these protein-rich ingredients, one the main barrier is their technological functionality and palatability. There is a huge gap to fill before we can efficiently incorporate insect- or microalgae-based protein-rich ingredients in the existing products obtaining delicious flavour and texture. Moreover the establishment of production chains leading to affordable cost in use for this product is still a big challenge. For example in the microalgae field not that much has been achieved in the last 20 years. On the top of this, regulatory issues should be tackle to free the enormous potentiality of new ingredients which has been tapped up to now. Ideological positions and political reasons often interfered with the scientific process aimed to verify the safety of the ingredients and the release for the authorization of use.

Risk and Benefits of the Application of Sophisticated Materials to the Food Sector

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1. Summary

Controlling bacterial contamination during food processing is critical to managing losses through spoilage and elevation of pathogen-borne health risks, as well as ensuring safe, nutritious and appetizing products. Sophisticated materials – including engineered nanomaterials – potentially offer novel capabilities for controlling bacterial contamination during production, and in particular reducing the formation of harmful biofilms on process surfaces. A number of options have been proposed for the use of sophisticated materials in reducing bacterial contamination during food processing, including utilizing nanoscale silver, zinc oxide and titanium dioxide particles. A particularly intriguing emerging technology that exemplifies the potential of sophisticated materials in this domain is the possible application of hybrid engineered material/liquid interface surfaces (HEMLI surfaces). These materials combine a material that is precisely patterned at the nanoscale and/or microscale with a lubricating liquid, to produce a permanently wet surface that potentially reduces bacterial adherence and inhibits biofilm formation. This case study considers the short and long term prospective development and use of HEMLI surface technologies in food production, together with the potential benefits and risks.

2. Case Study

Bacterial contamination presents substantial challenges within food processing, leading to spoilage, and potentially unsafe food products (Brooks and Flint 2008). While contamination can enter the food chain at multiple points during processing, the growth of biofilms and the subsequent transfer of unwanted bacteria from surfaces that are in intimate contact with food products is particularly problematic. Once established, biofilms are difficult to remove, and increase the likelihood of food spoilage and pathogen contamination, as well as increasing maintenance and quality control costs. The relative health and economic costs associated with biofilm buildup in food processing systems are likely to be greater in developing economies, where regulatory and economic factors may create barriers to costly biofilm inhibition, reduction and removal efforts.

The precise design and engineering of materials down to nanoscale dimensions provides a number of intriguing approaches to reducing biofilm buildup on food contact surfaces within processing systems (Banerjee, Pangule et al. 2011). These include embedding materials that allow the controlled release of bactericides (for instance silver nanoparticles which release Ag^+ ions, or nano-porous substrates containing antibacterial agents such as nisin); the formation of nanostructured surfaces that physically and chemically inhibit biofilm formation; and superhydrophobic surfaces that are designed to repel liquids.

Recent research has led to an additional approach to inhibiting biofilm formation that may have direct application in food processing: lubricant-impregnated microscale and nanoscale-patterened surfaces. Studies have shown that, by creating a regular array of micrometer-dimension pillars on a surface and impregnating the array with an appropriate lubricant, constantly "wet" surfaces can be produced that substantially reduce the surface adhesion of process liquids (Smith, Dhiman et al. 2013). By further patterning the pillars with nanoscale whiskers, surfaces that are highly resistant to liquid retention may be formed (Anand, Paxson et al. 2012).

Such constantly lubricated surfaces present a novel approach to preventing biofilm buildup by potentially reducing bacterial adhesion, and preventing the retention of the nutrients that are required to sustain such a film. These surfaces depend on a combination of precise surface design and engineering from the microscale to the nanoscale, and impregnation with a lubricant that provides an effective physicochemical barrier between the process liquid and the surface. As such, they represent a clear example of an emerging sophisticated material that may find extensive application in the food processing industry.

This concept is currently under development by the US company LiquiGlide™ (LiquiGlide(TM) 2015). While products are not yet commercially available, the company has filed a patent for their surface technology (Smith, Dhiman et al. 2012), and has demonstrated proof of concept in simple food-based applications such as plastic sauce containers, although as yet there is not clear information on biofilm inhibition.

In this case study, it is assumed that a technology similar to LiquiGlide™ will be applied in the food processing industry within the next 2 – 5 years. The technology – based on hybrid engineered material/liquid interface surfaces (HEMLI surfaces) – is assumed to consist of a plastic-based surface coating that is applied to food processing components used to transport and store liquid and high water-content products. The surface of this plausible but hypothetical coating will be patterned with a dense matrix of pillars between 1 – 100 µm in diameter and around 10 µm high. Such surfaces could conceivably be produced inexpensively using high-resolution imprinting from a master template. This matrix will then be impregnated with a food-grade lubricant that coats it to a depth of several tens of nanometers.

While this particular realization of a HEMLI surface is not a nanomaterial, it is a sophisticated hybrid material that exhibits novel properties due to its design and engineering.

If used in developing economies, such a material could confer a number of advantages on food safety and waste reduction during processing – assuming that the production cost is only marginally higher than that for conventional materials. The technology could conceivably improve safety and productivity by reducing the buildup of biofilms and pathogens under conditions where maintaining food safety and reducing spoilage is prohibitively costly and time-intensive. At the same time, it could reduce operating costs as the energy required to transport product through the processing chain is reduced.

3. Extrapolation to other realities

Potentially, HEMLI surfaces could have substantial impacts on food processing over the coming decade. While relatively crude microscale patterned HEMLI surfaces may conceivably pave the way to early adoption in food processing within developing economies, more sophisticated nanoscale patterning may open up new opportunities in developed economies. In addition to surfaces that resist biofilm development, these include the development of increasingly low frictional resistance surfaces that speed production rates, reduce in-process losses, and lower energy overheads. As more sophisticated HEMLI surfaces potentially become available, it is likely that they will become increasingly effective at preventing biofilm development through selectively reducing bacterial adhesion to surfaces. This could lead to substantial strides in reducing the risk of spoilage and pathogens entering the food chain during production and beyond.

As well as improving product safety and quality toward the beginning of the product cycle, there will conceivably be added benefits down the food chain as lower levels of bacterial contamination lead to longer shelf lives. Extending HEMLI surface technology to product containers could extend yet further shelf life for processed food products.

4. Identification of gaps and obstacles

The development of successful HEMLI surface technologies faces technological, economic, health and safety, and societal challenges. These will most likely vary according to the socioeconomic contexts within which they are used.

Technology: Early research on HEMLI surfaces relied on micro-machined silicon surfaces. While these were useful in demonstrating proof of concept, they are impractical for widespread commercial use. Test products developed by the company LiquiGlide™ indicate that more recent (and proprietary) technologies allow direct patterning onto plastic surfaces, and suggest that – with microscale patterning at least – this could be achieved at a reasonable cost-point. As the patent underpinning the technology notes, patterning at the nanoscale is more challenging (Smith, Dhiman et al. 2012). However, with developments in nanoscale imprinting technology, both may conceivably be achievable within the next 2 – 10 years. That said, it is likely that, at least initially, only microscale HEMLI surface technology will be accessible to developed and developing economies

Economics: Food production industries work under narrow profit margins, and so to be economically viable, any new technology needs to perform substantially better at a given price point than existing technologies that perform the same function. Microscale imprinting technologies may conceivably bring the cost of microscale HEMLI surface plastic processing components down to a realistic price in developed economies within the next 2 years. It is less likely that the same will occur in developing economies, unless there is substantial investment in local cost-effective production techniques. One barrier to this is likely to be patent infringement. The economics of nanoscale patterned surfaces are less clear. Unless the technology is shown to lead to substantial increases in productivity, and there are substantive breakthroughs in low-cost nanoscale HEMLI surface manufacture, large-scale adoption of nanoscale HEMLI surfaces is relatively unlikely within the next decade.

Health and Safety: The potential health impacts of the patterned surface, the lubrication fluid, and the combined surface and fluid within HEMLI surfaces, would need to be thoroughly assessed before regulatory approval was given for use – at least in the US and Europe. The complexity of the hybrid product may conceivably result in regulatory path uncertainty, which could slow down the approval process. Research would be needed on the potential for the surface material to enter food and the body – either as dissolved material, or abraded material – and it's potential health impacts once ingested. For instance, what is the probability of micro scale or nanoscale pillars and whiskers from the surface shedding or otherwise detaching from the surface, and entering the food chain? And with the substantially extended surface area of the HEMLI material, is there a health-relevant increase in the dissolution of potentially harmful component chemicals into food products? As HEMLI surface systems will be designed for contact between the lubricant and food, the degree to which the lubricant enters the food, and the level of risk this implied, also needs to be understood.

Societal: There remains some reticence within the food industry to adopt nanotechnologies, due to fears of loss of consumer confidence. It is not clear whether the use of hybrid sophisticated materials such as HEMLI surfaces would raise public concerns. However, for the long-term success of the technology, it would be advisable to explore public opinions on the technology's use, and to calibrate its development and application against consumer expectations.

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