Deliverable 4.1

Report on inventory of R&I breakthroughs

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Content

1 Summary

N.B.: This deliverable builds on the results provided by WP1, WP2, WP3. To avoid duplication not all the concepts already explored within these work packages are included in this deliverable.

The first task of WP4 aimed at identifying potential R&I breakthroughs that could move Food Systems towards Food and Nutrition Security (FNS). In order to do this, we suggest an iterative way, starting by looking at specific examples of past breakthroughs. By analysing those, we were able to identify common factors in them that can be used to validate additional past examples and identify new potential ones for the future.

2 Introduction

WP4 is positioned, together with WP3, at the start of the second phase of the FIT4FOOD 2030 project. During this phase transformation agendas will be developed by identifying showcases in food systems R&I and exploring potential R&I breakthroughs. These activities take place successively within the FIT4FOOD2030 platform.

This deliverable covers the first objective of WP4, which is the identification of potential R&I breakthroughs. Based on the intelligence generated from project partners, a survey among experts in the field (100 participants), literature study, and feedback from external stakeholders, deliverable 4.1 describes:

- the definition of potential R&I breakthroughs, and their link with trends and showcases
- inventory and analysis of past examples of R&I breakthroughs
- discussion on the common factors characterising R&I breakthroughs
- inventory of potential R&I breakthroughs in food systems

This document is therefore intended to serve as the basis for a common understanding within the FIT4FOOD2030 consortium when it comes to potential R&I breakthroughs, but also to stimulate the discussion taking place at the three interconnected structures of the FIT4FOOD2030 platform (City Labs, Policy Labs and the EU Think Tank) and support their roadmap definition.

The process to develop this report started with initial desk research and discussion within the project consortium to define key terms, in close cooperation with WP2 and WP3 to clearly distinguish trends, breakthroughs and showcases. The compilation of an inventory for past R&I breakthroughs was based on desk research and an internal meeting with WP4 partners. Findings from WP2 and WP3 were also used in the identification of potential R&I breakthroughs. Furthermore, the survey conducted in WP3 was used to direct questions on potential R&I breakthroughs to the participants. A preliminary discussion on R&I breakthroughs was also included in the second workshop (12 April 2018).

3 Concept definition and theoretical frameworks

FIT4FOOD2030 has defined R&I breakthroughs as potential, significant achievements that may lead to an increased impact of the current initiatives in the field of FNS and a step towards/radical change of the food system, making it more sustainable and resilient.

R&I breakthroughs are closely interlinked with the trends and showcases explored in WP2 and WP3. Trends are a general tendency or direction of a development or change over time affecting macro-scale social or natural processes[1]. Some examples are climate change, scarcity of natural resources, big data analysis. Trends are therefore the landscape where showcases and breakthroughs emerge.

[1] For more details on the trends identified by the FIT4FOOD2030 project, see Deliverable 2.1

The differentiation between these showcases and breakthroughs is based on their magnitude, scale and interactions in the system.

Showcases are initiatives, key findings, social movements, good practices, networks, (nationally- or internationally-funded) projects, case studies, demonstrations, technological inventions, process procedure improvements (e.g. in logistics/distributions), innovative educational approaches, new business models, etc. which offer opportunities for learning and inspiration (even if they might have ultimately failed to deliver on initial expectations) and have contributed to or affected the food system in some way. Cases of interest can be found in all research fields but also in different areas other than research and innovation[2].

While showcases have already been implemented in the past or currently ongoing, with an impact limited to their area of influence, breakthroughs imply more deep and structural long-term changes, with potential for a big positive impact on FNS. Showcases are backward-looking inspiring examples, with a learning capacity in them. Breakthroughs are potential pathways for system transformation that might imply a dramatic change in the future.

The linkages between trends, showcases and R&I breakthroughs are visualised in the context of the multi-level perspective. This is an analytical framework for understanding complex systems and finds its origin in transition studies, an interdisciplinary field developed by - among others - Geels and Schot (2007), Loorbach and Rotmans (2010) and Grin (2010). The multi-level perspective is a framework for analysing socio-technical transitions and distinguishes three analytical levels: regime, landscape and niche. An overview is presented in Figures 1 and 2.

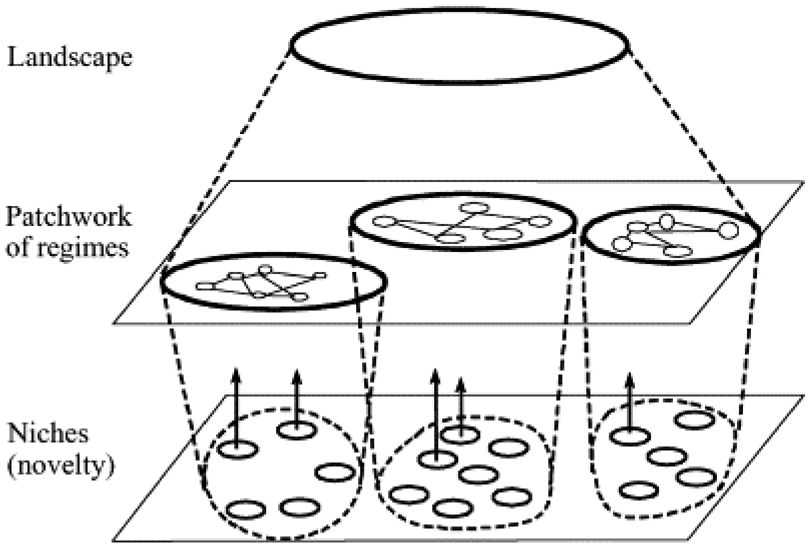

Fig. 1. An overview of the multi-level perspective. Taken from Geels (2002: 1261)

[2] For more details on the showcases identified by the FIT4FOOD2030 project, see Deliverable 3.1

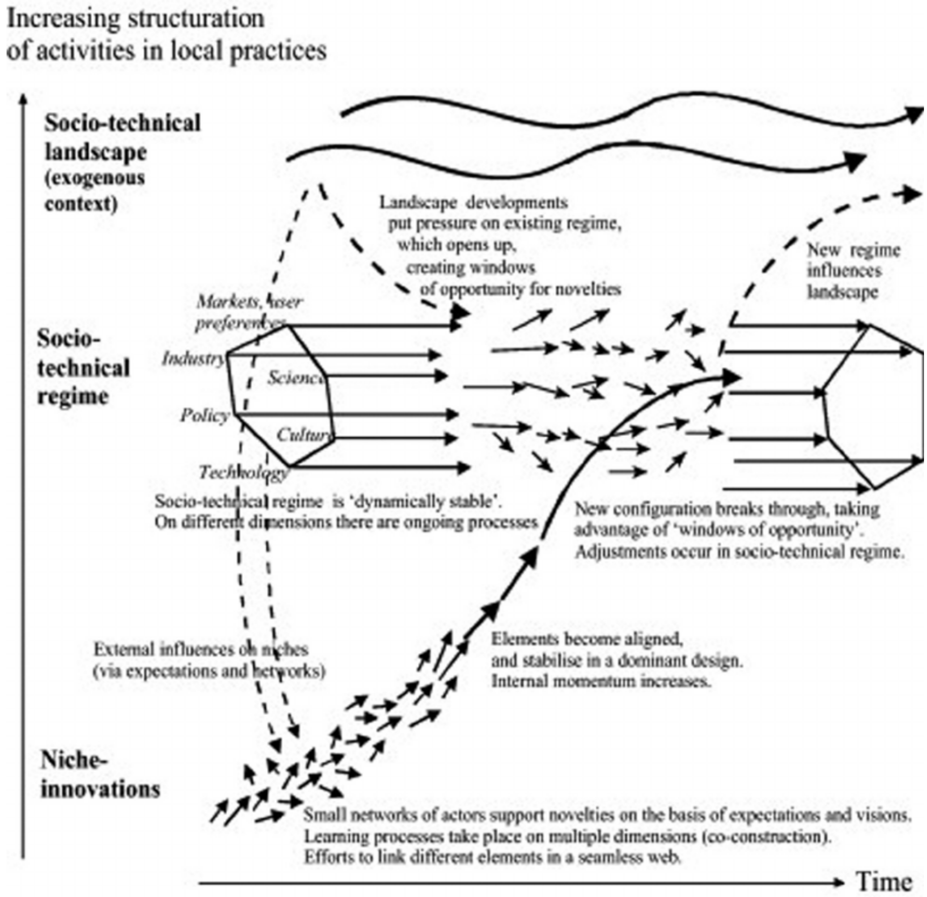

Fig. 2. Taken from Geels (2007)

In this scheme, the regime represents the incumbent/existing system with its norms and rules. It refers to the dominant infrastructures, technologies, actors, (financial) institutions and social practices in the system. Change does occur at the regime level, but it is normally slow and incremental.

Niches, however, are protected spaces characterized by novelty, room for experimentation and radical innovations. Some innovations will eventually gain dominance and change the existing regime while others fail.

The last level is the landscape, representing a broad range of external factors at the social or natural macro-scales; such as global political trends, economic markets, wars or environmental pollution. These trends interact with the regimes and niches. On landscape level, change generally occurs at an even slower rate than at the regime level.

There is therefore a parallelism between the concepts covered by the multi-level framework and the three concepts that are subject to analysis within WP2, WP3 and WP4: trends, showcases and breakthroughs (Fig. 2).

Showcases are small, individual innovations that significantly affect processes or behaviours (through mindset changes) which are directly relevant to the food system and as such have a small impact on at least one food system sector. As such, showcases act within niches (i.e. they are not mainstream).

When several showcases towards a common vision are successfully executed, or the same innovation becomes institutionalised in many local geographical and governance contexts, etc. the potential of a breakthrough (process) increases, which may lead to impact on several systems and institutionalized processes at once (be it in policy, in business or education approaches, etc.). Breakthroughs in a specific field can lead to breakthroughs in a different area of activity. In the multi-level perspective potential breakthroughs act on an existing regime (i.e. the dominant actors, technologies and social structures, as well as mainstream way of doing things and the mainstream mind-set).

Finally, trends provide the landscape in which breakthroughs and showcases happen and can have a positive or negative or neutral influence on a showcase to be successful or a potential breakthrough to happen. They differ over and their influence changes with time. Trends can be difficult to influence.

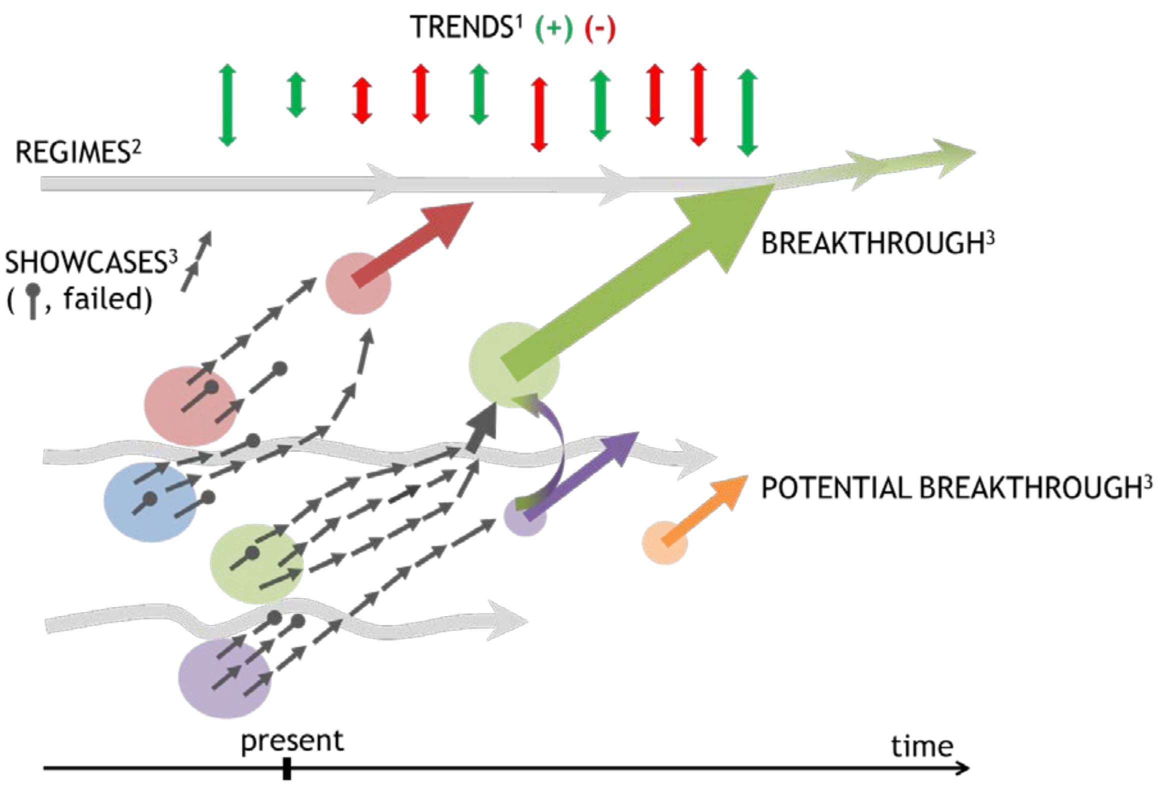

Fig. 3. The multi-level perspective applied to the FIT4FOOD2030 project. Different areas of activity are represented by different colours.

For the purpose of relating all these concepts in a tangible example, Table 1 describes for each concept an example in the case of the development of (semi) closed greenhouses, a particular R&I innovation in the field of agriculture considered to be a sustainable (energy-reducing) alternative to existing greenhouses with combined heat and power installations.

Table 1: Examples of the concepts for the implementation of the (semi) closed greenhouse in the Netherlands. Analysis is based on Elzen B (2008).

Concept	Example
Niche-experiment	• The development of a (semi) closed greenhouse

Showcase	• "The Glasshouse of the Future', a closed greenhouse exhibited at the 2002 Floriade • The research programme: "Glasshouse as an Energy source" • TransForum project: "Synergy"
Regime	• Glasshouses had natural gas fuelled heating installations • It was not allowed for growers to supply energy to the electricity grid.
Landscape trend	• Sustainability trend: The need to reduce CO2 emissions and energy consumption • Climate change
Breakthrough	• On a large scale implementation of the semi-closed greenhouse as replacement of the Greenhouses with natural gas fuelled heating installations • Glasshouse horticulture transformed from a major energy consumer into an energy supplying sector
Barriers	• It was not allowed for small producers to supply energy to the energy grid • High investment costs • Limited knowledge exchange between science (researchers) and practice (horticulturalists)
Drivers	• The 1989 electricity law allowed producers to supply electricity to the grid • Governmental subsidies that lowered the investment costs for horticulturalists • Large national research programmes on the development of an 'Energy producing Greenhouse'

4 Taking stock from the past – what does a breakthrough look like?

4.1 Examples of past breakthroughs

Past breakthroughs have been searched, looking at them from a timeline perspective, from the prehistory up to the present times, considering which factors where relevant and transversal in each case. The final objective of this exercise was to find common points among the different breakthroughs, so there could be outlined a framework in which we could define whether or not, a research, discovery, incremental innovation or casual finding was considered a breakthrough. It could be argued that there are more breakthroughs than the ones mentioned here, however, the aim of this exercise was not to find a compendium of all the breakthroughs of history related to food systems, but to collect clear examples with similar variables that could be extrapolated to possible present and future breakthroughs.

The history behind each breakthrough has been added to **Appendix 6.1** with the aim of avoiding an overload of information of this section. Nevertheless, the discussion below assumes much of that information and develops to discuss the insights on the factors that affected each particular breakthrough with the aim of extracting common factors.

Past breakthroughs are listed below, in a chronological order:

- Discovery of fire and cooking
- Domestication of animals and plants
- Fermentation
- Discovery of America: New raw materials

- Canning
- The supermarket
- Flash-freezing
- Vitamins
- Extrusion
- Microwave heating
- Freeze-drying
- Third agricultural revolution
- Microcredits
- Food e-commerce

The rationale behind the election of the cases is based on having different scenarios with diverse causalities to become a breakthrough. Always from the perspective of observing breakthroughs within the food system we tried to cover cases with these diverse variables:

Different timelines: The concept of time from a historical perspective but also considering the time to achieve a breakthrough, e.g. the discovery of fire with uncertain timelines of discovery ranging thousands of years vs. food e-commerce of just recent implantation in less than 10 years.

Perceived impact: Although impact is part of the definition of a breakthrough, not all the recognised breakthroughs have the same scale, e.g. neolithic revolution is considered to set the grounds of civilisation vs. freeze-drying which has a specific technological impact.

Stage at the value chain: From the agriculture to the consumer, e.g. third agricultural revolution which is at the starting point of food chain vs. supermarket at the contact point with consumers, all along through primary processing (fermentation), secondary processing (extrusion), logistics (e-commerce) to home use (microwave appliances).

Aspects from sociotechnical perspective: The process and impact of a breakthrough related to social changes or to scientific technical aspects, e.g. the discovery of America, which introduced many social, demographical and political scenarios vs. extrusion, which was a pure technical innovation.

Different causalities: The process leading to a breakthrough followed different triggers e.g. canning involved applied research on a specific posed problem, fire cooking was an evolution, microwave heating could be considered as a casual discovery, the supermarket had competitive grounds, extrusion acquired a knowledge transfer, and vitamins were discovered through fundamental research.

Resources: The roots to nurture a breakthrough had different resources e.g. the third agricultural revolution was pushed forward by governmental will, microwaves required private investment from a single company, flash-freezing was the result of the effort of an initial inventor, freeze-drying required multiple companies to develop, vitamins were researched mostly by universities, microcredits required investment from banks, e-commerce was promoted by start-ups.

4.1.1 Discovery of fire and cooking

The discovery of fire can be placed in the period of 1.5 to 0.3 million years ago, and there is no doubt that it changed the history of humanity, even from an evolutionary perspective. The hypothesis that the first human might have evolved in parallel to the discovery of cooking foods to adapt to a cooked diet has greater implications on our understanding of our species. Humans are the only ones adapted to eat cooked food, and **could not go back** to a raw diet without consequences on health (Wrangham R, 2003).

Therefore the discovery of fire and cooking foods provided a larger amount of nutrients available, reduction of toxins and higher food safety. It **changed the evolution of humans**, had **impact on social behaviour**, and was **transversal** to all food products. Considering the uncertainties on finding evidences on how and when humans started to master fire, it is reasonable to conclude that most likely it was an innovation with **clear**

milestones in its evolution. The initial control of fire first, with many different techniques that required years of evolution, and secondly, the different evidences of the use of fire to cook foods (direct fire, heating stones, heated stones under earth, boiling of water…), clearly shows a path of smaller technological breakthroughs of unknown genuine inventors, until the complete mastery of cooking evidenced before the evolution of the agriculture.

4.1.2 Domestication of animals and plants

There is scholarly agreement in many disciplines that the Neolithic revolution is one of the events of greater impact on human history. A clear breakthrough that **settled the grounds of civilization** in a **permanent** and **profound** manner. It happened in **different parts of the globe** at different times and resources but with similar outcomes. Archaeological records also state it as an innovation through many **cycles of developments** and evolution where changes occur in a generational scale. To develop the domestication of animals and plants to the species we know today, **thousands of years** were needed. This a breakthrough still valid today where the new biotechnological instruments allow to accelerate process of genetic selection and opens the possibilities of genetic improvements in much shorter periods of time.

4.1.3 Fermentation

Fermentation is one of the ancient food processes. The use of fermentation has **changed the way we perceive and use food today** and it enriches endlessly the offer that we can have in **many products** such as bread, beer, wine, cider, cured meat, yoghurt, cheese, fermented pickles, cocoa, coffee… Modern biotechnology keeps researching different fermentation processes that make novel products and new processes available even today.

There is no doubt that the use of fermentation by humankind has changed the way we perceive food and food products. It is a **transversal technology**, applied to multiple foodstuffs that had impact in the industrialisation of food as well as in society. The point here, is that there is no single link to a discovery but many. Fermentation is a natural process that existed before even the humankind exploited it, and it has been the **accumulation of discoveries and applications** that lead to the final breakthrough. Therefore, it could be considered an innovation towards time that still continues to develop.

However, and with many exceptions, there seem to be **points in history, milestones** where fermentation processes can be outlined. Little discoveries or advances that could be considered little breakthroughs that sum up to the overall knowledge and create an opportunity and a punctual jump on the scientific path. As it was argued previously, the first considered civilizations in Mesopotamia and Egypt advanced fermentation to the point of creating unit work operations similar to an industrial process. Although fermentation is a natural process, this level of specialisation on processing was new to humankind, and therefore it could be considered a breakthrough. Also, because of the discovery by Louis Pasteur on the link between fermentation and microbial growth, the first steps into biotechnology, and the development of the science of fermentation to the heavy industry that we know today, it could be considered a step forward in humankind history as well.

4.1.4 Discovery of America: New raw materials

The example of America's discovery had a clear **social, cultural, demographical, political, and economic impact** on the world, and particularly in the food sector. It has a clear **transversal and global impact**. But it was **not a scientific discovery or finding**, neither needed research at first. So, should it be considered a breakthrough?

The transfer of food crops and livestock from one place of the world to another is recurrent in history. The Greeks first and then the Romans extended much of the use of olive oil and vineyards all around the world known at the time, the Arab expansion also brought citrus fruits, eggplant, watermelon, or rice into the

European lands, also the trips of Marco Polo to China in the middle ages allowed great exchange of foods and spices in a transcontinental fashion. The discovery of America had the greatest impact because there had not been any kind of contact between both worlds, therefore the exchange of foods was completely new for the Old and the New Word as they were named afterwards, producing a complete clash of cultures.

It is necessary to consider, that the discovery of America was casual in the terms that Christopher Columbus was searching a different route to the known Indian and Chinese markets, and America was a finding in the middle way. If the breakthrough is measured in terms of impact, and we consider the discovery of America as a **casual discovery**, enhanced by the need of new commercial routes (**economically driven**), then it should be stated as a breakthrough. The introduction of new ingredients and foods to our food processes is still a trend, as the recent "superfoods" trend is proving, but the impact should be considered before defining it as a breakthrough. We should be taking into consideration not only the discovery of America itself, but all the following innovations that followed on the introduction of new raw materials into different environments, from an agricultural perspective, but also from a cultural perspective, to adapt the innovative materials into new recipes that changed the New and Old World's way of eating. Measuring the scale of the impact, is perhaps one of the difficult tasks on the agreement of what is a breakthrough, the **permanent** nature of the changes introduced should then have to be taken into consideration.

4.1.5 Canning

Certainly, there are evidences in this case to classify canning as a clear past breakthrough in history. We can locate a specific event and person who initiated **applied research** in a specific topic and time: Nicolas Appert with his publication of 'The Art of Preserving Animal and Vegetable Substances' in 1810. It is a **transversal technology** that covers many different foods categories but also one that **changed society** in the way that food was transformed into a long-standing commodity that could be stored for years, keeping its nutritional values and with reasonably good palatability. It changed the rules of warfare as armies could stand longer without starvation, it changed the availability of non-perishable food to the overall civilian society, it made a huge range of new products available that could be bought in the market and be stored at home to be consumed at any time. Although it is true that the consumers aim for an increase on the consumption of fresh vegetables and fruits as a trend for health, the changing of the market towards new packaging materials, reduction of additives, and even the introduction of organic products in canned foods, all at affordable prices, and combined with the increasing need of ready-to-go products to adapt to a more and more convenient environment, makes canned and bottled foods one of the most preferred references for consumption by consumers nowadays.

4.1.6 The supermarket

There is no doubt that the introduction of the supermarket model has **changed society** greatly in the way that we buy, transport and consume groceries. The breakthrough was **economically driven**, with the accompaniment of social, technological and even behavioural changes. All innovations in the supermarket model had a common aim, get products to consumers in the cheapest and most efficient manner to gain market share. Therefore, it is no surprise to discover that the leaders of this breakthrough have been **large companies** searching for **competitiveness** and large profits.

The drivers for the creation of supermarkets are **interdependent of many incentives**. The increase of urbanisation, the entry of women to the labour market, the increased demand for processed / convenient food, the ownership of refrigerators and freezers, the change from daily shopping to weekly or monthly shopping, the ownership of cars, the technology that allowed the improvements on logistics and inventory management, the globalised distribution of foods, the availability of foods at any time… these were all factors that favoured and still keep driving the tendency for an increasing number of supermarkets. Therefore, it is a breakthrough that depended on many different factors and responded to the evolution of society on technological advances, societal changes, demographical variations and even behavioural responses.

Some of the stages on the evolution of supermarkets could be considered **breakthroughs on its own**: For example, the supermarkets that Michael Cullen developed, were a new concept in logistics, consumer approach and marketing. Another example is the technological invention of scanners, UPC codes, and computerised control of stocks and delivery during the 1980s that led to a new era of supermarkets. Considering that a new age of technologies such as the internet of things and the massive use of data is coming, that there is a need for more efficient globalised logistics, that there are changes on the consumer demands, we could be arguing that we are heading to new possible **potential breakthrough** in the area of retail.

4.1.7 Flash-freezing

Clearly there are some common points with the other cases stated before. Flash-freezing appears to be a **casual discovery** initiated by the insight of Clarence Birdseye[3] on the Inuit fishing practices, but that is just the initial status of the breakthrough. Later on he had to invest an enormous amount of money and time to perform the actual development of the idea into machinery that could prove his hypothesis. He had to convince investors, he had to create a market to sell his higher quality products and compete in an environment where frozen products where not implemented yet. Nevertheless, there were many who saw the potential of his idea and finally the niche market became a complete trend. Following the initial argumentation, there was a breakthrough with a clear person, date and time of the creation of the idea, but needed further **applied research** to finally see the light.

There is no doubt that the results of that research are a technology that has **changed society** and the market as we know it today. There are all kinds of frozen products available, so it is a **transversal** technology that favours the storage of products at home with high quality standards. All homes in the first world have a freezer where frozen food can be stored and prepared at any time with a relatively high-quality standard. In terms of quality and food safety it stands as a growing market, where convenient food has a high asset. The webpage Research and Markets[4] points out that Europe and United States are the regions where major consumption of frozen products take place, but remarks how this market is increasing in developing countries. The major companies that lead the market are Nestlé and Heinz (with 19% marketshare), with other key companies such as General Mills, Maple Leaf Foods or ConAgra Foods in the leading market, according to this reference.

The newer technique of cryogenic freezing using liquid nitrogen could be considered a further development that has changed the freezing industry, bringing even higher quality products and optimising the efficiency of the process. This could be considered a newer breakthrough in itself.

4.1.8 Vitamins

The discovery of vitamins had a clear root on **fundamental research**, as many other discoveries in the area of nutrition. The process at which the breakthrough was accomplished required an enormous effort from different disciplines at a variety of research groups to define **the knowledge required to actually produce the innovation**. Vitamins can be isolated or synthesised and therefore be supplemented or added to foods to provide the nutritional requirements that humans need. An era in which the related diseases seem to be part of history, is something new to human kind. Pellagra, scurvy, rickets, blindness and many other symptoms of malnutrition, well known in the 19th Century, can be declared eradicated in developed countries, and well diagnosed and understood in the worst of cases in developing countries.

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[3] Birdseye: https://www.birdseye.co.uk/

[4] Research and Markets on frozen foods: https://www.researchandmarkets.com/reports/4332753/global-freeze-dried-foods-market-2017-2021#pos-0

There is impact to the area of **human health and nutrition**, contributing to wellness, but also in the way **policy** on fortified foods has been developed in the recent years. Also the knowledge provided, has open doors to **other areas of discovery**, some examples could be the bioavailability of nutrients on digestion, animals as human models, food analysis, synthesis, nutrient functionality, food interactions, etc.

4.1.9 Extrusion

The extrusion process of food is born from the **transfer of knowledge** of other sectors in material science (metal casting but mainly plastic extrusion) where it was widely used. It required knowledge from the engineering part of the use of industrial extruders and knowledge from food materials, so highly specialised technicians were required for the research and development of food extrusion. Companies such as Bühler or Baker Perkins were not initially food companies, but were experts on industrial engineering equipment (Bühler history, Baker Perkins history[5]). There is no doubt that the extrusion has brought new food items to our shelves that we could not have otherwise: Industrial pasta, breakfast cereals, snacks, pet foods, extruded meat or fish, texturised proteins, and ingredients that have further uses. Therefore extrusion is **global and transversal** in the food sector. Many of the advances in food extrusion could be considered as smaller **innovation breakthroughs** of the applications and engineering done in the area, many times coming from plastic extrusion research.

Perhaps, the debate in this breakthrough could be related to impact. It is clear that there is an impact on the food industry as a technology, but the real question in reference to other examples studied is whether there is or there is **not a social impact**. It is likely that most consumers might not know the answer to "what is the extrusion of foods" and "for which food items it is used", but it is true, that there is a **clear indirect impact**. Without extrusion there would not be dry pasta in the market at the low prices that it is offered, we would not have breakfast cereals or snacks as we know them, there would not be pet food available as we know it today. Therefore, we could conclude from this point, that although a breakthrough might not be recognised by the public, the indirect impact on the overall society (knowledgeable or not), should be considered as a breakthrough.

4.1.10 Microwave heating

The discovery of microwaves has many different ingredients in the path of becoming a breakthrough. Firstly, the **technology transfer** of radar technology to use in food applications through a **casual discovery** or bright inspiration of Percy Spencer at Raytheon in the 40s. This initial discovery needed a large investment on **applied research** which was possible by a vision of business of the company Raytheon, whose leaders clearly believed in the use of microwaves as a substitution of other heating methodologies, creating specific research divisions on the technology despite there were many doubting criteria on the success and applications of the technology during the 50s and 60s. Afterwards, even before the prices were affordable for common consumers, there was a **technological competition** by different companies such as Litton, Amana or Sharp to achieve the best home appliance at affordable prices for consumers, this effect speeded up the process of research and development in the 70s and 80s. The final decades have seen an even further development of microwave ovens at much more affordable prices up to the point that most households in the developed world own one and the spread in the developing world is exponential.

The spread of microwave ovens into the homes of citizens and the development of new applications at the industrial processes, makes microwave heating a **transversal and global** breakthrough with a high **social impact** in the way it reduces our cooking time and facilitates the use of convenient food, or even frozen food at home. This breakthrough is not at the end and new trends report new uses on foods (Orsat V, 2017) and

[5] Baker Perkins history: http://www.bphs.net/historyofkeybusinesses/snack/index.htm

even in not food materials (Horikoshi S, 2018), expecting that microwave and other radiofrequency heating processes still will be developed for new industrial applications, having a new era of process innovation.

4.1.11 Freeze-drying

Freeze-drying or lyophilisation is a technology developed through different inventors and researchers and somewhat an application taken from the advances in medical, pharmaceutical and biological studies. There is a **transfer of knowledge** from these fields to foods with a clear application focused on maintaining the most volatile and degradable components of the foods, such as colours and flavours, but also vitamins, flavonoids, carotenoids, fatty acids or Maillard reaction products.

The use of freeze-drying resembles a short history of innovation that needed **developments from different areas** (such as vacuum equipment for example) to find its best use. The **high cost** for its application has limited its use when compared with other widely extended technologies such as in container sterilisation, pasteurisation, or freezing. Therefore, although it is a clear advance in the food technology, there is the question of impact as a breakthrough. There is a clear advantage and penetration of the technology on the products that are launched in the market, lyophilised fruits can be found in breakfast cereals, mueslis, cereal bars, and baby foods or sold in their own, instant coffee of very high quality is produced using freeze-drying, other drinks and soups are also products produced using this technology as well as astronaut foods. It could be argued to which point freeze-drying has changed the way that we behave as consumers, but there is no doubt that like freezing or canning, it is a **transversal technology** that can be used almost in any food category. There is no doubt that freeze-drying has been one of the major advances in food technology of the late 20th Century and therefore it should be considered as a breakthrough.

4.1.12 Third agricultural revolution

The struggle on increasing the yields and the output of agriculture is not new for humankind. Since the beginning of the agricultural activities, there has been a continuous effort to find the best way to increase plant production and have enough food supplies for survival. Nevertheless, there have been specific periods of history where this improvement was significant enough to be considered a revolution. The name "revolution" itself indicates a change that affects society in a **global and transversal manner**, in a way that there is no return. There were some agricultural revolutions in human history. The first revolution happened in the Neolithic with the discovery of agriculture (previously discussed in this document). The Arab agricultural revolution also introduced many reforms on land management and irrigation. The mechanization of agriculture that followed the industrial revolution in the 18th and 19th centuries is classified as the second agricultural revolution. The third agricultural revolution (also called the Green Revolution), had a clear impact on the land management, the plant breeding systems, the implantation of mechanization, the improvements on irrigation, the changes on fertilizer use, etc. It brought a clear **social impact** reducing the poverty in the areas it was implanted and allowing for further increase of the global population in developing and developed countries.

Based on the way that the Third agricultural revolution took place, we could consider it a case of **applied research**, where different stakeholders joined efforts with a common vision of innovation, development and implementation of the research conducted. The investment in money, time and workforce is remarkable. Norman Barloug[6] is considered as the first promoter of the research conducted, but he is not the inventor or the person to credit the innovation to. There is a search and common interest on the results of a win-win situation that benefitted the economics of countries under development enormously, so research was paid to pursue and implement the measures needed to have a clear impact. The innovations facilitated by the

[6] Nobel prize Norman Borlaug biography: https://www.nobelprize.org/prizes/peace/1970/borlaug/biographical/

Third agricultural revolution needed also a great effort for **implementation and development**, a case that is not common with all the breakthroughs that we have discussed.

Different stakeholders from the agricultural area are currently discussing the need of a renewal of the Third agricultural revolution or as some may speak of it, a fourth agricultural revolution. Climate change, pollution increase, deforestation, excessive use of fertilisers, extension of arid zones, and increase in population are major drivers that ask for new advances on agricultural techniques. This will be discussed in section 5.2 on the potential breakthroughs upcoming, with some indicators of **new potential breakthroughs regarding agriculture**: the search of efficient urban farming, the improvements applied to highly controlled hydroponics, short market chains, the search for a less impact on environment, the increase on digital technologies such as the use of satellite data, global connectivity or intelligent use of irrigation, seeding and fertilization on a very focused use of resources, or the search for new uses of waste (circular economy).

4.1.13 Microcredits

Despite Microcredits are considered one of the major breakthroughs in economics of the latest years, it is a difficult example to analyse in terms of impacts. The aim of the microcredit was to empower the poor, to raise women from the obscurity of some developing countries, to make it possible that anyone could be an entrepreneur. It is also relevant in the food system because it is present in **the whole value chain** of food production, from the agricultural input to the final purchase in small businesses, it affects **business models** and pursues **sustainability** within the system. It clearly **affected society**, in the evolvement and improvement of the financial situation of the most deprived parts of the society.

Surely, there was an impact, but perhaps not the highly expected positive result that many expected. Some of the countries where microcredits have been implanted remain some of the poorest of the world, some authors even account for even worse that before microcredits existed (Cons J, 2008). Results are not clear on whether the impacts of microcredits were positive or negative, although many advocate for understanding microfinance as a tool, which remains positive when best used. Great arguments go to the best practices of microcredits, such as the existence of a business model beforehand (with clear goals), third parties controlling and assessing the beneficiaries, or a system that has the capacity to ensure that the money does not go into non-business associated expenses (e.g. a dowry for marriage). These arguments sustain the idea that not every person is a natural entrepreneur, and that the forces of liberal market still push loan beneficiaries into a competitive market (Washington Post: Microcredit isn't dead, 2016)[7].

The causal actors of the microcredit breakthrough are credited to Prof. Yunus and the Grameen bank, although much of the impact and success could be correlated to NGOs and government efforts alike to push forwards the original initiative.

4.1.14 Food e-commerce

In this case, we are analysing a breakthrough that is **happening today**. Therefore, it is a relevant analysis compared with other possible breakthroughs that have been classified still as trends or possible breakthroughs. There is no doubt that the e-commerce is already a breakthrough because we can **measure the impact**. The numbers of Amazon and other profitable enterprises that have made their fortune using e-commerce is enough evidence of the impact that it has had on the retailing world. There is a **social change** in the way that changes the shopping behaviour, linked to an internet era where there is no need to leave one's home, not even to have a time frame space to make a purchase: it can be done anywhere, anytime, even from a smartphone or tablet with internet connection. It is a **global change**, **transversal** to many areas of human life, with a change on the behaviour and expectations of individuals.

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[7] Washington Post: Microcredit isn't dead (2016). https://www.washingtonpost.com/news/in-theory/wp/2016/12/12/microcredit-isnt-dead/?utm_term=.9e7a69cb7abe

There are evidences that the food sector is summing up to this change. Convenient food and fast delivery shopping are already implanted (Just Eat is an example)[8], non-perishable foods are already in the on-line market in many channels, perishable food are offered by retailers in more and more easy-to-use appliances even for smartphones, Amazon started offering groceries in 2017, all an indication that **the breakthrough already happened**. The improvements on delivery systems, speed of service, reduction of margins per service, and the easy-to-use applications for mobile phones, will keep this market growing. Some of the changes that the online commerce of food will bring are tangible and in parallel with the e-commerce already implanted.

The free nature of e-commerce of foods brings also changes on the legislation that applies, the European Commission has launched a report analysing how to counteract against entries of non-permitted foods in the EU area using purchases online. Another report from PwC (PriceWaterhouseCoopers)[9] studies the new legislation applied in China towards Food Safety. Yet another EU report[10] states the challenges that the e-commerce will bring on consumer choice and management of consumer data. Therefore, we can state that food e-commerce is already a breakthrough.

4.2 Common factors

The model of Geels et al. (2007) discussed the differences in trends affecting the landscape, showcases as niche opportunities, and breakthroughs having an impact at regime level. This starting point on the argumentation was relevant as it was required to differentiate the concepts of trends, showcases and breakthroughs, always in the context of the process of research and innovation in the food system but also as guidance for the development of a strategy to ascertain the best arguments for the possible breakthroughs of the future. It is necessary to keep in mind that the major drivers for this exercise were the challenges launched by the UN development goals and the implementation of the Food2030 strategy, which were in turn our guidance addressing the challenges that future breakthroughs should undertake.

Trying to ascertain the odds for future breakthroughs is not an easy task. The objective of this section was to analyse the outcome from past breakthroughs and review if the factors for success were of appliance to a present environment. In this context we understand the environment as the conditions, whether they are social, technological or historical, in which a breakthrough acquires the impact that we have got to know.

Table 2 summarises the discussions taken into consideration regarding past breakthroughs.

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[8] Just Eat: https://www.just-eat.com/

[9] PWC Report: China's New E-commerce Food Safety Measures: https://www.pwccn.com/en/food-supply/publications/china-new-e-commerce-food-safety-measures/cfda-measures-for-e-commerce-food-safety.pdf

[10] EU report: The first EU coordinated control plan on online offered food products. Analysis of the main outcome of the implementation of the Commission Recommendation on a coordinated control plan on the official control of certain foods marketed through the Internet. https://ec.europa.eu/food/sites/food/files/oc_oof_analysis_main_outcome_en.pdf

Table 2: Analysis of factors of past breakthroughs

Breakthrough	Timeline	Impact	Value chain	Sociotechnical	Causality	Resources	Context
Discovery of fire / Cooking foods	Palaeolithic	Changed human evolution adapting physiognomy and physiology to cooked foods. Changed human social behaviour.	Food processing.	Society. Food safety. Health.	Milestones on the evolution of human species.	Unknown. Insightful tribe personalities. Trial and error.	Survival driver. Competitiveness against other species.
Plant/animal breeding	12.000 - 5.000 B.C.	Grounds of settlement of human kind and civilisation.	Agriculture.	Society. Technical. Trade. Health. Economy.	Milestones on the domestication of different animal and plant species.	Unknown. Insightful tribe personalities. Trial and error.	Survival driver. Competitiveness against other tribes.
Fermentation	10.000 B.C. - Today	Changed food availability. Produced new foods and ingredients.	Agriculture and Food processing.	Society. Technical. Trade. Economy.	Milestones on the discoveries of new processes and products.	Unknown. Insightful personalities. Trial and error.	Survival driver. Search for new food sources. Search for shelf-life.
Discovery of America: New raw materials	1492 - Today	Changed food availability. New raw materials, new crops, new livestock. New recipes.	Agriculture and Food processing.	Society. Trade. Economy.	Challenge to discover sea routes. Milestones on successfully introducing new raw materials in different countries.	Driven by the need of new routes to Asia (competitiveness). Christopher Columbus as discoverer of America.	Revolution on new ship technology and sea orientation. Investment on the search of new trade routes. Exchange of plant and animal species during centuries. Further research on adaptation of crops and livestock.
Canning	1810 - Today	Preservation of foods never seen before. Availability of foods.	Food processing.	Society. Technical.	Applied research.	Competitiveness for an economic challenge. Nicolas Appert as inventor. Further public and private investment.	Interest on shelf life of foods from military perspective but also from a humanitarian perspective.
The supermarket	1912 - Today	Availability of foods. Changed lifestyle.	Logistics. Retail. Consumers.	Society. Trade. Economy.	Competitiveness for market share.	Several actors. Private retail sector. Michael Cullen as reference.	Key changes in society: Women empowerment, automobile as affordable transport, change of cities demographical structure, chain production, longer shelf lives of foods, changes on social behaviour towards convenient shopping…
Flash-freezing	1915 - Today	Availability of foods. Changed lifestyle and convenient food concept.	Food processing. Consumers.	Society. Technical.	Applied research.	Insightful idea from Clarence Birdseye. Large investment from industry.	New technologies available to freeze foods. Need for further methods for food preservation.

Breakthrough	Timeline	Impact	Value chain	Sociotechnical	Causality	Resources	Context
Vitamins	19-20th Centuries	Grounds of knowledge for nutrition. Eradication of diseases such as pellagra, scurvy, rickets and xerophtalmia. Pharmaceutical industry and fortification of foods. Policy towards fortified foods	Transversal from agriculture to consumer.	Health. Consumers. Education. Fundamental knowledge. Policy	Fundamental research	Several actors. Universities at first, industry later on. Interdisciplinary.	Against the established knowledge. Concern about diseases not correctly diagnosed.
Extrusion	1930s - Today	New product availability in the market with very long shelf lives.	Food processing. Consumers.	Technical.	Knowledge transfer from extrusion technologies used for metal casting, plastics…	Investment from industries on the application.	The advances on the extrusion technology allowed the transfer into the food application.
Microwave heating	1945 (First patent) - Today	Adaptation at home habits. Lifestyle of consumers. Convenient Foods. Transfer to industrial applications.	Refectories. Restaurants. Consumers.	Society. Consumers. Technical.	Transfer of knowledge from radar technology.	Percy Spencer and Raytheon as trigger. Inversion from a company that believed on the idea's success. Industrial competitiveness.	Revolution on key technologies such as the magnetron. Vision of a company on an application. Interest from U.S. Government on uses for hospitals and military canteens.
Freeze drying	1949 - Today	Availability to new food categories. New method of food preservation with high quality of nutrients and aromas.	Food processing.	Technical.	Transfer of knowledge from medicine.	Earl W. Flosdorf as first to publish on the freeze-drying of foods. Public and private investment.	Key technologies that allowed the advance on the technology: Vacuum, freezing, fast heating.
Third agricultural revolution	1960 - 2000	Selection of new varieties of staple food. Improvement on implementation of crops. Fighting against poverty and hunger in developing countries.	Agriculture	Society. Technical. Policy.	Public investment to solve a global challenge. Fundamental research. Public Investment on implementation.	Investment on Research Centres dedicated to the challenge. Investment on implementation, from local to national. Education. Interdisciplinary and international collaboration. Norman Barlough as reference.	Key challenges to be solved.
Microcredits	1980 - Today	New business model that aimed to end poverty and hunger in third world countries.	Transversal from agriculture to consumer.	Society. Trade.	Fundamental research on business models.	Private investment from banks. Private investment from beneficiaries. Public investment from governments and mainly NGOs.	Key challenges to be solved running business models in third world countries.
Food e-commerce	1995 - Today	Changed trade and logistics. Lifestyle of consumers. Impact on business model channels.	Retailers. Consumers.	Society. Trade.	Start-ups first inversion. Competitiveness for market share.	Private investment from companies.	New technologies available (World Web Wide). Investment on a business model. Policy not established.

The clearest point on breakthrough definition is to have an **impact at the regime level** of knowledge. Regime, as introduced in point 3, is the state of the art established in a system and represents the *status-quo* achieved in a sociotechnical environment with a shared area of knowledge. Examples of this are: the policies and regulations applied, equipment and infrastructures, technical knowledge, the common ground science, the lifestyles of individuals, standardised methodologies, etc. Therefore, a breakthrough changes the regime status into something new that creates a new state of the art, a new paradigm, a new framework of interaction. This is one of the clear statements in a breakthrough (Geels et al, 2007). All the examples presented fit this premise: Fire cooking changed evolution of human kind, Neolithic revolution changed civilization, flash-freezing or extrusion changed the product availability in the market, vitamins changed our perception of nutrition and health, supermarket and e-commerce derived in new lifestyle models. Moreover, the difficulty here is to establish rules to measure the relevant impact. As discussed with extrusion or freeze-drying, relevant impact was detected, but the scale compared with the impact of, for example, the third agricultural revolution, was not equal. Therefore, there is the need to measure the amplitude, the scope, the type of change in the landscape to clarify whether the relevant event becomes a niche showcase with a clear end or the roots of development of a larger breakthrough. This discussion refers also to the point of evolution of the breakthrough. Taking a question such as: Is the e-commerce a breakthrough? Then, evidences of impact are searched. How many users has it? Is it a sustainable change? Will it stay at the regime level? Will it have a further evolution? Will it have impact in other areas of knowledge? Will it change society or lifestyles? Words like transversal, global, already implemented, are key to understand the impact of a breakthrough at the regime level.

The statement of a breakthrough measured in terms of impact is a matter of study. In terms of a project that aims to have a product having an impact in the market, Wheelwrith and Clark, 1993, defined three levels of projects. Breakthrough projects were stated as the ones that required major changes to existing processes and products and often required major invention. The other two levels were the platform projects, in which a family of new products is created, and the derivative projects, in which there is an incremental change resulting in cost reduction or the addition of an extra feature to a previous invention. The latest level is the one that we could identify with the concept of incremental innovation, very often used as an antagonist of a breakthrough. However, we have observed that certain amount of lesser innovations, perhaps considered niche accomplishments, become milestones of an overall breakthrough when observed with time.

One of the main common points of R&I breakthroughs is that they are all recognised through time. There was no way back, they were not forgotten, they stayed in our regime level, they became mainstream. Moreover, evolution might trigger new changes on the same breakthrough, but the change itself remains. That is common to all examples: The "*frites*" and chocolate of Belgium come from the exchange with America, they were foods that will remain in our culture. Cooking, domestication of plants and animals, fermentation, etc. are part of our past, and a world without these breakthroughs is unthinkable of. Changes such as microwaves, freeze-drying, freezing and extruding keep evolving in new processes and products into the market. Microcredits changed the way we see business models, the supermarket is part of our history of retail, and e-commerce is making a new history on consumer interaction. Breakthroughs are **sustainable over time**.

Another common feature of breakthroughs is that the impact would not stay in a single niche area of knowledge, a breakthrough would have a **transversal impact on different areas**. They usually affect more than one single aspect of the regime, creating a cascade of changes that overall amplify the impact. One example is the invention of microwaves and the number of applications it has in foods, covering almost all the spectra of food materials that can be warmed up using this heating method. Nonetheless, there could be controversy on how transversal is considered. Is a change applied in a specific food sector a breakthrough? How is it measured? An example could be the invention of industrial continuous processes for the formation of pastries such as croissants or "pain ou chocolat", this technology, which allows the production of many of the products that we can find on the market at affordable prices, is very exclusive of this type of products. The impact of the innovation, although advanced in the industrial processes of bakery, would not be qualified as a breakthrough. The quantification of how transversal a breakthrough might be is a difficult task, but it could be reasoned that the higher the impact at different sectors of knowledge, the greater the impact of a breakthrough.

A parameter that also arises from the analysis of past cases is the continuity of the innovation even after we consider the breakthrough has happened. There is a continuous evolution in the history of breakthroughs, where further research and innovation is applied, in some cases even bringing new breakthroughs. One example is the concept of agricultural revolutions. As it was discussed, there are key points of history where the agriculture faces a relevant development: First, the domestication of some plant varieties in the Neolithic revolution, second, the advances of the Industrial revolution, third, the innovation into plant breeding and agricultural techniques of the Third agricultural revolution. The advances in smart farming and biotechnology could be the fourth agricultural revolution if implemented appropriately worldwide. This is a powerful idea when reviewing the trends in which different areas of knowledge might have the **continuous potential** to launch new breakthroughs from existing ones.

Breakthroughs, as discussed on the Geels model, require niche innovations and trends that provide the **appropriate context** for the step forward. No R&I breakthrough, is accomplished without having the right ingredients to start with, most of the new ideas are born from other ideas. The funnel tunnel model on innovation (He X, 2008), also states the need of many creative ideas that follow a funnel flux towards a final concept: Not all the ideas reach a final concept, many ideas die in the process. The grounds in which all these ideas are nurtured, many times require creativity and capacity of doing, in both cases the knowledge available to the person/s working in the innovation gives the capacity of the insight. Reviewing the past examples: the invention of the microwaves required the radar, the breakthrough on freeze-drying needed the vacuum pump and freezing technology to move forwards, the discovery of America needed cartography and new available ships and advanced sea orientation to achieve success, vitamins required advances on chemistry for its isolation and synthesis, microcredits required all the theories developed for business models, e-commerce would not be a reality without the World Wide Web, and so on. Therefore, for an R&I breakthrough to take place, there should be a process in which the context provides the appropriate resources.

Another way of looking at the context of a breakthrough could be taken from the point of the observer. The question here is: Is the society, consumer, policy or research context ready for the research or innovation proposed? In many cases, the breakthrough might have happened, the greatest of the ideas have been developed, the ground for a new generation of sound science has been laid, but the receivers, the users, the buyers of the invention, are not ready to accept it. An example of this point, could be the launch in the 80s of the Videotex system by Michael Aldrich, who proposed the first commercial system using a TV device, he did not achieve the breakthrough that the e-commerce would become, and it was just too early for having a massive mainstream use from consumers to use the technology with that purpose.

One of the variable factors found reviewing former breakthroughs has been **the time dedicated to achieve a breakthrough**. Whilst the domestication of plant and animal varieties took an evolutionary stage ranging from 1,000 to 5,000 years, the breeding technology applied on the Third agricultural revolution just took some years of research. Another example, the development of traditional ways of cooking foods (roasting, charring, boiling, stone-cooking…) took thousands of years to develop, the invention of in-container sterilisation settled in decades, the invention of freezing, extrusion, microwaves and freeze-drying took some years for a suitable development. However, as it can be perceived by the examples provided, although an R&I breakthrough seems to arise when there is a specific pressure for an evolution on the established knowledge, the rate at which humanity requires to overcome new challenges is increasing. Therefore, the actual need of our society is to rise R&I breakthroughs faster than ever. At the actual time, if we take the UN Development Goals (SDG) as challenges, acceleration of research and innovation is required to adapt to these existential frame, and therefore science, technology, and education have to align into new R&I breakthroughs that can generate value for all stakeholders, including consumers, society and environment.

The factors related on how to speed up R&I breakthrough processes has been under study in the recent decades, with increasing interest from companies. Firms and private investors are the stakeholders that usually have the challenge to contextualise the innovation. Dreyer et al. (2017) make a distinction between research and innovation, they argue that research, that often is conducted by universities and research centres, puts an investment in place to obtain knowledge; whilst innovation, usually conducted by companies and enterprises, uses that knowledge to create value. The process for a breakthrough in the actual framework requires of both processes to achieve success, and both requires investment. The **investment** could be monetary, but could also be **time, resources, or enabling technologies**. Taking into consideration the cases from the past; the quantity of investment was not directly linked to breakthroughs. Some ideas such as the technical R&I breakthroughs flash-freezing or microwaves required huge investments to achieve impact, but others such as the Third agricultural revolution or microcredits required higher governance or political will. Moreover, when implementing a research and innovation process, usually the resources required for development of a product or an idea (e.g. Implementation) to a relevant scale, required about ten times more than the generation of a prototype or pilot trial (Dreyer 2017). The investment, taken from a 'learning from the past' perspective, has been linked to the risk management related to a research and innovation process, therefore there is a continuous search for minimising these risks whilst optimising the investment. Unfortunately, often the results of the investment are not seen until the end of the process, so there is no guarantee of a breakthrough despite the quantities invested in the R&I process.

The reviewed cases have shown different outcomes and **paths to achieve an R&I breakthrough**. In some cases we observed a casual discovery, in others an applied research, in some there was a transfer of knowledge, in others a brilliant insight, some had a great competitiveness, and in other cases there were a certain amount of milestones through an innovation necessary to achieve an overall impact. For example, the R&I breakthrough of fermentation required several steps to achieve an overall knowledge and impact, the application of sterilisation conducted by Nicholas Appert used an applied research, the invention of extrusion or freeze-drying was a knowledge transfer from other areas of research, the supermarket was a fierce competitive approach to market share, freezing and microwave cooking were brilliant insights followed by a faithful investment. Therefore, it could be argued that although some processes favour innovations that will lead to a breakthrough, there is no unique pathway. But historical pathways could be misleading on the actual frame and challenges that we face and the tools that are at the disposal for an R&I breakthrough. Colombo et al (2017) suggested insights referring to the organisation of R&I breakthroughs into companies taking into account factors such as workforce diversity, human resource practices, professional practices, resource management, open innovation strategies, organisational identity and alliance networks.

Recent studies highlight some practices that produce potential for an R&I breakthrough. For example Kamuriwo et al, 2017, studied the relevance of having external collaborative partners in an open innovation model to have a better outcome (compared with internal knowledge from a single company or institution). Also Dong et al, 2017, stressed the relevance of **alliance networks** to create consistent breakthrough innovation. Li et al., 2017, showed evidence on the management of uncertainty taking into account resource **structuring and strategic flexibility** within a company to optimise the output on breakthrough innovation. In this sense, Dreyer et al., 2017, linked the success of breakthrough innovations to concepts such as **Creating Shared Value (CSV) and Corporate Social Responsibility (CSR)** as relevant enablers for an innovative community of collaboration, including them in the concept of **Responsible Innovation**. Much attention is also oriented towards the concept of **Open Innovation** as a way to outsource creative thinking out of a company, joining forces with entrepreneurs and start-ups to overcome challenges in an oriented way from a flexible thinking environment (Stanko MA, 2017).

Single individuals are possibly one of the main keys for an R&I breakthrough, we have cases in history of key personalities such as Nicholas Appert (canning), Michael Cullen (Supermarket), Clarence Birdseye (flash-freezing), Percy Spencer (Microwaves), Earl W. Flosdorf (Freeze-drying), Norman Barloug (Third agricultural revolution), or Jeff Bezos (e-commerce). However, many of these breakthroughs required **many other ingredients such as competitiveness, technological advances, investment from stakeholders, and knowledge**, to allow this inventor's ideas to achieve success. Most of the times, R&I breakthroughs required the efforts of many individuals and other factors to realize impact. R&I breakthroughs such as the evolution of fire cooking, fermentation, or extrusion were the result of a number of advances and events that sum up to final impact. Therefore, we cannot conclude that individuals themselves are common grounds for a breakthrough, but **capacities and competences** of certain individuals can help to prepare and inspire a generation of genuine innovators. Muhammadi et al, 2017, in a study on ethnic and educational backgrounds showed evidence that individuals with diverse backgrounds and different disciplinary education facilitate working team abilities to make better use of the information and complement a team towards radical innovation. Aagaard A et al, 2017, also showed in a study cantered in Front End Innovation how specific human resources practices, such as training innovation teams, measuring innovation performance of individuals or creating ad-hoc innovation talents can speed up disruptive thinking. Also Radaelli et al, 2017, provide insight on how the structure of institutions (e.g. hospitals) can provide radical innovation thinking by having the right measures in terms of management of executives, medium managers and professionals, optimising the output towards practices that favours innovative thinking. Perra et al., 2017, takes a step further and discusses the relevance of introducing the concept of innovation identity within companies and corporations to create the different mind-set for the development of innovation. The individual factor on **human resources** would be critical towards a breakthrough innovation and education and institutions clearly have a greater impact in this point.

Following the discussion, we could come with the following relevant factors:

- Impact on regime
- Sustainable in time
- Transversal
- Continuous potential
- Appropriate context
- Timeline
- Path of innovation
- Investment
- Human resources

5 Identification of potential R&I breakthroughs

5.1 Results of the survey

The survey was conducted on 100 respondents coming from the areas of education and research (47%), business (21%), policy making of governmental organisations (17%), non-governmental organizations or civil society organisations (10%), funding agencies (2%), and others that would not fit in these categories (3%). Overall, 83% of the participants answered the question related to examples of future R&I breakthroughs, but they were given the opportunity to give at least 3 suggestions, therefore a total of 106 different proposals were obtained.

The answers were of varying size, scope and opinion, therefore, not all of the 106 inputs have been included, but a list of the main ideas was summarized and is provided below:

Breeding - New techniques
Several entries in the survey related to new techniques of animal and plant breeding, although most of the inputs referred specifically to plant breeding. Either by generating new varieties of plants by crosslinking species (e.g. Tritordeum), or by introducing new genetic methodologies. Many of the ideas behind the introduction of new varieties of plants were oriented to: increase of drought resistance, “less water” resistance, more resilient varieties, pest resistant or less fertilisers’ dependency. Some applications went further, suggesting varieties with increased photosynthesis, or plant seeds or leaves with a modified coating to provide higher resistance to drier climates.

Smart farming
The concept of smart farming includes many agricultural developments, from the increase in productivity and efficiency using precise farming on seeding, irrigation, fertilising and harvesting, to have a better use of land and growth data for the design and planning of the cropping. Many of the inputs referred to a more

efficient use of data to have a better forecast, increase field output, better use of resources, use of easy-to-use Apps with a precise application, free access to a web-net database, the use of mechatronics into the agricultural field, or the use artificial intelligence in decision making. The application of new ICT technologies into the agricultural environment could provide higher quality, ensured food safety, better traceability, improved productivity, higher efficiency, less fraud, lower costs and more benefits to a new era of higher sustainability of the agricultural ecosystem.

New agriculture

Some entries in the survey referred to new ways of tackling agriculture. Here there were a miscellanea of ideas which have been included in this group, which did not mention breeding or smart farming for a better agricultural model, most of them tackled the implementation of new models of agricultural management. Some of these were: the use of hydroponics as the total control of plant growth and development in green houses under controlled environment (concept of vertical farming or hydroponic towers), the higher intelligence on crop rotation to enrich soil nutrients (e.g. use of legumes on cereal intercropping), the use of agroecology principles to local farming, permaculture principles further applied, or the reduction of synthetic pesticides and fertilisers using a new family of compounds, e.g. use of bioactive compounds for soil regeneration or the use of microorganisms with a natural pesticide action (BCA) for an Integrated Pest Management (IPM).

In terms of agricultural policies some advocated to continue with the Partnership for Research and Innovation in the Mediterranean Area (PRIMA) or to include Africa in policies such as mobile grain storage for unsecure farming output (Paepard project).

Trade – New systems

Still in line with primary production, some inputs in the survey suggested new policies and management of the agricultural system towards a new food revolution on the supply chain and use of resources for a more sustainable trade from the first producer to the final consumer. Thus, taking into account the margins gained on the process by middle-men and a more balanced equity on the costs of production.

Empowered consumers

The use of living labs, social sciences, but also the advances on technologies of communication allows for a new framework of consumer empowerment into the food value chain. Consumers, from the point of view of society, can be part of the Research and Innovation inputs into the food system. There is a space for innovative ways to empower consumers in a supply driven food chain.

Blockchain

The proposal with the highest number of suggestions from individual opinions was the application of blockchain (6 out of 106), thus it has been included as a concept of its own. Blockchain could allow a quick tracing of food products to their source for enhanced food authenticity, therefore increasing transparency and trust in the food value chain.

Change on dietary habits

From the area of health and nutrition several inputs were entered as possible future R&I breakthroughs: An increased research and implementation of nutraceuticals, the advent of multi-omics in a combination of metabolomics and metagenomics, plant-based substitution for animal products, improvements on the reduction of nutritional "unhealthy" ingredients such as sugar and salt, or sustainable resource of omega-3 as feed for fish.

Biotechnology

Several entries were related to the advent of a new biotechnological era. The further exploitation of microbiota/microbiome knowledge can impact the way that food is produced and the nutrients that it provides. The development of biotechnological tools on the knowledge of genome and its sequencing, opens the possibility of new applications and implementations. Some examples were the conversion of biomass and residues into a new range of new sub-products and ingredients, the use of actual biorefineries to separate protein and energy into protein usable for humans, or the use of microalgae to produce nutraceutical components without impacting food agriculture.

The future ICT

The use of Information and Communications Technology is implicit in other entries of the survey such as the Smart Farming or the use of consumer data. Nevertheless, it has been included as a separate entry because the examples given provide a wide range of implementation that also should be taken into consideration. Some other insights referred in general to the use of Big Data in industrial applications (e.g. traceability or processing) but also in consumer data gathering, the increase of sensors and data gathering appliances in the food sector and industry, the digitalisation of industrial processes but also of control, supply chain and delivery systems using digitalisation and the Internet of Things (IoT), or the wider use of robotics for an agro-food mechatronic era.

New industrial processes

New potential breakthroughs should also arise in food processing and the way food is manufactured. Some examples were given on the use of high pressure and osmosis preservation, the use of low-oxygen mild processing techniques, low input technologies, new heating technologies, new sterilising processes with no heat, novel, greener and more efficient food processing technologies, or the application of robotics, including also the overall application of new ICT technologies such as Big Data, Internet of Things or Integrated use of data between sensors and production input and output.

Several entries suggested nanotechnology as a potential breakthrough in itself. The use of nano-material is arising in many cases and implementations and the future for food is promising, as soon as policy might allow further applications on or in food.

Packaging – New perspectives

The incoming challenges are claiming for new packaging solutions, the survey provided some insights on possible future evolutions from the materials and packaging technologies. Some of the proposals were the use of plastic substitutes from almond shelves or other waste streams, the introduction of sensors on packaging that can detect the real self-life of a product, new packaging materials that can be biodegradable at cost effective prices, improving the waste streams for plastic recycling, or the reduction of packaging materials from food packages.

New ingredients

The exploration of new food sources appeared also in the survey. Some of the ideas were the exploitation of algae or insects in a wider range of applications, the use of new sources of proteins, the increased use of legumes in new implementations, the use of "cultured meat" (i.e. meat produced not using animals), substitution ingredients for animal products, or the use of microbiota (biotechnology) to obtain new sources of nutrients.

New aquaculture

There is space for improvement from the aquaculture farms, to find new sustainable feeds and to improve growth while investigating food safety aspect. The H2020 project from FP6, Aquamax, was mentioned to remind this area of research and innovation.

Developments in Food Analysis

The area of food analysis is under continuous improvement. Some possible breakthroughs were taken from the genome-based technologies for detecting and monitoring quality/safety/authenticity of foods, or the policy regulation and analysis of allergen thresholds to improve efficiency and common understanding between industry, research and consumers.

Circular economy
The use of residue or waste is recurrent on circular economy and still a global breakthrough is waiting to take place. Some of the inputs into the survey was the reminder of the H2020 project REFRESH EU; a "funded project on food waste halving per capita food waste at the retail and consumer level and reducing food losses along production and supply chains, reducing waste management costs, and maximizing the value from un-avoidable food waste and packaging materials". A more specific idea was suggested on the use of edible insects based on the consumption of non-used by products from the food industry.

Bioeconomy
The survey also had some entries on the area of bioeconomy. A higher controlled-environment production systems for the efficient use of water, nutrients and land. Also, a robust production eco-system based on biodiversity and resilience. To achieve these R&I breakthroughs, some examples were given, such as the use of algae biomass to produce renewable energy, or the H2020 project ReProtect: "Development of a Novel Approach in Hazard and Risk Assessment for Reproductive Toxicity by a Combination and Application of In Vitro, Tissue and Sensor Technologies".

New Policies and Management
Some possible R&I breakthroughs were stated in terms of new policies or management proposals. Some inputs on management suggested an increased efficiency on translating project results to factual implementation, a higher cooperation between funded projects and the private sector for technical transfer, a higher involvement of public-private initiatives, and higher networking between the ongoing European funding schemes such as EIT-Food, JPIs and H2020 projects. In terms of policy, some argue for a higher policy implementation on measuring the impact of scientific output to innovation.
From a different policy perspective, some had foreseen a better regional labelling implementation, sectorial responsibilities on decision making for implementation on regional food systems, and a multi-scalar, multi-level policy approach to enable higher innovation output.

New inputs in education
Some inputs of the survey focused potential R&I breakthroughs on education. Addressing the way that the society is educated in food systems and a global awareness of the SDGs and its relation to the research and innovation output, education should also be considered and used to boost the future framework of new ways of thinking.

5.2 Potential R&I breakthroughs

The aim of the overall task was to obtain a coherent inventory of potential R&I breakthroughs. To achieve this goal the following inputs have been taken into account:

- Food2030 agenda.
- Considerations from past cases and drivers of breakthroughs in WP4.
- Survey FIT4Food2030 on future possible breakthroughs.
- Trends from WP2.
- Show cases from WP3.
- Literature review of key documents.
- Other suggestions by experts from industry, research institutions, organisations…

The inventory has been constructed in a dynamic table (table 3). This table is divided in four major domains with areas of R&I breakthroughs and a list of specific topics that could be related to the breakthrough, then a text explaining briefly the area of impact of the breakthrough, and information referring to which areas of the Food2030 agenda are best represented, which trends identified in WP2 the breakthrough could have impact, and which cases identified in WP3 could be evidences of the niche activities taking place. For the last two references in WP2 and WP3, we refer to deliverables 2.1 and 3.1 of the Fit4Food2030 for detailed explanation. Due to the confidentiality of the names of the companies, projects and organisations involved in the study of the cases, only the number of the case related to the breakthrough topics has been included, the Deliverable 3.1 of the Fit4Food2030 project contains the full list of the cases under study and the link to the numbers of reference. Also, at the time of submission, only 75 references have been included, further versions are expected to have at least 150 cases aligned.

It is not the intention of this document to explain all the topics proposed. References have been added to better understand the content of the list of topics after the table summary.

The main domains and breakthroughs have been summarised in the following information below to facilitate the search:

The **new approach of primary food production and distribution**

- Breeding - New Techniques and applications
- Smart farming
- Non-conventional production systems
- Reduction of impact of production
- New value systems
- New aquaculture

An **engaged and healthy consumer**

- Empowered consumer
- Change of dietary habits
- New tools to improve nutrition and health
- New methods in education

The **tools of a future proof food system**

- Logistics - New systems
- Smart traceability in the food supply chain
- A novel approach to biotechnology
- Information and Communication Technologies (ICT) applied to Food System
- Food Industry 4.0 - Novel and efficient food processing
- Sustainable packaging
- Diversity on the diet
- The global food analysis

A **sustainable and dynamic value-based food system**

- Circularity in food systems
- Efficient use of resources
- Food for society
- Policy and management within the food system

The following Table 3 shows the inventory of possible R&I breakthroughs:

Table 3: Inventory of possible R&I breakthroughs

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
The new approach of primary food production and distribution	Breeding - New Techniques and applications	- New varieties of animal and plants. - New genetic methodologies and new applications.	Plants: Increase of drought resistance, "less water" resistance, more resilient varieties, pest resistant or less fertilisers' dependency. Some further suggestions: Varieties with increased photosynthesis, plant seeds or leaves with a modified coating to provide them higher resistance to drier climates.	CLIMATE, NUTRITION	- Climate change. - Malnutrition. - Scarcity of natural resources. - Agricultural pollution. - Biodiversity loss. - Transboundary pests and diseases. - Genome engineering. - Bio-fortification.	- 010 - 036 - 061 - 072 - 073
	Smart farming	- Precision farming: Use of local data (e.g. Apps, terrain data, irrigation data, foliar growth). - Use of global data (e.g. Web platforms, forecasts). - Applied mechatronics. - Artificial intelligence applied.	Higher quality, ensured food safety, better traceability, improved productivity, higher efficiency, less fraud, lower costs and more benefits to a new era of higher sustainability of the agricultural ecosystem	CLIMATE, CIRCULARITY	- Climate change. - Malnutrition. - Demographic change. - Scarcity of natural resources. - New and Game-Changing Digital Technologies in Agriculture. - Changes in farm structures. - Agricultural pollution.	- 021 - 022 - 027 - 026 - 033 - 060 - 064 - 066 - 069 - 071
	Non-conventional production systems	- Hydroponics. - Vertical agriculture. - Intelligent cropping. - Agroecology. - Permaculture. - Organic awareness - Urban farming. - Biodiversity	Higher quality of crops, better use of resources and land, less "intensive" agriculture, use of waste streams, higher sustainability of the agricultural ecosystem.	CLIMATE, NUTRITION, CIRCULARITY	- Climate change. - Malnutrition. - Demographic change. - Scarcity of natural resources. - New and Game-Changing Digital Technologies in Agriculture. - Changes in farm structures. - Agricultural pollution. - Organic farming. - Indoor cultivation systems. - Urban agriculture / Urban farming. - Permaculture.	- 003 - 006 - 008 - 009 - 011 - 015 - 018 - 025 - 027 - 030 - 034 - 039 - 047 - 051 - 055 - 056 - 057 - 064 - 067 - 076

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
	Reduction of impact of production enhances	- New approaches to fertilizers. - New approaches to pesticides. - New approaches to animal antibiotics.	Better footprint of production, better use of natural resources, less environmental impact.	INNOVATION, CLIMATE	- Climate change. - Malnutrition. - Scarcity of natural resources. - Agricultural pollution. - Biodiversity loss. - Transboundary pests and diseases. - Alternatives to conventional pesticides. - Changes in farm structures.	- 027 - 030 - 034
	New value systems	- Business model for the primary sector. - Short value chains. - New models on developing countries (Microcredits, Crowd funding). - Social innovation relating to food production and distribution, Food coops, social markets etc.	New policies and management of the agricultural system towards a new food revolution on the supply chain and use of resources for a more sustainable trade from the first producer to the final consumer. Thus taking into account the margins gained on the process by middle-men and a more balanced equity on the costs of production.	CLIMATE, CIRCULARITY, INNOVATION	- Demographic change. - Migration. - Economic globalisation. - Changes in farm structures. - Responsible consumers. - Concentration in Food Retail Markets. - Short food supply chains. - Chain clustering along the food supply chain.	- 003 - 005 - 011 - 023 - 048 - 049
	New aquaculture	- Advanced fish farms. - New feeds. - New on sea production with lower impact on nature.	There is potential for a better exploitation of our seafood resources, from the feeding system to food safety and authenticity.	CLIMATE, CIRCULARITY	- Climate change. - Scarcity of natural resources. - Food from the sea. - Closing the loop in aquaculture. - Food waste recovery up-cycling / waste cooking.	- 015 - 017 - 027 - 028 - 047 - 055 - 061

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
An engaged and healthy consumer	Empowered consumer	- Innovation in social sciences. - Living labs. - Optimised use of big databases. - Informed consumer. - Active and engaged consumer - Cocreation - Due diligence - Value based food system - Domotics (technologies at home for preparation, storing, menu selection, etc.)	Consumers from the point of view of society, can be part of the Research and Innovation inputs into the food system. There is a space for innovative ways to empower consumers in a supply driven food chain.	INNOVATION, NUTRITION	- Big data analysis. - Economic globalisation. - Health and food consciousness. - Responsible consumers. - Destabilised consumer trust. - Fast and convenient food. - Changing households and food. - Consumer engagement. - Social media and food. - New shopping behaviour. - Physical internet. - Responsible research and innovation.	- 023 - 059 - 065
	Change of dietary habits	- Awareness of healthy habits - Reduction of targeted ingredients (salt, sugar, trans saturated fats) - Reduction of targeted additives (clean label)	A healthier population with all the consequences this enables: Less communicable diseases, healthier growth and ageing of individuals, a sustainable lifestyle...	NUTRITION	- Rise of non-communicable diseases. - Demographic changes. - Biofortification. - High/Ultra processed foods. - Clean eating / transparent labels. - Novel foods. - Natural preservatives and milder processing methods. - Alternative protein sources. - Functional foods including pro&prebiotics. - Health and food consciousness. - Responsible consumers. - Special diets like vegetarian, vegan or low carb. - Destabilised consumer trust. - Fast and convenient food. - Low prices, high calories. - "Free-from" products. - Smart personalised foods. - Globalisation of diets. - Consumer engagement. - Traditions and Do It Yourself. - Social media and food. - Food regulation.	- 024 - 040 - 043 - 044 - 045 - 050 - 052 - 062 - 063 - 075 - 077 - 078

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
	New tools to improve nutrition and health	- Personalised nutrition. - Multi-Omics. - Nutraceuticals - Functional foods. - Human genome knowledge and application.	Further knowledge on human health and the tools available to measure and to influence an adequate nutrition and healthy habits.	NUTRITION	- Rise of non-communicable diseases. - Demographic changes. - Biofortification. - High/Ultra processed foods. - Clean eating / transparent labels. - Novel foods. - Functional foods including pro&prebiotics. - Health and food consciousness. - Responsible consumers. - Special diets like vegetarian, vegan or low carb. - Fast and convenient food. - Smart personalised foods. - Globalisation of diets. - Consumer engagement. - Traditions and Do It Yourself. - Social media and food. - Food regulation.	- 036 - 044 - 046 - 062 - 073
	New methods in education	- New models for education (e.g. Learner cantered / personalised education, New approach to MOOCs - Massive Online Open Courses, Do It Yourself Education, Problem solving learning – Participatory research) - Awareness of Food-system. - Innovation and entrepreneurial behaviour (e.g. Innovation through Hackathons, MakerSpaces, FabLabs, Science Shops). - Guidance to Start Ups and SMEs, new models of collaboration and impact. - Open researh and open innovation concepts.	Society and new generations need to think differently to achieve new solutions to the actual and future incoming challenges.	INNOVATION	- Malnutrition. - Rise on non-communicable diseases. - Demographic change. - Migration. - Scarcity of natural resources. - Rise in energy consumption. - Economic globalisation. - Agricultural pollution. - Biodiversity loss. - Health and food consciousness. - Responsible consumers. - Destabilised consumer trust. - Changing households and food. - Globalisation of diets. - Consumer engagement. - Social media and food. - New shopping behaviour. - Food waste recovery up-cycling / waste cooking. - Women's empowerment. - Responsible research and innovation.	- 009 - 032

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
The tools of a future proof food system	Logistics - New systems	- Physical internet - Service "at the door at any time"	A new way of transferring materials from one place to another globally would change the way we understand trade and acquisition of goods in a rapid market.	INNOVATION, CIRCULARITY	- Urbanisation. - Demographic change. - Economic globalisation. - Changing households and food. - Consumer engagement. - New shopping behaviour. - Physical Internet.	- 022 - 023
	Smart traceability in the food supply chain	- Transparency and trust through the value chain.	Blockchain could allow a quick tracing of food products to their source for enhanced food authenticity, therefore increasing transparency and trust in the food value chain	CIRCULARITY	- Economic globalisation. - Blockchain Technology for secure food supply chain. - Destabilised consumer trust. - Concentration in food retail markets. - Food regulation.	
	A novel approach to biotechnology	- New biotechnological tools. - New applications.	The further exploitation of microbiota/microbiome knowledge can impact the way that foods are produced and the nutrients that they provide. The development of biotechnological tools on the knowledge of genome and its sequencing, opens the possibility of new applications and implementations. Some examples were the conversion of biomass and residues into a new range of new sub-products and ingredients, the use of actual biorefineries to separate protein and energy into protein usable for humans, or the use of microalgae to produce nutraceutic components without impacting food agriculture.	INNOVATION, NUTRITION, CIRCULARITY	- Malnutrition. - Scarcity of natural resources. - Genome engineering. - Novel food. - Natural preservatives and milder processing methods. - Alternative protein sources. - Functional foods including pro&prebiotics. - "Free from" products. - Food waste recovery up-cycling / waste cooking.	- 012 - 014 - 041 - 050 - 052 - 053 - 054 - 058 - 062 - 063 - 074 - 077

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
	Information and Communication Technologies (ICT) applied to Food System	- Full exploitation of big data. - Internet of Things. - New sensors applied to multiple applications. - Digitalisation of industry. - Robotics. - Augmented reality. - Artificial intelligence.	Transversal to many sectors in the food system, from the efficiency of industrial processes to new business models on the interaction with consumers.	INNOVATION	- Industry 4.0 - Digitisation in food industry. - Big data analysis. - New and game-changing digital technologies in agriculture. - Blockchain technology for secure food supply chain. - Consumer engagement. - Social media and food. - New shopping behaviour. - Physical internet.	- 016 - 022 - 026 - 031 - 033 - 042 - 066 - 069 - 071
	Food Industry 4.0 - Novel and efficient food processing	- Mild processing - Low input technologies. - New robotic applications. - Nanotechnology (New applications, novel packaging, novel foods, policies applied). - Integrated input-output responses. - 3D Printing (Personalisation, Mass production, DIY). - Emulgation (membrane, microfluidisation, ultrasound). - Cutting tech (water-beam, laser, ultrasound). - Separation (membrane, adsorption technologies). - Extraction (Hypercritical CO2). - Heating (super-heated steam, microwaves, induction, sous-vide, radio-frequency). - Preservation (IR, UV, radiowaves, pulsed electric fields, high pressure treatment, osmosis, cold plasma). - Filling (Aseptic filling, clean room tech, super cooling). - Packaging (see packaging breakthrough).	More efficient processes in productivity and energy consumption, more environmentally sustainable processes, less production of waste, products of higher nutritional quality.	INNOVATION, CIRCULARITY, NUTRITION	- Rise in energy consumption. - Industry 4.0 - Digitalisation in food production. - Big data analysis. - New technologies in food production. - High/Ultra processed food. - Novel food. - Natural preservatives and milder processing methods. - "Free from" products. - Packaging 4.0. - Food waste recovery up-cycling / waste cooking. - Food regulation.	- 020 - 045 - 052 - 053 - 054 - 070

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
	Sustainable packaging	- New materials. - Biodegradable materials. - New recycling methods. - Reduction of package. - New models in the food system.	Higher sustainability of the food system, less environmental impact, better use of resources and waste streams.	CIRCULARITY, CLIMATE	- Scarcity of natural resources. - New shopping behaviour. - Responsible consumers. - Bio-based packaging. - Packaging 4.0. - Reduction of plastic packaging. - Packaging and health. - Food waste recovery up-cycling / waste cooking. - Food regulation.	- 065 - 068 - 070
	Diversity on the diet	- New sources not fully exploited. - New protein sources (biotechnology). - Full exploitation of algae. - Full exploitation of insects. - Cultured meat.	Exploring new ingredients allows a higher diversity on use of resources, technological applications and health impact on consumers. Always from a sustainable perspective and environmental impact perspective.	CLIMATE, CIRCULARITY, NUTRITION	- Malnutrition. - Scarcity of natural resources. - Cultured / in vitro meat. - Novel food. - Alternative protein sources. - Health and food consciousness. - Special diets like vegetarian, vegan or low carb. - Globalisation of diets. - Food regulation.	- 012 - 013 - 014 - 017 - 019 - 029 - 050 - 058 - 074 - 075 - 077 - 078
	The global food analysis	- Higher efficiency, better detection, global standardisation, world food regulatory standards.	Food analysis is basic for the correct use and interpretation of data. The importance of the information output requires evolvement for higher capacity and impact.	INNOVATION	- Agricultural pollution. - Transboundary pests and diseases. - Destabilised consumer trust. - Social media and food. - Packaging and health. - Responsible research and innovation. - Food regulation.	- 046 - 059 - 065 - 067

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
A sustainable and dynamic value based food system	Circularity in food systems	- Reduction of waste (Zero waste). - New uses of waste. - New recycling business models. - New structure in food system.	Transversal to all value chain, the use of waste streams has a greater impact on efficiency and sustainability of the food system.	CIRCULARITY	- Climate change. - Urbanisation. - Demographic change. - Scarcity of natural resources. - Economic globalisation. - Health and food consciousness. - Responsible consumers. - Bio-based packaging. - Packaging 4.0. - Reduction of plastic packaging. - Food waste recovery up-cycling / waste cooking.	- 004 - 007 - 015 - 016 - 029 - 031 - 032 - 037 - 038 - 040 - 041 - 053 - 055 - 068
	Efficient use of resources	- Efficient use of water. - Efficient use of land. - Efficient use of nutrients. - Efficient use of energy.	Optimisation of our processes from agricultural input up to consumer behaviour is relevant for the overall sustainability of the food system.	CIRCULARITY	- Urbanisation. - Scarcity of natural resources. - Rise in energy consumption. - Economic globalisation. - New and game-changing digital technologies in agriculture. - Changes in farm structures. - Agricultural pollution. - Biodiversity loss. - Urban agriculture / urban farming. - Consumer engagement.	- 003 - 006 - 021 - 027 - 035 - 038 - 039 - 054 - 056 - 057 - 072 - 076

Domain	R&I Breakthrough	Specific R&I breakthrough topics	Impact	Food2030	Trends aligned (from WP2)	Cases aligned (from WP3)
	Food for society	- Community driven social innovations (City labs, Community based participatory research, Citizen science, urban cropping, urban beekeeping, rent a tree). - Innovative public procurement (meals in nurseries, schools, residences, senior people's homes). - Social entrepreneurship. - Awareness of waste in social context (homes, schools, restaurants, take waste food at home). - Trade norms (Dismissed fruits by shape or form). - Do It Yourself. - Collaborative production. - The European cultural food heritage (maintaining the local characteristics considering new options of geographic diversity).	How the society interacts with the food system and how there is an overall awareness on the impact of the power of small individual actions and public policies is relevant for a social innovation breakthrough.	INNOVATION, CIRCULARITY	- Urbanisation. - Demographic change. - Migration. - Scarcity of natural resources. - Rise in energy consumption. - Economic globalisation. - Urban agriculture / urban farming. - Health and food consciousness. - Responsible consumers. - Destabilised consumer trust. - Consumer engagement. - Traditions and Do It Yourself. - Social media and food. - Food waste recovery up-cycling / waste cooking. - Women's empowerment.	- 004 - 007 - 008 - 025 - 037 - 043 - 048 - 049
	Policy and management within the food system	- Applying Responsible Research and Innovation. - Improving the R&I Network. - Public-Private transfer. - Impact of Research and Innovation. - Higher implementation of knowledge. - Regional aspects of food system. - Food marketing and labelling (New approaches).	Optimisation of our processes for knowledge transfer, for implementation of knowledge, for a full public-private collaboration, for a better measurements of impact.	INNOVATION	- Industry 4.0 - Digitisation in food production. - Big data analysis. - Novel food. - Destabilised consumer trust. - Consumer engagement. - Social media and food. - Responsible research and innovation. - Food regulation.	- 024 - 026 - 030 - 035 - 042 - 060

Appendix

A.1 Overview of past breakthroughs

The following section includes the history behind the selected past breakthroughs for further understanding of the selected topics.

A.1.1 Discovery of fire and cooking

The controlled use of fire by humans is still a theme of controversy in the world of anthropology. There is not an agreement on the exact period of time where humans mastered fire, neither on the effects it had on the evolution of humans, but as Darwin stated in relation to the discovery of fire: "probably the greatest ever [discovery] made by man, excepting language" (Darwin R, 1889, Wrangham R, 2010). There is some certain data: Archaeological evidences prove a clear mastery of fire by humans as late as 250.000 years ago. There are earlier archaeological sites in which evidences of use of fire exist, but there is controversy of whether it was due to fire controlled by humans or just use of wildfire. Anthropologists use other theoretical approaches based on physiognomy and dietary habits to try to understand the discovery of fire. Wrangham and Gowlett (Wrangham RW, 2010, Gowlett, 2013) shows evidence that there are dietary and social hypothesis that supports the theory that *Homo erectus* already knew how to make fire at least 1.5 million years ago at the early Pleistocene. Other researchers do not share the same vision and state that there is not sufficient evidence to locate knowledgeable use of fire earlier than 400.000 B.C. (Roebroeks W, 2011).

In any case, it is interesting to review the theory of Wrangham related to cooking. Firstly, there is evidence that the actual humans would have adverse health consequences such as decreased energy or less fertility on women if cooked foods are not consumed. This is relevant, as it is a distinctive feature that separates humankind to any other animal species on Earth. The *Homo sapiens* is not prepared to eat raw food, our molar pieces are not adapted nor to break cellulosic material neither to chew raw meat. Our small intestine and colon is not prepared to digest an herbivorous diet neither a carnivorous. The dietary theory states that the physiognomy of *Homo erectus* was already evolved to eat cooked food, therefore many of the features that were characteristic of this hominid such as bipedalism or the life at the African savanna (in contrast with life on the trees), were characteristic of a certain control of fire. The interesting part of this hypothesis is that the hominids have evolved after the discovery of fire and the use of cooked food to the *Homo sapiens* as we know it today. Therefore, cooked food is key on the evolution of humankind to a distinct species, the only one that has a physiological aptitude to eat cooked food. Further on, Wrangham defends that the availability of nutrients such as sugars and proteins, the reduction of pathogens and toxins, has prepared our body to adapt to the ingestion of Maillard reaction compounds (produced by cooking) and other heat generated toxicants, a feature that no other animal would have evolved.

A.1.2 Domestication of animals and plants

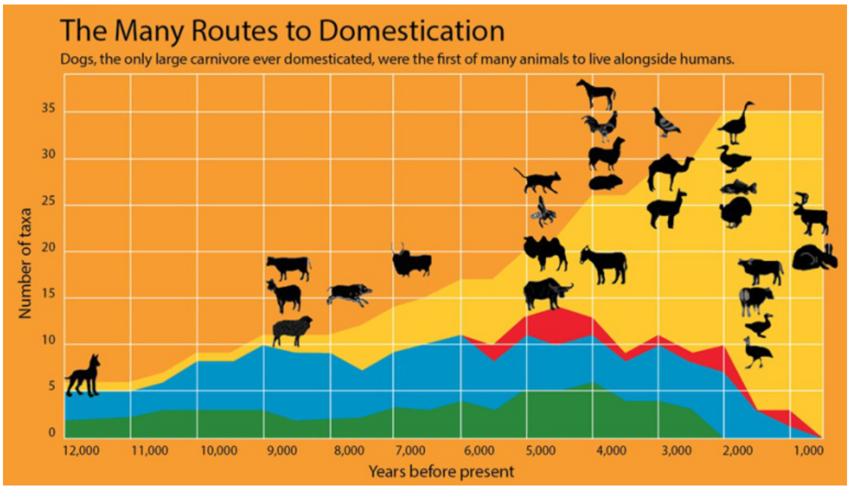
The first agricultural revolution, also called the Neolithic revolution, is the transition of hunting and gathering behaviour to the lifestyle based on agriculture. This innovation is considered one of the most important events on human history after de discovery of fire and tool management. Agriculture is considered responsible of creating the basic grounds for densely populated settlements, the creation of non-food specialisation of the population, trade of goods, hierarchy among citizens, property ownership, the evolution of writing, war… in other words, civilization (Weisdorf JL, 2005).

Agriculture is considered to have been evolved in different cultures between 12.000 and 5.000 years ago, considering the Levant (actual Iraq, Syria, Lebanon and Israel area) the first civilization to implement it, although different civilizations followed in an autonomous manner (Former China, Pre-Inca culture, Central Africa).

The main technological improvement of the Neolithic era is based on the domestication of animals and plants. Zeder suggests three pathways for animal domestication: The commensal pathway, the prey pathway and the directed pathway. The commensal pathway suggests a coevolution of an animal to humans in a symbiotic pathway, driven by a genetic predisposition to get close to humans, which would be the case of the transition from wolf to current dogs. The prey pathway suggests a predisposition of an animal that is a natural prey to be herded and gathered in groups, examples could be the cattle, pigs, sheep and goats, some of the first animals to be domesticated by humans in the Levant. The directed pathway implies a desire from human to domesticate a species; this would be the case of the domestication of horses and donkeys. It is relevant that some other animals have never been domesticated, e.g. gazelles and zebras, therefore there is a genetic predisposition followed by an adaptation to the domestication process. Although there are arguments supporting the domestication theories, usually a period of 1.000 to 5.000 is considered as a minimum need for that adaptation (Zeder MA, 2015, Larson G, 2014).

The domestication of plants had even a greater impact on environment and the settlement of civilizations, and it needed the selection and the continuous research and development of the plants that offered the best yields, outputs, survival rates, and stability. It is argued that the first domesticated crops were some tubers like the turnips, but the truly revolutionary crops were cereals such as wheat, barley (Levant), rice (China), millet (Africa) and maize (America). The selection of the best varieties changed the genetic output of plants, which led to the desired phenotypes. Also the selection and mixing of breeds of the same species led to the development of new varieties. For example, there are 25.000 different known varieties of wheat and only a few of them are used today, being the latest developed during the Third agricultural revolution (Fuller DQ, 2014, Roucou A, 2017).

Although the impact of the Neolithic revolution is clear, there are still uncertainties on why humans changed their model of lifestyle from hunter-gatherer to agriculture (Weisdorf JL, 2005) and recent studies explore the process of domestication with the aim of helping the new plant and animal breeders can use it for actual implementation using the newest techniques of breeding.



Domestication of animals in years before present. From Today in history blog, adapted from Zeder (2015).

A.1.3 Fermentation

The fermentation process existed much earlier than humanity. All the chemical and enzyme processes needed for a food to be fermented were present in plant materials as part of the recycling reactions of microorganisms to break down its components as part of their life cycle. For example, the fermentation of fruits and fruit juices into wine and vinegar, germinating of grains as previous process to brewing, or the souring of milk.

Foods provide, through microorganism alteration, new aromas, flavours, and textures that in some cases were pleasant and in others not. This trial and error are the basis for the development of fermented foods, drove our primitive ancestors to choose the processes that gave the most desirable sensorial attributes to the food, discovering also other beneficial attributes such as extended preservation, improved digestibility, nutritional enrichment or other specific attributes that were part of a novel food product.

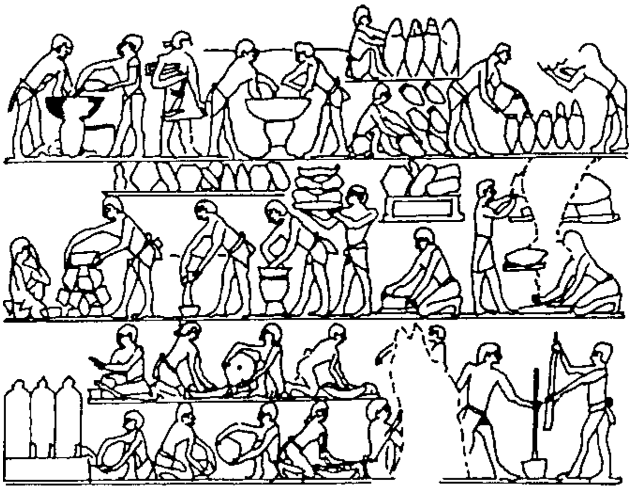
There is a vast application of fermentation in food products that through history has been developing and improving the food products we have today. Hui et al (2004) suggested the following classification: Vegetables (sauerkraut, cocoa beans, coffee grains, vinegar), cereal processed foods (bread, pastries), semisolid dairy products (sour cream, yoghurt), solid dairy products (cheese), meat products (sausages, salami), soy products (soy sauce) and beverages (beer, wine, cider, mead, distilled beverages).

The primitive humans likely encountered fermentation processes accidentally and there is no record on when exactly the first discoveries might have happened. It is likely that the dilution of natural honey and further fermentation derived into the first mead drinks, or that the storage of fruits and cereal grains could have produced the first wines and beers, or that the deterioration of milk under heat conditions could have transformed it into the first sour cream or primitive cheeses. Some cultures even might have used mastication as a way of releasing sugars from the foods through the amylase of saliva to facilitate food products, that is the case for example of the production of African Kafir (Steinkraus KH, 1996) or the production of chicha on cultures from the Andes region of South America (Escobar A. 1977). Rice wine or Sake in Japan is another example of fermentation induced by chewing the rice grains to reduce starch to free sugars prone of fermentation (Yoshizawa K, 1979).

Nevertheless, there is a consensus that the conscious production of fermented products happened when humanity did settled down in villages and cities due to the discovery of the agriculture. The need of food storage likely accelerated the discovery of useful fermentation processes that could be replicated and transformed into a certain type of manufacturing process. Therefore, there is an agreement that the first fermentation processes can be dated between 10.000 – 8.000 at the late Neolithic era in the Near East cultures of Mesopotamia and Egypt. There are archaeological evidences that bread and beer were produced in Egypt by 6.000 B.C. (Hornsey IS, 2003), showing that manufacturing processes were in place for this production, but also that it had a social and hierarchical impact on the way these cultures ruled themselves. As an example, beer and bread were used as payment in the wages of Egyptian labour (Kemp, 1994).

It seems, however, that different cultures have developed different foodstuffs through their own discoveries and traditions on fermentation, resulting on the variety and richness that we have today. One example is the development of cocoa fermentation in Aztec cultures, probably produced in Mesoamerica 2.000 years earlier than Hernan Cortes brought cocoa beans to Europe in 1528 A.C. (Schwan RF et al, 2004), this process is critical to the quality and flavours that the cocoa will have afterwards. Another example could be the development of cheese and yoghurt in Europe (Fisberg M et al, 2015) or beer (Hornsey IS, 2003) where there are local processes identified with specific regions that provides the actual richness on food variety.

It is important to note that before Louis Pasteur, there was not a specific link between the fermentation and the growth of bacteria and yeast in the process (he called it, “life with no air”). He is considered the father of modern biotechnology, and so, fermentation is one of the key processes that has been developed in the latest century, increasing the offer on fermented products that consumers can enjoy today.



The making of bread and beer from the tomb of Ti in ancient Egypt (Reproduced from Geller JR, 1992)

A.1.4 Discovery of America: New raw materials

Most of historians dedicated to research the history of foods mark the discovery of America as a clear and undisputable milestone on the timeline. When Christopher Columbus put his first step on the island of actual Bahamas in 1492, he was not aware of the huge transformation that the Old World and the New World would have (Tannahill R, 1988, Montanari M, 1994, Flandrin JL, 1999, Toussaint-Samat M, 2009). The discovery of America brought foods to the Old World such as potato, maize, cassava, sunflower, tomato, avocado, cacao, peppers, pineapple, peanuts, or vanilla to put some examples. The transfer of foods to the New World also changed America's landscape, bringing wheat, barley, sugar-cane, or coffee crops as well as many new livestock such as pigs, poultry and cattle (Suarez, T, 1994, Nunn N, 2010). Many of the main recipes of European countries would be unthinkable without the acquisition and adaptation of many of these crops to the new lands; to put an example, the cuisine of Belgium is known for inventing the "frites" (fried potatoes) and is recognised for having some of the best chocolates worldwide, two clear American imports. Another example to state the impact of the discovery of America was the introduction of potatoes to the Old World. Potato was adopted with great success, it complemented the crops because it needed different soil nutrients, but also allowed to create cultivars in colder regions adapting a new staple to the food supply, Ireland could be a very good example of this adaptation (Nunn N, 2010). Also the adaptation of wheat to the New World has made the United States of America the major wheat supplier of the world, adaptation that clearly has produced a global benefit. Still nowadays, there is an exchange of non-exploited foodstuffs from the New World to the Old and vice versa: The trends in food consumption and the advances in logistics have allowed to bring foods that were non-sufficiently known, with new researched properties, that were not able to be cropped in the new lands. That is the case of foods like quinoa, chia, or amaranth, which are having a new wave of success on European markets thought as superfoods (or very high nutrient foods), another example is stevia, brought as a natural sweetener in a market with a higher demand for sugar-less products.

Some foods brought to the Old World from the Americas. Picture taken from Christopher Columbus anniversary (webpage Aceites Betis, Torres & Ribelles).

A.1.5 Canning

The history of canning or in-container sterilisation has a clear beginning that dates to the Napoleonic Wars: Napoleon Bonaparte had the problem of supplying food to his armies during the military campaigns. At the beginning of the French imperial expansion (1800), he offered an award of 12.000 francs to anyone who could provide a system to preserve foods for long periods of time. In 1809, Nicolas Appert, an experienced French chef, developed a method of food preservation in glass jars using thermal treatment. Still at that time a canning process could take long times and was expensive to produce, so the war finished before his invention could be fully developed to an affordable industrial scale. Nevertheless he published in 1810 the book "The Art of Preserving Animal and Vegetable Substances", one of the first books ever published on preservation of foods.

Two years later, an English man called Peter Durand developed the method to seal the food in tin containers (patent also attributed to Philippe de Girard). The patent was sold to Bryan Dorkin and John Hall, who settled the first canning factory in United Kingdom in 1813, selling their products to the Royal Navy with great initial success. During the initial stages of the 19th century, cans were considered an expensive novelty, even a symbol of status within the English middle classes who could afford it. But the need of canned foods on the different wars of the century (Crimean war, American Civil War, Franco-Prussian war) accelerated mechanisation and industrialisation of the process in Europe and the United States. By the end of the century, civilian working classes were able to afford canned foods thanks to companies such as Underwood[11], Nestlé, Heinz, Borden or Crosse and Blackwell[12] (owned nowadays by Princes Food and Drink).

The Great War brought further developments on the industrialisation of the canning process but also on the variety of canned foods. Many of the specialties such as prepared pasta dishes, stews, and fruit preserves were developed already at the beginning of the 20th Century. With little exceptions almost any kind of food can be canned or better said, sterilised, with a good result on the nutrients preservation. The extension of the variety of foods that can be canned comprises: Meat (Sausages, beef, ham, spam…), legumes (beans, lentils, chickpeas), vegetables (carrots, peas, potatoes, asparagus, maize, spinach, tomatoes…), fish (sardines, oysters, tuna, salmon…), fruits (pineapple, peaches, pears, coco…), dairy (baby foods, pasteurised milk), mushrooms, pet foods and all type of prepared dishes (stews, soups, prepared pasta dishes, sauces, spreads…).

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[11] Underwood: https://underwoodspreads.com

[12] Crosse & Blackwell: www.crosseandblackwell.co.uk

Canning processing at J.S. Frarrand Packing Co, Baltimore, Md (1909). Image from the prints and photographs online catalog of the Library of Congress Prints and Photographs Division Washington D.C. USA.

A.1.6 The supermarket

The food retailing as we know today has a history of very recent phases that certainly has changed completely the way we buy and consume our groceries. With no doubt, it is an invention from the United States of America, which has been the leader on introducing innovations and different formats all along the 20th Century, a concept that continues spreading all along the globe into the developing countries yet.

Four major eras are considered in the evolution of the supermarket (Ellikson PB, 2016):

1912-1930: The introduction of the chain store

1930-1970: The birth and evolution of the supermarket.

1970-1995: Computerisation of the systems.

1995-Present: The hypermarket.

The new era of food retailing is considered to start in 1912 with the introduction of the “economy” grocery store format by the Great Atlantic and Pacific Tea Company (A&P). Before 1900, the standard shopping model in U.S.A was an activity taken on foot, near to the consumer’s home, with a wide array of specialty shops and general stores. A&P changed that model introducing a cash and carry model in the shops (which reduced shop vendor’s activities and costs) and started reducing logistics costs by its own network of warehouses and trucks (that avoided the middle man on supplies), even having production of their own goods. This model had a clear drive, reducing costs in logistics and in product management at the store, the final product value could be decreased. The model was so successful that A&P went from 650 to 4224 outlets in the period 1914 to 1919. Other supermarket brands briefly followed such as Kroger, American Stores, and Safeway, having a total increase of market share from 4.2 % in 1919 to 28,8 % in 1932 (Tedlow RS, 1990).

There is a person considered a visionary of the supermarket as we know it today. Michael Cullen was an employee of Kroger when in 1930 he announced a new breed of super-store. He is credited with the introduction of the concept of the supermarket out of town, using warehouses with lower rents (forcing the use of automobiles) and with the increase on surface area (not known at the time). He introduced the concept of low margins / high volume principle that permitted to be more competitive on price, he also introduced concepts such as self-service, cash only, no delivery, and very high loaded marketing campaigns. These first supermarkets were crude, pallets stocked in a warehouse, but were cheap. The existing chains were initially reluctant to this model, in fact, Mr. Cullen developed his own chain, King Cullen Supermarkets, as Kroger did not commune with his revolutionary ideas, not before long many others followed. The success of this model was confirmed, the number of supermarkets increased from 386 to 26.640 from 1935 to 1982, confronted with the reduction of traditional stores from 400.000 to 162.000 in the same period of time, calling the attention of politicians and anti-trust authorities (Tedlow RS, 1990, Charvat, 1961, Ellickson PB, 2016).

The 80s and 90s saw the development and introduction of technology in supermarkets. The invention of the UPC code and scanning register allowed the engagement of market research and data-based marketing. The first code scanner was installed in a Marsh supermarket in Troy, Ohio in 1974; by 1990 the adoption was almost universal in the U.S. and Europe (Ellickson PB, 2016). Also the computerised logistics allowed higher traceability and better control of stocks.

We could consider also the 80s and 90s the real boom of the supermarket concept in Europe, following a model very similar to the U.S.A and with a high increase on market share. Dobson and Waterson (1999) and Dobson (2005) already reported a market share of 65% in 1999 leaded by the top five U.K groceries retailer. In other countries, the same trend followed: France, 56%, Spain, 52%, Germany, 36%, Italy, 26%. But the most recent reports (EU report, 2014) [13] shows an enormous increase of these numbers during the crisis (2007-2015), reaching values of 80 to 90 % market share overall. The developing countries are catching up even more steadily, with Latin America, Asia and African countries adopting market shares higher than a 50% (Reardon, 2003).

The 21st Century has known the hypermarkets, a store for all the possible needs of the consumer. Walmart is still the top seller by income and volume, but the competence is high and there are major Supermarket brands that follows closely such as Costco, Kroger, Aldi, Carrefour, Tesco or Lidl (Deloitte's retailer report, 2018)[14]. The overall retailers income in U.S.A. has been 4.4$ trillion with a Compound Annual Growth Rate (CAGR) of 4.8%. Consumer trends keep changing in the developed world and new challenges appear such as the health consciousness in food trends, environmental awareness, ethnic food in more globalised environment, and more convenience foods (EU report, 2014). Nevertheless, the real challenge for supermarkets, are the shopping online, the concept of no-store, with an increase on CAGR of an almost 20% in the recent years and a revenue of 96 M$ in 2016 (Deloitte's retailer report, 2018). Therefore, this phenomenon will be considered a different breakthrough.

A.1.7 Flash-freezing

Although the first works in freezing are attributed to the English businessman Thomas Sutcliffe Mort and the research of Eugene Dominic Nicolle, whom presented the first ice-making patent in 1861 at Sidney, Australia (Barnard, 1974), it is Clarence Birdseye who is considered the father of modern flash-freezing technology.

Mr. Birdseye was an adventurer from Brooklyn and he was at that time (1912-1915) working in a hospital ship at Labrador, Canada. He observed the fish catching technique of the Inuit Canadian tribes and it called his attention the speed at which fresh caught fish froze at -40 °C (Kurlansky M, 2012, Karwatka D, 2016). He observed that when thawing, the fish kept its flavour and textural properties almost intact. This was due to the freezing rate of ice crystals; conventional freezing created large ice crystals that damaged the structure of frozen products, creating excessive dehydration and loss of flavour and texture when thawed. The flash-freezing technique, created smaller crystals that did not break the structure of the frozen material and therefore allowed a product of much higher quality.

Back in America in 1920, Clarence Birdseye worked for a small fish company (Clothel Refrigerating Company) and observed the problems that the frozen products presented at that time: Low quality, losses previous delivery, low sales… and he saw the opportunity to use the idea that he grasped in Labrador. He created his own company (Birdseye Seafood Inc.) and started research and development on the freezing techniques at -

[13] EU Report: The economic impact of modern retail on choice and innovation in the EU Food sector. http://ec.europa.eu/competition/publications/KD0214955ENN.pdf

[14] Deloitte: Global Powers of Retailing 2018: Transformative change, reinvigorated commerce. https://www2.deloitte.com/content/dam/Deloitte/at/Documents/about-deloitte/global-powers-of-retailing-2018.pdf

45ºC. His first company went bankrupt but he continued his research founding a new one in Massachusetts (centre of the fish industry) and kept developing new patents for production (Birdseye, 1945). He faced many difficulties apart from the development of the freezing equipment such as the lack of frozen logistics at the time and few display cases at the shops. In 1929 he sold his company and patents to the cereal company Postum, later on renamed General Foods (merged with Kraft Foods in 1990), where he kept conducting experiments and research on the development of flash-freezing technologies. During the World War II, there was a scarcity of tin in the U.S.A and frozen foods acquired higher relevance, as the wives of the fighting husbands searched for convenient food for cooking at home (Kurlansky, 2012).

A further step on the history of freezing is the development of cryogenic freezing applied to foods using liquid nitrogen or other gases such as carbon dioxide or ammonia. Cryogenics allows a much quicker freezing time in temperatures of -59ºC or much lower (American Cryogenic Society[15]). Cryogenic freezing tunnels were evolved since the early 60s and its implementation in frozen processes has been increased more and more in the recent decades due to the high quality of the final products and the efficiency of the process (Bald WB, 1991).

Freezing applies to almost all foodstuffs such as meat, fish and seafood, vegetables, fruits and particularly to processed foods such as bakery, frozen desserts, pizzas, ice-creams, and ready to eat dishes.

Clarence Birdseye at Labrador, Canada (1912-1915). Image taken from Birdseye history roots.

A.1.8 Vitamins

The discovery of vitamins was not the making of just one single pioneer, but a history of contributions from many researchers from different discipline areas which included epidemiologists, physicians, physiologists and chemists. Perhaps we can set up the discovery of vitamins to 1912 when the scientist Casimir Funk suggested that diseases such as pellagra, scurvy and rickets were caused by deficiencies on the lack of common factors of similar character with the characteristic of vital amines, therefore vitamines, later on called vitamins (Carpenter KJ, 2003). Funk had the honour to have set the name of vitamins, but others would argue that the history started 100 hundred years earlier with the studies of François Magendie in 1816, who is reported to use dog studies to research if gelatine was a complete food that could nourish a person. He researched this issue during 10 years, he was a pioneer on using animals as a model for human research, and he suggested that chemists should investigate what essential material it was that was leached out of meat and was essential for nutrition apart of nitrogen intake (Carpenter KJ, 2003).

[15] Cryogenic Society of America: https://www.cryogenicsociety.org/resources/cryo_central/food_processing/

During the 19th Century, research carried by different scientists created the bases of two established dogmas (Semba RD, 2012): 1) That as Louis Pasteur and Robert Koch had discovered, most of diseases were linked to infections from microorganisms, and 2) that four essential elements were essential for nutrition; proteins, carbohydrates, fats and minerals (Justus von Liegig, Carl von Voit, Max Rubner). These statements overlooked some discoveries that were taking place by some scientists like Christiaan Eijkman and Gerrit Grijns that showed how polished rice was the culprit of beri beri in some prisons of the Dutch Indies, they already had suggested a nutritional deficiency. Similar reports were taken from diseases like scurvy, which was persistent on long distance trips to the artic, rickets, a well-established disease during the century, pellagra or xerophtalmia, from physiologist working around the globe (Carpenter RD, 2003). Already in 1906, Frederick Gowland Hopkins articulated in a speech given in London that: "no animal can live upon a mixture of pure protein, fat, and carbohydrate, and even when the necessary inorganic material is carefully supplied the animal still cannot flourish (…) Scurvy and rickets are conditions so severe that they force themselves upon our attention, but many other nutritive errors affect the health of individuals to a degree most important to themselves, and some of them depend upon unsuspected dietetic factors" (Semba RD, 2012).

Against the dogma of the time, much credit on the discovery of vitamins is given to the research of Elver V. McCullom and his volunteer assistant Marguerite Davis (Underwood BA, 1998). McCollum is recognised as a pioneer working with rats as a human model and to him we owe the terminology of a "fat-soluble factor A" and "water-soluble factor B", later renamed as vitamin A and vitamin B families. They were some of the first to reconcile the deficiency of factor A substance to the apparition of severe ophthalmia (Carpenter KJ, 2003).

Nevertheless, it would be unfair to set all the credit of vitamin research to a few number of scientists, because there were an overall effort on research from different academia, medical schools, and industry later on, working on the matter on animal studies. Not to mention also the chemists that were able to synthesise all these compounds, surprisingly early since its discovery (Carpenter KJ, 2003). Accordingly to Combs GF, 1992, thiamine was proposed in 1901, isolated in 1926 and synthesised artificially in 1936, vitamin C proposed in 1907, isolated in 1926 and synthesised in 1933, vitamin A proposed in 1915 and isolated in 1939, vitamin D proposed in 1919, isolated in 1931 and synthesised in 1932, and so on. Certainly the 20th Century has seen thousands of publications on vitamins, but also in nutrition, gathering an information than just a hundred years ago, was a mystery to human kind.

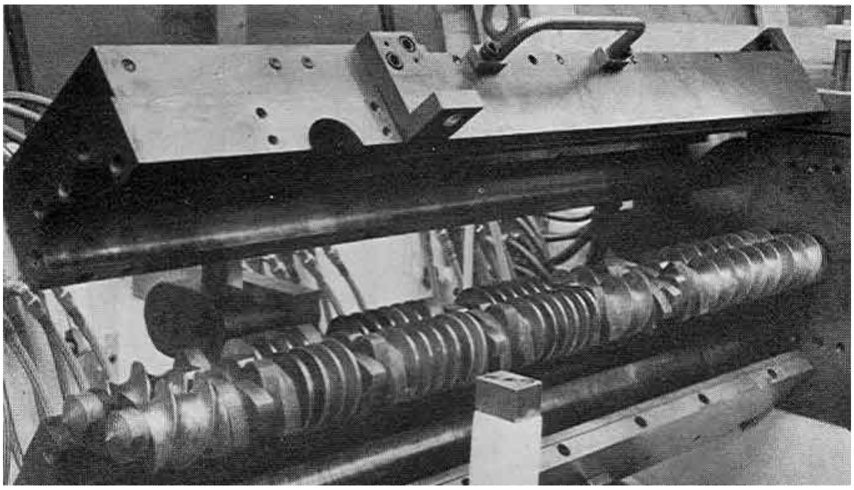
Laboratory of vitamins and fish oils capsules (1982). Taken from Seven Seas historical record.

A.1.9 Extrusion

The design of a screw within a barrel chamber, which is the principle of extrusion, is credited to Archimedes of Syracuse, a Greek mathematician and inventor in the years 287-212 BC. He invented it to move water from a lower level to an upper level, a very clever invention at the time. But it is not until 1779 that Joseph Bramah patented the first invention in what we call extrusion, its use, the metal casting. So the invention of extrusion comes from the heavy industry of material science, used to mould and form metal pieces, ceramics, plastics, polymers, and also foodstuffs. In fact, many of the developments on extrusion technology used the knowledge acquired on plastic extrusion and forming (Maskan M & Altan A, 2012).

The beginning of the application of extruders to food processing came in the 1930s within the pasta business. First food extruders were used for the mix of semolina flour and water to shape a variety of pasta products. Companies like Bühler, long-time known for building industrial equipment, were some of the first to launch in 1934 one of the first pasta extruders (Bühler history[16]). Some years later, the first breakfast cereal was produced using an oat flour, formed in the shape of a doughnut, incorporating precooking stages. During the 40s, collet extrusion was developed for the production of highly expanded cereal collets, which were enrobed with oil and flavours to produce a variety of snacks (Guy RCE, 2003). In the 50s, larger extruders were developed to cook pet foods and animal feeds (Harper JM & Clark JP, 1979). During the 80s further developments were introduced to high moisture or conventionally called "wet" extrusion, a novel technology that allowed the use of enzymes, producing high maltose syrups into the process. Wet extrusion also allowed the texturisation of new products such as meat and fish, which were not able to be extruded otherwise (Akdogan H, 1999). The following years the development of extruders allowed the production of several products that could not be able to be produced: precooked and modified starches, ready-to-eat cereals, snacks, bread substitutes, pet foods, confectionery, baby foods, and texturised soy flour. Nowadays new applications continue to be researched and the development of extrusion technology continues into the texturisation of different ingredients or the extrusion of flours to eliminate e.g. anti-nutrients and off-flavours (Harper JM & Clark JP, 1979).

Extrusion allows food items that we would not know without this technology and it is a widely used technology in the food industry. It is versatile (more than one product can be produced in the same industrial line), efficient, highly productive, low cost, keeps many nutrients intact and allows new shapes and forms. Extrusion also transforms foods into new subproducts that can be used with new purposes; as an example of this latest point, extrusion of flour from pulses allows creating new flour with better hydration properties, less undesirable flavours and with better digestibility properties (Alonso R, 2000).



A twin extruder for industrial snack production at the final 70s. Extracted from Baker Perkins historical society archives.

[16] Buhler history: https://www.buhlergroup.com/global/en/about-buehler/corporate-profile/history/history-html5.htm

A.1.10 Microwave heating

The anecdote referring microwave heating and the invention of the microwave oven refers to Percy Spencer. During the World War II, he was a technician and inventor at the enterprise Raytheon working with magnetrons for radar appliances. While managing one of those radars, he noticed that the candy bar that he had in his pocket had melted. Later on, he tried heating maize kernels to make pop-corn, and even heated an egg that exploded in the face of one of his co-workers (William JB, 2017). Percy Spencer is credited on the discovery of microwave ovens as he placed a patent in 1945 which described the use of microwave for foods and he claimed drastic reductions on energy requirements for cooking, calculating that an egg could be boiled using 2 kW/s compared with the 36 kW/s needed in conventional heating. This patent is considered the precursor of the microwave ovens as the kitchen appliance we know today.

Despite the fortuitous discovery that is credited to Mr. Spencer, there are many persons, and mainly companies that led the pathway to the modern microwave oven. Raytheon was the first company to create a Food Laboratory division under the research team of the company with the aim of launching a microwave appliance, they did it under the name of Radarange. This early equipment was much heavier and voluminous than the ones we know today and the first market was found in restaurants and restoration services during the 50s. The Raytheon company dominated the market this years, launching more than 250 patents, but during the 60s many competitors appeared in the US market such as General Electrics, DuPont, Litton or Allis-Chalmers. These companies invested in research for microwave heating and tested different models of magnetron and tube technologies which were the key for the reduction of margins to bring the microwave oven to consumers. The interest for the microwave technology increased to the point that in 1966 the International Microwave Power Institute was founded in Canada, where academic research was conducted on microwave heating and its appliances (Osepchuck JM, 1984).

The 70s saw a booming application of microwaves for consumers at home. U.S had had the leadership on microwave technology, but Japan with companies like Sharp, Toshiba or Hitachi soon were competitive enough to enter the American market. In fact, Sharp was one of the major competitors during the 70s and 80s, placing into the market affordable microwave ovens to consumers. At the late 80s the Korean company Samsung also took the leadership on microwave appliances for consumers. A report of 1997 about the expense of living in America, revealed that in 1956, 0% of the population had a microwave, in 1996, 85% of the population owned one (Liegey PR, 1997). Although it is indisputable the penetration at homes of microwave ovens in developed countries, in developing countries is still ongoing, a report on Indian market stated that 5.3% of households owned a microwave against a 31% ownership of a fridge in 2013 (Statista)[17].

The use of microwaves as heating source has also been introduced in other industrial applications apart of food, such as environmental/pharmaceutical industry, medical uses, films and paper, wood or ink and paint applications, mainly with the aim of degradation, sterilisation, dehydration or sealing purposes (Horikoshi S, 2018). In food processes, microwave heating is used for thawing, blanching, baking, pasteurisation, drying, precooking, tempering and microwave-assisted extraction of bioactive compounds (Orsat V, 2017).

[17] Statista: https://www.statista.com/statistics/370635/household-penetration-home-appliances-india/

One of the first microwave ovens for home use, launched in 1967. Promotional image for the Amana Radarange, 1967.

A.1.11 Freeze-drying

Different sources coincide in the opinion that the first freeze-dried food was developed by the Peruvian Inca culture freezing tubers and potatoes atop the Andes Mountains. They left the frozen staples under the sun to evaporate, so the ice evaporated directly from the solid state to the vapour state. The product obtained is called "chuño", a staple in their diet that they obtained after grinding the tubers into a fine powder that they could use in soups and stews (Ratti C, 2008). There are also other reports on the use of freeze-drying in the manufacturing of "koyadofu" in Japan or the fish being preserved by Vikings freezing the foods in the snow at high altitudes (Mercer Foods)[18].

However, the main discoveries related to freeze-drying come from the medicine and pharmaceutical industry researchers. It is not until Richard Altmann in 1890 that a tissue was dried and rehydrated for the first time in a laboratory. And not until 1927 that the first patent for freeze-drying was presented by Henri Tival, a French inventor. The next step forward was in the World War II when the US Red Cross used freeze-drying to lyophilise plasma serum as medium to transport it to hospitals. Soon enough, vaccines were also freeze-dried.

In 1949, the Earl W. Flosdorf, who already had contributed to the freeze-drying of serum blood and plasma, presented a work reviewing the lyophilisation of foods: "Freeze-Drying: Drying by sublimation". Already in his work he presented the freeze-drying of fruit juices, milk, meat, fish, sea-food, coffee and tea (Flosdorf EW, 1949). During the 50s and 60s many developments were conducted from different researching groups to develop further the technology to obtain higher quality products and to have more efficient equipment. The incorporation of vacuum for example, or the continuous system for freeze-drying evolved greatly the technology that continues improving nowadays. In 1965 Nestlé launched the Nescafé Gold Blend, a high-quality instant coffee, first of its kind to be produced using lyophilisation. Also, the development of freeze-dried products for astronauts (freeze-dried ice-cream) and military, contributed greatly to the advances on the technology.

The use of freeze-drying on foods has many applications but its costs reduce the commercial products that finally are seen in the market. The main purpose is to maintain the qualities of sensible products, almost untouched when hydrated again. Examples of food that are lyophilised with commercial purposes are mostly fruits such as strawberry, blueberry, raspberry, blackberry, apple, banana, peach, pineapple…, vegetables such as corn, peas, cauliflower, broccoli… coffee and tea extracts, baby foods and ready meals ready for rehydration (Mercer, Nestlé). Fruits like berries retain most of its vitamins and flavonoids as well as the volatile flavours and colours (Prosapio et al, 2017), as well as high quality coffee, where aromas and key fatty

[18] Mercer Foods: http://www.mercerfoods.com/2017/11/01/history-of-freeze-drying/

acids are preserved (Dong et al, 2017). Some of the companies that mostly commercialise freeze-dried products are Nestlé, OFD Foods, Unilever, Wise Company, Mondelez, Mercer Foods, Chaucer, Asahi Group Holdings, Harmony House Foods or Honeyville (Research and Markets).

Freeze-dried ice-cream.

A.1.12 Third agricultural revolution

The Reverend Thomas Robert Malthus had developed a theory in his "An Essay on the Principle of Population", first published in 1798. It stated that the growth of human kind followed an exponential behaviour, whilst the growth of food production followed a linear progression. Therefore, great poverty and hunger would arise on the world in the 20^{th} Century to compensate for the food shortage, somewhat a Darwinian approach to the population growth (Seidl I & Tisdell C, 1998). The green revolution changed that prediction drastically in the late 1960s and although population had doubled, the production of staple crops tripled during this period, with only a 30% increase in land area cultivated in the period from 1966 to 2000 (Pingali PL, 2012).

The Third agricultural revolution, also known as Green Revolution, is considered to have a father: Norman Barloug. He was an American geneticist and plant pathologist that got appointed director of the Cooperative Wheat Research and Production Program in Mexico (Nobel Prize Norman Barloug biography). This program was a joint undertaking of the Rockefeller Foundation with the Mexican Government with the aim to increase crop yields by researching new varieties of wheat and improving agricultural technologies. They focused on producing high-yielding varieties (HYVs) for wheat, but also on improvements on time to maturation of grains, use of fertilisers, improvement on irrigation techniques, improved mechanisation, and to certain extents, rational use of pesticides. These studies brought a great success in Mexico, more than doubling the output of wheat and maize yields and providing the grounds for prove of concept.

The Mexican Green revolution was possible thanks to investment, mostly public, to develop research mainly in the area of plant breeding. The International Maize and Wheat Improvement Centre (CIMMYT) had demonstrated the success of the changes applied, and the model was copied in Philippines with rice, where the Rice Research Institute (IRRI) shown also a great development of the yield capacity at the rural areas. Those successes lead in the 1970s to the Consultative Group on International Agricultural Research (CGIAR), which was established to generate technological advances to countries that were not capable to invest on agricultural research. Thus, countries like India and Brazil benefited largely on those activities, putting in place new seeds and technologies that allowed greater yield output (Evenson RE & Gollin D, 2003).

The Third agricultural revolution focused mainly on staple foods, having a great impact in some of the countries where it was implemented. In the period between 1960 and 2000, yields increased 208% for wheat, 109% for rice, 157% for maize, 78% for potatoes, and 36% for cassava (Pingali PL, 2017). The Third agricultural revolution is considered to have happened in the period 1966-1985, but its consequences lasted to 2000, being considered one of the major factors for impact against starvation and poverty on those countries where it was successfully implemented. Norman Barloug was awarded the Nobel Peace Prize in 1970 and he stated: “a temporary success in man’s war against hunger and deprivation”.

While the Third agricultural revolution was eminent in fertile lands, there are many researchers nowadays calling for a fourth agricultural revolution oriented to infertile soils or arid areas of the world such as sub-Saharan Africa and the Levant (Kush GS, 2001, Lynch JP, 2007).

Norman Barloug in a wheat field, photograph issued in the magazine LIFE, 1970.

A.1.13 Microcredits

Although there are many claims that microcredits have existed from the 18th or 19th Centuries, the concept of modern microcredits is attributed to Professor Muhammad Yunus and the creation of the Grameen Bank of Bangladesh. The story is said to start in the 70s of the 20th Century, when a young Mr. Yunus returned to Bangladesh after finishing a PhD in economics in the United States of America and started to lecture at the Chittagong University. He observed a devastated country by the war in need of food aid and with high rates of poverty, it is said he wanted to put into practice some of the theories he had learned and apply the postulate that “if people got access to credit, they could increase their profitability, or diversify their economic activities, in ways that would allow them to raise their incomes” (Hulme D, 2008). Therefore, a microcredit is a small amount of money lent to poor people, which allows them to grow and prosper, improving their lives and being able to pay the loan back. Prof. Yunus biography says that he started by using his own money in sums of 10 to 20 $ to poor, rural women and creating small cooperatives to control their output and weekly payment of loans. In 1983 the Grameen Bank was created, achieving great success and enthusiasm all over the world in the following years (Yunus M, 1999).

In 1997 there was a Microcredit summit hosted by the UN, clearly stating the microcredits as one of the best innovative ways of applying banking to overcome poorness. Prof. Yunus received the Nobel Prize in 2006. The Grameen bank model was replicated in other countries, mainly in Asia and America, with great enthusiasm in the developed and developing countries by NGOs and Governments alike. The premise of the loans stating some clear initial rules: The loans were directed to poor, women, and small amounts in a high rate interest and short time payback (Seibel, 2003).

Today microcredits still have a great drive. In 2010 the European Union launched the EU Microfinance Support[19], the concept has been implemented in more than 75 countries, but there is a lot of criticism on

[19] EU microfinance support: http://ec.europa.eu/social/main.jsp?langId=en&catId=836

results and impact. Some claim it as the most innovative banking solution of the 20th Century, others claim is a clear debt trap and that many users of the loans are poorer than when they started. The need for clear and non-biased results is still controversial in ongoing publications, which keep debating if the microcredit is one of the key tools to overcome poverty in poor and rural areas of the world (Banerjee AV, 2013).

A.1.14 Food e-commerce

The year 1995 could be considered the birth of e-commerce (also named online shopping). That year Amazon and eBay opened online purchase services just four years after the publication of the World Wide Web by Tim Berners-Lee in 1991. Jeff Bezos, CEO of Amazon and now one of the wealthiest men on Earth, sold his first book online in 1995 with a very small company of 300 employees in a two-bedroom house in Seattle. In two months his earnings reached 20.000 $ a week, selling books in more than 45 countries (Hansen et al, 2013). In 1995 Amazon had yearly sales of 510.000 $, in 2011 reached 17 $ billion, 136 $ billion in 2016, with a Compound Annual Growth Rate (CAGR) of 17%, being the 6th top retailer on the world (Deloitte report 2018). It is worth mentioning here Michael Aldrich, an English entrepreneur that already had the vision to create a shopping system online using the TV, the Videotex system (as it was called) was already born in 1979, but the society was not ready yet for the online shopping at that time.

The first food to be sold online is claimed by Pizza-Hut, which stated in a commercial campaign that they sold their first pizza online in 1994, even before Amazon had sold their first book. Apparently this could be true (not trustful reference could be found), but the point here is that convenient foods were the first to offer services of online purchase and delivery. Big retailers in UK were also some of the first pioneers to launch internet sales, Tesco has the credit, although Sainsbury's and Morrisons rapidly followed in the years 1996 and 1997.

There is no doubt that the e-Commerce is changing the way that society behaves and it is a revolution for the retail world. However, groceries and foods are one of the last markets to be fully conquered, because many foods are perishable and consumers still want to see what they buy, have a first experience with the product at the shop. But all of these is changing and the online shopping of food has already started and the previsions are an enormous market share for the first ones to master the e-market (Belavina E et al, 2016, Bernon et al. 2016, Mortimer et al. 2016).

The latest report launched by the FMI and Nielsen[20] foresees a growing market for online purchase of groceries in the U.S.A. The report claims that 2017 has seen a boost in the expectations of online shopping of foods, 49% of the American population does the shopping of groceries online, and they expect a growth up to 70% in the following 5-7 years. They observe that there is a turning point on the population segments and that up to 61% of millennials, 55% of Generation X, 41% of Boomers and 39% of Greatest Generation buy online. They claim that by 2022, there will be a 100 $ billion market for the retailers and manufacturers prepared for it, although not all the retailers are ready for the e-commerce change, concludes the report.

[20] FMI/Nielsen report: https://www.fmi.org/digital-shopper

A.2 Online questionnaire on breakthroughs

The following questions regarding breakthroughs in FNS were added to the online survey in WP3:

> *Give a brief description of your first potential breakthrough.*
>
> *In which area of activity (research, policy, social movement, education, etc.) do you see them happening?*
>
> *Does this potential breakthrough contribute to meeting any of the four challenges?* [i.e. FOOD2030 pillars]
>
> *Do you have another example of a potential breakthrough in R&I?* [system allowed for up to 3 breakthroughs]
>
> *In your opinion, what are the barriers and the incentives that will determine the successful implementation and application of these breakthroughs?*

A.3 References for potential R&I breakthrough topics

Inventory of topics and some general references per topic:

Breeding - New Techniques and applications
- New varieties of animal and plants: Aquaah G (2015).
- New genetic methodologies and new applications: Araki M (2015), Singh V (2017), Borlaug N (2000).

Smart farming
- Precision farming: Use of local data: Stepan I (2015).
- Precision farming: Use of global data: Wolfert S (2017).
- Applied mechatronics: Negrete JC (2015).
- Artificial intelligence applied.

Non-conventional production systems
- Hydroponics: Kledal PR (2018), Benton Jones J (2004).
- Vertical agriculture: Despommier D (2011).
- Intelligent cropping.
- Agroecology: Ferguson RS (2014).
- Permaculture: Krebs J (2018), Ferguson RS (2014).
- Organic awareness: Reganold JP (2016), Rahmann G (2016).
- Urban farming: Thomaier S (2014)

Reduction of impact of production enhances
- Biodiversity: Duru M (2015).
- New approaches to fertilizers: Timilsena YP (2014).
- New approaches to pesticides: Nicolopoulou-Stamati P (2016).
- New approaches to animal antibiotics: Franklin AM (2016). Hoelzer K (2018).

New value systems
- Business model for the primary sector: Bocken NMP (2015).
- Short value chains: Stevenson GW (2011).
- New models on developing countries (Microcredits, Crowd funding): Bruton G (2014), Short JC (2017).
- Social innovation relating to food production and distribution: Gibson-Graham JK (2008).

New aquaculture
- Advanced fish farms: Joffre OM (2017).
- New feeds: Tacon AGJ (2015).
- New on sea production with lower impact on nature.

Empowered consumer
- Innovation in social sciences: Phillips W (2014).
- Living labs: Gasco M (2017), Leminen S (2015).
- Optimised use of big databases: Hofacker CF (2016).
- Informed consumer: Chen CH (2018).
- Active and engaged consumer: Jimenez-Zarco AI (2015).
- Cocreation: Jaakkola E (2014), Frow P (2015).
- Due diligence: Howson P (2017).
- Value based food system: Galt R (2016).
- Domotics: Garroppo R (2016).

Change of dietary habits
- Awareness of healthy habits
- Reduction of targeted ingredients: Romagny S (2017).
- Reduction of targeted additives (clean label): Asioli D (2017).

New tools to improve nutrition and health
- Personalised nutrition: Ordovas JM (2018).
- Multi-Omics: Hasin Y (2017).
- Nutraceuticals: Mahabir S (2016).
- Functional foods: Mellentin J (2001).
- Human genome knowledge and application: Camp KM (2014).

New methods in education
- New models for education: Littleljohn A (2018), Domingo-Coscollola M (2016).
- Awareness of Food-system.
- Innovation and entrepreneurial behaviour: Briscoe G (2014), Van der Sar (2013).
- Guidance to Start Ups and SMEs.
- Open Science and Open Innovation concepts: West J (2014), Chesbrough H (2014).

Logistics - New systems
- Physical internet: Montreuil B (2011).
- Service "at the door at any time": Flint D (2005).

Smart traceability in the food supply chain
- Transparency and trust through the value chain: Yiannas F (2018).

A novel approach to biotechnology
- New biotechnological tools.
- New applications.

Information and Communication Technologies (ICT) applied to Food System
- Full exploitation of big data.
- Internet of Things.
- New sensors applied to multiple applications.
- Digitalisation of industry.

- Robotics: Iqbal J (2017).
- Augmented reality.
- Artificial intelligence.

Food Industry 4.0 - Novel and efficient food processing
- Mild processing: Barba FJ (2017).
- Low input technologies.
- New robotic applications: Iqbal J (2017).
- Nanotechnology: Gupta N (2012), Handford CE (2014), Huang S (2015).
- Integrated input-output responses.
- 3D Printing: Godoi FC (2016), Sun J (2015), Sun J (2015).
- Emulgation (membrane, microfluidisation, ultrasound): Fryer PJ (2008).
- Cutting tech (water-beam, laser, ultrasound): Fryer PJ (2008).
- Separation (membrane, adsorption technologies).
- Extraction (Hypercritical CO2).
- Heating (super-heated steam, microwaves, induction, sous-vide, radio-frequency).
- Preservation (IR, UV, radiowaves, pulsed electric fields, high pressure treatment, osmosis, cold plasma).
- Filling (Aseptic filling, clean room tech, super cooling).
- Packaging (see packaging breakthrough).

Sustainable packaging
- New materials: Han JH (2014).
- Biodegradable materials.
- New recycling methods.
- Reduction of package.

Diversity on the diet
- New models in the food system.
- New sources not fully exploited.
- New protein sources (biotechnology).
- Full exploitation of algae.
- Full exploitation of insects: Van Huis A (2013).
- Cultured meat: Alexander P (2017), Bhat ZF (2016), Post MJ (2017).

The global food analysis
- Higher efficiency, better detection, global standardisation, world food regulatory standards.

Circularity in food systems
- Reduction of waste (Zero waste).
- New uses of waste.
- New recycling business models.
- New structure in food system.

Efficient use of resources
- Efficient use of water.
- Efficient use of land.
- Efficient use of nutrients.
- Efficient use of energy.

Food for society
- Community driven social innovations: Capdevilla I (2015).
- Innovative public procurement.

- Social entrepreneurship (Atlas of Social Innovation[21]).
- Awareness of waste in social context.
- Trade norms (Dismissed fruits by shape or form).
- Do It Yourself: Domingo-Coscollola M (2016)
- Collaborative production.
- The European cultural food heritage: Brulotte RL (2016).

Policy and management within the food system
- Applying Responsible Research and Innovation: Dreyer M (2017).
- Improving the R&I Network.
- Public-Private transfer.
- Impact of Research and Innovation.
- Higher implementation of knowledge.
- Regional aspects of food system (Future Global Food Systems)[22].
- Food marketing and labelling – New approaches.

Other relevant non-specific information: Innovation with a purpose[23], FAO How to feed the World in 2050[24], Top 20 of the Royal Society[25]

[21] Atlas of Social Innovation: https://www.socialinnovationatlas.net/

[22] Future Global Food Systems: *http://www3.weforum.org/docs/IP/2016/NVA/WEF_FSA_FutureofGlobalFoodSystems.pdf*

[23] Innovation with a purpose: *http://www3.weforum.org/docs/WEF_Innovation_with_a_Purpose_VF-reduced.pdf*

[24] Food and Agricultural Organization of the United Nations (FAO) (2009). How to feed the world in 2050. Rome, Italy: FAO. http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

[25] Top 20 of the Royal Society: https://royalsociety.org/news/2012/top-20-food-innovations/

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