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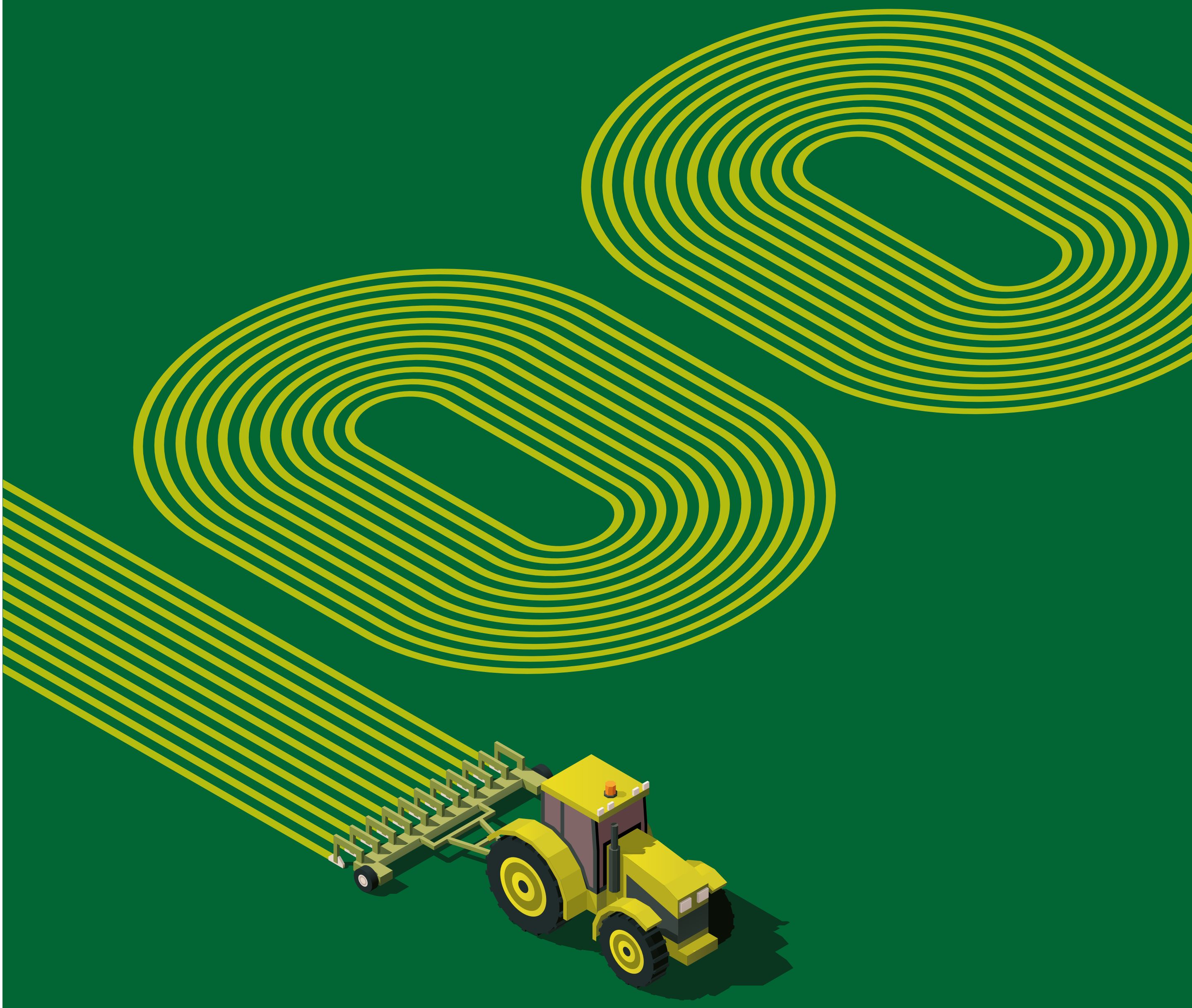
Innovation and knowledge transfer

January 2020



Research and knowledge transfer in the agrifood, forestry and fishery sector in Catalonia

Generalitat de Catalunya
Departament d'Agricultura, Ramaderia, Pesca i Alimentació

Rural Cat

Índex

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15 years - 100 *Dossiers Tècnics*

With the publication of this *Dossier Tècnic*, for which it is my pleasure to write the foreword, the Ministry of Agriculture, Livestock, Fisheries and Food (DARP) has reached the hundredth issue of this collection.

The *Dossier Tècnic* was created in 2005 as a monograph for the DARP to engage in strategic dissemination, in order to enhance agrifood, forestry, fisheries and the rural companies' knowledge of the research and innovation undertaken in universities, research centres and technology companies and by the Government itself. The last 15 years have seen the participation of 562 experts, 2,912 pages have been produced and 93 interviews have been published, in 462 articles characterised by scientific and technical precision, and the variety and broad-based nature of the subject matter covered, which has always been related to the specific needs of the various productive sectors.

The *Dossier Tècnic* published today, issue 100, showcases the work done on innovation and research and technology transfer in Catalonia in various areas: food, gastronomy, agriculture, livestock farming, fishing, forestry, tourism, climate change and biodiversity, among others. Catalonia has a great wealth of research centres, universities and other institutions that generate knowledge to develop and improve the agrifood, forestry and fisheries sectors, and the rural world and this *Dossier* highlights Catalonia's potential.

Society's challenges related to food in its broadest sense will require new knowledge and systems to turn those challenges into innovations in order to address those needs. To this end, we must exploit and reinforce our research, innovation and knowledge transfer system, while at the same time enhancing its transformational capacity for our sector.

The National Agreement on Food and the second Agrifood Research, Transfer and Innovation Plan will be the tools that enable us to meet the challenges of the twenty-first century, which will incorporate the values of the agrifood, forestry, and fisheries sector, and the rural world in general in Catalan society as a whole.

Finally, I would like to thank all those people who have contributed to the *Dossier Tècnic*, and who have made these 100 monographs possible. This milestone, which is a source of pride and motivation to continue doing our job well, has been reached thanks to their knowledge and dedication.

THE AGRIFOOD KNOWLEDGE AND INNOVATION SYSTEM IN CATALONIA

Knowledge and innovation play a key role in addressing the economic, environmental and social challenges facing the agrifood, livestock, fishing, forestry and rural sectors. That is why innovation is a cross-cutting priority for the EU's objectives, because it helps to create a more efficient, smarter and more sustainable sector.

A good innovation system must be able to turn knowledge into innovations in order to support society in the challenges it faces, and to improve the competitiveness of the productive sector.

Catalonia has an atmosphere that is ready for innovation, with a system that is rich, diverse and highly active in the generation and transfer of knowledge, and a productive fabric of small and medium enterprises and potential agents of innovation. These include universities, research centres, agrifood companies, consultants, professional organisations, producers' associations and clusters.

The DARP is committed to working towards an improved coordination and operation of the Agricultural Knowledge and Innovation System (AKIS), a concept used at a European level to describe how people and organisations come together to promote mutual learning, and to generate, share and use agricultural knowledge and information at national and regional levels.

01 A clear commitment to innovation in the agrifood sector in Catalonia

The Government of Catalonia has been making significant efforts in the research and innovation field for some years. It aims to boost the economy and generate wealth and added value through the creation of knowledge.

The Government of Catalonia's commitment to innovation in the agrifood and forestry sectors was reinforced by the creation of the Sub-Directorate-General for Agrifood Transfer and Innovation within the Ministry of Agriculture, Livestock, Fisheries and Food in 2000. Among other roles, this unit is responsible for implementing and monitoring policies, strategies, programmes and plans in the field of technological innovation, advising the agricultural sector and providing training in the agricultural and rural world, and particularly for coordinating:

· initiatives aimed at training for agricultural and livestock farmers and others working in rural areas and the dissemination and transfer of agrifood knowledge,
· increasing the recognition of innovative and entrepreneurial actions in agrifood, and
· agrifood research, transfer and innovation (R&T&I) and the definition thereof, as well as measures to promote R&T&I in agrifood companies and the natural environment.

Although the Catalan Research and Development System is a mature and productive system focused on excellence and productivity, the sector must be equipped with the knowledge that generates innovation and the tools that drive it. The DARP has been carrying out initiatives to promote innovation and to hasten the incorporation of the results of research for some years. These initiatives include:

Enhancing the value of the agrifood sector and improving the innovation system

Strategic planning and a model for governance and improvement of the ecosystem are key factors in adding value to the agrifood sector. For this reason, the Government of Catalonia approved the Catalan Strategic Plan for Agrifood Research, Innovation, and Knowledge Transfer 2013-2020 (Government Agreement GOV/85/2013 of 18 June, Official Journal of the Government of Catalonia 6401, 20.6.2013). Since then, the Plan has become the instrument which enables effective coordination of inter-ministerial R&D&I policies for Catalonia's agricultural, agrifood and forestry sectors, led by the Ministry of Agriculture, Livestock, Fisheries and Food. These policies are aimed at reinforcing and consolidating these sectors' competitiveness and sustainability, by means of high quality, integrative, effective and resource-efficient R&D&I.

The Catalan Council for Agrifood Innovation was established as the governance model of the R&D&I system, as a stable and permanent body for studying and implementing initiatives related to Catalonia's agrifood, forestry and rural sectors.

The Agrifood and Rural Innovation Network of Catalonia (Xarxa-i.cat) was created in order to improve knowledge transfer. This network is the main instrument for disseminating the results of agrifood innovative initiatives and projects, and its goal is to encourage collaborative work. It is Catalonia's branch of the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI), which is a major policy and networked initiative designed to accelerate innovation on the ground through the interactive in-

> The Government of Catalonia aims to boost the economy and generate wealth and added value through the creation of knowledge.

novation model, which is based on collaboration between the various agents in the system and identifying the needs of the end users. The EIP-AGRI is the European instrument that enhances Agricultural Knowledge and Innovation Systems (AKIS).

Promoting the generation of knowledge

The Government of Catalonia has invested heavily in research and generating a critical mass to create an economy in which knowledge is one of the main assets.

Catalonia has a network of research centres and universities with levels of scientific production in agrifood among the highest in Europe.

The DARP is committed to generating knowledge, and to that end, it promotes and supports research centres to make them into scientific benchmarks and engines of innovation and technology transfer by means of their national positioning and international profile, the valorisation and commercialisation of their results, their attraction and administration talent, and their operational efficiency and continuous improvement.

Mobilising resources

The DARP race considerable investment in financing R&D&I activities. During the 2018 financial year, it allocated more than €28 million of its own funds to R&D&I activities and their dissemination and transfer, as well as supporting agrifood companies and other organisations to make them more efficient and active in attracting competitive funds.

Within Catalonia's Rural Development Programme (RDP) 2014-2020 the DARP manages a line of grants amounting to 17.6 million euros (DARP-EAFRD co-financing) aimed at supporting the creation and implementation of operational groups in the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI).

Operational groups are comprised of agricultural and forestry companies, processing industries, research centres, universities and other agents in the agrifood and rural sectors, working together in the field of innovation to solve a specific problem or take advantage of an opportunity. The aim is to foster cooperation between the various agents, and to build connections between the sector and universities and technology and research centres. The DARP has approved a total of 172 projects in annual calls since 2015, with 771 companies participating.

Promoting the culture of innovation in the agrifood sector

One of the key factors to make companies in the agrifood sector internalise the culture of innovation is training as a force for change and progress, enabling progress towards a knowledge-based society.

A wide range of training related to the agrifood, forestry and rural sectors is available in Catalonia, in a network of 14 agricultural schools providing intermediate and advanced-level vocational training courses for different professional groups. Continuous training courses are also available for professionals who are already working and who want more in-depth or updated learning. The number of students at DARP agricultural schools in initial and continuous training in 2018 was 750 and 8,742 students, respectively.

Meanwhile, the DARP also promotes innovation in the sector by other means, including the Food Innovation Awards (PITA), the Ruralapps Awards and the Food and Agriculture Innovation Mornings, among others.

> Training is one of the factors with a key role in internalising the culture of innovation for companies in the agrifood sector.

The Food and Agriculture Innovation Mornings are social seminars for those involved in a specific field or sector to help them to discover, focus and define research, innovation and knowledge transfer activities. These seminars have been running for over 10 years, and have taken place on 24 occasions and been attended by around 1,400 people.

Knowledge transfer

The DARP acts as a driving force and facilitator of knowledge transfer through various channels facilitating the transfer and dissemination of knowledge, including the Annual Technology Transfer Plan (PATT), demonstration activities, RuralCat and Technical Dossiers, among others.

The PATT is a tool used by the DARP that has been operating for over 17 years, and it has become the leading programme in Catalonia for organising technical seminars for the agrifood, forestry, fisheries and rural environment sectors. This programme is based on networking: it involves more than 120 promoter organisations, and a thousand annual collaborations. More than 2,500 presentations have been presented over the last year, at more than 710 technical seminars attended by around 30,000 people.

Demonstration activities are a line of grants from the 2014-2020 RDP, endowed with 5 million Euros (co-financed by the DARP and European Agricultural Fund for Rural Development) and support the transfer of technical and management knowledge adapted to the territorial conditions of Catalonia's agriculture, livestock farming, forestry and food sectors, by carrying out demonstration activities such as demonstration projects, experimental plots, pilot plants and facilities, test fields and demonstration routes. Universities, research centres, technology centres and/or TECNIO centres and organisations linked to universities engaged in research are eligible for these grants.

The RuralCat portal, which was created by the DARP in 2002, provides tools and services to incorporate ICTs into the rural, agrifood, forestry and fisheries world, and uses the latest technologies and enhances the sector's competitiveness and connectivity. It is designed to be a website with content and services aimed at the professional sector, which adds value to the country's productive fabric, responds to the sector's shared interests and needs, and above all encourages innovation and knowledge transfer and participation by professionals. The website contains various sections, including news, reports, technical documents, courses, seminars, tools providing support in decision-making (irrigation, phytosanitary warnings, etc.), virtual offices (oil, fertilisation, irrigation, the agrifood industry, plant health, etc.), distance learning (online) and a community of users which currently consists of about 40,000 professionals in the sector.

The Technical Dossier is a monographic DARP publication covering important aspects of agriculture, livestock farming, food, fishing, forestry and the rural world, which is produced with the participation of experts from the Government, universities and research centres and the sector. With this issue, we are celebrating the publication of 100 Dossiers.

Advising the sector

The DARP is committed to an advisory model that integrates the technical structures into a network of organisations providing advice for agricultural entrepreneurs as a means to improve the productive model of the Catalan agricultural sector. This network has become a platform for cooperation between the various agents in the sector.

02 Conclusions

The Government of Catalonia, through the Ministry of Agriculture, Livestock, Fisheries and Food, contributes through research, innovation and knowledge creation to Catalonia's agrifood, livestock farming, forestry and fisheries sectors' competitiveness, and boosts the economy by generating wealth and added value.

Future initiatives and tools in the agrifood research, innovation and transfer system in Catalonia will increase the impact of projects between the sector and the country, and identify strategic challenges and future goals, including bioeconomics, climate change, digitalisation, etc., which are key factors for the economic, social and sustainable development of companies in the sector.

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THE CATALAN RESEARCH SYSTEM. The agrifood sector

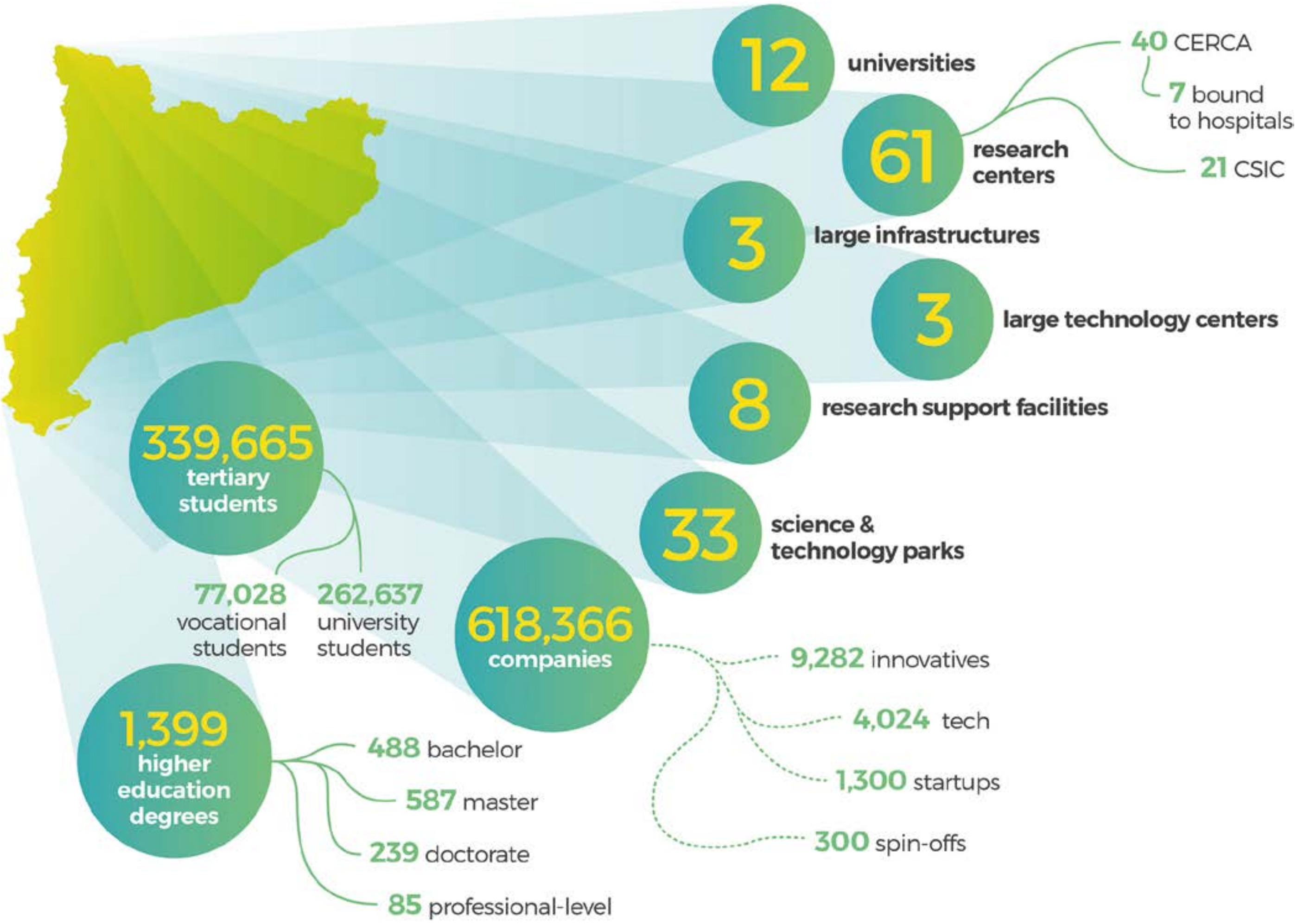

Figure 1. *The Catalan research system. Source: Secretariat for Universities and Research (SUR).*

01 The Catalan research system. An overview

Research systems are multidimensional and contain many variables, as well as being highly complex. They can be described based on the agents involved, and how they interact with each other. One possible model[1] is the "knowledge triangle", which contains three main groups:
· Knowledge generators,
· The business sector, and
· the Government.

In Catalonia, the knowledge generators consist of universities, research centres, technology centres, major research infrastructures, hospital institutions, science and technology parks, reference networks and research groups. The business sector is made up of the R&D departments of companies. The Government sector, which acts as a catalyst and facilitates research and knowledge transfer, consists of the ministries and departments of the different levels of government bodies.

Catalonia has been designing its research and innovation system model since the late 1990s, and the three main priorities of its R&D policies have been to attract and retain renowned researchers, to support universities, to create and consolidate its own research centres model, and to establish large research infrastructures. This model has improved Catalonia's position in European and global terms.

Public research and innovation policies are implemented at various institutional levels (basically the Government of Catalonia, Spanish Government, local government and the European Commission). The Government of Catalonia launched the first Catalan Research Plan (1993-1996) which laid the foundations for scientific policy in 1993, and the first Research and Innovation Plan was formulated in 2005.

Specific policies in the agrifood sector include the Catalan Strategic Plan for Agrifood Research, Innovation, and Knowledge Transfer 2013-2020 (PRITAC), which coordinates interdepartmental policies on research and innovation aimed at the agricultural, agrifood and forestry sectors in Catalonia. Other plans include the Annual Technology Transfer Plan (PATT) by the Ministry of Agriculture, Livestock, Fisheries and Food (DARP).

The Catalan Strategic Plan for Research, Innovation and Agrifood Transfer means that inter-ministerial policies can be coordinated in the area of research and innovation aimed at the agricultural, agrifood and forestry sectors of Catalonia.

Other comprehensive Catalan agreements and strategies have been established over the years, including the Catalan Agreement for Research and Innovation (2008-2020) and the Research and Innovation Strategy for the Smart Specialisation of Catalonia (RIS-3CAT 2015-2020).

The country's future involves the Catalan Knowledge Society Agreement (PN@SC), the Catalan Science Act and the Emerging Companies, Technology and Disruption Act. The PN@SC, which is currently being drafted, is an Agreement to design a joint strategy that involves higher education, research, innovation and the productive economy in order to build the Catalonia of the future, where one of the main goals is to have a percentage of knowledge-intense activities comparable to leading countries.

02 Research in the agrifood sector

If the knowledge triangle is applied to R&D in the agrifood sector, the role of knowledge generators is played by universities, research centres and technology centres, which basically fulfil the role of supply.

The institutional sector of the Government of Catalonia, as the body facilitating research and knowledge transfer in the agrifood sector, basically consists of the Ministry of Agriculture, Livestock, Fisheries and Food, which is the main actor involved, with the Ministry of Business and Knowledge (DEMC) – through the Secretariat for Universities and Research (SUR) and the Agency for Business Competitiveness (ACCIÓ) – which works on a cross-disciplinary basis in all knowledge areas.

Finally, the role of the "consumer" of the knowledge generated in the agrifood R&D system is played by agricultural and agrifood companies, which can also be knowledge generators.

In specific terms, the knowledge generators are:

· Public and private universities. All the public universities and two private universities carry out research in the agrifood field, although some do not have a specific department in this area.
· CERCA research centres. There were 40 CERCA centres in 2017, of which 5 are in the agrifood field (IRTA[2], CTFC[3] , CREAF[4], CRAG[5] and Agrotecnio), and 13 have knowledge with great potential for the sector (see fig. 3).
· TECNIO Agents. Through ACCIÓ, the Government of Catalonia provides the TECNIO seal accrediting Catalan institutions which develop and provide technology for SMEs and companies to make them more innovative and competitive. These technology developers include universities, research centres, technology centres, and (private) technology-based companies. The facilitators include technology transfer offices. There are currently 67 TECNIO developers, of which 40 work in areas of interest to the agrifood industry, according to the RIS3CAT classification. They include 4 CERCA centres (IRTA, CVC[6], CTTC[7], i2CAT[8]), 4 technology

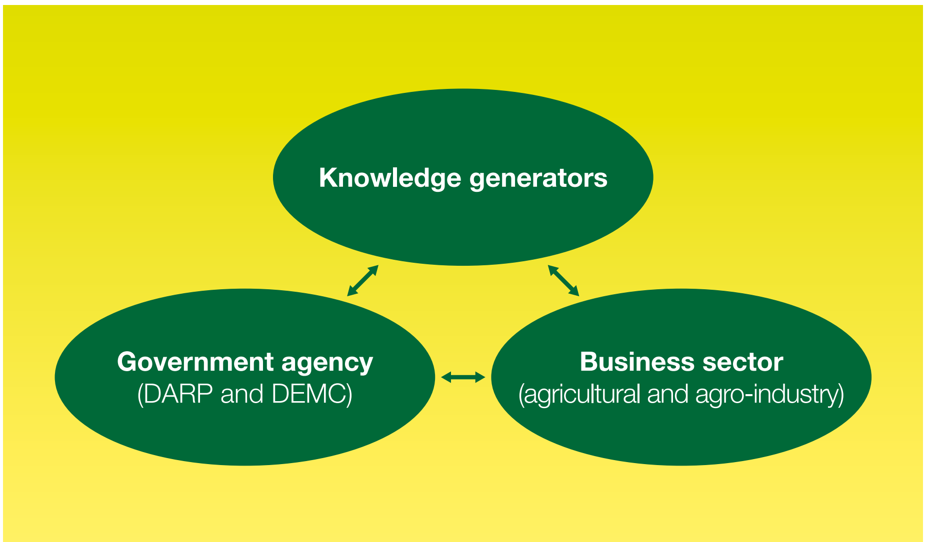

Figure 2. *Knowledge triangle for the agrifood research system in Catalonia. Source: PRITAC (DARP).*

centres (Eurecat, Leitat, CTQC[9] and ICSuro) and 3 technology-based companies. The others are groups and institutions directly affiliated to universities.

· Spanish National Research Council (CSIC) Centres in Catalonia. The Institute of Marine Sciences is a CSIC centre. There are also 3 CERCA centres working with the CSIC, which have already been listed above.

The following sections describe the current situation in the sector, highlighting various aspects of research done by knowledge generators in the agrifood field.

02.01 Excellence in R&D personnel

· The Government of Catalonia's ICREA programme has a major impact on the recruitment of talent, and on the quality, quantity and impact of research results. There were 254 ICREA researchers in 2017, nine of them carrying out research in the field of agrifood. Five of them work at universities, three at CERCA centres and one at a CSIC centre.

· The European Research Council (ERC) awards grants to researchers to carry out high-risk, ground-breaking projects that contribute to surpassing the boundaries of knowledge. A very large number of researchers at Catalan centres have received a grant since its inception in 2007. In fact, Catalonia is the fourth-ranked country in the number of ERC grants per capita, behind Switzerland, Israel and the Netherlands. Between 2007 and 2017, 285 grants were awarded to researchers at Catalan institutions. Five of these researchers work in agrifood, three at universities, one at a CERCA centre and one at a CSIC centre.

02.02 Scientific production

Publications are one of the main instruments for disseminating R&D within the scientific community. The latest figures available for scientific production in the agrifood sciences come from a study[10] carried out by the FCRi using the WOS database[11]. According to this study, 13,262 papers involving researchers from Catalonia working in the field of agrifood sciences were published between 2012 and 2016, and these accounted for 16.4% of the total for Catalonia.

The normalised impact[12] of the publications in Catalonia's agrifood sector was 12% higher than the international average. As for excellence, i.e. publications that are cited extensively and have a significant influence within their discipline, 289 of these publications were included in the 1% most commonly cited in the world in this period. There was also a high level of international cooperation, which amounted to 54% during the period, with a maximum of 60.4% in 2016.

As a whole, according to the analysis carried out by the FCRi, agrifood research is active, has an impact and meets scientific excellence goals, with high rates of international collaboration.

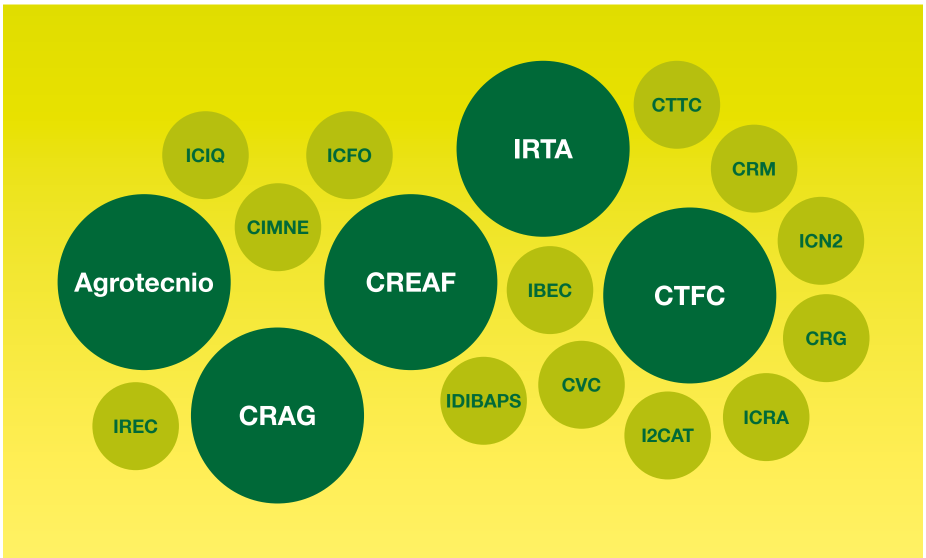

Figure 3. *CERCA centres in the agrifood field[14] or with potential knowledge for the sector. Source: own research.*

02.03 Universities and research centres

02.03.01 Research groups

The Government of Catalonia recognises and supports research groups in Catalonia in order to foster their activity and scientific, economic and social impact, and to enhance their international profile, through the call for applications for "Research group support grants (SGRs)". The groups belong to Catalonia's universities, research centres and hospital foundations whose main activity is research.

Altogether, 108 research groups working mainly in the agrifood field out of a total of 1,744 groups[13], received recognition in the "Life Sciences 1" knowledge area in the last call (2017-2019).

02.03.02 Universities

Training available

The first step in generating knowledge is the courses available at universities. There were 79 qualifications available in the field of agrifood[15] in the 2017-18 academic year, which accounted for 7.07% of the total. In specific terms, 50 bachelor's degrees and 29 master's degrees were offered. The University of Lleida (UdL) and the University of

Barcelona (UB) offer the most courses, and the UdL has the highest percentage in comparison to its total number of qualifications, at 20.8% in the 2017-2018 academic year.

A total of 10,818 students registered for university courses[16] related to agrifood in the 2017-18 academic year, accounting for 4.4% of the total number of students. The universities with the most students in absolute terms in this field are the UB, the Autonomous University of Barcelona (UAB), UdL and the University of Girona (UdG).

Of all the theses read in the 2017-18 academic year, 177 [17] were in the agrifood field, accounting for 8.6% of the total.

Networks and collaborations

One way to quantify the collaboration between knowledge generators in the agrifood field and other agents in the R&D system, and collaboration with companies in particular, is by means of the source of funding obtained to carry out R&D projects through contracts and/or agreements with companies and institutions rather than through competitive calls (Table 1).

Valorisation of technology.

Spin-offs, companies created by researchers, and industrial protection are two of the mechanisms that knowledge generators can use to add economic and social value to their technology and research results.

The figures for public universities are as follows:

· There were 7 spin-offs in the agrifood field in 2017, accounting for 5.6% of the total number of spin-offs.
· Between 2010 and 2017, 64 of the patents resulting from public universities were applied in agrifood, of which 22 were priority applications[18]. Patents in the agrifood sector accounted for 4.81% of priority applications and 6.32% of the total number of patents applied for (table 2).

02.03.03 CERCA centres

As mentioned above, there are five CERCA centres in the agrifood sector, and 13 others with knowledge which has great potential for the sector. These centres are shown in Figure 3. The largest circles are the leaders in the agrifood sector.

Expenditure on R&D at CERCA centres based on the socio-economic objective[22] "Development of agriculture, livestock, forestry and fishing" amounted to almost €50 M in 2016[23], which is 11.1% of the total research expenditure by all CERCA centres.

It is important to note that in addition to this socio-economic objective, some of the research for the agrifood sector also takes place as part of the "Production and industrial technology" socio-economic objective, but no figures for the agrifood sector are available for this objective.

Sector	The agrifood sector		All areas		% of the agrifood sector compared to all areas	
	Amount (€)	Focus Contracts and/or agreements	Amount (€)	Focus Contracts and/or agreements	Amount (€)	Focus Contracts and/or agreements
Private sector [19]	7,139,406.07	1,981	45,267,739.4	8,583	15.77%	23.08%
All sectors	11,562,586.43	2,113	72,937,394.5	11,841	17.84%	17.84%

Table 1. *Source of funding through contracts and/or agreements for public universities in Catalonia. 2017. Source: Own research based on UNEIX (SUR) data.*

	Priority rights patents			Total patents		
Patent territory	The agrifood sector	All areas	% agrifood of the total	The agrifood sector	All areas	% agrifood of the total
Spain	8	324	2.47%	8	337	2.37%
EPO [20]	10	95	10.53%	17	187	9.09%
PCT [21]	1	17	5.88%	13	178	7.30%
Total	**22**	**457**	**4.81%**	**64**	**1.012**	**6.32%**

Table 2. *Patents in the field of agrifood applied for by public universities. 2010-2017. Source: Own research based on UNEIX (SUR) data.*

Further reading

RIS3CAT Strategy (2015-2020).
http://catalunya2020.gencat.cat/ca/ris3cat/

National Knowledge Society Agreement PN@SC
http://empresa.gencat.cat/ca/intern/pnsc

PRITAC
https://ruralcat.gencat.cat/web/guest/xarxa-i.cat/pritac

iCERCA
http://cerca.cat/

TECNIO
https://www.accio.gencat.cat/ca/serveis/innovacio/tecnologia-per-a-lempresa/tecnio/

ERC
https://erc.europa.eu/

NABS socio-economic objective:
https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=CL_NABS07&StrLanguageCode=EN&StrLayoutCode=HIERARCHIC&IntPcKey=

MÉNDEZ-VÁZQUEZ, R.; SUÑÉN-PINYOL, E. (2018) "Mapa de la recerca en ciències agroalimentàries, 2012-2016" ["Map of agrifood science research, 2012-2016"]. Observatory of the Catalan Foundation for Research and Innovation (FCRi), Barcelona, December 2018. Available for download at:
https://ruralcat.gencat.cat/documents/20181/2734255/20190625_Mapa+de+la+recerca+en+Agroaliment%C3%A0ria+definitiu1.pdf/2aff6ef2-490e-4095-b622-58ede0d99f47

Footnotes

[1] Other models also include citizens as one of the agents.
[2] Institute of Agrifood Research and Technology.
[3] Forest Sciences and Technology Centre of Catalonia.
[4] Centre for Ecological Research and Forestry Applications.
[5] Centre For Research In Agricultural Genomics.
[6] Computer Vision Center.
[7] Telecommunications Technological Center of Catalonia.
[8] Internet and Digital Innovation in Catalonia.
[9] Chemistry Technology Centre of Catalonia.
[10] Agrifood sciences research map, 2012-2016. *Méndez-Vázquez, Raúl; Suñén-Pinyol, Eduard.* Observatory of the Catalan Foundation for Research and Innovation (FCRi), Barcelona, December 2018.
[11] WOS:Web of Science.
[12] Citation average compared to the international benchmark or normalised impact: an indicator that measures the impact of publications by means of the number of citations in other publications, compared to the international average.
[13] Source: Agency for Management of University and Research Grants.
[14] IREC: Catalonia Institute for Energy Research, ICIQ – Institute of Chemical Research of Catalonia, ICFO – Institute of Photonic Sciences, CIMNE – International Centre for Numerical Methods in Engineering, CRM – Centre for Mathematical Research, CRG – Centre for Genomic Regulation, IDIBAPS – August Pi i Sunyer Biomedical Research Institute, IBEC – Institute for Bioengineering of Catalonia, ICRA – Catalan Institute for Water Research.
[15] Including: Physical anthropology, animal biology, botany, economics, sociology and agricultural policy, agricultural edaphology and chemistry, agroforestry engineering, cartographic, geodesic and photogrammetric engineering, landscape engineering, hydraulic engineering, plant physiology, animal medicine and surgery, microbiology, nutrition and bromatology, animal production, plant production, animal health, food technology, environmental technologies, toxicology and zoology.
[16] Includes bachelor's degree and master's degree students only.
[17] Includes theses for doctoral programmes in the European Higher Education Area (EHEA).
[18] Includes companies and private NPO in Catalonia and Spain (i.e. institutions with their own tax identity number). NPO: nonprofit organizations.
[19] When a patent application is filed in different territories, the one filed in the first territory is designated as priority patent.
[20] EPO: European Patent Office. Currently includes 38 countries. For more information, see https://www.epo.org/about-us/foundation/member-states.html
[21] PCT: Patent Cooperation Treaty. Currently includes 152 countries. For more information, see https://www.wipo.int/pct/en/pct_contracting_states.html
[22] The NABS economic objective classification is an OECD classification used for the analysis and comparison of budgets and scientific programmes. https://ec.europa.eu/eurostat/cache/metadata/Annexes/gba_esms_an1.pdf
[23] Latest data available as of the date of publication of this article.

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NEW KNOWLEDGE VALORISATION MODELS: collaboration between start-ups and corporations

01. Business innovation is speeding up

The advent of new technologies in recent years has seen exponential growth at a global level. One of the main indicators that enables us to determine the volume of new technologies which are appearing is directly related to the number of patent applications worldwide.

The number of annual patent applications worldwide has increased as much in the last 15 years as it did in the previous 120 years.

According to the latest report by the WIPO (the *World Intellectual Property Organization*) in late 2018, the number of patent applications worldwide currently stands at over 3 million. To understand this figure, we must put it in the context of its evolution over time. The Paris Convention of 1883 marked the beginning of the modern patent system, and the number of patent applications worldwide stood at around 1.5 million per year just 15 years ago. In other words, after the Paris Convention, it took 120 years to reach 1.5 million patent applications, and only another 15 years to reach 3 million (Fig. 1).

This upward trend is apparent in the figures for the top 5 patent offices worldwide (Fig. 2). The direct relationship between patents and exploitation in a particular market shows how these markets are evolving, and trends in terms of the specific importance of various economies.

These figures throw up some questions:

· What is the effect of this avalanche of technologies on business innovation?
· What would be the most efficient way to turn new technology into business opportunities?

The vast array of new technologies available is leading to the emergence of business models which are sometimes disruptive and which were impossible only a few years ago, and this is changing the rules of the game of innovation. As a result, new products, new processes and new services are appearing that come into direct competition with existing ones, with the consequent shortening of the life cycles of new products and gre-

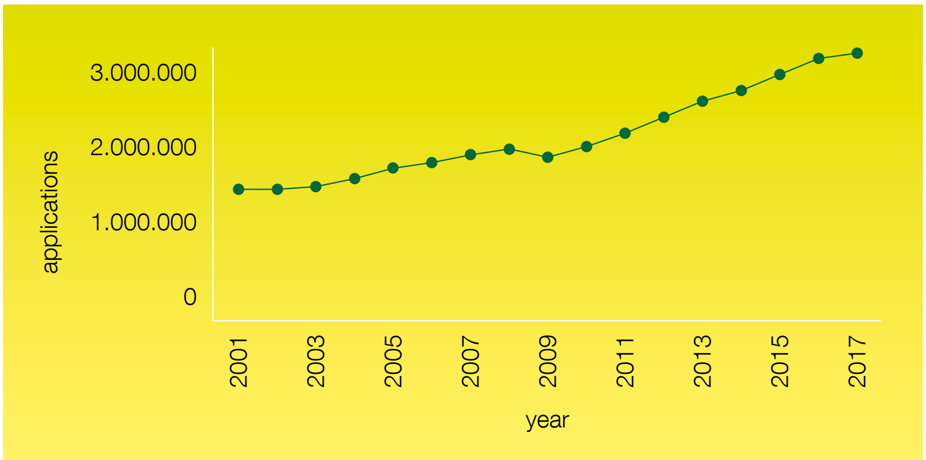

Figure 1. *Patent applications worldwide in recent years. Source: WIPO.*

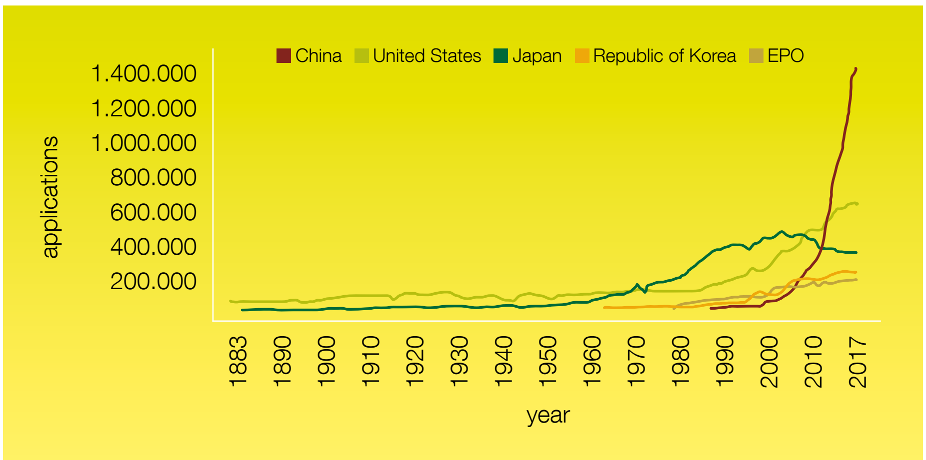

Figure 2. *Patent applications by office. Source: WIPO.*

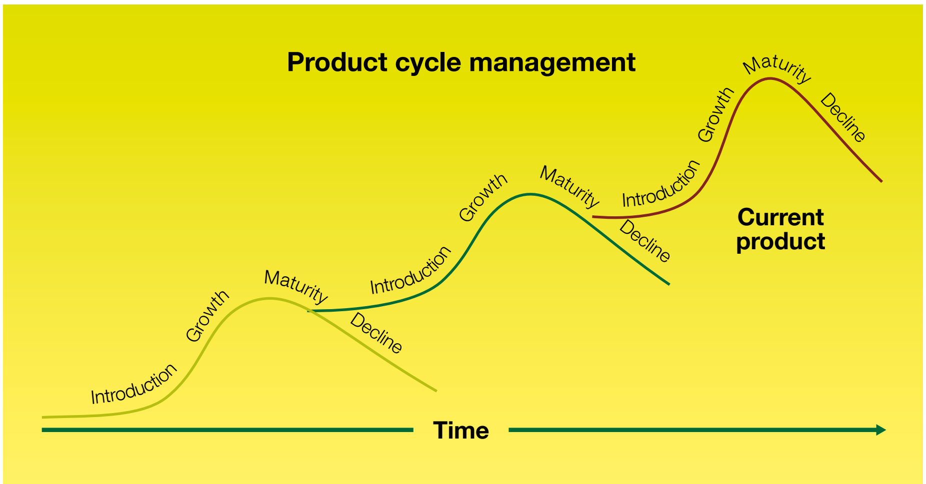

Figure 3. *Shortening of products' life cycles. Source: ACCIÓ.*

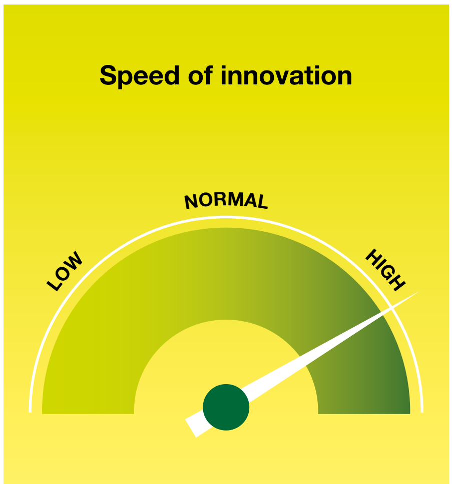

Figure 4. *Faster rate of innovation. Source: ACCIÓ.*

ater pressure on companies to innovate more quickly (Fig. 3 and Fig. 4).

In order to increase the pace of innovation within an organisation, the research and development and innovation department needs to overcome the limitations imposed by internal resources, and look outwards and seek ways of cooperating with various sources of knowledge that are external to the company. This applies to all sectors, but it is particularly important in the digital and high technology sectors, where the pace of innovation is very fast and the increase in new knowledge transcends their boundaries. Companies' competitive advantages will be determined by their ability to establish and maintain successful partnerships. Open innovation must be promoted in the era of the Fourth Industrial Revolution.

Recent studies show that executives in large companies are under pressure to launch new products much more quickly, and this pressure is largely driven by the need to defend themselves against smaller, newer businesses: start-ups.

The distinguishing features of start-ups are:

- They are recently established.
- They are scalable, with a high potential for growth.
- They have an ambitious and highly committed entrepreneurial team.
- They have a high level of technology and risk.
- They focus on a global market.
- They are highly adaptable to changes and new trends.

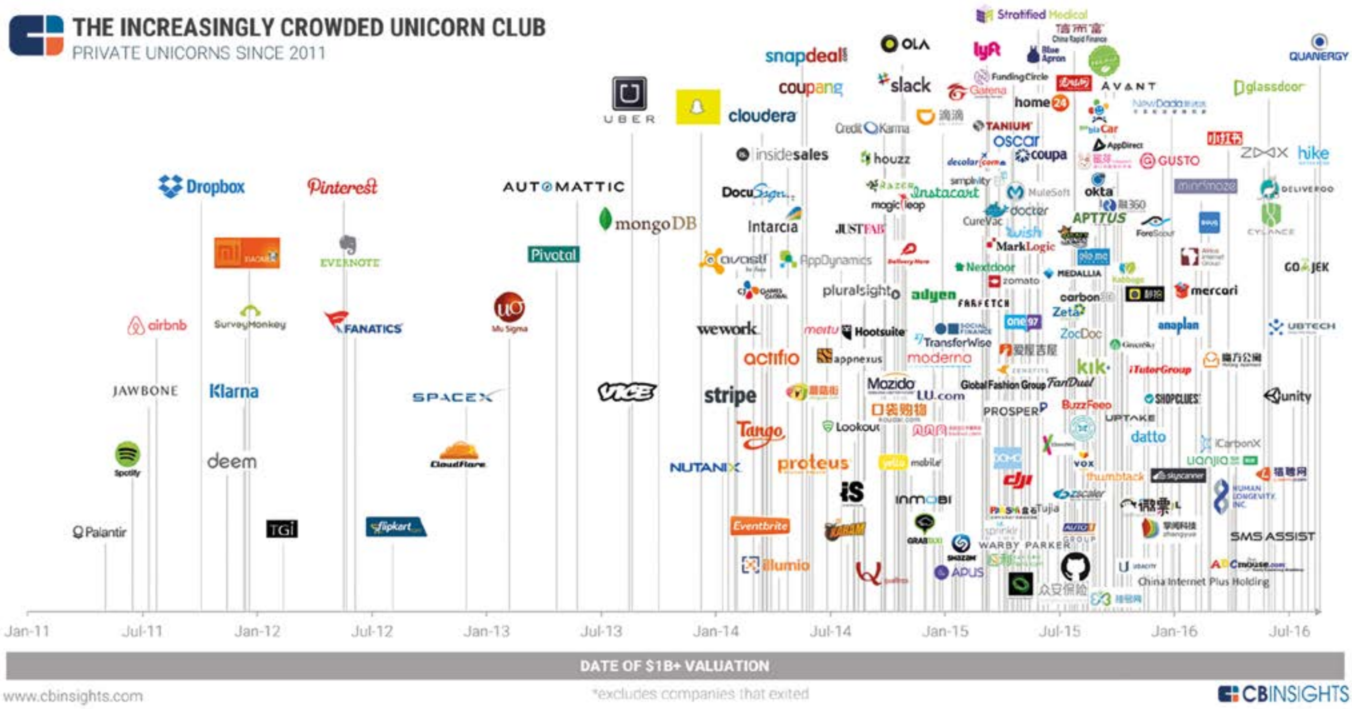

Figure 5. *Emergence of unicorns with a capitalisation of over 1 billion USD. Source: CBInsights.*

These companies have been attracting attention from investors all over the world in recent years. For example, investment in start-ups in Spain increased from just over €500 M in 2016 to more than €1.2 bn in 2018. This is also apparent internationally, in the figures showing how the number of unicorns (high scalability technology start-ups valued at over USD 1 billion) has skyrocketed in just a few years (Fig. 5).

02. Collaboration between corporations and start-ups

In a world in which technology and business models are changing rapidly, companies that are able to work successfully with start-ups are much more likely to survive the disruption in their business and maintain their competitive advantage in the long term.

Start-ups have become the ideal means to bring more disruptive innovation to the market.

Companies have always established collaborative relationships with customers, suppliers and strategic partners to create joint ventures, but working with start-ups means defining new relationships that are tailored to their characteristics.

Various types of collaborations have emerged as a result, which depend on the resources committed by each party involved (Fig. 6).

The relationship between a corporation and a start-up is a beneficial one for both parties: start-ups find visibility and market access particularly useful, while corporations highlight access to new markets and the incorporation of disruptive technology (Fig. 7).

Although collaboration between corporations and start-ups is not always straightforward, it is far more risky to do nothing and ignore opportunities. Corporations must explore the best ways of collaborating, depending on their goals. However, there are some standard recommendations for improving their chances of collaborating successfully.

For corporations, being organised internally is very important for facilitating a relationship with a start-up. This may include defining a single point of entry for the start-up, having people who are aware of its dynamics who act as a link with the business units, simplifying and standardising contract documents as much as possible, fast-tracking client-supplier agreements, and being very clear about issues related to intellectual property rights.

For start-ups, the recommendations are as follows: having a good understanding of the corporation's needs and the benefits it can bring, being realistic about planning, not concentrating all their relationships in a single corporation, and knowing when to end the collaboration.

03. How is Catalonia coping with this new type of innovation?

On the one hand, there is an ecosystem of start-ups basically located around Barcelona, which has now matured. This is confirmed by a figure

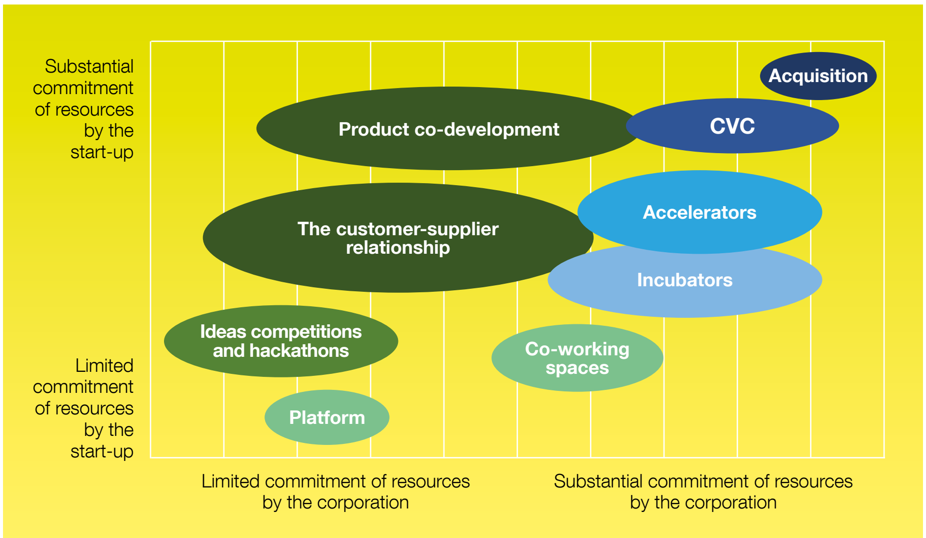

Figure 6. *Possible types of collaborations between corporations and start-ups. Source: ACCIÓ.*

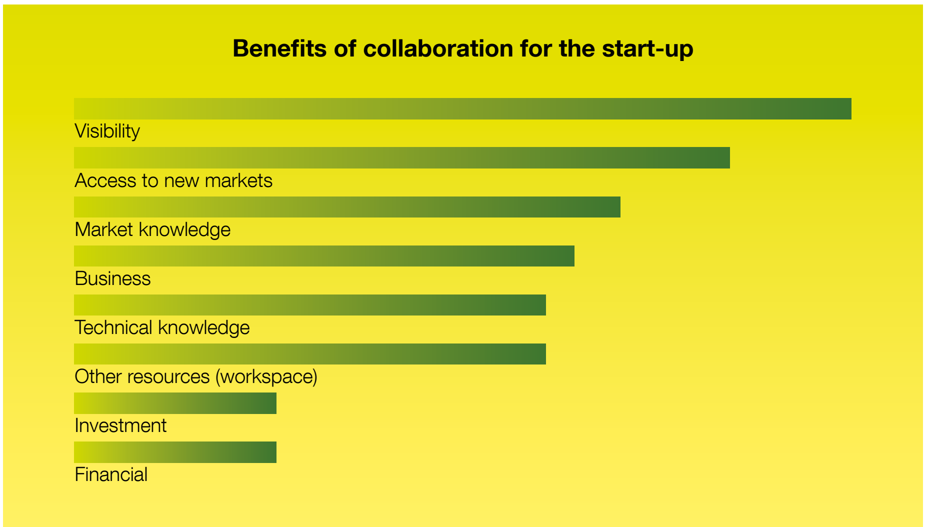

Figure 7. *Benefits from the point of view of the start-up. Source: ACCIÓ.*

Figure 8. *Companies that are promoting collaboration with start-ups. Source: ACCIÓ.*

for the investment received: Catalan start-ups attracted €871 million in investment rounds in 2018, making Barcelona the fifth ranked European city in terms of money raised, and accounting for approximately 2/3 of the total investment in Spain.

Almost nobody in medium and large Catalan companies was talking about collaboration with start-ups only 5 years ago, and the few people who were thinking in those terms were generally considering it as a financial investment or a social responsibility programme. More than 100 Catalan companies now have measures in place in their innovation strategy aimed at promoting this type of collaboration (Fig. 8).

The process these companies have followed has been quite similar in all cases:

- In the first phase, the company becomes aware of the opportunity to speed up their innovation processes that this kind of collaboration provides. The unconditional support of the company's general management is essential in this phase.

- An action plan is then defined, which must be fully aligned with the company's strategy. There is no "one size fits all" plan that works for every company. Rather, each company must define its own plan, based on its needs and the value proposition that it can offer the start-up.

- The next step is to implement this action plan, and the most important factor is the involvement of the various areas of the company, in order to identify the most significant challenges and to redefine the internal processes that will facilitate the relationship with the start-up and the effective integration of projects.

- Finally, the start-up identification phase begins, in which measures to connect the company with the local and international start-up ecosystems are important.

Companies acquire knowledge and experience which leads to change in organisations throughout this process. Companies are adopting the methodologies used by start-ups for their own internal management processes, involving concepts such as design thinking, agile methodologies, lean start-up and customer discovery are now part of corporate language, as is the design of entrepreneurship programmes to enhance the existing talent in the company, and to speed up its internal innovation projects.

In conclusion, given the need for corporations to innovate as quickly as possible, the characteristics of start-ups make them the ideal vehicle to bring the most disruptive innovation to the market, and partnerships between companies and start-ups are here to stay as a result.

Partnerships between corporations and start-ups as a mechanism to accelerate innovation are here to stay.

Further reading:

www.accio.gencat.cat
www.wipo.int
www.cbinsights.com

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SUSTAINABILITY OF THE AGRIFOOD SYSTEM

01. Introduction

Global demand for agricultural products, driven by a growing world population, new uses and aims in agriculture (biofuels, biofarma, CO_2 absorption) and improved living standards in many emerging economies means that continuous increases in agricultural productivity are necessary. At the same time, environmental sustainability is increasingly important. This article is an extensive summary of a scientific article published[1] by researchers at Agrotecnio[2], a Government of Catalonia CERCA Institute[3] centre, located on the Agrifood, Forestry and Veterinary Campus at the University of Lleida. It examines the challenges affecting the various components of food, feed, raw material and value chains, and discusses how technology can help solve these problems. It also discusses Agrotecnio's strategy for addressing local and global food challenges. We emphasise the need for translational and multidisciplinary research to establish links between the various areas of food and feed production, including primary production systems, the environment, food processing and distribution, nutrition and health. In order to

Multidisciplinary research is needed, which establishes links between the various areas in the agrifood chain in order to transfer the basic science to the productive sector.

Genotypes of bare grain barley for human consumption, segregated by colour and type of starch, with high content of betaglucans and phenolic compounds. Photo: Healthy Barley group, Agrotecnio – Aula Dei Experimental Station, CSIC – Semillas Batlle, Agrotecnio.

Bare grain and purple barley (anthocyanins), high in beta-glucans and phenolic compounds for human consumption. Photo: Luis Cistué, Healthy Barley group, Agrotecnio – Aula Dei Experimental Station, CSIC – Semillas Batlle.

consider the importance of the ability of Agrotecnio's R&D&I to address these challenges, let us briefly consider some aspects of the socio-economic importance of Catalonia's agrifood system[4]. It accounted for 4% of Catalan GDP in 2018, if we take the primary and industrial processing sectors into account. The latter amounted to 18.6% of Catalan industry, was ranked third in terms of exports, and with 70,000 companies, was the industry that provided the most jobs.

02. Sustainability of Agricultural Systems

Agriculture is the human activity that uses domesticated living organisms to produce the food, feed, fibres, fuels and raw materials needed to maintain the human population. Agricultural systems are natural ecosystems which have been transformed to varying degrees of intensity, and therefore depend on the environment. Sustainable agriculture is a general strategy that promotes the use of agricultural technology and agricultural practices to maintain or increase productivity without depleting or irreversibly damaging natural resources (such as soil, water, climate and biodiversity). Agricultural output is determined by potential productivity and limited by abiotic and biotic stresses. Agricultural research aims to improve productivity by increasing crop potential and reducing the impact of stress, either directly (by crop management) or indirectly (by making crops more tolerant, mainly through crop improvement). This requires research of a more agronomic nature to be integrated with related disciplines such as soil science, crop physiology, plant improvement, biotechnology, engineering and management of pests, diseases and weeds. The conservation, restoration and improvement of water and soil resources are essential for ensuring sufficient yields. Proactive soil management is needed to stop and reverse soil degradation and avoid the need for chemical fertilisers. Between 200 and 600 m³ of water are needed to produce 1 kilogram of dry biomass, depending on the crop. The availability of water is a major limitation on productivity in both dry farming and irrigated crops. Crop management strategies that promote efficient use of water and its retention in the soil are vital. In recent years, increased agricultural productivity has been reflected in a simultaneous rise in the environmentally unsustainable use of pesticides. Weeds, pests and pathogens severely restrict agricultural productivity and lead to a loss of about half the potential crop, despite the widespread use of chemicals. Research on new control methods has therefore focused on understanding the causes of infestations, and trying to replace conventional pesticides with biological and genetic methods. The challenge now is not the limited long-term effectiveness of pesticides, but instead understanding why agricultural pests exist, and using this understanding to manage them more effectively.

> Now more than ever, we need to develop efficient and sustainable agricultural practices, and standardise them across the value chain.

03. Sustainability of Livestock Farming Systems

Intensive livestock farming is becoming increasingly important in both developed and emerging economies as the demand for meat and dairy products increases, and this demand is projected to double by 2050. Further research is needed to enable the livestock sector to meet the growing demand for animal products while at the same time contributing to reducing poverty, and to food security, environmental sustainability and human health. In fact, the problem of slurry is probably the most significant environmental problem arising from agriculture in Catalonia. The sustainability of livestock production in the context of global climate change, population dynamics and the quality of the agroecosystem is a subject of heated debate. A uniform approach to sustainability is unlikely to be successful, because livestock systems differ widely in terms of their intensity and their efficiency in using resources. Before 1950, most animals were raised on diversified small farms with access to pastures. Since the industrialisation of agricultural production, traditional livestock farming has been replaced by an industrial model that reflects the increase in cereal production, more efficient transportation, and other technological developments. Animal production has also become more specialised. Large agricultural farms focusing on just one phase of production have replaced farms involved in all stages of production. These changes have improved efficiency and productivity, food quality and ethical standards for animal welfare, while reducing the footprint of livestock production and encouraging the adoption of new technologies.

> Research is required to enable the livestock sector to meet increasing demand while simultaneously contributing to food safety, environmental sustainability and human health.

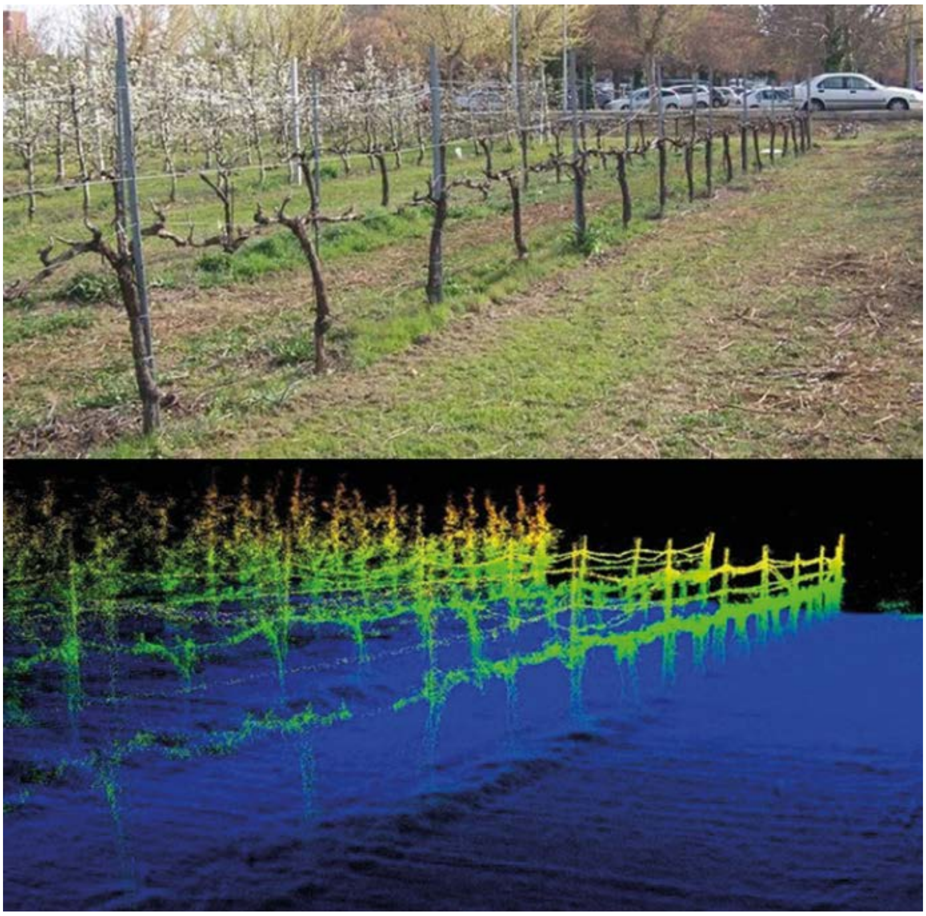
04. Sustainability and agro-industry

The sustainability of agriculture and manufactured foods is more important to consumers than ever before. However, as the global demand for processed foods increases to meet the needs of the growing population and rising living standards, the consumption of global resources such as energy and water is rising at an alarming rate. Sustainability can only be ensured by reducing the green footprint of food production and processing by a more rational use of resources, reduced waste production and by seeking new uses for by-products. This is a major challenge for industry, but it can also be considered

Consumers now demand natural, healthy, safe, high-quality and nutritious products, made from processed raw materials and using environmentally sustainable methods.

If we wish to continue maintaining and increasing productivity, today's challenges must be addressed more holistically, integrating research throughout the entire food production and processing chain.

an opportunity for reducing energy consumption, increasing the efficiency of the process and improving the quality of processed foods. This drive towards greater sustainability involves accepting key principles in order to provide the foundations needed to meet food security goals. These include an integrated farm-to-table approach, transparency, applying risk-benefit analysis, and introducing preventative measures throughout the entire food chain.



Experimental plot scanned at high resolution with a georeferenced LiDAR system. Photo: AgròTICa Agrotechnics and Precision Agriculture group, Agrotecnio.

05. The need to integrate research throughout the food production and processing chain

According to a study by the Economic Research Service of the United States Department of Agriculture, the average increase in global agricultural productivity in recent decades (of around 2.5% per year) has made a transition from being based primarily on increased inputs to improving Total Factor Productivity (TFP), which is closely related to the application of knowledge. In the decade between 1961 and 1970, in the middle of the Green Revolution, TFP only accounted for 0.2% of increased productivity, compared to the annual figure of 1.8% due to new varieties and the use (and abuse) of fertilisers and other agrochemicals. The continuous and responsible application of knowledge has led to a drastic change in these figures in the current decade. The annual figures are now 1.7% for TFP and only 0.4% due to the increase in inputs, which are falling significantly in the most industrialised countries according to the latest OECD reports.

No area of the food production and processing chain operates in isolation, which means that any decision at any level has a wider impact. Livestock production has an impact on agricultural production and environmental pollution, but good practices can mitigate those impacts. The environment has an impact on plant health and food security. Developing crops with better nutritional properties (e.g. higher levels of vitamins, minerals and antioxidants) not only makes processed foods healthier and more nutritious, but also protects the crops themselves from microbes and fungi, while reducing the problem of mycotoxins in the field and in storage. An improved understanding of the thermodynamic and kinetic aspects of the behaviour of crop nutrients and contaminants can help improve agronomic practices and reduce damage to the environment, while increasing the quality and nutritional value of food. The links between the different areas of the food chain are also important in creating a productive and sustainable balance with other agricultural economies. We need to understand the interactions between these component parts, and to ensure that technologies are used to maximise yields, protect the environment and minimise waste, while maintaining nutritional quality and food safety.

06. Addressing local and global agrifood challenges: Agrotecnio

Agrotecnio focuses on the major challenges in the Agriculture – Environment – Food – Health nexus. First, it promotes the adoption of sustainable agricultural systems that are more efficient in production, optimising the use of resources, and reducing the impact of pests, diseases, and weeds and other emerging threats. Second, it develops and promotes more efficient innovative systems in the food chain with higher end-use quality and improved links in primary production, processing, nutrition and health. These challenges are directly linked to three objectives which have been identified as critical for the coming decades (sustainable intensification, efficient food processing and health and nutrition). Agrotecnio works in seven activity areas (AA): (1) Creating new high-value plant and animal genotypes for industry/society; (2) Developing improved agricultural and livestock farming systems; (3) Producing new integrated systems for pest management and animal disease control, using cutting-edge technologies; (4) Reducing pollutants/waste in the environment and end products; (5) Using emerging food processing technologies to create valuable products for the industry and the consumer; (6) Developing and implementing new food safety programmes; and (7) Acquiring high-value, innovative, functional foods.

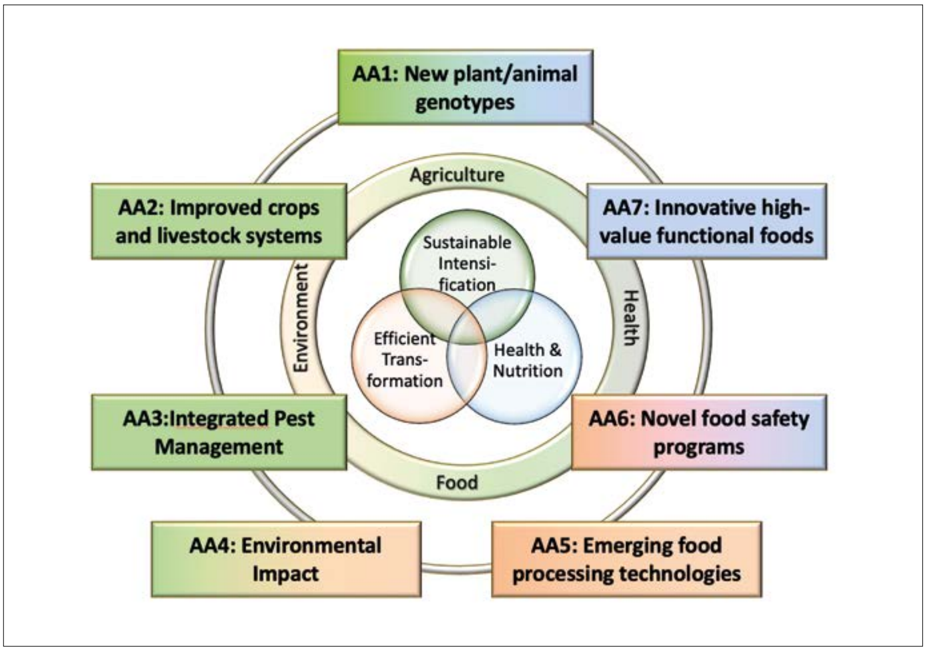


Figure 1. *Agrotecnio's strategic objectives (circles at the centre of the figure) and areas of activity (rectangles on the outside) at the Agriculture – Environment – Food – Health nexus. Source: own research.*

Pigs in a Duroc line with high intramuscular fat and oleic acid content. Pork loin with different proportions of subcutaneous and intramuscular fat content. Photography: Animal Genetic Improvement group, Agrotecnio.

Is Agrotecnio's strategy for meeting agrifood challenges the right one? The American Academies of Science, Engineering, and Medicine have just released a consensus report on the research needed to address the food and agriculture challenges of the coming years. They identified five strategic areas enabling recommendations to significantly improve the capabilities of agrifood research and development to be made. Despite the vast socio-economic distance that separates the Catalan and American agrifood sectors, these recommendations are not unrelated to the strategic policy adopted by Agrotecnio. The first recommendation focuses on the need for multidisciplinary agrifood research to address very complex agrifood issues. Determining the nature of the interactions that take place between the various elements in agrifood systems is essential for finding holistic solutions to food and agricultural challenges. The second recommendation focuses on developing, validating and using sensors and biosensors to monitor various agricultural and food activities on farms and

Agrotecnio is in an excellent position to successfully meet the challenges of agrifood R&D&I in and for the sector.

in the food industry. The third recommendation is related to generating value associated with the increased amount of readily available digital data. The development of agrifood computing and the recording and integration of large volumes of data in artificial intelligence must lead to a more accurate analysis of production conditions, in order to optimise the management of food and agricultural systems. Some of the disciplines recommended in the United States, such as using new genomic tools, do not have the same potential for our agriculture due to the European legal framework, as the report recommends genetic editing for precise and rapid genetic improvement of productivity and quality. Other disciplines have no restrictions in the European Union, including high-performance genotyping and phenotyping tools able to evaluate hundreds of genotypes, which can accelerate the selection of favourable individuals for improving productivity, resilience and tolerance to stress, for example. The latest strategic focus is on studying the microbiome of animals, plants and soils in order to understand their importance in improving agricultural production. A better understanding of the molecular interactions between soil, plant and animal microbiomes could revolutionise agriculture by improving the structure of the primer, increasing feeding efficiency, nutrient availability, and enhancing resistance to stress and disease.

07. Conclusions

The research needed to meet agrifood challenges must be based on a holistic understanding of the interactions between all the components in the food chain, to ensure that cutting-edge technologies are implemented to maximise yields, protect the environment and minimise waste, while maintaining the nutritional quality and safety of food and feed. Agrotecnio is a relatively young centre, but its experience in these fields is internationally renowned.

Further reading

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[3] http://cerca.cat/

[4] https://web.gencat.cat/es/actualitat/detall/Catalunya-a-lAlimentaria

[5] FUGLIE, K. and RADA, N., (2013). "Growth in global agricultural productivity: an update". (USDA Amber Waves No. 1490-2016-128359) https://ageconsearch.umn.edu/record/212282/files/http---www_ers_usda_gov-amber-waves-2013-november-growth-in-global-agricultural-productivity-an-update_aspx__VkY64CH5SMz_pdfmyurl.pdf.

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NEW IDEAS IN LIVESTOCK FARMING

Xisqueta sheep. Photo: EA Vallfogona de Balaguer.

01. Introduction

Livestock farming has played a key role in humanity's development and its well-being. As part of the Sustainable Development Goals (SDG), in 2015 the UN General Assembly reaffirmed the importance of challenges that remain significant for livestock farming today and in the future, including: sustaining the productive base and its competitiveness; food sovereignty; production models; animal welfare; reduced antibiotic use, food safety, environmental impact. The major challenge for the future of livestock farming is to find a means of sustainable growth that will feed the population in a way that is responsible and safe but also efficient, making it accessible to everyone. Some of the innovations we believe will help us meet those challenges are outlined below.

02. New tools in genetic improvement

A wide variety of new technologies for genotyping and sequencing the genome of different livestock species have emerged in recent years. Almost all the species used in livestock farming now have commercial chips that can examine thousands of *single nucleotide polymorphism* genetic markers quickly and cheaply, and sequencing platforms will soon enable complete genomes to be sequenced at a cost below the psychological barrier of four digits. This all creates a massive source of information that is being used in both genetic research and in innovation and transfer.

The impact of genomics (mass genotyping) on livestock in intensive sectors such as dairy cattle, pigs, and poultry is now beyond any doubt. In fact, it is ten years since the first selection programme to use genomic information was launched in the milk industry in the United States, and improved genetic progress and reduced the impact of inbreeding on the cow population. This technology is now also being rolled out to other less intensive sectors, such as the Latxa breed of sheep, and will become the standard technique for most breeds in the near future. The falling costs of genotyping processes and the ability to incorporate an increasing amount of information from the animal's genome will define the near future of genetic selection programmes for livestock species and the conservation of endangered breeds.

The major challenge for the future of livestock farming is to find a means of sustainable growth that will feed the population in a responsible and safe way.

The ability to characterise the genome of domestic species means that it is possible to identify the mutations responsible for both genetic diseases (early detection) and morphological patterns (meat conformation) and physiological patterns (resistance to heat stress) patterns in animals. Examples include the dominant red factor in Friesian cows, the presence of A2 beta-casein in the milk from various breeds of dairy cows, some mutations that cause embryonic mortality in pigs, and the recent discovery of a hyperproliferation mutation in the Rasa Aragonesa breed of sheep. Genomic engineering techniques, which are still in the experimental phase use this information to add, delete, modify and replace specific and delimited regions of the animal's genome. This method has created pigs resistant to the PRRS virus and cows with low levels of susceptibility to tuberculosis, although a great deal of work remains to be done before these animals can be used conventionally on commercial farms.

However, the variability observed in domestic livestock populations also comes from other intermediate biological levels. For this reason, the future of genetic research must involve considering genes (the genome) and the morphological and productive characteristics of interest in livestock farming (the phenome), and integrating information about the genes that are expressed (the transcriptome), the proteins that are produced (the proteome), the metabolites found at a given point in time (the metabolome), and any other external influences (e.g. the microbiome determined by the microorganisms present in the various parts of animals' anatomies) and internal factors (e.g. the epigenome, understood as temporary or permanent modifications of the genome and its expression). Taken together, these factors will create new opportunities for knowledge, with direct implications for the production, health and well-being of our animals.

03. SmartFarming. Smart livestock farming or precision livestock farming

Precision livestock farming is a recent technological innovation, involving precise measures and monitoring of production processes, including: a more efficient use of raw materials (sensorisation of productive parameters such as ingestion and live weight), reduced environmental impacts (sensorisation of environmental gases), improved traceability and food safety, and optimised animal health and welfare (automatic activity detection systems for oestrus, lameness and births, and early indicators of illness). Many of these

Monitoring of disease indicators in bullocks using automatic activity systems. Photo: Lorena Castillejos.

applications use electronic identification and radio frequency. The variables to be measured could be all those related to the resources used in livestock (food, water, area), production (milk, weight, eggs), health (temperature, lameness, coughing), behaviour (activity, fighting, rumination, rest) and environmental factors (temperature, humidity, air velocity, toxic gases). For example, several studies have shown how ruminal boluses can be used with temperature and pH sensors, in addition to external sensors, to optimise feeding conditions. Collars with GPS locators are available, as are drones that locate grazing animals on the ground (cattle, sheep, and goats), determine their activity (distance travelled), and create virtual enclosures. When an animal is not mobile or leaves the previously defined virtual enclosure, it creates an alarm that enables corrective measures to be taken.

Both the facilities and the handling have a significant effect on animal welfare. Photo: Xavier Manteca.

Falling costs of genotyping processes will define the short-term future of genetic selection programmes for livestock species and the conservation of endangered breeds.

In short, precision livestock farming means that animals can be monitored continuously and in real time, in order to take immediate action in the event of a problem and to analyse data for use in future decisions. The automation and integration of technology in livestock farming means that intensification will be compatible with sustainable and environmentally friendly growth that respects animal and human welfare. However, the implementation, adaptation and validation of technology for livestock farming must be studied to make it economically profitable, together with the valorisation of data and its processing using computational tools to enable decision-making.

04. Animal welfare at the core of our work

Improving animal welfare contributes to increasing productive efficiency and animal health in most cases. Precision livestock farming is a critical tool for identifying changes in behaviour, and predicting stress situations before they occur. There is increasing evidence to suggest a relationship between animal welfare and the risk of disease (e.g. due to associated stress). The effects of good management, feeding and animal welfare on a possible direct reduction in the use of antibiotics in livestock need to be studied, and their effect on animal health and their relationship to the immune system must be considered.
The effects of climate change on animal production and behaviour are crucially important, as these have an impact on the animals' physiology and welfare (e.g. body temperature, heart and respiratory rate, immunocompetence), their nutrition (e.g. nutrient and water needs), product quality (e.g. milk and cheese, eggs), and their behaviour.

Another area that needs to be studied in the field of livestock farming is animal consciousness, in order to distinguish the animal's conscious behaviour at an early age from the automatism acquired as a result of environmental restrictions. This knowledge will enable us to modify and improve the management and welfare of animals in livestock farming.

Improving animal welfare contributes to increasing productive efficiency and animal health in most cases.

05. New tools for discovering the microbiome

The gastrointestinal microbiome plays a key role in animals' food efficiency and health, as evidenced by its effect on the immune system,

Selective grazing in sheep by conditioned aversion. Photo: Elena Albanell.

among other areas. Molecular techniques such as 16s rRNA sequencing and bioinformatics mean we can identify microbial mechanisms and/or markers and study them in depth. In the near future, we will also be able to comprehensively describe the genes that microorganisms express in the animal (the transcriptome), which will help to understand their role in animals' digestion, reproduction and health.

In the future, these microbial markers may give us the ability to select animals which are more efficient when using food, or which are healthier, or which have a more effective immune system. Understanding the microbiome may also enable us to modify the profile of the microbiota, using prebiotics, probiotics, symbiotics, organic acids, enzymes, and phytogens to benefit the animals' health, welfare and efficiency.

06. The circular economy and sustainability as a principle for reduced environmental impact

Grazing herds in natural and arable areas continues to provide wealth for the livestock farming system and the balance needed in conservation of the landscape and the natural environment. We now have positive experiences that show that it is possible to use conditioned aversion strategies to train sheep and goats so that they graze on the grassy cover in vineyards and olive groves. Now more than ever, we need to think about the identification, characterisation and valorisation of the new by-products created by the agrifood industry which can be used for animal feed and can be incorporated safely, and focus our efforts on sustainable animal production based on reusing resources and reducing waste. The food industry has also created numerous enzymes, which can also be incorporated into feed as additives to improve the use of fibre and protein (carbohydrases), and plant phosphorus (phytases). They can be used to design formulas that meet the animals' needs, and which reduce the environmental impact of their excretions.

Acknowledgements

This review is a collective contribution by our colleagues Joaquim Casellas, Lorena Castillejos, Elena Albanell and Gerardo Caja.

Now more than ever, we need to think about the identification, characterisation and valorisation of the new by-products created by the agrifood industry

Further reading

https://www.uab.cat/web/recerca-1345750254756.html

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CATALONIA'S FORESTS: our green infrastructure as an engine of bioeconomics

Landscape in the agroforestry mosaic. Photo: CTFC.

01. Catalonia's forests

Catalonia has approximately 2 million hectares of forest, which amounts to 62% of the country's total area; densely wooded forests (with at least 20% of cover on the ground) occupy 47%. The vast majority of our forest systems are located in a Mediterranean climate, characterized by hot dry summers and cold winters, with the factor of altitude also playing an important role in their environmental conditions. These environmental conditions also need to be placed within the current context of climate change. Of the total, 77% are privately owned forests, and the rest are publicly owned. Forty per cent of our forests have a forest planning instrument, which is either a technical plan for forest management and improvement or a management plan (Catalan Forest Observatory, www.observatoriforestal.cat). About 300,000 hectares are certified by the Programme for the Endorsement of Forest Certification. Despite these figures, we only manage 30% of the total forest area, while the average figure for management in Europe is around 60%. As a result, the densely wooded forest area has increased by more than 13% over the last 40 years, and the volume of standing timber has tripled.

> Catalonia's forests are our great green infrastructure, which provides multiple goods and services.

Catalonia's forests are also our major item of green infrastructure, which provides multiple goods, services and functions which are strategic for the country, enabling us to: offset about 10% of anthropogenic CO_2 emissions, produce various wood and non wood products and services (e.g. cork, hunting, wild mushrooms, biofuels and renewable energy...), conserve biodiversity (40% of the total forest area belongs to the Natura 2000 network), regulate the water cycle, improve air quality, etc. It is also necessary to consider biotic risks (pests, diseases) and abiotic risks (wildfires, droughts, storms, etc.) which are an increasingly important factor due to global change (climate change, new diseases related to imports). Another important issue is the breadth of agroforestry mosaic landscapes (see photograph on previous page), which is important for both preventing fires and for preserving and improving biodiversity.

The La Borda Cooperative Housing Building, Barcelona. Made with CLT (cross laminated timber) pine. It is currently the tallest wooden building in Spain. Photo: INCAFUST, CTFC.

02. Resilience

The increasing impacts and growing complexity of global change mean that forests must play a new strategic role in promoting socio-ecological resilience in Europe. In a highly urbanised Europe, where cities account for 80% of the population and energy use, urban forests, green spaces and solutions based on wood and other renewable materials such as cork and natural fibres are essential for developing climate-smart and environmentally friendly cities (Hetemaki) *et al.*, 2017). A better understanding of the principles of forest resilience is required, in order to determine how the impacts of climate change and disturbances affect forests, and the role forest management plays in conserving biodiversity and regulating the water and air cycle and protecting soil. This all requires new interdisciplinary research linking the sciences of forest management, forest ecology, and other land-use disciplines, to lay the foundations for effective integrated urban and rural land management policies.

03. Bioeconomics[1]

For the past 200 years, we have relied on a fossil-based economy which has given us unprecedented economic and demographic growth, as well as technological development and social prosperity. However, this has created environmental and social challenges that endanger the well-being of present and future generations (Hetemaki *et al.*, 2017). Preserving a sustainable future requires a paradigm shift so that we can continue to enjoy nature and its heritage within the confines of sustainability that the planet can offer us. We need to rethink the economic model, and to move from a linear economy based on fossil fuels to a circular bioeconomy.

In this context, we must take the current state and situation of our forests into account in this context. Despite the efforts by the Government and many stakeholders in the sector (owners' associations, industries, forestry workers, etc.) forests are often unprofitable, and increasingly vulnerable to the risk of major forest fires and other disturbances (pests, diseases, winds, snowfall, avalanches, etc.). In addition, the goods and services provided by our forests are often underused. A quick diagnosis of the main reasons for the current state of our forests in Catalonia is as follows: (1) the high degree of fragmentation (there are more than 200,000 owners in Catalonia, and many properties are under 5 hectares in area; this is a challenge for implementing uniform landscape management); (2) topographic variations and limited infrastructure (a lack of forest paths) leading to high costs in implementing sustainable forest management; (3) Around 90% of the wood and cork is used to produce important but low value-added products (bioenergy, packaging) which barely cover the costs of administration; (4) other products, such as mushrooms/truffles and pine nuts can attract high prices, but are currently subject to unclear regulation and insufficient traceability (with no return to the owners of forests). As a result, the primary forestry sector only accounts for 0.03% of Catalan GDP, whilst all the economic activities in the forestry chain account for around 1.7% of the total number of Catalan workers employed in the forestry chain (Fig. 1; Catalan Forest Observatory, www.observatoriforestal.cat). Meanwhile, the number of workers employed in forestry also declined significantly as a result of the crisis between 2008 and 2014, which aggravated the overall situation.

We still have a great responsibility and work to do as a society to improve these factors and integrate them into the Catalan economy, regenerating rural areas, creating employment and diversifying agricultural incomes, etc. To that end, we must make a firm commitment to bioeconomics, in order to make it a real and tangible tool for implementing policies and measures that improve people's well-being and the management of the territory, and connecting value chains in industrial sectors that are strategic for the country, in the fields of construction, food, mobility and health. We must create a strong and balanced link between the economy of Barcelona and its metropolitan area and the rest of Catalonia.

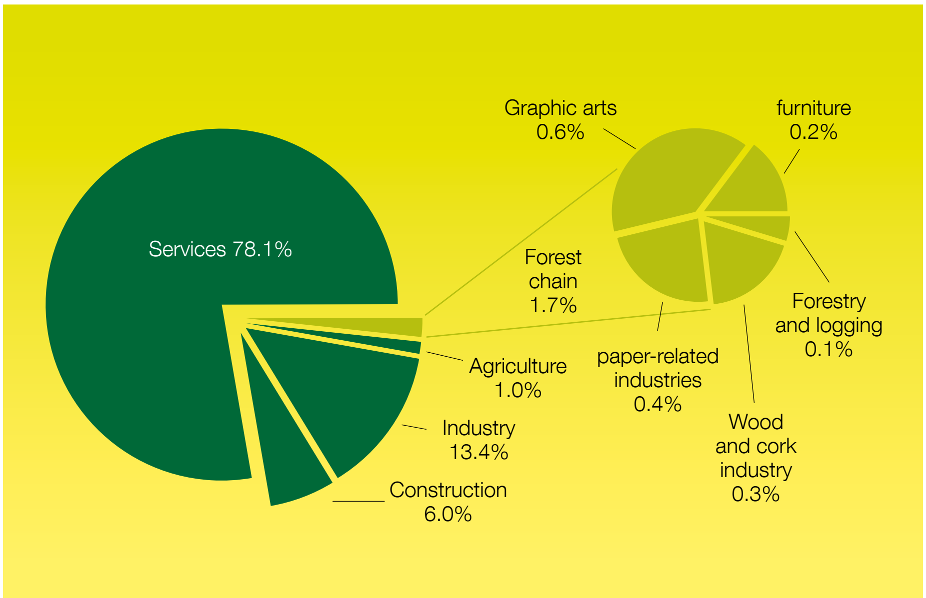


Figure 1: *Segmentation of the forest value chain in Catalonia.*
Source: Catalan Forest Observatory (OFC), CTFC. http://www.observatoriforestal.cat/

The CTFC team, the institution's offices in Solsona and the auditorium. Photography: CTFC.

The CTFC's mission is to contribute to the modernisation and competitiveness of the forestry sector, to rural development and to the conservation and sustainable management of the natural environment.

04. The role of the CTFC

The Forest Science and Technology Centre of Catalonia (CTFC) has been working to enhance knowledge of our forests, to conserve the natural environment, reinforce the forestry sector by means of the connection between the territory, the sector and industry, and to promote innovative value chains for more than 20 years. The institution is attached to the Government of Catalonia. It belongs to the CERCA network of centres, and is also a TECNIO Agent. It has also been an OTRI (Research Results Transfer Office) since 2009. The CTFC group also includes INCAFUST (the Catalan Wood Institute) and the spin-off FBS (Forest Bioengineering Solutions) that works to valorise the knowledge of the technical and scientific teams working at the CTFC, and to focus their results towards the market.

The institution has a staff of around 100 people (of whom 41% are doctors). It has an annual budget of around 6 million euros and has been responsible for more than 1,000 R&D&I projects, more than 700 publications listed in the Science Citation Index, more than 1,000 conferences aimed at professionals in the sector, 47 doctoral theses read, 7 strategic collaborative international research units (the University of Chile, Switzerland, Canada and the European Forest Institute) and 2 research groups recognised by the Government of Catalonia in the SGR Research Groups Support call. It has been behind the foundation of several institutions and sectoral associations over the last 20 years (INCAFUST, GEIE-Forespir, ACPPAM, Biomass Cluster, etc.).

Likewise, and in order to offer a high quality service, the CTFC has quality management systems (ISO 9001 in some laboratory processes, ISO 14001, Eco-Management and Audit Scheme (EMAS)), an Equal Opportunity Plan (EOP) and has received Human Resources Excellence in Research (HRS4R) recognition from the European Commission.

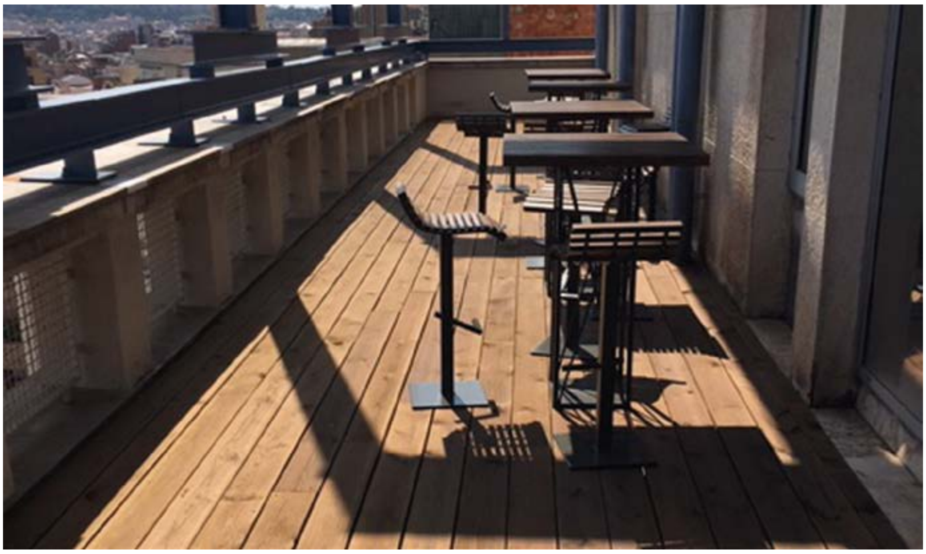
How do we meet this challenge? By taking advantage of synergies at an internal level in three major Work Programmes (Multifunctional Forestry Management, Landscape Dynamics and Biodiversity, and Bioeconomics and Governance), while aligning our 2019-2025 strategy with other consolidated international research agendas, such as the agenda of the European Forest Institute (EFI), and working on a coordinated basis with other public and private institutions at local, national and international levels.

Key concepts in the CTFC research strategy

The CTFC has adopted the general research strategy proposed by the EFI, and uses its general framework to work in more specific areas, and mainly on Mediterranean forests, with a particular focus on Catalonia and Southern Europe.

Strategic goals:

· Cutting-edge forestry research and innovation in Europe.
· Science-based policies to address the challenges and opportunities facing society.
· Raising social awareness of the importance of forests.



Pilot Test: street furniture (tables and stools made from Scots pine timber (Pinus sylvestris) from forests in the Alt Urgell region (owned by the Government of Catalonia) installed at the DARP and registered as a utility model. Photo: CTFC.

Black truffle (Tuber melanosporum). Photo: CTFC.

Knowledge transfer, R&D&I and the CTFC

Through the three CTFC Work Programmes: Bioeconomics and Governance, Landscape Dynamics and Biodiversity and Multifunctional Forest Management, and through its spin-off Forest Bioengineering Solutions (FBS), focused on developing new market-oriented advanced technology products and services, and with INCAFUST. In all these areas, the institution is actively working to promote knowledge transfer, making it into tangible products that help us to boost, connect and give tools to the Catalan forestry sector to improve its competitiveness, and to manage the territory sustainably in the current context of climate change.

Examples of these products include: patents, utility models, brands, software to support decision-making in forestry planning and management, manuals and guides for best forestry practices, production in combined agroforestry systems, truffle cultivation technology, ORGEST forest management guidelines, categorisation of the main species of wood in Catalonia (uses and applications), seminars to transfer results within the PATT and other knowledge transfer channels, in-


Technification of cultivation and production of combined agroforestry systems as an alternative to income diversification, Montant de Tost (Alt Urgell). Photo: PAM Group, CTFC.

cluding European thematic networks and transfer projects such as Life, Interreg, demonstration projects and DARP operating groups, etc.

05. Challenges

Managing our forests in a time of change means that the role of research, planning and innovation is more important than ever. The synthesis and contextualisation of scientific knowledge are crucial for supporting science-based policies and decisions that address challenges and opportunities of the present and the future.

In this context, the CTFC's overall strategy is based on three interdisciplinary and interconnected areas: bioeconomics, resilience and governance. Within these three areas, its vision is focused on "A world where forests make a significant contribution to sustainable well-being."

Forests, the conservation of biodiversity and the environment, forestry and the forestry sector are an essential part of European bioeconomics, and the main factor contributing to climate change mitigation. The speed and extent to which forestry bioeconomics is implemented on a European scale depends on a number of critical factors, including: technological and market developments inside and outside the forestry sector; the international dynamics of supply and demand for biomass; the European and international regulatory framework; globalisation, the digital economy and synergies with other sectors (construction, chemicals, textiles, energy, etc.) and the ability to manage forests on a sustainable basis.

Meanwhile, the dynamics of the supply and demand for water, food, energy, raw materials and land will be drastically altered in the near future, as a result of global change and the need to make the transition to a circular bioeconomy. Resources will become increasingly scarce, and conflicts related to obtaining them will lead to global political instability. We must be ready to provide innovative and interdisciplinary research that provides support for forest and environmental governance and helps reconcile different interest groups (urban/rural needs).

A "flexible" perspective will therefore be required, ranging from local to global knowledge and from rural to urban knowledge and vice versa, in order to lay the foundations for new approaches and new European governance policies for forestry and rural development, which may ensure compatibility with the objectives related to the resilience of agroforestry systems and bioeconomics, among other effects.

In short, interdisciplinary and intersectoral research which links the territory with products, markets, policies and society, according to the European bioeconomics strategy, will undoubtedly be a priority.

Further reading

www.ctfc.cat
www.fbs.cat

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Footnotes

[1] Bioeconomics involves the knowledge-based use of biological and renewable resources to produce goods and services in all economic sectors. Bioeconomics also seeks to reduce dependence on fossil products, to encourage improved integration of environmental services and biodiversity into the economy, and to promote economic growth and the creation of new jobs in accordance with sustainable development principles.

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FISHING AND THE SEA

Trawlers leaving port. Photo: Anabel Colmenero.

01. Introduction

Oceans all over the planet are subject to overfishing, which has led to the collapse of many fisheries (FAO, 2016). The Mediterranean Sea is no exception (Fernandes et al., 2017; STECF 2016, 2017). This overfishing is mainly due to the enhanced technological capacity of modern fleets and the high power of their engines. These issues of technological overcapacity, coupled with the global lack of information on the state of the populations subject to fishing and a lack of effective fishery monitoring programmes, mean that restoring overfished populations is very difficult. Apart from ecosystem changes, the main consequences of this overfishing are a reduction in the total available biomass and in the average size of captured specimens.

Over the last 10 years, various fishermen's associations along the Catalan coast and several researchers at the Department of Renewable Marine Resources of the ICM-CSIC have been working together on Spanish and European scientific projects through a number of grants from structural funds. Several fishery management initiatives have been established as a result of these partnerships: some have been included in Management Plans established by the European Commission; others have been published in ministerial orders in the Spanish Official Gazette (BOE), and others have been attached to documents and internal agreements between associations. Specific measures include those covering the fisheries of the Mediterra-

The main consequences of overfishing, apart from changes in the ecosystem, are a reduction in the total available biomass and size of captured specimens.

nean sand eel in the provinces of Barcelona and Girona, the shrimp in Palamós, the hake in Roses, the Norway lobster in Roses and Palamós, the octopus in Vilanova i la Geltrú and finally, the more recent cases of the blue fish fishery in the Northern Empordà and the red shrimp at Cape Creus (Fig. 1). All these specific management initiatives have been agreed upon between the sector and the scientists and finally endorsed by the various government bodies concerned.

02. The fisheries monitoring and management programme in Catalonia

Given that the latest assessments of the state of the populations of the main commercial species on the Catalan coast suggest that the vast majority are overfished, catches are declining and smaller specimens are increasingly those caught, with many smaller than the size at first maturity (Fernandes et al., 2017), specific and/or general fisheries management measures are urgently required to restore the main populations subject to commercial fishing on the Catalan coast.

ICATMAR (the Catalan Research Institute for the Governance of the Sea) was established in May 2017 to accommodate these management initiatives and to create a governance model for professional fishing in Catalonia, under the auspices of the Directorate-General for Fisheries and Maritime Affairs of the Government of Catalonia. The ICATMAR aims to have an impact on regulating resources by means of management plans for environmental, social and economic sustainability, with the participation and involvement of the Government, the fishing sector, the scientific world and associations.

The management measures must be implemented with the agreement of the fishing sectors involved, and they must be finally endorsed by the various government bodies competent in the field (Catalan, Spanish and European), in a process commonly known as co-management. The ultimate goal is for these management measures to improve the biological indicators of the populations and the ecosystems they inhabit. Accordingly, the aims are to:

a) Establish and consolidate the co-management measures that are currently being implemented on an individual basis in the various fisheries on the Catalan coast.

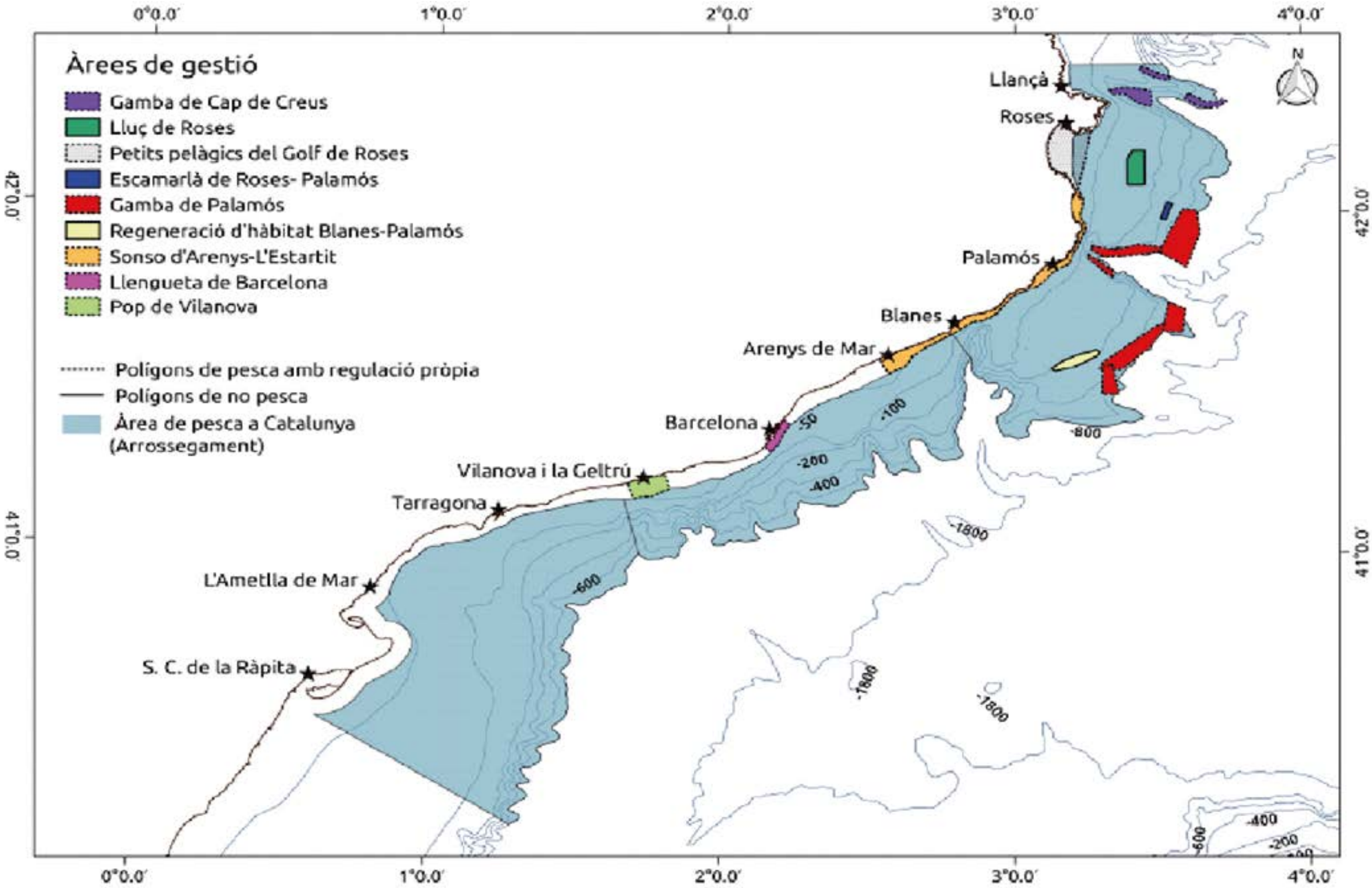

Figure 1. *Map of the various management initiatives being carried out for the main species of commercial interest along the Catalan coast. Some were approved in spring 2018 at the General Meetings of each of the associations involved. Others have been approved for some time (the Sand Eel Fishing Management Plan, the Palamós Prawn Management Plan, the Roses hake fishing restrictions), and others have been approved more recently (the Cape Creus red shrimp, the Norway lobster fishing restrictions between Roses and Palamós, the Blanes-Palamós fishing restrictions, the blue fish fishery in the northern Empordà and fishing for the common octopus in Vilanova i la Geltrú). Source: Institute of Marine Sciences.*

Working on the hake (Merluccius merluccius) in the ICM laboratory. Photo: Elisabetta Broglio.

Catch of shrimp (Aristeus antennatus). Photo: Anabel Colmenero.

Working on the sardine (Sardina pilchardus) in the ICM laboratory. Photo: Marc Balcells.

b) Share all the experience gained in recent years, and to work with the sector to transfer the scientific knowledge acquired to all the associations on the Catalan coast.

The fishery must first be monitored properly if the management measures are to be implemented. A collaborative project between scientists and fishermen, funded by European Funds (FEMP) is being carried out (July 2018 – September 2020), as well as a sampling programme also funded by European Funds, but channelled through ICATMAR. The initial aim of these two programmes, which are operating on a coordinated basis, is to improve the state of the main populations of commercial species on the Catalan coast by the combined efforts of the fishing sector and the scientists involved.

The project is taking place along the entire Catalan coast, and focuses particularly on monitoring the fisheries of the most important species from the economic and social point of view and their populations. To that end, the Catalan coast has been divided into three sectors: North, Centre and South. The most important species and/or fisheries have been determined in each one.

The main tasks within the project are: monthly biological sampling at the main fishing ports for at least two years, to acquire historical and current fishing data for the entire coast (catch maps and their distribution geographically and over time) and the creation of a data bank that enables fish stocks to be analysed and evaluated.

The details of the fisheries and their specific areas of action are as follows:

1. Mediterranean sand eel and transparent goby fishery. Subject to a European Union Management Plan. This fishery runs from Barcelona to L'Estartit. The sand eel fishery has been intensively sampled since June 2012 in order to obtain the data necessary for

scientific study. The Sand Eel Fishing Co-Management Standing Committee, composed of two representatives from each of the parties involved, agrees on a series of technical management measures and a schedule for ships during the scientific study carried out by the ICM-CSIC. This Committee meets monthly at the control sessions established to assess the details of the catches and quotas assigned to fishermen, and to monitor the activity.

2. Demersal fishing with trawling that involves a study of the communities subject to fishing on the shelf, the upper slope and middle slope. The target species in this case are hake and horned octopus on the shelf, Norway lobster on the upper slope and red shrimp on the middle slope, all along the Catalan coast. The mantis shrimp and prawns are also included in the study in the South (Fig. 2). Voyages measure the size of all commercial species, and a sample of the discard is also taken to assess the impact on benthic communities.

From left to right: Mediterranean sand eel (Gymnammodytes cicerelus); sand eel fishermen raising the net, and sand eel fishing boats. Photo: SONSO project.

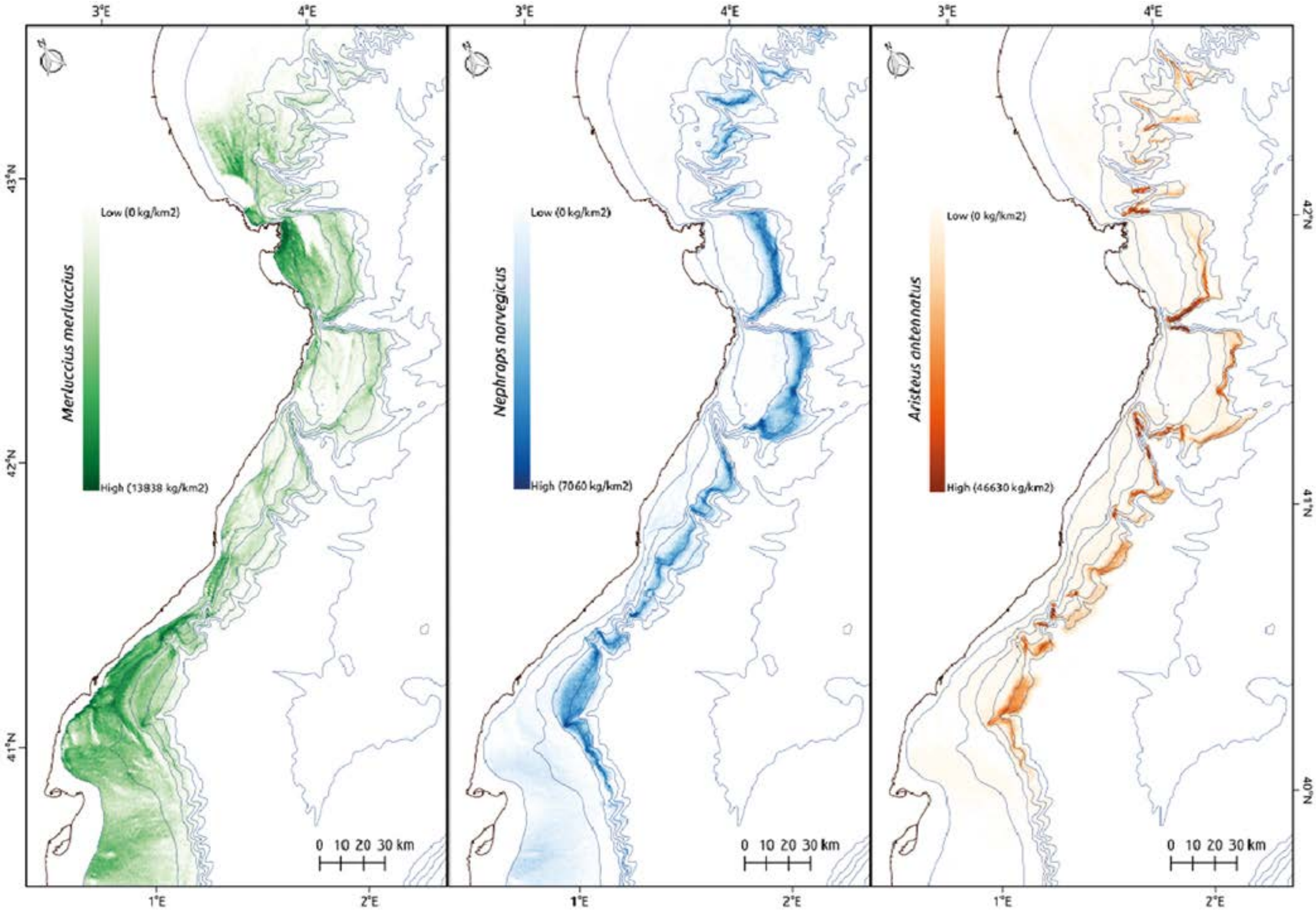

Figure 2. *Spatial variability along the Catalan coast of catches of hake (Merluccius merluccius), Norway lobster (Nephrops norvegicus) and red shrimp (Aristeus antennatus), highlighting the 3 main areas of demersal fisheries on the Catalan coast: the platform (green), upper shelf (blue) and middle shelf (brown), respectively. Map: José Antonio García.*


Working on the common octopus (*Octopus vulgaris*) in the ICM laboratory. Photo: FEMP/SAP project.

3. Small pelagic fishing. This fishing uses the seine fishing technique. It is studied along the coast, from Roses to Tarragona, and the sardine and anchovy are the target species. Samples are obtained from fish landed at the port when the boats arrive, from the associations' fish markets. Some voyages are also planned (especially in the Gulf of Roses, where a bluefish co-management committee has been established) to obtain real catch and by-catch species data for that fishery.

4. Common octopus fishing. This fishing sometimes involves traditional methods (pots and traps), and sometimes trawling. It is currently being studied in the port of Vilanova i la Geltrú, where samples have been obtained from trawling, and they are now being obtained from traditional fishing methods. Sampling of this species is also planned in Sant Carles de la Ràpita.

One of the main objectives of this project is that the combined work done by scientists and fishermen all over Catalonia will eventually improve the governance of fisheries through the various co-management initiatives.

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FOODS OF THE FUTURE: research and innovation

01. Introduction

Providing sufficient, safe, nutritious, healthy and affordable food for the population is a basic requirement for satisfying people's right to food and for creating an economy that provides smart, sustainable and inclusive growth.

One of the main challenges in R&D&I that the European food sector must address stems from the growth of the world's population and the increase in the number of consumers with high purchasing power. These consumers will demand foods that they consider appropriate for their lifestyle, which have been made with environmentally friendly processes (energy and water savings) and which guarantee animal welfare.

The food industry must also be able to market nutritionally enhanced foods which help fight chronic diseases associated with sedentary lifestyles, such as obesity and the diseases arising from it. The population's health may improve with well-prepared foods and well-informed consumers, and costs related to health may fall as a consequence.

R&D&I will help the food industry to design and market food for people with special needs, such as older people. For this reason, incorporating the knowledge provided by other scientific disciplines such as nutrition, medicine and physiology is essential when developing new processes and technologies.

It is becoming increasingly clear that food innovation must be geared towards meeting consumers' expectations and demands, and these must therefore be some of the main driving forces for innovation in the food industry. Consumer empowerment is now a cornerstone in the decision-making process in some sectors, including the food industry. Innovation in food must therefore be the result of a combination of technological possibilities, consumer priorities and the applicable legislation.

02. Areas of innovation for food

The report published by Food and Drink Europe (2018) on innovation trends in the European food industry lists 15 areas that can be grouped into 5 categories: pleasure, health, appearance, functionality and ethics (Fig. 1). The factors that drive innovation in the food sector include: the increase in obesity and overweight (especially in developed countries), consumers' growing interest in and concern about health, the importance of food during the early years of life, population ageing, and the increase in cases of allergy, as well as new lifestyles.

The category of pleasure, which includes the trend towards a variety of sensations (tastes, aromas, colours, etc.), sophistication (rare ingredients, very elaborate processes, etc.), exoticism (products from countries with very different culinary traditions from local tastes) and surprise (fun, entertaining and interactive products) is the main area of innovation, and accounts for 51.8% of the total.

> The population's health may improve with well-prepared foods and well-informed consumers and health-related costs may fall as a consequence.

The category of health is ranked considerably lower but nevertheless in a prominent position, and accounts for 28.6%. This category includes the trend towards being natural (natural compositions), medical trends (healthy ingredients) and vegetable trends (health benefits are mainly provided by vegetables).

Figure 1. *Innovation trends. Source: Food and Drink 2018- XTC World Innovation Panorama, 2018.*

The category of convenience accounts for 11.8%. This includes the trend towards easy handling of the product (the product or its packaging provides benefits in terms of ease of handling) savings in time (the products have advantages in terms of time-saving because of how they are prepared or cooked) and nomadism/"on the go" (the products are designed and prepared so they can easily be consumed anywhere).

The redefinition of the concept of healthy nutrition by the consumer has led to increased interest in nutrition related to natural and ecological concepts.

Another interesting scenario relates to consumers who are on a restricted meat consumption diet.

The area of physical appearance accounts for 5.1%, and includes the trend for slimming (products with a low energy content), wellness (the ingredients of the products stimulate the body to promote a sense of well-being) and cosmetic foods which suggest a cosmetic improvement.

Finally, the area of ethics accounts for 2.7%. These include the trend for solidarity (the manufacturers guarantee that their production does not violate fundamental freedoms, and that the products are not produced by disadvantaged groups) and ecology (the products are obtained in a way that respects nature, animals and the environment in general).

03. New scenarios

The fusion between the concepts of nature and health fosters lifestyles related to "green foods". The consumer's redefinition of the concept of healthy nutrition has led to a decline in interest in slimming diets, and an increase in interest in nutrition related to natural and ecological concepts. Some 58% of millennials (the generation born between 1980 and 2000) are therefore willing to pay more for premium products (Kleinschmit, 2017) because they are interested in the sustainability of food processing and ethical consumption, which increases the tendency towards minimising waste.

Another interesting scenario is related to consumers who follow a limited diet in terms of meat consumption, and who base their diet on vegetable products. The growing numbers of flexi-vegetarians/flexitarians have forced meat companies to develop new high-quality meat products. Estimates suggest that a significant number of consumers want to change their consumption of meat products to other similar products if the taste and texture are similar to those of meat. This means there is a great opportunity for developing new non-meat products which have sensory characteristics similar to meat.

The problems associated with excessive consumption of sugar, salt and fat in developed countries have led to major concerns. This abuse has been linked to diabetes, obesity and cardiovascular problems. However, reducing these ingredients should not lead to food losing its taste. Government agencies will continue to educate and inform consumers so that they can make informed choices about the products they buy and consume.

Nutrigenomics will be essential in designing personalised diets, as knowledge of individual genetics will enable recommendations for living longer and better to be made.

The trend towards both "clean labels" (with fewer unhealthy ingredients and fewer additives) and "clear labels," i.e. the consumer being able to clearly understand them, is important in this respect.

According to the experts, constant health concerns are leading to significant interest in foods made with ingredients that are antibiotic-free, contain probiotics, and have personalised characteristics that can meet individual nutritional needs. Nutrigenomics will be crucial for designing personalised diets, as knowing individual genetics will enable recommendations for living longer and better lives to be made.

Gluten-free products provide diversification, and encourage the use of cereals that do not naturally contain gluten, such as corn, rice and oats. Many consumers who do not suffer from gluten intolerance have incorporated these and other cereals that come from ancient varieties that do not contain gluten, because they consider them to be healthy. As a result, given the importance of the health area, it is to be anticipated that gluten content will also affect food consumption.

According to the study by Mintel (2017), the evening is a key time for consuming convenience/practical and functional foods. At this time of day, food needs to be focused on helping the stressed consumer to relax; however, these foods must also make the consumer feel full throughout the night.

A behaviour associated with consumers concerned about their health and well-being is that they allow themselves to indulge in an occasional pleasure in their diet, even if these pleasures are not considered healthy. The packaging and presentation of these products in small or moderately sized portions helps to satisfy this desire. Their presentation is therefore another key factor for the foods of the future.

Meanwhile, the limited time spent on meals sometimes means that consumers have to replace them with a concept of food that is consistent with the "on the go" or "in the air" trend. this trend assumes that consumers look for quick ways to consume fresh, nutritious and convenience foods. Both the quality of the preparation and the nutritional composition is a key factor in these products. Consumers want more information about what they are consuming, and have more confidence in food which has a tangible connection with traditional cooking methods. The link between foods with traditional recipes and the emotions that they generate is therefore another factor to take into account.

Gastronomy is a today very highly rated concept. The study of the relationship between food and culture, the art of preparing and serving appetising foods, the style of a region's cuisine, and the science of good food have been brought to the market by great chefs in the form of *ready-to-eat* and ready-to-prepare dishes. Furthermore, this trend has had and will continue to have major impact on the vending sector, where a growing number of companies have begun to include this demand in their products.

Foods targeted at specific age groups (e.g. children, adolescents, young people, older people) or based on their physiological condition are also a niche for innovation. As a result, the number of senior citizens who will continue to work after retirement or who are retiring later than they currently do is expected to grow, which means that they will need functional foods to remain productive and competitive at work. This means that claims related to vitality and energy to keep seniors active and strong in the final years of their careers will increase. "Healthy ageing," i.e. foods that help to add life to years, rather than years to life will be an important concept.

Shorter mealtimes means that consumers are looking for quick ways to consume food that is fresh, nourishing and presented in a convenient format.

Transparency is one of the priorities for consumers. More and more consumers are asking for information about ingredients, products and manufacturers. Transparency is one of the conditions for making an informed choice about foods required by European law (on nutritional and health declarations). To make a product transparent, its origin and its traceability must be readily apparent, and its authenticity must be conveyed effectively.

Another important characteristic in recent years is the sustainability involved in avoiding food being thrown away and preventing waste. This has had an impact on consumers' perceptions of food production. Reducing and recovering waste is essential for resource efficiency. Plastic materials will be examined in terms of waste. The EU will require all plastic containers to be recyclable by 2030 to prevent environmental impact.

Another key point to take into account is the influence of information and communication technologies on the development of food, especially by some groups such as millennials, who have a very good grasp of and a high level of dependence on information and communication technologies. Apps on smartphones can be a very effective tool for conveying the properties of foods, and when related to each person's individual needs, they can become a routine tool that is integrated into each person's diet.

Consideration must also be given to how future technologies such as nutrigenomics, biotechnology and nanotechnology will affect innovation in terms of the foods consumers will want, which foods that cannot currently be offered will be available in the future, which packaging materials will be available and the information food will provide or give access to by means of smartphones.

Finally, there is 3D-printed food and cultured meat. 3D printing technologies are beginning to be considered as tools for preparing new food products. Cell culture is an emerging technology that means that agricultural products and foodstuffs can be produced from cell cultures in a bioreactor. Technology provides opportunities, but is fraught with challenges at the same time. One of the opportunities it provides is the use of cultured meat as an alternative source of protein. It will be necessary to overcome the aversion that European consumers may feel to both cultured meat and to insect by-products.

The conclusion is therefore that food will change gradually and continuously due to the need to adapt to consumer demands, the requirements of sustainability and constraints on resources, and will be affected by scientific and technological breakthroughs that will create new opportunities and new concepts of food.

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VALORISATION OF WASTE FROM THE AGRIFOOD INDUSTRY

Tests at the waste valorisation laboratory. Photography: U_MÈDIA, UVIC-UCC.

01. Introduction

Agriculture, livestock farming and the agrifood sector in general are critical sectors of the European Union's economy, providing food, feed and fodder and bioresources that help sustain society. This particular sector is at the centre of the challenges associated with population growth, food security, climate change and resource scarcity.

The agrifood sector has traditionally been an economy with a linear structure: a significant proportion of the large amounts of resources it consumes is not converted into marketable products. This classic paradigm of a linear economy is being replaced by a new model, known as the Circular Economy.

The Circular Economy (Fig. 1) in the agrifood sector must focus on production that minimises the amount of external inputs, closing the nutrient cycle, the valorisation of waste and by-products and reducing discharges (in the form of waste and emissions) with negative effects on the environment, with the ultimate aim of: *creating a sustainable and competitive agrifood sector that 'produces more from less' and ensures a constant supply of food and bioproducts and the sustainable management of natural resources, working in harmony with the environment.*

The Circular Economy aims to keep the value of products, materials and resources within the economy for as long as possible.

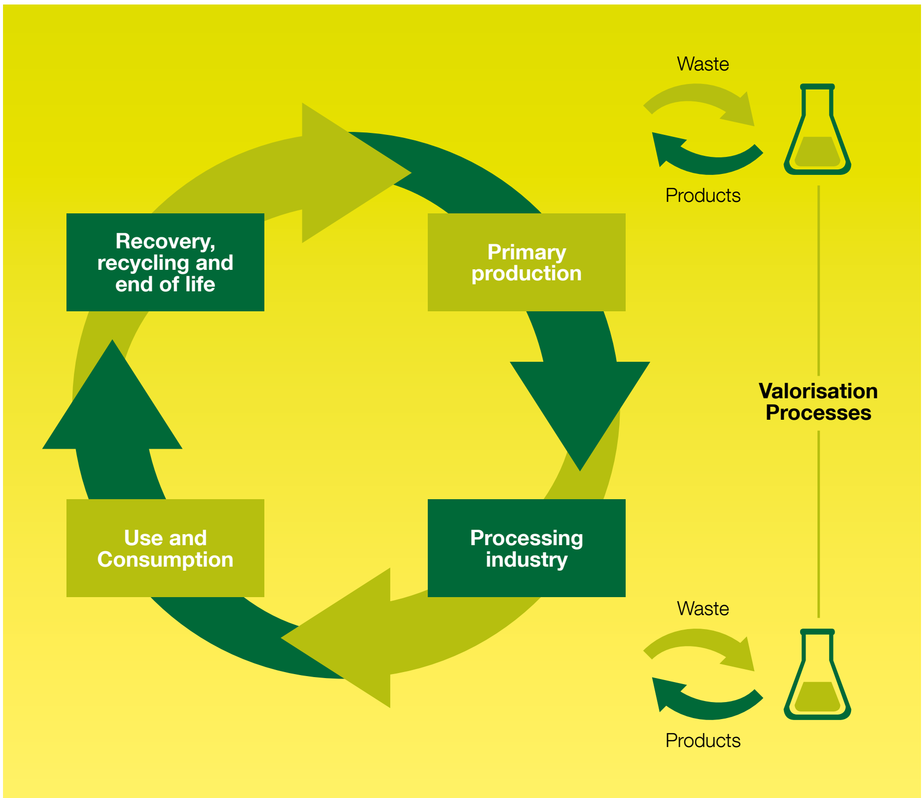

Figure 1. *Concept of the circular economy applied to the agrifood industry. Source: own research.*

Research and innovation are key factors in the implementation of the Circular Economy in the agrifood sector. The European Union has made major efforts in this area. For example, it allocates significant funds to publicly funded programmes (e.g., EUR 19 bn to the 7th Framework programme, and EUR 38.5 bn to Horizon 2020) or through the EIP-AGRI which has fostered innovation through EAFRD funds and by creating focus groups, such as the group on nutrient recycling.

02. Production of waste and by-products

The agro-industrial sector can be divided into two broad subcategories: the primary sector (agriculture, livestock farming, fisheries and forestry) and the processing industry. As shown in Figure 2, these subsectors generate large amounts of waste and by-products that can be valorised and reintroduced into the economy (in both the same value chain and in other productive sectors).

According to the Catalan Institute of Statistics, the waste generated in Catalonia's industrial sector involving agriculture, horticulture, forestry, hunting and fishing, and food preparation and processing amounted to 748,744 tonnes in 2016, of which 161 tonnes were considered hazardous waste and 748,582 tonnes were non-hazardous waste. This waste amounted to 18.3% of the industrial waste generated in 2016. Table 1 shows that waste production in the sector remains stable, with a slight downward trend.

Figure 2. *Main types of waste generated in the agrifood sector. Source: own research.*

Apart from the waste mentioned above, Catalonia has more than 50 million head of livestock (table 2), which generate thousands of tons of livestock manure each year that has to be managed.

This manure can be managed within agriculture (by using the manure for agriculture), outside agriculture (by a waste manager) or by a combination of the two types of management.

03. Main forms of valorisation

Although there are ways to valorise all the wastes mentioned above (or most of them), this article considers the main (innovative and/or conventional) ways to valorise organic agro-industrial waste, such as livestock manure, agricultural waste and food processing waste. Nutrient extraction technologies and others that do not produce a value-added product are not discussed. As shown in Figure 3, the main ways to valorise organic waste can be divided into 3 main groups: products with agronomic value, energy valorisation and valorisation in products with high added value.

03.01. Products with high agronomic value

Although a large proportion of the nutrients and organic matter contained in agrifood waste is returned to the soil in agriculture (e.g. 90% of livestock manure in the EU-27), this is not done in the most efficient and sustainable way.

In order to optimise the use of these resources, the products with agronomic value from this waste must be reliable and predictable, with a highly efficient use of nutrients, no unwanted compounds (seeds, pathogens, metals, antibiotics, etc.) and a ratio of nutrients (NPK) that meets plants' needs. Products with agronomic value can be divided into the following categories: (i) organic conditioners and organic fertilisers, (ii) mineral fertilisers and (iii) biostimulants.

(i) Organic conditioners and organic fertilisers are conditioners from carbonate materials of plant or animal origin which are primarily used to maintain or increase the soil's organic content, enhance its physical properties, and improve its chemical or biological activity or properties. The main organic conditioners are compost and biochar produced using composting or pyrolysis technologies.

(ii) Mineral fertilisers are products which are mainly used to provide plants with nutrients. There are various technologies for recovering mineral fertilisers from organic waste:

· Nitrogen fertilisers, such as $(NH_4)_2SO_4$, $(NH_4)(NO_3)$ and NH_4OH are obtained using technologies such as N-stripping + acid washing and membrane contactors.

· Phosphorus fertilisers such as struvite, H_3PO_4 and $(NH_4)_3PO_4$ by precipitation, biological acidification, ion exchange and advanced phosphorus extraction techniques from ashes after a thermal recovery process.

(iii) Biostimulants, i.e. substances that encourage plants to grow and develop, as well as improving their

	2012	2013	2014	2015	2016
Hazardous waste (t/year)	1,061	128	109	139	161
Non-hazardous waste (t/year)	797,691	776,993	765,805	759,403	748,582

Table 1. *Waste generated annually (in tonnes) by agriculture, horticulture, forestry, hunting and fishing, and food preparation and processing. Source: IDESCAT, 2019.*

	2005	2007	2009	2013	2016
Cows	532,708	476,975	544,135	545,350	570,935
Sheep	687,312	621,493	600,082	579,825	599,730
Goats	75,137	74,179	71,748	71,151	72,776
Pigs	6,522,814	6,422,889	6,742,638	6,705,208	6,564,718
Horses	13,259	15,879	19,352	20,141	20,981
Poultry	40,786,700	39,436,718	43,890,563	44,734,669	43,032,805
Breeding does	320,111	349,494	335,054	336,382	362,071

Table 2. *Heads of livestock by species. Source: IDESCAT, 2019.*

metabolism. This makes plants more resilient to adverse conditions, pests and diseases. The most common biostimulant production technologies are macro- and microalgae production and the subsequent extraction of amino acids, proteins, etc. Organic conditioners with and without supplements (e.g., microorganisms) have also been shown to have biostimulant activity.

Examples of high value-added fertiliser recovery in the agrifood industry include projects such as FERTIMANURE[1] (a recently funded Horizon 2020 project) and Nutri2Cycle[2], which aims to recover nutrients from livestock manure with the ultimate goal of obtaining high value-added tailor-made fertilisers.

03.02. Energy valorisation

Most energy valorisation is based on recovering electricity and/or heat from the energy contained in organic waste.

The main energy valorisation technology applied to organic waste is anaerobic digestion, which enables the biogas produced (which has an LCV of about 22-25 MJ/m^3) to be used and transformed into electricity and/or heat. This technology is widely used in Catalonia in the processing industry and to a lesser extent in the primary sector (agriculture and livestock farming).

Other energy recovery technologies are also being developed, or have not yet been implemented on an industrial scale in the agro-industrial sector in Catalonia. These are well-established technologies, such as pyrolysis and gasification (bio-oil production with an LCV of 30-40 MJ/kg and syngas with an LCV of 3-5 MJ/Nm^3), and more innovative technologies such as biodrying (biomass production with an LCV of between 7 and 12 MJ/kg) applied to low-porosity waste (sludge and manure) and bioelectrochemical

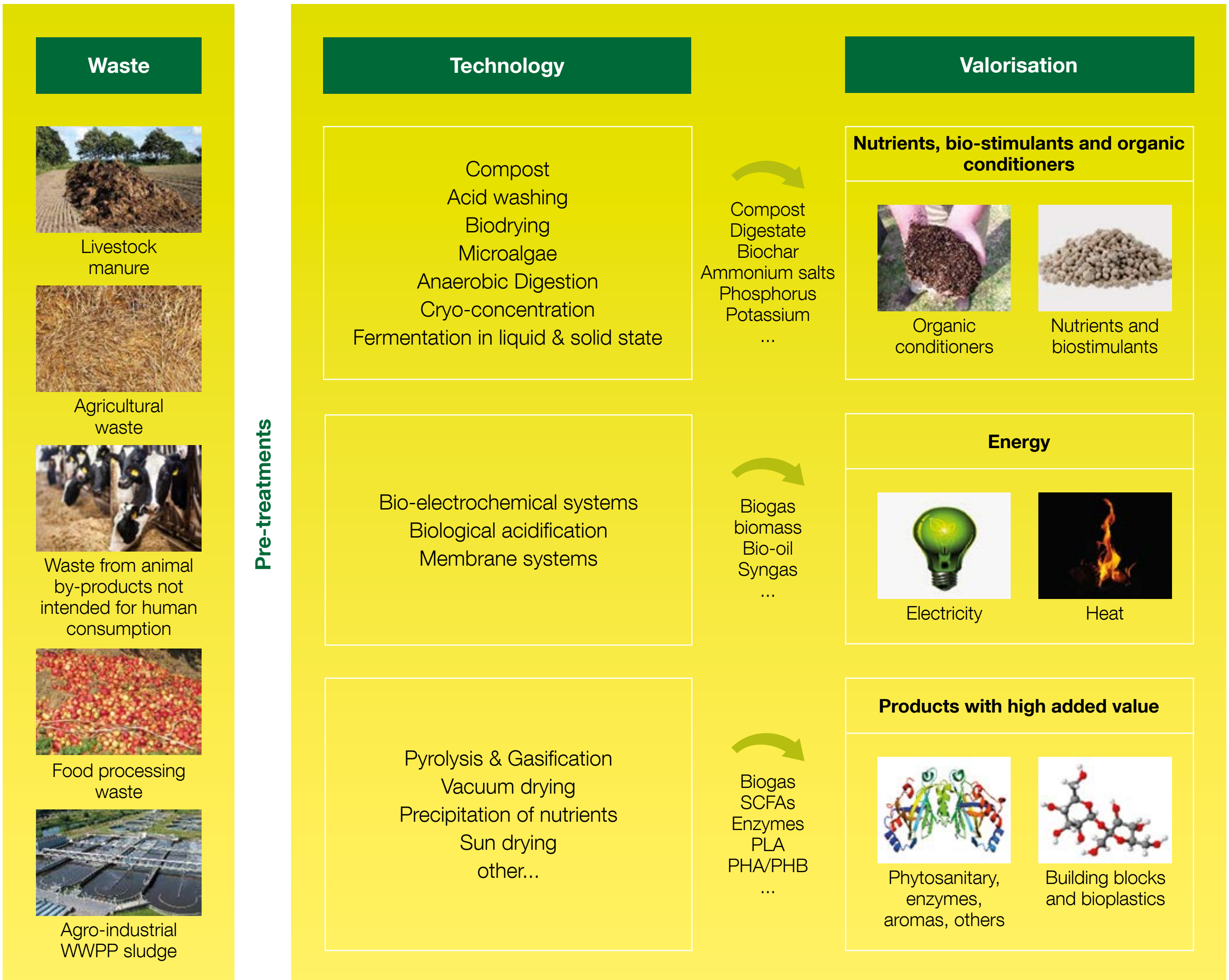

Figure 3. *Main technologies for the valorisation of waste and the products obtained. Source: own research.*

systems mainly applied to wastewater treatment. All of these technologies have great potential for maximising the energy recovery of organic waste in the agrifood sector in the future.

The main ways to valorise organic waste involve: products with agronomic value, energy valorisation and production of monomers and molecules of interest.

Examples of energy valorisation from waste in the agrifood industry include projects such as ENERGYCow[3] and INNOTRANSLACT[4] which aim to recover energy from cow manure (biodrying) and whey (anaerobic digestion) generated in the dairy sector.

03.03. Products with high added value

The chemical industry uses various monomers and simple molecules, mainly from fossil resources, to produce more complex compounds that are used as solvents, fuels, polymers, textiles, nutrients, aromas and pharmaceuticals.

There are a wide variety of technologies for the valorisation of waste and by-products of the food industry as bioproducts with significant commercial interest, such as alcohols (ethanol, propanol, etc.), organic acids (volatile fatty acids, lactic acids, citric, succinic and itaconic acids, etc.), amino acids, enzymes (cellulases, proteases, lipases, etc.) and diamines and terpenoids, among many others. The most widely used technologies for obtaining these products are fermentations (liquid and solid). Meanwhile, new ways of material valorisation are being developed, which use consolidated technologies such as (i) biogas recovery to produce methanol and even graphene, and (ii) the extraction of high added value compounds such as phenols, olefins and paraffins from thermal processes including pyrolysis.

Examples of the recovery of high value-added products from waste in the agrifood industry includes projects such as VALPRA[5] and DECISIVE[6] which aim to produce bioplastics and enzymes from organic waste.

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More information on the research projects mentioned in the text:

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[4] INNOTRANSLACT
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HEALTH AND NUTRITION.
Bioactive or non-nutrient components

01. Introduction

It is a well-known fact that proper nutrition is essential for good health. A sufficient, complete and balanced diet is essential for providing all the energy and plastic nutrients needed to maintain a homeostatic balance.

A lack of nutrients leads to malnutrition, which is unfortunately still very common in our society, and often leads to people dying – and they are often children. Hunger is still a fact of life in many parts of the world and in our own country, and is a problem that is difficult to eradicate in today's society.

Meanwhile, excess nutrition leads to obesity – a pathology associated with many diseases that are very common in our society. Hypertension, dyslipidemia, type 2 diabetes and inflammation are pathologies that are often caused by the excessive accumulation of triacylglycerols due to obesity, and are increasingly ranked among the leading causes of mortality in wealthier social groups.

Both too much and too little nutrition therefore clearly play a crucial role in people's health, and it is essential to maintain a sufficient, complete and balanced diet, such as the theoretical Mediterranean diet or other diets that evolution has provided as the usual way for feeding people.

The items providing energy and building our body that we need to survive are not the only parts of our diet. Food also contains non-nutrients, which are found above all in the vegetables we eat. These are molecules that have various functions in vegetables, but which have no energy or building function in humans, but interact with our metabolism and partially affect it. There are basically phenolic compounds – a very large family of molecules with functions in plants such as defence and giving some flowers their colour. However, they also include molecules such as microRNAs, which have functions regulating the expression of inter-tissue genes.

Non-nutrients are molecules that have various functions in vegetables, and have no energy or plastic function in humans, but interact with our metabolism by partially conditioning it.

Non-nutrients and their interaction with metabolic processes have been studied since the middle of the last century. Today, we know that they can interact with proteins regulating metabolism, affecting their function, and especially – but not only – nuclear receptors that control gene expression. They affect proteins, both enzymes and others, which are their main targets, as well as molecules such as microRNAs and processes such as the availability of free Zn in the cell.

The interaction of phenolic compounds and other bioactive compounds with metabolic processes is usually a positive factor for homeostatic balance. In other words, they have a positive effect on the metabolism, especially when consumed in moderate doses. Indeed, plants and plant extracts have been used as medicine since ancient times, precisely because of their abundance of non-nutrients, and their effects on health. This has to a large extent led to these non-nutrients or bioactive components being used in industry, as they are the basis for the production of what are known as functional foods, when bioactive substances are incorporated into a food, or nutraceuticals, when they are consumed as pills or syrups.

Functional foods and nutraceuticals produced by the food and/or pharmaceutical industry are of twofold interest for our society. On the one hand, they are important prevention strategies in the health field by enabling consumption of natural products, with no side-effects and with very low production costs, in comparison to the costs of producing drugs. On the other, their use is associated with intense research, which has led to a major transformation of the food industry.

02. Xenohormesis

The question is: why do bioactive components, the non-nutrients, have a positive effect on people's health? The theory of Xenohormesis was proposed by David Sinclair and his colleagues in the USA to explain this in 2004. In short, the theory says that animals and plants have co-evolved: in response to various stress situations, plants manufacture a number of phytochemicals which vary and are specific to each particular stress situation, such as hydric stress or fungal infection stress;

We have studied this with cherries, which were consumed when summer (with 18 hours of light and 6 of darkness) and when winter (with 6 hours of light and 18 of darkness) were simulated. Cherries ripen and are consumed at times of long hours of daylight, when they have virtually no effect on the metabolism. However, when they are consumed at times of year with limited daylight hours, they significantly affect the metabolism. To name just one important effect: insulin resistance increases significantly. These are early results, and need to be transferred to humans, but they are quite interesting, as they suggest that an additional factor needs to be included in the definition of healthy diets: the time of year when different foods are consumed. This is clearly an important argument for local and seasonal products as consumer products for maintaining good health.

when animals eat the plants, they receive signals that tell them about the stress received by the plants. This enables animals to act accordingly, and modulate their physiological or biochemical processes to adapt to the results of the stress experienced by the plant. This means that in years with a good harvest, the signals they receive will encourage animals to try to reproduce, because they will have enough food for their young. In years with a poor harvest, they will tend not to breed, and try to store enough fat to survive.

Although this is very attractive theory, it is still not widely accepted by the scientific community. However, it would account for many of the phenomena that have been observed to date, and which are difficult to understand, particularly because consuming phytochemicals – bioactive components – always has positive effects. This is often explained by their antioxidant properties, which may explain some of the phenomena observed. However, it does not account for all of them, and that is why xenohormesis is interesting.

03. Research by the nutrigenomics group

During our research work focusing on nutrigenomics, which involves studying how bioactive components interact with gene expression mechanisms based on xenohormesis theory, we formulated the following hypothesis: eating fruits out of season sends the wrong signals to the body, which disrupts its metabolism. In other words, co-evolution has made us accustomed to receiving certain signals when fruits are naturally ripe, at a particular time of year. If we eat them at another time, we will receive the wrong signals, which will disrupt our metabolism.

> The results of the nutrigenomics research group suggest that an additional factor must be added to the definition of healthy diets: the time of year when certain foods are consumed.

Apart from that, we have carried out experiments with grape consumption, and in this case we compared grapes obtained from an organic farm and grapes of the same variety from a neighbouring property which were not cultivated organically. We found that the phytochemicals were clearly different, which means that the signals they send to the humans consuming them are also different, and they therefore must undoubtedly have different effects on the metabolism.

Seasonality and the type of cultivation are not the only factors in the effects of vegetables consumed. The time of day when we consume them is also important. We have performed other experiments, albeit with provisional results, which show that the effects of bioactive components are not uniform, and depend on the time of day they are consumed. Consuming them in the morning at breakfast and in the evening at dinner often do not have the same results. Chrononutrition is becoming increasingly important.

Diet has a profound effect on the ecosystem that shapes the gut microbiota.

The world of microbiota is also becoming significant in the context of health and nutrition. Intense research to understand the role of the microbiota in our body has been under way since new DNA sequencing technologies have become available to everyone. We have found that diet has a profound effect on the ecosystem which shapes the intestinal microbiota, and is directly correlated with obesity. We found that faecal transplant from a pair of twins (one lean and the other obese) to lean rats makes them obese when the stool comes from the obese twin, and keeps them lean when it comes from the lean animal. All the components of food therefore have a significant effect on the microbiota; non-nutrients also have a proven effect as prebiotics.

We need to continue working and broadening our research on bioactive components, chrononutrition and microbiota in order to take advantage of every opportunity to use food and its components to keep people in a good state of health.

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HORTICULTURE AND THE CITY

Test field for lettuce varieties in a periurban area (Agrópolis, Viladecans). Photo: Miquel Agustí Foundation.

The Barcelona School of Agriculture (ESAB) was founded in 1912, with the aim of providing knowledge to the agricultural world and facilitating progress in agriculture and livestock farming in the Catalan countryside, based on the needs of the society of the early twentieth century. As a school, it was based on the architectural and engineering schools of the day, with the objective of training professionals, but was also committed to developing technology. That School, which was founded on Carrer del Comte d'Urgell in the heart of Barcelona's Eixample district, and which subsequently expanded to premises at Torre Marimon (in Caldes de Montbui), was administered in various ways until it became part of the Polytechnic University of Catalonia (UPC) in 2004. Since 2005, it has had new facilities in the Mediterranean Technology Park (Castelldefels) and in Viladecans, where it runs the Agrópolis experimental farm.

With the other Catalan universities, the Lleida Technical School of Agricultural Engineering currently runs various bachelor's degree and master's degree programmes in the field of agrifood. The Lleida School was founded in 1972, and at that time, with the rapid expansion of intensive agriculture based on maximising yields, the presence of an agricultural school in the city was the subject of considerable scepticism. Linking agriculture and the city, and the rural and urban spheres, seems to be contradictory because they are perceived as opposite spheres, due to the city's recent detachment from the land which feeds its population. As we know, this is a recent idea that is ultimately due to changes in how fresh food products are supplied, as a result of the development of new and faster means of transport since the industrial revolution. This has led to a break in the spatial, physical and emotional link between the countryside and the city for the first time in history. However, agriculture and the city were born at the same time. The first stable settlements were established as a result of the ability to produce enough food on a regular basis. All big cities – and Barcelona is no exception – were founded on or near fertile land that made them possible. For many years, the relationship between agriculture and the city was considered as one involving conflict, and this interpretation has led to responses that have aggravated their drastic separation.

There is a current tendency to talk about the "food system" instead of agriculture and the city, or production and consumption.

Traditional tomato varieties. Photo: Miquel Agustí Foundation.

The expansion of cities and increasing environmental problems have led many citizens to identify agriculture with nature, and consequently to consider urban development and activities as an 'attack' on the rural environment and by extension, on the environment. This has all led to this relationship – and especially the distance involved – being reconsidered as a key factor in adaptation. As a result, we no longer think of agriculture and the city, or production and consumption, in separate terms, but instead the food system and food are considered a flow, and this enables us to address many of the challenges we face which are closely linked to each other. We are seeing how cities change, how allotments are being added to schools, municipal spaces and parks; they are not aimed at production in themselves, but today they make a significant contribution to raising awareness among urban consumers, and have benefits for those who use them.

The Miquel Agustí Foundation is responsible for keeping, studying and returning to Catalan farmers the collection of traditional varieties kept in the ESAB which has more than 2000 entries, in order to conserve Catalonia's plant genetic resources.

In this context, the presence of a Food and Agricultural Engineering school and its commitment to working across the entire spectrum of this relationship in this urban environment becomes more relevant and increasingly valuable. A quick overview of the ESAB's work shows that it covers research and transfer fields as varied as agronomy, food and environmental engineering, on the one hand, and gastronomy and the landscape, on the other, taking in rural development. Examples of this research work at ESAB include studying the problem of how to use reclaimed water as a water resource for allotment crops, and the use of sewage sludge as fertiliser, and assessing the impact of air pollution on horticultural output in urban areas. This work is always focused on promoting the responsible use of resources, their involvement in horticultural production and food security. Other research groups at the UPC are working on the development of cutting-edge technology for use in agriculture to reduce inputs, increase sustainability and contribute to the development of Agriculture 4.0. The ESAB has been working meticulously to preserve agrobiodiversity since 1992, collecting plant material from traditional agricultural varieties to conserve Catalonia's phytogenetic resources, and the Germplasm Bank of Catalonia's horticultural varieties was created to that end, and is physically located at the ESAB. This bank is Catalonia's primary ex situ collection of horticultural species, and contains traditional varieties with more than 2,000 items. The Miquel Agustí Foundation (www.fundaciomiquelagusti.cat), established in 2007, is responsible for conserving, studying and returning this collection to Catalonia's farmers. The Foundation works on publishing this genetic library in open access format, in various projects linked to the productive sector, as well as in areas including social agriculture (www.tomaliers.cat) and promoting producers' associations based on cultivating specific traditional varieties (www.espigallsdelgarraf.cat). The research group has also published numerous scientific papers studying genetic variability in traditional crops, identifying the characteristics that distinguish these varieties in the market, and their link with the territory. At the same time, the team is working on various genetic improvement programmes that aim to select new competitive varieties with high agronomic, sensory and nutritional quality, providing the sector with varieties such as the "Montcau" ganxet bean, the "Croscat" Santa Pau bean, the "Roquerola" and "Montferri" calçot onions, and the "Montgrí" tomato.

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GASTRONOMY AS AN ACADEMIC AND SCIENTIFIC FIELD

Mozzarella di mandorle. Example of the interaction between science and cooking. Photo: web https://www.innaturale.com/

01 Background

One of the first serious attempts to study the global, multidisciplinary and multisectoral aspects of the role of gastronomy in Catalonia came about with the drafting of the Gastronomy Plan of Catalonia 2017, under the auspices of the Ministry of Agriculture, Livestock, Fisheries and Food. As has already been pointed out by various committees of experts, there is a lack of definition and differentiation throughout the entire document, between what we generally consider to be food and the aspects that help us to define gastronomy and discuss its potential. Gastronomy is considered part of the broader field of food (which is today understood in terms of a global food system), but it has major influence on many other fields and sectors.

Some of the areas where gastronomy is involved are clearly defined in this Plan: its role, and that of tourism, in local and territorial development, and its role as culinary and gastronomic heritage. Gastronomy's influence on the restaurant sector and the role played by communication are also clearly defined, especially with the influence of new digital communication technologies.

However, the idea of gastronomy as an academic field or as a field of research and innovation is neither well consolidated nor clearly defined. Neither were the prospective areas of influence of gastronomy on the future Europe Horizon 2020 (EU) framework programme to implement European strategies between 2021 and 2028 clearly defined.

In this article we consider those issues and challenges, which are included in the following sections of the Plan: gastronomy and training, gastronomy and innovation, and one of the areas of application that seems to be the most obvious for gastronomy in Catalonia: gastronomy, nutrition and health (which is sometimes known as "nutritional gastronomy").

02. The concept of gastronomy

In addition to the historical aspects of the concept of gastronomy (described by J.A. Brillat-Savarin in *The Physiology of Taste*) and in sectoral aspects such as tourism and catering, a new world of gastronomic activity has begun in recent years, involving a new, more multidisciplinary academic definition, in which the experimental sciences and engineering applied to it provide new economic and employment opportunities. Higher education, considered in terms of the development of the EHEA (European Higher Education Area) which includes higher level vocational culinary and gastronomic training, and university studies on cooking and gastronomy, now provides a great opportunity for modernising the sector, moving beyond well-established agrifood training activities.

The best explanation of the future that is opening up for gastronomy in Catalonia in terms of its definition and applications has been provided by the Alícia Foundation, which has developed the idea of gastronomy as "the art of preparing foods well so that they are healthier (nutrition), better (in sensory and emotional terms), and more sustainable." That is why training, dissemination and the creation of culinary knowledge and its application to innovation is being promoted; since it was created, interest in gastronomy has gained some degree of access to generally conservative academic faculties at Catalan and Spanish universities, by means of new bachelor's degree and master's degree programmes. Meanwhile, gastronomic research still has some way to go in order to distinguish itself from agrifood research and find its niche with its own identity, enabling it to move towards a rich and diverse gastronomic knowledge and innovation ecosystem, in a similar way to the consolidation of biotechnology in Catalonia.

03. Gastronomy as a Science: Higher education and gastronomy.

When we talk about gastronomy and culinary arts, and we mean the university courses and activities related to it, it is impossible to overlook the *Basque Culinary Center (BCC),* a strategic cornerstone of the Faculty of Gastronomic Sciences of the Mondragon Unibersitatea in the Basque Country. This institution was first to see the future of gastronomy as a tool for knowledge, research and innovation, beyond the consolidated areas of tourism and gastronomic heritage. Its presentation of its bachelor's degree course in Gastronomy and Culinary Arts in 2011 to the Spanish National Agency for Quality Assessment and Accreditation (ANECA), which has since been complemented by specific master's degrees, the creation of a third-cycle training programme and the enhancement of the doctoral programme are part of a national strategy, which is complemented where necessary by a significant investment in excellent infrastructure, and has the capacity to become an international training and research centre. The Alicia Foundation covers around 2,000 m2 in a building of extraordinary quality and design located in the cultural-tourist complex of Món Sant Benet, which was constructed in 2007 at a cost of EUR 5.6 M. The BCC has a floor area of 15,000 m^2, and was completed in 2011 after an investment of EUR 17 M, and is located in the Miramón Technology Park.

Two of the best lecturers at the University of Barcelona contributed to the design of the Alicia Foundation project – Doctors Antoni Riera and Jesús Contreras, and more recently, in partnership with ESAB-UPC, CETT-UB and the Alícia Foundation, the University established the first inter-university bachelor's degree (UB-UPC) in Culinary and Gastronomic Sciences, which began in the 2014-2015 academic year.

Various bachelor's degree and master's degree programmess have begun in Spain since the introduction of the European Higher Education Area, and they are clearly aimed at promoting gastronomy (Table 1). In general terms, there is a group of degree courses related to gastronomy and the business environment. This group includes some of the courses offered by private universities; a second group focuses on the multidisciplinary scientific aspect, with an in-depth study of gastronomy and experimental and health sciences. It is organised by faculties of Pharmacy and faculties of Sciences. There is a third group with a combined commitment to promoting the Culinary Arts and Gastronomic Sciences, which includes the BCC at Mondragon Unibersitatea, among others.

A second approach shows that training in this "academisation of gastronomy" can take place in university courses in Food Science and Technology (FST), and other related bachelor's degrees, and is complemented by specialist master's degrees in Gastronomic Sciences with 60 ECTS credits. The BCC offers a combination of gastronomic bachelor's degree and master's degree courses, and a streamlining of its doctorate. This centre currently has a major advantage and enviable clarity in its strategy of positioning itself as a leading international institution.

A study of the rationalisation of the range of courses available at Spanish universities (a kind of "white paper") was carried out in 2019 under the auspices of the "*Campus of International Excellence with Agrifood Activity Network*" *(the Triptolemos Foundation)* and the Spanish National Agency for Quality Assessment and Accreditation (ANECA).

04. The development of gastronomy as a science

Gastronomy, considered as a culinary activity, has a long-standing tradition in twentieth-century Europe: from *Nouvelle Cuisine* in France, to the arrival of Ferran Adrià with his restaurant El Bulli. However, the dialogue between chefs and scientists took place with varying degrees of intensity throughout the nineteenth and twentieth centuries. One of the milestones occurred on 14 March 1969, when the physicist Nicholas Kurti (born Budapest 1908, died Oxford 1998), who worked at the *Clarendon Laboratory* at the University of Oxford, gave a lecture to the members of The Royal Society (London) as part of the legendary Friday Eve-

University		Centre	Title	Branch	Places available 18-19	Credits (ECTS)	Type	Dates
Mondragón Unibertsitatea	Private	Faculty of Gastronomic Sciences	Bachelor's Degree in Gastronomy and Culinary Arts	Social and Legal Sciences	100	240	O	1/6/2011 ANECA* 6/1/2012 BOE* 15/7/2016 (S) UNIBASQ 7/7/2017 (RA) UNIBASQ
U. València (Estudi General)	public	Faculty of Pharmacy	Bachelor's degree in Gastronomic Sciences	Sciences	50	240	O	24/12/2015 BOE 29/9/2016 (PE) BOE
University of Barcelona Polytechnic University of Catalonia (UPC)	public	F. Pharmacy and Food Sciences (UB); ESAB-UPC;	Bachelor's degree in Culinary and Gastronomic Sciences	Social and Legal Sciences	80	240	O	15/12/2015 BOE 21/1/2016 (PE) BOE
University of Alicante	public	Faculty of Sciences	Bachelor's Degree in Gastronomy and Culinary Arts	Social and Legal Sciences	75	240	O	15/12/2015 BOE 21/1/2016 (PE) BOE
University of Cardenal Herrera (CEU) (Castellón)	Private	Faculty of Law, Business and Political Science	Bachelor's Degree in Gastronomy	Social and Legal Sciences	110	240	O	31/3/2015 ANECA 15/12/2015 BOE 29/1/2016 (PE) BOE
San Antonio Catholic U. of Murcia	Private	Faculty of Legal and Business Sciences	Bachelor's Degree in Gastronomy	Social and Legal Sciences	60	180	O	23/9/2013 ANECA (240) 7/12/2016 ANECA (180) 5/2/2018 BOE
Francisco de Vitoria University (Madrid)	Private	Faculty of Economic and Business Sciences	Bachelor's Degree in Gastronomy	Social and Legal Sciences	48	240	O	22/4/2014 ANECA 4/11/2014 (PE) BOE 6-1-2012 (PE) BOE
University of Malaga	public	Faculty of Tourism	Bachelor's Degree in Gastronomic Sciences and Hotel Management	Social and Legal Sciences	--	240	Pending	Subject to verification 2019-2020 academic year
Mondragón Unibertsitatea	Private	Faculty of Gastronomic Sciences	Master's Degree in Gastronomic Sciences	Social and Legal Sciences	20	90	O	26/1/2017 BOE
U. San Pablo-CEU	Private	Faculty of Pharmacy	Master's Degree in Gastronomy, Nutrition and Business	Health Sciences	30	60	O	30/7/2014 ANECA 20/2/2015 BOE 18/3/2015 BOE
Universities of Granada and Cordoba	public	F. of Pharmacy and F. Tourism (UGR) Faculty of Veterinary Medicine and F. of Agrifood (UCO)	Master's Degree in Gastronomic Sciences	Technology			pending approval	

O=official qualification. WEB: (1) https://www.mondragon.edu/es/grado-gastronomia-artes-culinarias; (2) https://www.uv.es/uvweb/grau-ciencies-gastronomiques/ca/grau-ciencies-gastronomiques-1285938692692.htm; (3) https://www.cett.es/es/oferta-academica/cursos/grado-de-ciencias-culinarias-y-gastronomicas/presentacion/introduccion, (4) https://www.uchceu.es/estudios/grado/gastronomia; (5) https://www.uchceu.es/estudios/grado/gastronomia; (6) https://www.ucam.edu/estudios/grados/gastronomia-presencial ,(7) https://www.ufv.es/estudiar-grado-gastronomia-madrid/ ; (8) https://www.uma.es/facultad-de-turismo/cms/base/ver/base/basecontent/113677/grado-en-ciencias-gastronomicas-y-gestion-hotelera/ (Documento RED CEIs Agroalimentarios /F. Triptolemos & Spanish National Agency for Quality Assessment and Accreditation 2019). ANECA* Spanish National Agency for Quality Assessment and Accreditation. BOE* Spanish Official Gazette.

Table 1. *New bachelor's and master's degrees related to Gastronomic Sciences. Source: own research.*

ning Discourses, entitled The Physicist in the Kitchen. Later, from 1986 to 1987, scientists from diverse fields of knowledge who were members of The Royal Society, followed in Kurti's footsteps, by writing about cooking, and culinary facts or processes, based on their scientific experience. The result was published in a historic book, *But The Crackling is Superb* (1988). At around that time, *Proceedings of the First Catalan Cooking Congress* (1984) was published in Catalonia.

The collaboration between Nicholas Kurti and a young French doctoral student, *Hervé This* led to a series of publications on the concept of *molecular gastronomy*, an evolutionary term arising from "physics and chemistry in culinary processes" (*Molecular and Physical Gastronomy* 1988, N. Kurti & H. This) which sought to join academia as a scientific discipline.

Starting in the 1990s, a group of innovative chefs and scientists working in the kitchen set up an annual meeting at one of the renowned venues for cultural and scientific events (the *Ettore Majorana Centre*, established by the physicist Antonio Zichichi in 1963), in the town of Erice in Italy. This was named the Erice *Science and Gastronomy Workshop*, and later became the International *Workshop on Molecular and Physical Gastronomy* and finally, after Kurti's death in 1998, the *International Workshop on Molecular Gastronomy* (1999-2004).

Ferran Adrià, the chef who has been the undisputed leader of an extraordinary culinary movement since creating the Alicia Foundation (2004), inaugurating the Alicia culinary area at Món Sant Benet (2007), and being named Doctor *honoris causa* by the University of Barcelona (December 17, 2007), also became involved in the new project outside Catalonia to build bridges between the great scientists and chefs of the late twentieth century. This marked the beginning of the Harvard University Science and Cooking Public Lecture Series, after an agreement (MOU) signed on 10 December 2008 by Ferran Adrià, on behalf of El Bulli and the Alicia Foundation, and the heads of the *Harvard School of Engineering and Applied Sciences*. The event has taken place every year for the last ten years in the USA.

Meanwhile, the Science & Cooking World Congress Barcelona 2019 took place in the Historical Building of the University of Barcelona from 4 to 6 March 2019. It was chaired by Pere Castells, who was initially a member of the scientific department at elBullitaller (2003), and joined the Alicia Foundation as head of the Department of Scientific and Gastronomic Research between 2004 and 2012, and was subsequently a member of the UB-Bullipedia Unit on the Torribera Food Campus until 2016. The congress was attended by researchers, scholars, innovative chefs and communicators involved in current Culinary and Gastronomic Science and in the process of open dialogue between science and culinary innovation that has taken place for the last 25 years.

05. New scientific fields building gastronomic knowledge.

The best examples of institutions dedicated to enhancing culinary knowledge were discussed over the three days of the Congress, with lectures that emphasised the importance of the research being carried out in the culinary world. The value of applications related to gastronomy and culinary sciences was highlighted in other sectors including health and the food industry, as well as in the restaurant and gastronomy industry. The role of gastronomy as a factor in regional economic development was also highlighted. Finally, the organisers of the Science & Cooking Barcelona congress of chefs and scientists released a statement on the need for governments and stakeholders to value the role of scientific gastronomy as the basis of new gastronomic knowledge and culinary innovation. In conclusion, new areas of knowledge in the field of gastronomy have been consolidated in recent years, in the wake of the path that was initially created between gastronomy and tourism, heritage and agrifood. Some of the areas related to gastronomy that currently receive the most public interest are listed in Table 2.

06. Science and Cooking Congress; Copenhagen 2018 – Barcelona 2019: A holistic overview of cooking.

One of the tools used to make progress in defining the academic and research framework for gastronomy and cuisine, considered as culinary and gastronomic sciences, is regular short conferences organised by the institutions leading the way in this new area of knowledge. The leaders in this field include the University of Copenhagen, through its *Department of Food Science* (UCPH FOOD), the institution that organised the science and cooking symposium entitled GASTRO-SCIENCE-CHEF 2018, which took place on the Frederiksberg Campus on 23 and 24 May 2018.

The initiatives at these events over the past 25 years, led by innovative food and culinary ecosystems, have been focused on Harvard in the USA, Oxford in the United Kingdom and Copenhagen in Denmark. The movement arrived in Catalonia in 2019 with the Science & Cooking World Congress Barcelona 2019, an initiative that was part of the Third Catalan Cooking Congress 2018-2019.

Two of the various contributions made by the speakers highlighted the need to take full advantage of the current chef-researcher relationship. One was by Joan Roca and Salvador Brugués: "The role of science in culinary research at the Celler de can Roca". In the other, the excellent duo consisting of Davide Cassi (University of Parma) and Massimiliano Alajmo (Le Calandre) showed how science helps culinary excellence by explaining various dishes and techniques.

Discipline	Founders	Institution	Reference	Keywords
Molecular Gastronomy	N. Kurti and H. This (1988)	University of Oxford & INRA-París	H. This, "Molecular gastronomy is a scientific discipline…" *Flavour* 2013, 2:1, 1-7.	Science applied to cooking Scientific Gastronomy Culinary and Gastronomic Science
	J. Risbo, O.G. Mouritsen, H.B. Frost, J.D. Evans &B. Reade (2013)		"Culinary Science in Denmark: Molecular Gastronomy and Beyond." J. Culinary Science & technology 11, 111-130 (2013)	
Computational Gastronomy	S. E. Ahnert (2013)	University of Cambridge	"Network analysis and data mining in food science: the emergence of computational gastronomy"; Flavour 2:4 (2013)	Big Data applied to gastronomy Interactions between food and medicines Gastronomic knowledge management
	A. Bidal-Chanal & M. Vila (2017)	University of Barcelona		
Nutrition Gastronomy	V. Navarro, G. Serrano, D. Lasa Andoni L. Aduriz, J. Ayo. (2012)	AZTI & Restaurante Mugaritz	"Cooking and Nutritional Science: Gastronomy goes further" Int. J. Gastronomy & Food Science, 1, 37-45 (2012)	Textures Appetite
	Mònica Povedano, Núria Luzon Foundation & Iberostar Project	Bellvitge Hospital Universitari (IDIBELL) University of Barcelona Alícia Foundation	"Study of dysphagia in patients with Amyotrophic Lateral Sclerosis (ALS) and the improvement of their quality of life with personalised nutritional gastronomy" 2017-2018	Chronic diseases and taste Malnutrition Personalised nutrition
	Pere Clavé & Pilar García Peris (2015, 3rd. ed.)	Hospital de Mataró Alícia Foundation	"Guide to Diagnosis, Nutritional Treatment and rehabilitation of oropharyngeal dysphagia," pub. Glosa, Barcelona, 2015.	Gastronomy of Ageing Dysphagia and texture control
Neurogastronomy	Gordon M. Shepherd (2006)	Columbia University	"Neurogastronomy," 2012 Columbia University Press	Food and neuroscience Culinary emotional intelligence Culinary sensory sciences
	Miquel Sanchez Romera (2008)		"Neurogastronomy: Culinary emotional intelligence" 2008, 2nd ed. Grupo Saned, Madrid (2008)	
Gastrophysics	Charles Spence	University of Oxford	"Gastrophysics" Paidós ed., Barcelona 2017	Gastronomic sciences of perception Perception, consumer, and food Neuromarketing
	Charles Spence & Betina Piqueras-Fiszman	University of Oxford Wageningen University	"The perfect meal: The Multisensory Science of Food" Wiley Blackwell, Oxford, 2014	
Gastronomy & Fermentation	René Redzepi & David Zilber	University of Copenhagen & NOMA The Nordic Food Lab	"Le guide de la fermentation du Noma" (2018) Editions du Chêne	Intestinal microbiota
Gastronomic Engineering	José Miguel Aguilera	Pontifical Catholic University of Chile	Gastronomic Engineering eBook Catholic University of Chile Editions, Santiago, 2011	Food microstructure engineering

History and Anthropology of Gastronomy	Jesús Contreras and ODELA A. Riera Melis M. A. Pérez Samper	University of Barcelona	"Food and culture. Anthropological Perspectives", ARIEL, Barcelona, 2004 "Gastronomy and politics at the courtly banquets of the Late Middle Ages." In "Food in the Crown of Aragon." R. Melis Ed., Lleida 65-100, 1995 "Tables and kitchens in eighteenth-century Spain," Gijón TREA, 2011	Gastronomic and culinary culture Anthropology of food History of gastronomy and cuisine
Gastronomic Heritage and Tourism*	F. X. Medina	Open University of Catalonia	Tourism Atlas of Catalonia Gastronomy and wine and gastronomy routes	Gastronomic heritage Food tourism
Gastroeconomics*	M. Bernardo, R. Escalante and A. Arbessà	University of Barcelona	"The international success of Catalan cuisine. Beyond creativity and innovation." UB Edicions. 2019	Gastronomic business management Gastroentrepreneur

Table 2. *Gastronomy as a science: scientific fields. Source: own research.*

07. Conclusion: An opportunity for Catalonia.

Despite the decline in opportunities in Catalonia in relation to other European gastronomic hubs, there is still sufficient impetus to establish a strategic Catalan policy within the Horizon 2025 programme, which, based on the Gastronomy Plan of Catalonia, will bring together all the initiatives and institutions, stakeholders and experts around a proposal that will finally place Catalonia in the international arena with a structured and consistent project.

Further reading

ALICIA Project: www.alicia.cat.
http://jaumeprat.com/ca/clotet-paricio-adria-fundacio-alicia/

OLIVÉ, M., CASTIÑEIRA, À., LOZANO, J.M. (2010) "Món Sant Benet: Utopia, Ambition and Passion. A case of territorial leadership in Central Catalonia". ESADE, Barcelona. Leadership and Democratic Governance Chair, pp. 1-95. Barcelona

THIRD CATALAN COOKING CONGRESS 2018-2019. Science & Cooking World Congress. Barcelona 2019.
www.congrescataladelacuina.cat.
www.cienciaicuina.cat
University of Barcelona. Torribera Food Campus:
www.ub.edu/campusalimentacio

Speech by Claudi Mans during the investiture of Ferran Adrià with a Doctorate Honoris Causa: https://cercabib.ub.edu/iii/encore/record/C__Rb1817638?lang=cat

CETT-UB. Higher School of Hospitality and Tourism:
www.cett.es

ESAB-UPC. Barcelona Higher School of Agriculture:
www.upc/esab.edu

La Masia Project. Restaurant Celler de Can Roca:
https://cellercanroca.com/menu/menu.html

F.P. MILLER, A. F. VANDOME, J. McBREWSTER, Eds. (2010) Molecular Gastronomy, Alphascript Publishing (VDM).

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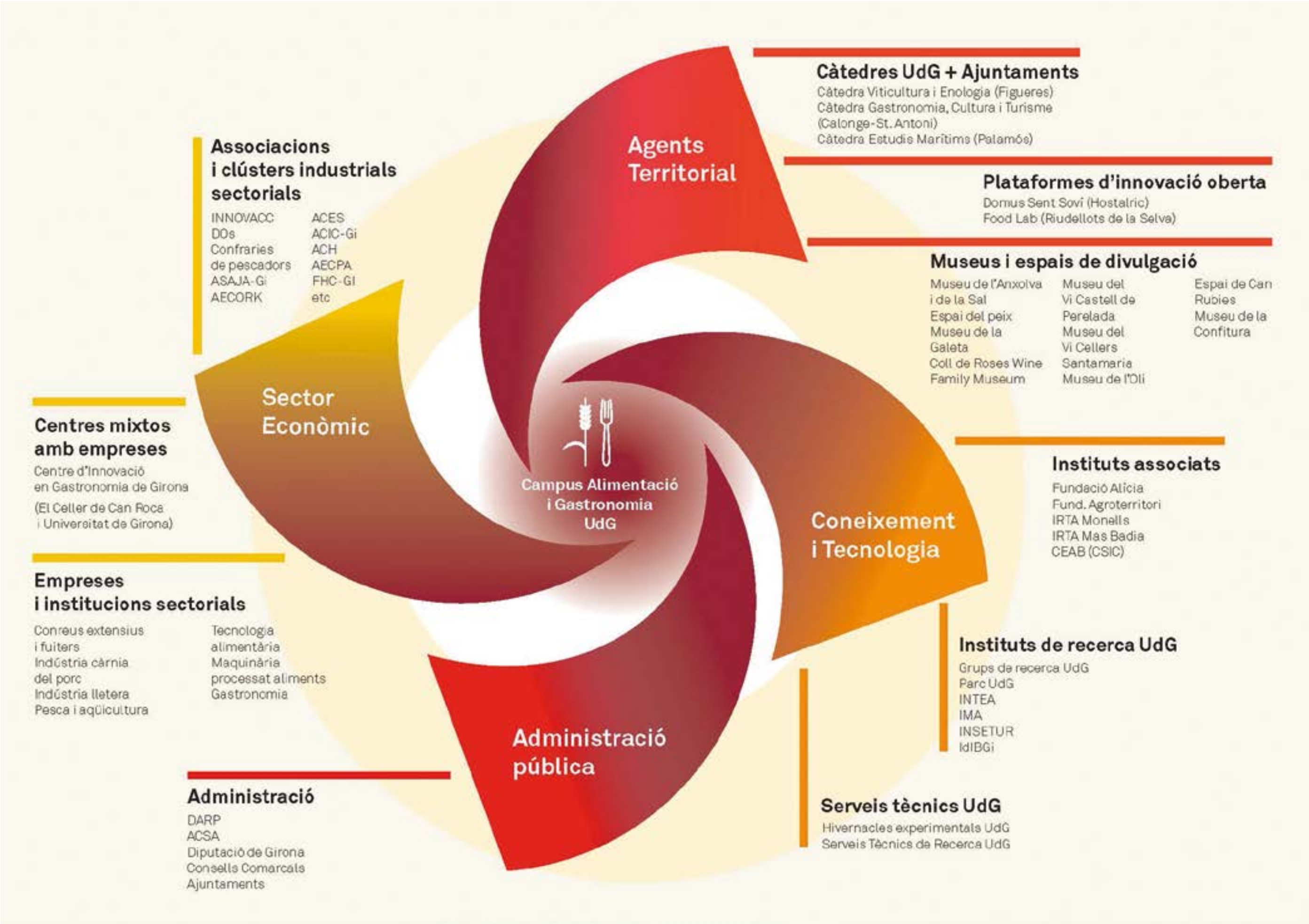
INNOVATION AND TOURISM IN THE AGRIFOOD SECTOR: cooperation strategies between different agents



Institutions associated with the University of Girona's Food and Gastronomy Campus in relation to the quadruple helix. Source: Food and Gastronomy Campus of the UdG.

01. Introduction

Catalonia's recognition as a European Region of Gastronomy in 2016 enhanced the international image of Catalan gastronomic tourism, and created an opportunity to reflect on the challenges for Catalan gastronomy in the coming years. The candidacy was based on three factors: local produce, the territory and cuisine, and was an opportunity for the Ministry of Agriculture, Livestock, Fisheries and Food, through the Promoter of Catalan Agrifood Exports (PRODECA) to work with the Ministry of Business and Knowledge, through the Catalan Tourist Board.

At the same time, the Sectoral Campuses project is taking shape at the University of Girona, and involves platforms for establishing relationships

> Through its Sectoral Campuses and Chairs, the University of Girona is seeking the active involvement of academia, business, government bodies and society.

created in order to proactively facilitate networking between companies and institutions and the University of Girona. This project became the UdG's territorial strategy to meet the challenge of intelligent specialisation promoted by the European Union, which has been implemented in Catalonia through the Research and Innovation Strategy for the Smart Specialisation of Catalonia (RIS3CAT). This also creates a paradigm shift in the relationships between the parties involved in the quadruple helix of the innovative ecosystems in each socio-economic sector. Although there have been some very successful experiences of knowledge transfer in Catalonia, the Sectoral Campuses initiative at the UdG is practically unprecedented in the Catalan university system, in the sense that it uses a market-driven approach to identifying needs which involves the smart specialisation of an entire University and the surrounding area.

In addition to the Campuses, the University of Girona has other units that enable it to better interact with the region. These include two major chairs in the agrifood and tourism sectors: the Empordà Wine and Oil Chair in Figueres, and the Gastronomy, Culture and Tourism Chair in Calonge-Sant Antoni. Both have the shared aim of disseminating the culture of food products in three basic areas: promoting outreach, training and research.

02. Research and transfer in the field of gastronomic tourism

ACCENT Gastronomy

The University of Girona coordinated the ACCENT Gastronomy project, a COSME project funded by the European Union, which sought to adapt gastronomic tourism experiences to the needs of people with sensory disabilities. The aim was to provide SMEs, industry professionals and entrepreneurs with tools to develop an accessible range of gastronomic tourism. The project's most important activities were identifying disabled people's needs when vi-

Flowering apple trees. Photo: Jesús Francés.

Round table at the opening ceremony of the Third Catalan Cooking Congress in Girona, featuring chefs and cooking students). Photo: Girona Territorial Committee of the Third Catalan Cooking Congress.

Training sessions in the ACCENT Gastronomy project at the Empordàlia cooperative. Photo: Neus Crous.

Visit to the La Vinyeta olive groves. Photo: Jesús Francés.

Tourism visit to the cooperative winery in Espolla. Photo: Jesús Francés.

Participants in an Enokaiak activity in the Empordà region. Photo: Pau Calero. SKKaiaks.

siting gastronomic tourism venues (including interpretation centres and museums, production areas such as wineries and restaurants) and providing training sessions.

MEDFEST

The MEDFEST project is funded by a European Union MED programme, with participation by the University of Barcelona, and the University of Girona's involvement as a member of the Advisory Committee. It aims to create culinary heritage-based tourism experiences in order to sustainably develop inland regions. One of the areas it focuses on is therefore involvement of local producers and respect for the local environment and tradition. In Catalonia, the Alt Urgell region has been selected for the pilot test, and the organisation of a series of routes involving various local producers has begun.

03. Tourism experiences related to the agrifood sector

Several initiatives have taken place in the gastronomic tourism field in Catalonia, but we will highlight some of the most innovative in this article. Adapting hectares of cultivated land to organic farming, both for sale as fresh produce and for processing and preparation, e.g. compotes, juices, cider, etc., and providing restaurant and tourism services has been one way that some entrepreneurs have chosen to add value to their product. Producing the product and offering related services, short itineraries and tourist experiences is a way of obtaining higher returns.

The Empordà DO wine route includes several companies that offer visitors the opportunity to combine visits to wineries with restaurants, accommodation and other activities.

"Welcome to the Farm"

One of the initiatives that has probably had the greatest impact on local communities is the "Welcome to the Farm" campaign; this activity consists of organising a weekend (the first in June) when agrifood farms all over Catalonia "open the their doors to show us their fields, their herds, their boats and their workshops." Over the weekend, producers in the various agrifood areas allow visitors into their work spaces and facilities (farms, workshops, fishing boats, etc.). The event took place for the fourth time in 2019, and the number of participating companies and visitors has increased every year.

Other experiences

The Pro-Mediterranean Foundation through the Espai del Peix Fish Zone in Palamós aims to contribute to increasing knowledge of seafood and its gastronomy, and adding value to species that are not highly rated in culinary terms, and to improve the recognition of the work done by fishermen. The facility has three areas: the Fish Zone, the Fish Market and the Fishing Museum. The Fish Zone is the venue for courses, workshops and outreach activities for all types of audiences (primarily school students and tourists); the Fishing Museum is an interpretation centre and a space for raising awareness of the work done by fishermen, and finally, the Fish Market has begun a project involving selling fish immediately after auction, which aims to promote the consumption of fresh fish.

Enotourism. A significant number of wineries have started tourism-oriented activities in recent years, involving visits to the winery and its facilities. The number of visits available increases every year, and the new activities include dinners with music, cinema, poetry recitals, dancing, yoga sessions, astronomy sessions and many others. For example, the Costa Brava – Girona Tourist Board is working with the Empordà Designation of Origin on coordinating the wine route, which contains a wide variety of places of interest. Highlights include the Vivid festival, which takes place every April, where various wineries run activities related to wine, such as guided tours and tastings accompanied by poetry and music.

If it takes place at a local level, gastronomic tourism can be an opportunity for small producers and a means to preserve traditional heritage and the landscape.

Other more innovative activities include enokayaking – a kayak trip along the Costa Brava that ends with a wine tasting at the Hugas de Batlle winery, and Naturalwalks, which combines guided walks with pairings of wild flowers and wines.

Oleotourism. Olive oil production has seen initiatives oriented towards tourism in recent years, including visits to production facilities showing how olive oil is produced, as well as other experiences involving accommodation, gastronomy, exhibitions, plays and festivals. Finally, there are even combined wine and olive oil agritourism initiatives.

04. Working in the future

Gastronomy is becoming a key factor in enhancing tourist destinations, and one of the main identifying and distinguishing characteristics of a place. Gastronomic tourism is an area that increases the importance of local ingredients, and learning about and appreciation of their consumption, as well as the importance of culinary resources, which fosters local economic development through various distribution channels. Numerous important initiatives are under way to restore, conserve and valorise gastronomic heritage as a result. The projects listed above are some examples.

Enhancing the value of the ingredients and the various items in the extensive value chain in the gastronomic tourism experience, such as agriculture, fishing, livestock farming, the culture of the market and distribution, and factors linked to traditional cuisine is a strategic issue. The inclusion of local communities, agricultural and livestock farmers, cheeseries, markets, wineries, craftspeople and interpreters of the region and everyone who creates a place's identity enhances a destination's value proposition and is a crucial factor in this process.

Further reading

Website of the Food and Gastronomy Campus of the University of Girona:
http://www.udg.edu/campusalimentacio

Website of the University of Girona Gastronomy, Culture and Tourism Chair in Calonge-Sant Antoni:
https://www.udg.edu/ca/catedres/Gastronomia-Cultura-i-Turisme

Website of the University of Girona Empordà Wine and Oil Chair:
https://www.udg.edu/ca/catedres/Vi-i-oli-Emporda

Gastronomy plan, Ministry of Agriculture, Livestock, Fisheries and Food:
http://www.pladegastronomia.cat/

Accent Gastronomy. "Offering Food tourism experiences to people with sensory impairment":
http://www.accentgastronomy.eu/

Website of the Third Catalan Cooking Congress:
http://www.congrescataladelacuina.cat

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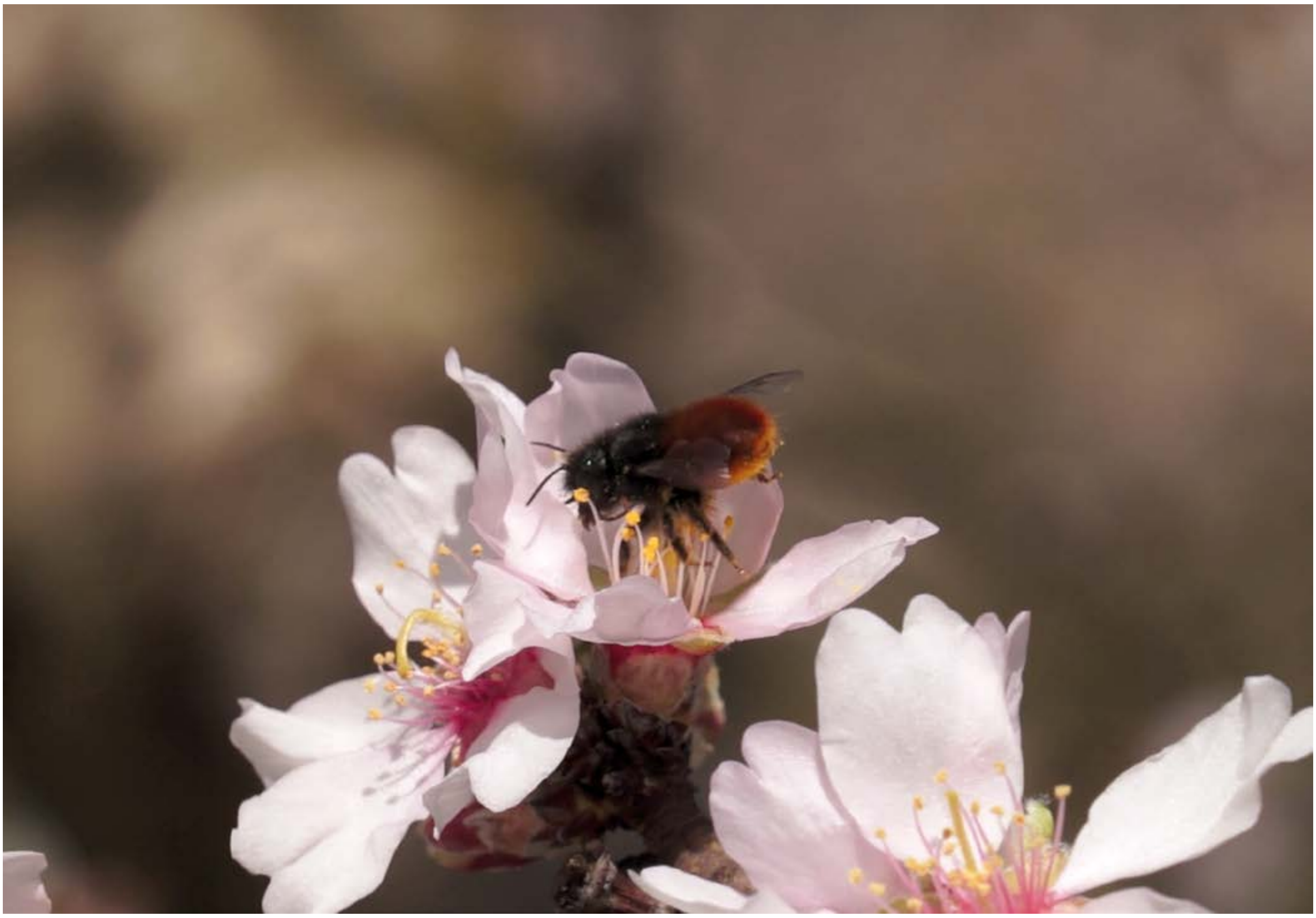
CREATING BIODIVERSITY?
Beyond conservation



Pollinating Osmia cornuta.. Photo: Jordi Bosch.

01 Background

The Mediterranean Basin is one of the main centres for the concentration of biodiversity on the planet. It is known as a hot spot because it has a higher species concentration than the levels considered normal.

Maintaining this biodiversity is one of the greatest environmental challenges we have faced in recent decades. Without biodiversity, it would be impossible to obtain the vast array of ecosystem and environmental goods and services we need to live: pollination, the degradation of organic material beneath our feet and its transformation into nutrients for plants, pest control, etc.

At the Ecological and Forestry Applications Research Centre (CREAF), we study the mechanisms that create and maintain biodiversity in terrestrial ecosystems. We study the distribution of biodiversity in the region, how populations of certain key species fluctuate, and the factors that endanger them. We work with species and communities of fungi, plants and animals, carrying out studies at both molecular and ecosystem level.

02. How can the value of biodiversity be integrated into forestry?

Forests more diverse and mature have a richer, more flexible ecosystem that is more resilient to climate change. For this reason, the CREAF believes that forestry can also be a tool that contributes to biodiversity, and can even help to foster it in forests. As a result, the centre is working on projects to test innovative forest management strategies which also take the promotion of biodiversity into account. For example, the new LIFE+BIORGEST project will involve a wide variety of initiatives, ranging from eliminating exotic tree species, increasing the amount of large pieces of dead wood in forests, maintaining some larger trees, encouraging regeneration by creating gaps in more mature forests, and favor accompanying tree species among other measures. This will take place in Catalonia's three most widespread Mediterranean forest habitats (holm oak, Aleppo pine and Mediterranean oak forests). As a result of these measures, the Centre also hopes to develop tools such as guidelines and management manuals to assist in decision-making, and to integrate this perspective into the Catalan government's policies and regulations.

The CREAF is also working within the LIFE+RedBosques project to study the role of mature forests as biodiversity reserves and as benchmarks for ecological integrity and naturalness. Mature forests are the habitat of large numbers of highly specialised and often highly endangered species which are unable to live in the younger areas of the forest, and are restricted to more mature stands. These forests contain very large trees some of them in decline stage next to standing and fallen dead trees, which all creates a diversity of micro-habitats that are essential for many forest species that depend on them. Studying the structure and workings of these forests can provide useful guidance for forest management.

03. How can the value of biodiversity be integrated in agriculture?

Fruit trees in Catalonia often do not attain the anticipated production levels because of poor pollination. This may be for several reasons. First, fruit trees bloom in late winter and early spring, in unstable weather conditions which are not suitable for pollinating insects. Furthermore, Catalonia's populations of wild pollinators are often too small to pollinate large areas of crops. This situation is particularly acute in areas where intensive farming takes place. Pesticides are used in these areas, and the natural habitats of these insects have been destroyed, and the flora that accompanies them has been eliminated. As a whole, this means that pollinating insect populations are low and fruit tree pollination is limited. Finally, many varieties of fruit trees are self-sterile, which means that high levels of cross-pollination between varieties is needed if they are to bear fruit. In recent years, the CREAF has been working on methods for breeding and managing populations of the *Osmia cornuta* bee, and is working to show that this native species is a good alternative for improving the pollination of Catalonia's crops and the economic results of almond, cherry and pear tree orchards in Catalonia. The pollinating efficiency of *Osmia cornuta* has been proven to be practically 100%, which means that every flower it visits is pollinated. its natural period on wing coincides with the flowering of the fruit trees, and they have a strong predilection for the fruit tree flowers; their short flight range means that it is easier for them to focus on the field to be pollinated. *Osmia cornuta* is also active under climate conditions with low temperatures and cloudy skies, thereby providing many more hours of pollination than the honey bee. The CREAF has many years' experience breeding populations of *Osmia cornuta* and testing them on crops in partnership with the IRTA. It is now working with a Swiss company which produces nesting materials for solitary bees, on a demonstration project

> The *Osmia cornuta* is an indigenous species that is a good alternative for improving pollination on almond, cherry and pear tree farms and enhancing their economic results.

Insect hotel. Photo: Jordi Bosch.

Pollinating Osmia cornuta. Photo: Jordi Bosch.

funded by the Ministry of Agriculture's demonstration activities grants. This project aims to show that using native populations of *Osmia cornuta* is an effective alternative for improving the pollination of various fruit trees in the fruit-producing area around Lleida.

The CREAF has also worked on designing and applying various insect hotels all over Catalonia (see photo on previous page). These hotels provide nesting areas for insects which have lost their natural habitat. That is why they are made of natural materials and have various cavities and characteristics designed to accommodate the widest range of insect life possible. The project is being undertaken in partnership with the Catalan company Let it bee, and the hotels installed include the insect hotel at the Barcelona Botanical Garden. This hotel, which is 2.40 metres high, is made from Catalan oak and Douglas fir, and can accommodate a wide variety of solitary bee and wasp species. This helps to pollinate the vast majority of botanical species in the Garden, and in the biological fight against aphids and other insects which are harmful to the plants there.

04. The role of soil biodiversity in conserving ecosystem services

Soil organisms play a central role in processes that are vital to the ecosystem as a whole. Underground life, the soil biota, is crucial because it decontaminates the soil, breaks down organic waste, and mobilises the nutrients it contains, making it available to plants. Many soil organisms (known as ecosystem engineers) give it the structure and porosity it needs to regulate the hydrological cycle properly. Whether the soil acts as a carbon sink or emitter, with serious implications for climate change mitigation, ultimately depends on the underground biota's metabolism. These soil microorganisms are in fact closely linked to the plants that have their roots in the soil, and plants must be considered complex organisms for this reason. This organism includes both the plant itself, and the microorganisms that inhabit the rhizosphere and the phyllosphere (the areas around the roots and leaves respectively). These two areas are largely responsible for the plant's efficiency in capturing nutrients, and its level of resistance to stress and pests.

The CREAF has been researching the role of underground biota, the environmental services it provides, and how to conserve or restore it in the face of current threats caused by climate change and human pressure. In specific terms, the CREAF assesses the taxonomic and functional diversity of the different species of microorganisms, who they are and what they do. We also study the structure and underground trophic networks of forest and agricultural ecosystems, how they are organised and who eats whom. We look at how climate change, changes in land use, intensive farming and pollution are affecting this biodiversity, and study how to restore degraded soils using nature-based technologies.

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CLIMATE CHANGE AND AGRICULTURAL SYSTEMS: grape and wine growing, I2Vi (INCAVI-IRTA)

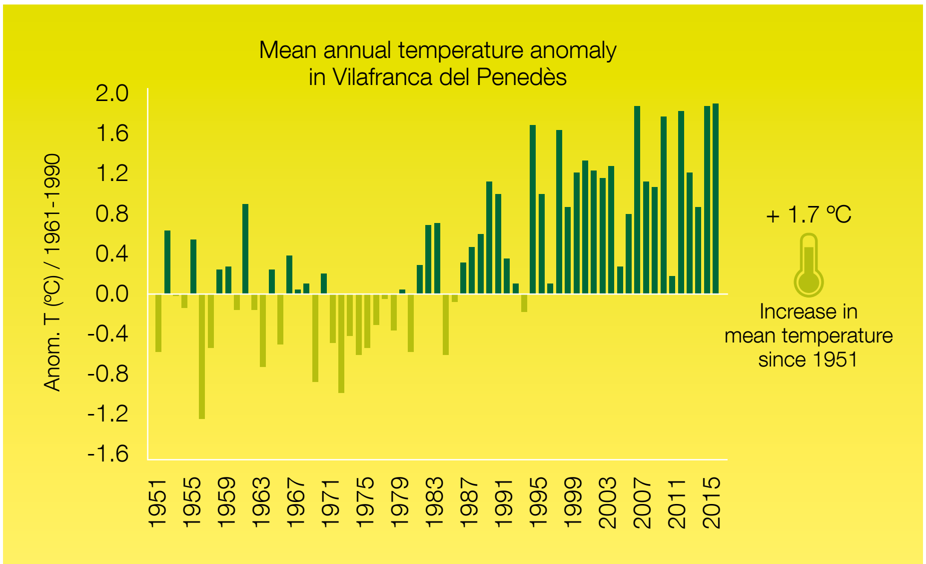

Figure 1. *Mean annual temperature anomaly in Vilafranca del Penedès between 1950 and 2015. Source: own research based on SMC-IRTA graphs.*

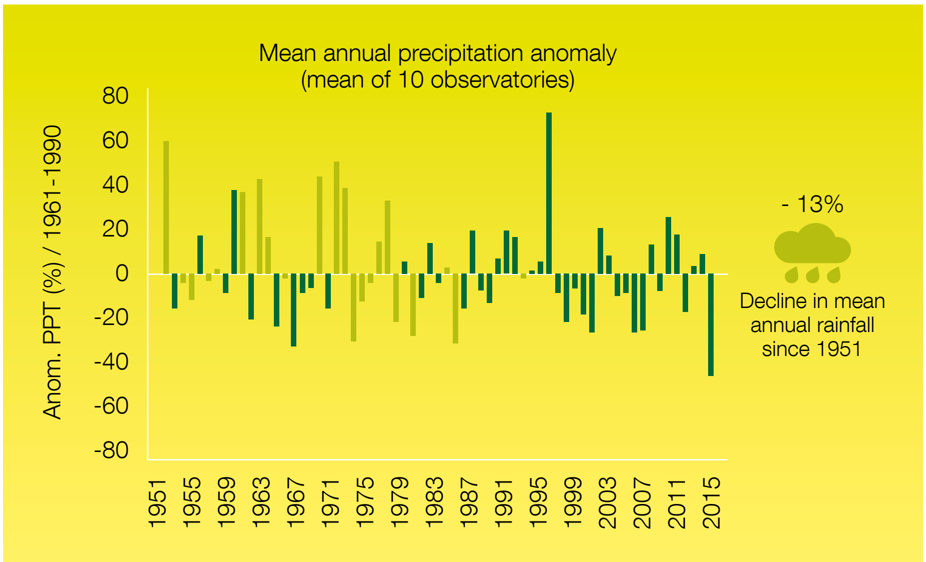

Figure 2. *Mean annual rainfall anomalies in Vilafranca del Penedès between 1950 and 2015. Source: own research based on SMC-IRTA graphs.*

Grape and wine growing in the Mediterranean region, including the Iberian Peninsula, has become internationally renowned thanks to continuous improvement in the cultivation and the quality of the deliverable end product, as well as the development of agronomic methods based on ecophysiological and genetic knowledge of the varieties, clones and stocks cultivated there. Nevertheless, the growth, yield, and quality of grapes and wine depend largely on the climate, which has been changing since the 1970s and 1980s. Climate conditions have begun to change and this will not stop until our common sense slows it down or at best, stops it.

The Meteorological Service of Catalonia's climate model projections show a decline in the total amount of water available in the current century, and if global change is also taken into account (which includes land use, energy costs, a rising fixed and mobile population, the needs of industry and the maintenance of biodiversity, among other factors), we must anticipate increased real competition for water, which must be adjusted based on needs. Climate change will also lead to rising global temperatures. However, where it will be particularly apparent is in local changes, as these small changes in temperature/evaporation can have a major effect on the carbon source/sink balance, on the growth of plants (both morphological and metabolic) and on changes in the phenology of species and therefore on their relationships, whether these involve predation, competition, symbiosis or pathogenicity. Climate change will have varying degrees of impact over these short distances (within the Designation of Origin, the terroir, and the individual estate).

In addition, the current international wine market is highly competitive, mainly due to emergence of new producer countries, the high quality of the wines produced, price wars, the increased costs of vine production, etc. However, in Catalonia the sector's exports have risen steadily over the last 10 years, which is an even higher growth rate than the European average. Meanwhile, domestic consumption has dropped to levels well below the European average. For this reason, the sector needs the various stakeholders involved to consider how to improve their processes and products, or to invest in them or to innovate in order to support a process of internationalisation as the only way of increasing their businesses' competitiveness and long-term sustainability.

We must invest in business research, development and innovation in order to ensure profitable growth in the sector and to optimise production.

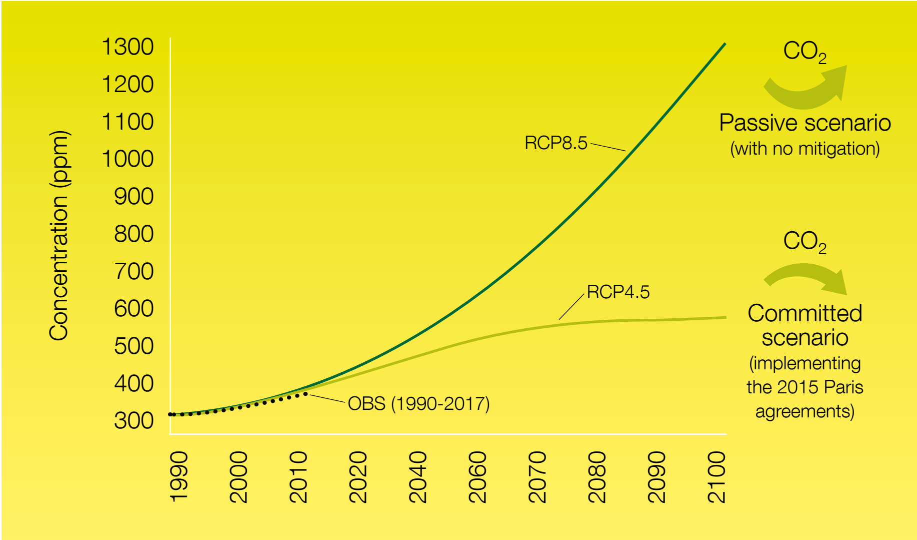

Figure 3. *Atmospheric carbon dioxide concentration in a passive scenario and in a committed scenario. Carbon dioxide levels between 1990 and 2017 are represented by the dotted black line. Source: own research based on SMC-IRTA graphs.*

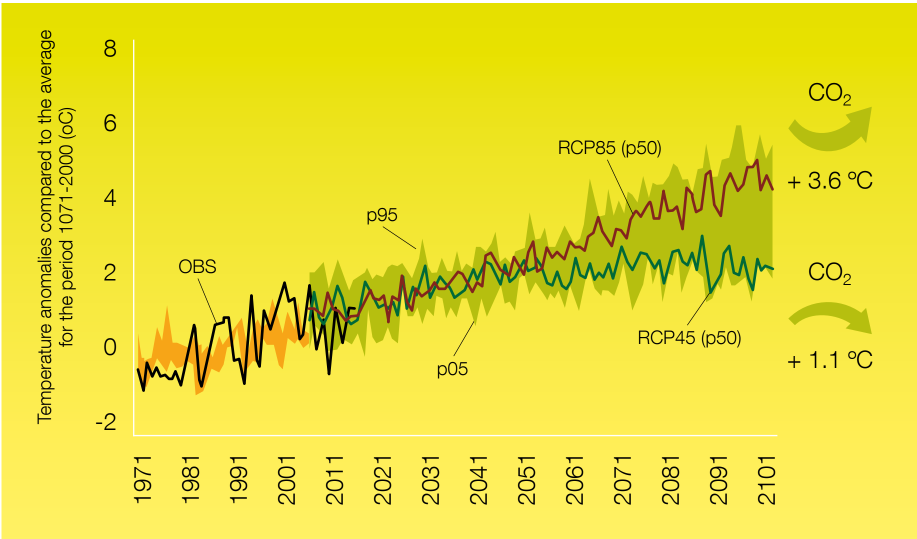

Figure 4. *Temperature anomalies according to different scenarios: passive (red) and committed (green). The temperature anomalies between 1970 and 2017 are shown in black. Source: own research based on SMC-IRTA graphs.*

According to a report by the International Organisation of Vine and Wine (the OIV), Spain is a leading country in terms of its vine-growing area, with about 900,000 hectares, which accounts for 13% of the world's total production area (almost 8 Mha). In overall terms, Spanish wine production is practically stable at around 40 million hectolitres. It is also the world's second-ranked wine exporter, with some 22,300,000 hectolitres. This volume accounts for 22% of the world's total. There are currently around 5,500 wine-producing companies in Spain, of which about 630 are cooperative wineries. This large number of businesses highlights the enormous fragmentation in the wine sector, and the small size of the vast majority of the businesses within it. However, the average size of the cooperative wineries is much larger than the average for the whole, as they account for around 12% of the total number of wineries, and produce more than 60% of the sector's total products.

Meanwhile, according to figures from the Spanish Wine Markets Observatory, domestic consumption has continued to fall, in both the domestic food channel (-1% in volume and -4.2% in value) and in restaurants, where the decline has been even more marked (more than -9% for both volume and value). The growing gap arising from the divergence between production and domestic consumption has forced the wine sector to look for new solutions and alternatives in order to bring Spanish wine production to foreign markets.

In the current situation in the Spanish wine sector, the challenge is still one of taking advantage of the growth of the international market as a result of Spain's wine-producing potential, in order to ensure profitable growth for the sector without neglecting the domestic market, while at the same time making a commitment to research, development and business innovation as ways to optimise production and adapt the qualities of the wines to their prices for the foreign and Spanish end consumer.

Spain has 85 areas producing high-quality wines covered by Protected Designations of Origin (PDO), which are strictly controlled by the European Union's regulatory system governing the volume produced, wine-making practices and the quality of the wines produced in each area.

Catalonia has traditionally been a wine-producing region. Catalonia's wine sector currently ranks fourth in economic value in the country's food industry, and accounts for approximately 25% of Spain's total wine production. This has been around 45 million hectolitres/year for the last decade, a similar figure to production in France and Italy.

Due to its geographical location, Catalonia is a land of wide bioclimatic variety: it has mountains (the Pyrenees), plains and valleys (such as the Ebro Valley) and the coast (the Catalan coast). This wide climatic variety means that white and red grapes can be cultivated, and red, rosé and white wines can be produced as well as cava, which accounts for more than 60% of wine production in Catalonia. The vineyards of Catalonia cover about 55,000 hectares, and supply wines to the twelve protected designations of origin.

In view of this situation, the DARP has established a policy for concentrating and enhancing synergies between the R&D centres with skills in the winemaking world. The two institutions to do this are the IRTA and the INCAVI. This partnership has been known as "I2Vi" since November 2014.

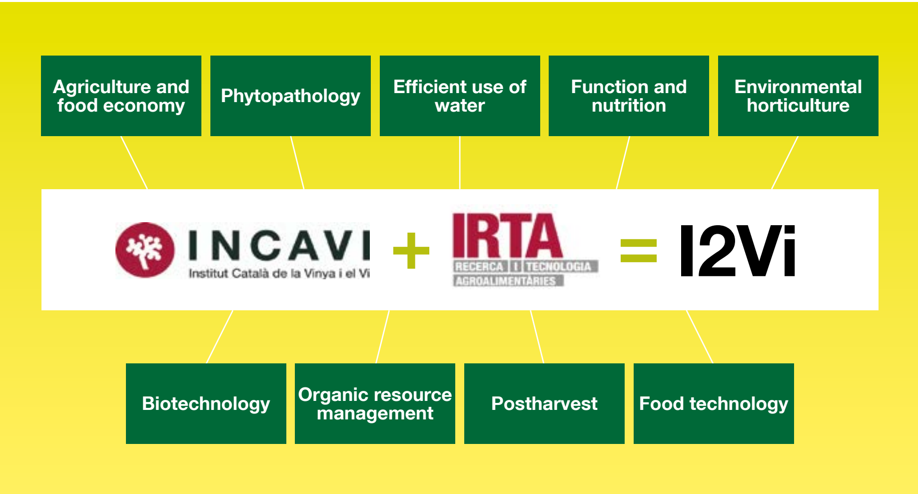

***Figure 5.** INCAVI and IRTA form I2Vi. Two R&D centres in the wine-producing world. Source: own research.*

However, given the challenges that this important Catalan socio-economic sector (the country's third most important after the meat and agrifood industries) will have to face during this century, we can state categorically that there is a great deal of detailed and confirmed information available about the phenomenon of climate change, and its effects on vineyards and wine. Specific knowledge regarding vineyard agronomy is also available, as well as information from other agricultural sectors that can also be applied to viticulture. It is therefore important to acknowledge the situation, assess its consequences and propose appropriate solutions for each edaphoclimatic situation, for each type of plant material (variety/rootstock/clone), for each age and for each deliverable end product (still wine or cava, specificity and large-scale production).

The recognised Designations of Origin in Catalonia are Empordà, Pla de Bages, Costers del Segre, Alella, Penedès, Conca de Barberà, Tarragona, Montsant i Terra Alta, and DOQ Priorat. Others are the DO Catalunya and the DO Cava.

Based on this assumption, it is reasonable to commit to viticulture with a low environmental impact which implemented based on common sense, which restores the soil's importance in controlling erosion and maintaining biodiversity, due to its great potential as a carbon sink and consequently, the soil's impact on mitigation strategies, as well as on the capture and storage of water, which are crucial for drylands, which account for 60% of our viticulture.

Photo: R. Savé. IRTA-INCAVI.

The best variety/rootstock combination for each area must also be taken into consideration, and the pathology must be evaluated in an overall context for the crop: seeking the comprehensive and long-lasting solution rather than the problem.

Establishing overall indicators in each plot and in each winery, in the context of their Designation of Origin and/or geographical location, such as the amount of organic matter in the soil, its water content, the water balance according to the canopy and fruit load, the ratio between organic phytosanitary applications and production, the biodiversity indices associated with green soil cover and other indicators described by various Catalan research groups, is essential if our low-impact viticulture is to adapt to climate change.

Winemaking techniques must be continuously improved to enable adaptation to climate change to continue inside the winery, while at the same time incorporating of technological processes that leading to more expressive and sustainable wines, and the implementation of constructive procedures and criteria for wineries to improve their energy efficiency, reduce and control their water consumption, and reduce their environmental impact.

I2Vi, with its (external and internal) partnerships with the public and private sectors, involving tried and tested or new formulas, must help define strategies for adapting grape growing and wine production to climate change in a situation of global change, and therefore involving mitigation of this change, bearing in mind that there is no single solution and that there are therefore many suitable alternatives for being resilient. This means: being productive in terms of quantity and quality.

We need to take responsibility and bear in mind that our decisions will have even greater consequences for a crop such as grapes, which is anticipated during the years of most severe climate change.

In this situation, the only impossible alternative is to do nothing, and this is particularly true bearing in mind the potential at our disposal.

Acknowledgements

This study was written by two people, but is a reflection of the high quality, effective and painstaking work done by hundreds of professionals at both institutions, in the world of vines and wine.

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NEW GENOMIC EDITING TECHNOLOGIES. Impact on plant improvement

01. Introduction

Virtually all of the plant varieties we use in agriculture are the result of an intensive selection process carried out by farmers over millennia, and more recently by professionals working in the field of genetic improvement. The selection process needs to identify the plants that carry the characters of interest from among existing populations; this requires access to plants with the highest levels of variability. For this reason, seed conservation policies are advocated (Casals et al. 2019), and seed banks have been set up around the world to maintain collections of varieties of the world's main cultivated species, and to distribute them to improvers that need them. However, the existing populations sometimes do not have the variability responsible for the character that is to be introduced, and as a result, methodologies to produce mutations in the genomes of animals and plants have been developed, and the most recent of these techniques is known as genome editing.

02. The CRISPR-Cas9 system

We have been able to create precise mutations in the genomes of virtually any species and in particular plants since 2012. This is due to the availability of information on genomes, which has been accumulating on an exponential basis since the first results were published in around 2000. It is also a result of the emergence of techniques that allow precise mutations to

Genome editing is the most recently developed method for creating mutations in the genomes of animals and plants.

Greenhouse at the CRAG. Melon cultivation. Photo: Josep Casacuberta.

be made in the genome of many organisms. The most commonly used technique today is based on a bacterial protective mechanism against virus infections known as CRISPR-Cas9, which has several variants and a number of applications in humans, animals and plants (see Lluís Montoliu's website: http://wwwuser.cnb.csic.es/~montoliu/CRISPR/). When used in humans, these applications have led to a wide variety of ethical considerations.

To use it, it is necessary to transfer the CRISPR-Cas9 system using the standard techniques for transforming or transferring RNA and protein complexes, which may limit its use. They have been shown to increase the type of plants can be improved and the characters that can be modified, and do so in a much more direct manner than conventional transgenics. This means that these techniques are potentially very interesting for a wide range of seed companies, and even those that focus on relatively small market niches because of the type of company or product. They are also techniques that could enable products to be tailored to local consumption or targeted at smaller groups of consumers, such as consumers with allergies, intolerances or specific nutritional requirements. Furthermore, they may be particularly useful in addressing issues of access to food in the current scenarios of growing populations and climate change (Shan-e-Ali Zaidi et al., 2018).

03. Regulation of plants obtained by genome editing in the EU

The future of these products depends on having effective methods for genetic modification and obtaining cultivable plants, knowing which genes are of interest for improvement and which modification is worthwhile, and how the marketing will be regulated (Scheben and Edwards, 2019). If the marketing of plants in Europe beco-

> In plants, genomic mutation techniques have become a basic tool for molecular genetic research because they allow genes to be cancelled or modified at precise locations in the genome, and this to be done in many places at the same time.

mes subject to the same regulation as genetically modified plants, with the same consequences in terms of cost, time and unpredictability, then seed companies, farmers and European consumers are likely to be left on the sidelines of this new revolution. The first product from a transgenic plant was marketed in the EU in 1994, only 10 years after the first gene transfer in plants had taken place in the laboratory. Four years earlier, in 1990, in the wake of the first legislation passed in the US, Directive 90/220/EEC established a strict legal framework for authorising the marketing of these products, and required a thorough analysis of the potential risks associated with them. This legislation, which has been supplemented and become more complicated over the years (Casacuberta et al. 2017), applies to all products derived from genetically modified organisms (GMOs), according to the definition established by European legislation. Directive 2001/18/EC defines any organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur "naturally" as a GMO. Although it does not define what it means by "natural", the directive contains a list of techniques which are not considered to lead to genetic modification, including in vitro fertilisation and polyploidy induction, and those that do create GMOs, which are mainly any technique that uses recombinant DNA techniques. It also lists some techniques, such as mutagenesis, which are excluded from the regulation, despite being considered as leading to a GMO. Classification as a GMO and therefore being subject to specific regulation thus depends on the technique used to modify the organism. This is a specific characteristic of European regulation that sets it apart from the regulations of other countries, such as the USA and Canada, where the need to comply with specific regulation depends on the novelty and the characteristics of the final product obtained, rather than the method used to obtain it (Eriksson et al. 2019). However, what accounts for the big difference in the number of GMOs approved in the EU compared to other countries such as the USA, Argentina, Brazil and Canada, is that in the EU the political decision to approve a new GMO after a favourable risk report may take a long time, or may never happen. There are many reasons for this, and they are partly linked to the structure of the EU itself, which consists of states with very diverse policies and interests (Casacuberta *et al*. 2017).

Despite the limited presence of GMOs in European fields, the EU has approved the importation of more than a hundred products from GM plants grown outside Europe.

The result is that the EU imports large quantities of GM products, but both seed companies and European farmers have been virtually excluded from the potential benefits of this technology.

This explains why the cultivation of only one GM plant, the MON 810 corn, has been approved in the EU since 1994. However, that does not mean that the European market is practically GMO free. In fact, despite the very limited presence of GMOs in European fields, the EU has approved the importation of more than a hundred products from GM plants grown outside Europe (for a description of the GMOs marketed or being assessed, see Parisi *et al.* 2016) and large quantities of GM soybeans and maize are used in Europe every day, mainly for animal feed. The EU does not produce enough soy and corn to maintain its livestock farming, and therefore depends on importing these products, which are now largely or even entirely genetically modified in the exporting countries, such as Argentina, Brazil and the USA. The result is that the EU imports large quantities of GM products, but both seed companies and European farmers have been virtually excluded from the potential benefits of this technology.

Regulating genome editing techniques has been a subject of heated debate in Europe since 2007, when the EU created a working group, including experts from all the Member States, on what was called "New genetic improvement technologies," to seek consensus on the regulation of such products. For over ten years since then, countless working groups have been created, articles and reports from scientific societies and scientific advisory agencies have been published, and several competent authorities in the field have given their verdicts in various countries, without the EU reaching a consensus. Finally, the first step in defining the legal status of these products has come from the courts of justice and not from the political authorities. At the request of the French Council of State, and after questions were raised by non-governmental organisations opposed to biotechnology, the European Court of Justice ruled that according to its interpretation of current legislation, and Directive 2001/18 in particular, organisms obtained by gene editing must be considered GMOs in the EU, and they must therefore be subject to the same regulation as transgenic crops. This ruling has been vigorously contested by associations of companies in the sector, who believe that there is a risk that Europe will once again fail to take advantage of a technology with enormous potential, and by scientists who find it difficult to provide a justification for classical mutagenesis, which is not subject to regulation despite making random mutations in the genome, while gene editing, which makes directed changes, is regulated in the same way as transgenic plants (Custers et al. 2019). However, apart from the possible flaws in the scientific grounds for the arguments, the decision involves significant practical issues, such as the difficulty in developing specific detection methods for products derived from edited organisms, which are mandatory for any GMO. As a result, the debate is still ongoing, and there are several proposals on the table. These range from redefining the legal framework governing transgenics, to adopting a system that focuses more on the characteristics of this product and less on the process used to obtain it, as occurs in other countries, to including gene editing on the list of techniques exempt from regulation, which already includes conventional mutagenesis (Eriksson *et al.* 2018), and even applying the current regulatory framework using the flexibility provided by Directive 2001/18, which has declined in recent years (Casacuberta & Puigdomènech 2018). Whatever happens, the future of the use of gene editing in plant genetic improvement in the EU will largely depend on how these techniques are finally regulated.

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EMERGING TECHNOLOGIES APPLIED TO THE AGRIFOOD SECTOR

Robot for automatic harvesting of garden produce depending on its ripeness, developed as part of the SWEEPER project funded by the European Union's Horizon 2020 programme. Photo: www.sweeper-robot.eu

01. Introduction

The sustainable development goals proposed by the 2030 Agenda include: putting an end to hunger, achieving food security, improving nutrition and promoting sustainable agriculture. Many different initiatives will be required to meet these challenges, but they undoubtedly require the application of the latest scientific and technological breakthroughs to transform a sector that is strategic for our society.

The report *Eating the future: for a productive, sustainable, resilient, healthy, responsible and universal food system in Catalonia*, produced by the Advisory Board for Sustainable Development, makes several recommendations: it emphasises that research into the most environmentally friendly production techniques must be enhanced, that research and innovation in precision farming and information and communication technology (ICT) must be encouraged to ensure the optimum management of resources, and that tools and instruments for transfer and advice for the production sector must also be strengthened to improve efficiency in the management of inputs (water, energy and fertilisers).

It is therefore necessary to continue research in the fields of biotechnology and plant genetics in order to obtain more resilient plants, which make better use of nutrients, consume less water and fewer phytosanitary products, and which are more efficient in capturing and transforming energy. However, we also need to determine how to apply technologies that have been developed in other sectors in order to improve productivity, or simply to use innovation to introduce new ways of making manual tasks easier.

We are approaching an emerging agricultural management model called the Smart Farm, which is based on an intensive use of ICT and automatic systems, and therefore increases the quality and quantity of production and reduces the human effort involved. In this article, we will focus on the technological aspects which can lead to the most disruptive changes when applied to the agrifood sector.

02. Remote sensing systems

One of the most widespread applications in agriculture today is the use of satellite remote sensing systems in combination with the use of remotely piloted aircraft systems (RPAS, also known as drones).

The European Space Agency's (ESA) *Sentinel-2* Earth Observation mission is one of the most widely used systems in agriculture. It consists of two satellites in a low orbit at an altitude of 786 kilometres, which provides global coverage of the entire world in five days. The satellites are equipped with a 13-band multispectral cameras in the visible, near infrared and short-wave infrared bands of the spectrum, which provide a resolution of 10, 20 and 60 metres respectively, in a scan area of the Earth's surface 290 kilometres wide.

Other satellites, such as *Satellite Imaging Corporation*'s Pleiades, can provide daily imaging at optical resolutions of 0.5 metres, and multispectral images at a resolution of 2 metres. By processing these images, which can be complemented with those obtained from drones flying at low altitudes, it is possible to calculate the Normalized Difference Vegetation Index (NDVI) and other similar parameters, which can be used to estimate the development, quality and quantity of vegetation and crop stress.

This makes it possible to perform a careful diagnosis of the state of the crop, and consequently to determine the measures that need to be applied on a precise and localised basis. The result is an optimisation of the resources applied and an improvement in the crop's efficiency as a result. This gives rise to what is known as precision agriculture.

Remote sensing systems can be used to visible and infrared images which when they are properly processed, can show various parameters of the state of the soil, crops and vegetation.

03. Precision agriculture

This is based on the combined use of geographic information systems (GIS), which provide highly accurate information about the terrain, and a satellite navigation system (GPS, Galileo or Glonass). It is possible to precisely determine the geographical point where an inputs treatment needs to be applied using the results of the analysis of the terrain provided by remote sensing systems.

This treatment (phytosanitary, nutrients or irrigation), can be applied semi-automatically using a manual guide for the tractor, with the help of a satellite navigator, and the treatment is dispensed at the place instructed beforehand; or it can be done completely automatically using autonomous vehicles, both on land and in the air, which are guided by these GPS systems and go to the specific place where the programmed treatment needs to be applied. Several manufacturers of agricultural machinery incorporate integrated navigation systems in their vehicles, or they can be fitted to automate these tasks.

These navigation systems also often contain other types of sensors (such as infrared and ultrasonic distance meters, gyroscopes and inclinometers) which when combined with contact sensors and vision systems, make it possible to determine the condition and unevenness of the terrain, and the presence of unexpected obstacles or other unforeseen problems. They can therefore create alarms and apply the appropriate remedial measures. These vehicles may include sensors that measure the NDVI index directly, or use laser diode reflectivity to determine the chlorophyll content of plants, and calculate and dispense the treatment which needs to be applied on the spot.

There are some benefits to using drones for phytosanitary applications, but there are also some limitations. They can reach areas or places that are difficult to access, which makes it easier to apply specific pesticides or equivalent products when taking precise measures against a particular pest; flying over the crop also means that the phytosanitary treatment can be applied more precisely to the specific area of the plant that needs it. Their limitation is the product's load and dispensation capacity (which ranges from 5 to 15 litres, with a maximum aircraft weight of 25 kg). Their autonomy is around 25 minutes flying time, and they have a maximum speed of approximately 8 m/s. However, because they are remotely piloted aircraft systems (RPAS), according to Spanish legislation, they must be piloted by a drone operator authorised by the*Spanish Air Safety Agency* (AESA), who must meet all the relevant legal safety requirements.

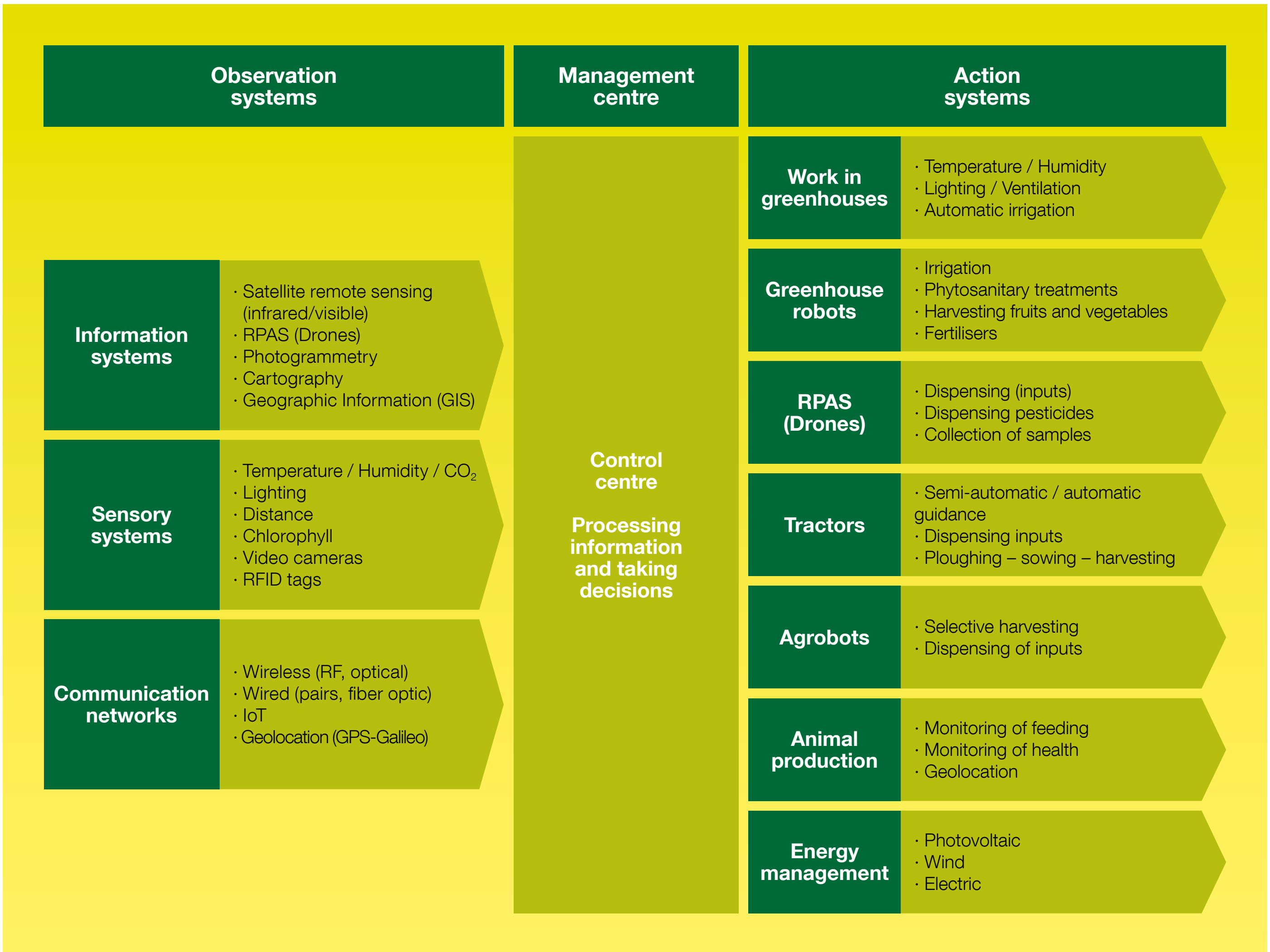

Figure 1: *Diagram of the various technologies for observation and action in agriculture and livestock farming. Source: Jordi Berenguer.*

The Agricultural Mechanisation Unit (UMA) at the UPC is participating in the European *Optimised Pest Integrated Management to precisely detect and control plant diseases in perennial crops and open-field vegetables* (OPTIMA) project, which aims to develop smart phytosanitary application equipment enabling products to be used safely, in smaller quantities and with lower risks of environmental pollution, and to improve the quality of the food produced.

The same group at the UPC has also developed the mobile application DOSAVIÑA, for use by wine producers, which calculates the optimum amount of the phytosanitary product and the appropriate volume to be distributed in espalier vines. It contains a practical guide for selecting the appropriate working parameters (forward speed, working pressure, type and number of nozzles, etc.) based on the structural characteristics of the plantation and the type of machinery used, and the amount of phytosanitary product used on the plants can be adjusted to reduce the risk of pollution.

04. Robotics and automatic systems

One of the areas where technology can be most disruptive is in the application of robotics and its systems associated with agricultural tasks, both outdoors and in greenhouses. For example, the combination of image processing techniques and artificial intelligence means that robots capable of detecting the optimum degree of ripeness of fruit and vegetables and collecting them automatically can be designed.

One of the first benchmark projects was the CROPS project, funded by the European Union between 2010 and 2014, as part of the 7th Framework Programme. This consisted of the development of a robotic platform for use in both fumigation and selective harvesting of fruits, based on identifying their ripeness. This project continued with the SWEEPER programme (photo p. 74), which was also funded by the EU (2015-2018), as part of the Horizon 2020 Programme to develop an autonomous robot able to pick vegetables in greenhouses under conditions with high temperatures and humidity levels, and it is expected to be marketed in the near future.

Panasonic has also developed a robot to harvest tomatoes grown in greenhouses. The robot moves along a track located between the rows of tomatoes, and uses an image recognition camera to detect the tomato. It determines whether it is ripe by analysing the colour, and then makes the decision whether to harvest it or not.

The Industrial Equipment Design Center (CDEI) at the UPC designed a leaf stripper to mechanise the process involved in cleaning wheat during the harvesting process a few years ago. It is made of stainless steel, and is equipped with a system of vulcanised rubber-coated rollers which separate the leaves surrounding the grain with the help of a small motor. The clean cobs are placed in a container, ready for the next step in the management, storage and distribution process. The equipment increases productivity by 150%, as it increases the rate from 6-8 manually stripped cobs per minute to the 18-20 that the machine can process in the same time.

05. Sensor networks and facility monitoring

Information from satellite and drone remote sensing systems can be supplemented by information obtained from sensors on the farm itself. These sensors are based on the Internet of Things (IoT), and provide a networked connection and remote access, making it possible to continuously monitor buildings, greenhouses and crops based on the measurement of physical parameters (temperature, humidity, brightness, etc.) and chemical parameters (concentrations of CO_2, nutrients, etc.). Analysing and processing the data obtained provides an accurate diagnosis of the crop or the agricultural or livestock farm, and consequently helps in decision-making processes. These systems are complemented by a set of actuators that regulate the ventilation, irrigation, lighting and heating of the facilities remotely, manually or automatically, so that they are always kept under optimum conditions for production.

The amount of robotic application systems and equipment will increase both in greenhouses and outdoors in the coming years, and they will make intensive cultivation and automatic harvesting of fruit and vegetables possible by day and by night.

The RFID system brings traceability to the entire food chain:
it identifies the animal from its source until it reaches the end consumer.

It contains all the information which can be used to provide all the guarantees that food health regulations require.

06. Identification and traceability systems

RFID (*Radio Frequency IDentification*) systems are smart tags that can be read remotely by a reader antenna. They were designed to replace bar codes printed on paper. They are available in different formats and capacities. Some are completely passive, with a very low cost and do not need any power supply; these tags can be used for remote reading of stored code. Others can store information which can be updated and modified, and may even incorporate a type of temperature or humidity sensor, as well as a GPS receiver (a battery power system must be incorporated in these cases).

These systems are widely used in livestock farming, as they enable animal to be identified individually and remotely. For meat production, each individual is assigned a unique RFID-tagged code, so that for example, the amount of feed to be dispensed can be individually controlled when the animal approaches the trough. If the tag is active (battery-powered), it can incorporate body temperature sensors that can automatically generate veterinary alerts if the animal becomes ill, and administer the appropriate drug treatment in time. If they also have motion sensors or GPS systems, it is possible to determine the animal's movements in semi-wild conditions, or its location when it is released in mountain pasturelands.

These systems also provide traceability in the entire food chain: they identify the animal from its source until it reaches the end consumer. They therefore incorporate all the information about their growth process as far as the abattoir, including processing, storage and distribution, which means that it is possible to provide all the guarantees required by food health regulations.

As an example, in April 2018 the French INRA (*Institut National de la Recherche Agronòmique*) introduced a new RFID-based heat sensing device for sheep, which allowed farmers to monitor reproduction in their herds and avoid hormone treatments.

Finally, Figure 1 shows the various technologies for observation and action applied to agriculture and livestock production.

07. Agriculture 4.0

The new concept of Industry 4.0 is taking root as a connected model of industry, involving an intensive use of the IoT, Big Data, and the application of algorithms and artificial intelligence to process data and make decisions. The aim is to make better use of resources, and to adapt better to production needs. The same concept could be transferred to the agricultural and livestock sector to define Agriculture 4.0, which would include precision agriculture and Smart Farming, as well as other key areas including meteorology and remote sensing. If in addition to all the above we consider how Big Data is used to process historical data series (for climate, environmental, population, supply and demand, etc.) which are then used to create predictive models for behaviour of supply and demand, and real-time data about that supply and demand, it is possible to describe the agrifood sector as a complex global system and to manage it as such. This would indirectly help us to fight food wastage, based on more efficient production and the application of dynamic distribution logistics, which can be adapted to the demand from the market. This would therefore lead to an optimal management of food, which is an essential resource for our society.

08. Conclusion

The Polytechnic University of Catalonia is renowned for its research and technology transfer work in the fields of information and communication technology, artificial intelligence, robotics and mechanics, energy and materials, chemistry and agriculture, aeronautics, infrastructure and building. While these research activities took place in their respective vertical fields not so long ago, the current trend is towards cross-disciplinary work in the application of these technologies to other fields, such as agriculture, where their application can create more disruptive changes. The UPC aims to contribute with technology to the transformation of the agrifood sector that Catalonia needs.

Further reading

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THE DIGITAL TECHNOLOGICAL REVOLUTION and its consequences in the sector

01. Introduction

The agricultural, livestock and forestry sectors, the agrifood industry and the rural environment are crucial for the economy and territorial structure, and their value chain contain very varied capacities and processes throughout the life cycle. Like many other socio-economic activities, the sector will undergo an unprecedented transformation, driven by trends that are having a profound impact on society today: demographic changes; transformation of the economic map; urbanisation; a lack of resources; climate change, and technological revolution.

Within the technological revolution, the introduction of digital solutions (such as the use of sensors for accurate tracking of factors in food production, remote sensing techniques for optimising crops, and the automation of predictive warnings for pest control, precision breeding, efficient irrigation management and image interpretation in forestry, among many other areas), will optimise the sustainable management of the rural environment and food production processes, and ensure its sustainability, security and competitiveness. The increasing availability of information will also lead to significant growth in the need for accurate and frequent decisions on food, forestry and rural management.

02. The digital technological revolution

The introduction and effective deployment of new enabling digital technologies in our economy and society has been a constant feature of recent years. Concepts such as smart farms, the Internet of Things, Big Data and Industry 4.0 are the focus of increasing attention. Even sectors of the economy that have traditionally been reluctant to implement new technological standards in their production and business processes have decided to change, and have climbed onto on the bandwagon of digital innovation.

The agricultural and livestock sectors, the agrifood industry and the rural environment are the ideal scenario for applying these new technologies and the results of scientific research. Cybersecurity, Autonomous Robotics, the Internet of Things, Big Data and Artificial Intelligence are driving the technological revolution that is profoundly changing the way we live. New technological tools, sensors, autonomous machines and systems, the integration of multiple sources of information, and improved traceability by means of blockchains are having an impact on all areas of the economy. Their impact will be so wide-ranging that they will radically change food production and the overall workings of the value chain, with the emergence of disruptive business models that will lead to profound structural changes at all levels.

03. The digitalisation of the value chain in the food and rural sectors and its consequences

The food and rural sectors are becoming a perfect testing ground for a vast array of solutions and innovations. The list is a very long one, and new ones are being added every day. It is anticipated to be one of the sectors where robotics, automation and digitisation solutions will experience the fastest growth in the coming years, which will lead to the emergence of new participants and break down traditional paradigms and models.

The sector is moving towards the concept of Intelligent Management, and is beginning to use of disruptive digital technologies, in solutions ranging from one-off tools to integrated systems.

Data analysis, information and knowledge will be available and crucial for optimising production systems, efficient resource management and fostering ecosystem services.

We must not lose sight of the fact that we are at the dawn of a new era,

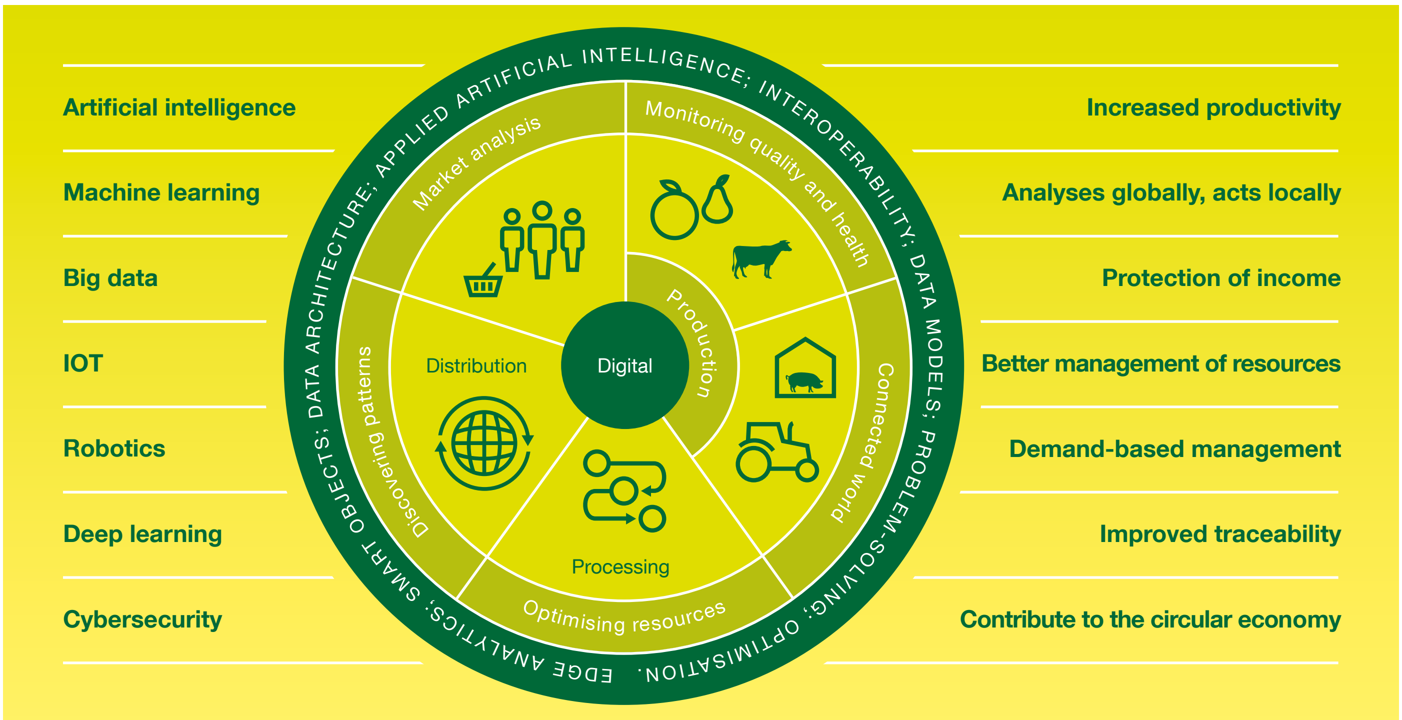

Figure 1. *Benefits of systematically applying disruptive digital technologies. Source: Eurecat.*

in which artificial intelligence, together with massive data analysis and an increased processing capacity, will make efficient decision-making in real time possible. Using these types of solutions, the sector will move towards the concept of Intelligent Management, and will begin to use of disruptive digital technologies, especially by means of a systemic approach to each value chain. Managers must start transforming their solutions into more automated, connected and smart systems.

04. Digital systems and technologies

Today, as well as increasing productivity and improving quality, the effective deployment of digital systems and technologies will: i) facilitate the exchange of information and knowledge between all the parties involved; ii) bring the physical and the virtual world together in a simple and ergonomic way; iii) improve the quality and speed of the decision-making process, on both small and large farms; iv) enhance the broad-based nature of solutions by simultaneously considering multiple factors (energy, health, social, water, etc.), and v) create new products, services and business models (Fig. 1).

Many digital technological breakthroughs have been made in recent years, which allow food production to be carefully planned, in the field, on the farm and in industry. Other potential breakthroughs in the near future include checking individual animals for tailor-made treatment of diseases, monitoring the most suitable feeding according to the animal's characteristics, creating rankings of the best animals for inclusion in batches depending on business aims, etc. This involves using sensors, collecting large amounts of data, and developing data model-based decision support tools. Apart from having technologies that can to some extent control the conditions of crops, on livestock farms and in industrial processes, the goal is to improve decision-making.

04.01 The Internet of Things (IoT)

The added value that smart device networks provide is invaluable for each stage in the food value chain. For example, monitoring during the growing phase provides real-time knowledge of the need for water, nutrients and phytosanitary products, enabling immediate action to be taken and problems to be resolved in order to optimise harvests and use energy, water and nutrients sustainably. These are essential issues, as the aim is to reduce carbon, chemical and water footprints.

> With the development of new data-driven models, production processes will be fully optimised and complementary to today's technological vision.

> The deployment of rural infrastructure for exchanging data will reduce the digital divide in rural areas.

> Interoperability will provide greater flexibility, scalability and precision in decision-making.

Within the RIS3CAT Agrifood Production Technologies community, the IoECrops project (funded by the European Union's European Regional Development Fund within the framework of the ERDF Operational Programme for Catalonia 2014-2020) aims to improve the productivity, efficiency and resilience of extensive farms, by supporting agronomic management using technologies based on the Internet of Things and Artificial Intelligence. Various European initiatives (e.g. IOF2020, SMARTAGRIHUBS, agROBOfood) are also creating synergies and experiments by deploying these disruptive digital technologies in multiple scenarios across Europe.

This use of devices in agricultural and livestock environments will be based on new communications infrastructures, which seek to overcome the lack of connectivity in the rural environment. The challenge this scenario poses is how to define communication standards between the different data collectors that are able to create a pattern of smart networks so that secure and stable connectivity is guaranteed. Some recently developed networks, known as LPWAN (Low Power Wide Area Networks), such as LoRaWan or NB-IOT, guarantee interconnectivity at an affordable cost.

In the medium term, 5G technology will offer a vast array of opportunities in terms of increasing access speeds, connecting massive numbers of devices, reduced latency, and the ability to define multiple virtual networks that respond to each scenario for use on the same physical network. Regenerating the countryside is one of the most important applications for pilot tests.

04.02 Interoperability

When we talk about connecting everything to everything, data from various structured sources is available: agricultural and livestock farmers, cooperatives, food industries, technology companies, machinery companies, government agencies, universities and research centres, as well as from other unstructured sources (data with no identifiable internal structure).

If we want to avoid end users being captives of closed platform technologies and/or platforms, we must work to foster interoperability by establishing open standardised ontologies and languages (Fig. 2).

We need to work on developing platforms that allow information to be exchanged, and users to share opportunities for better services and/or products on other platforms. This will undoubtedly have an impact on the ability to develop a dynamic and robust technological ecosystem, in which small and medium-sized technology enterprises can also compete and develop, where end users, farmers, livestock farmers, cooperatives and food industries can have the freedom to choose what information they work with at any time without creating captive markets, and where their investments will not become obsolete simply because they are unable to choose the technologies that are most suited to their needs from the range available on the market.

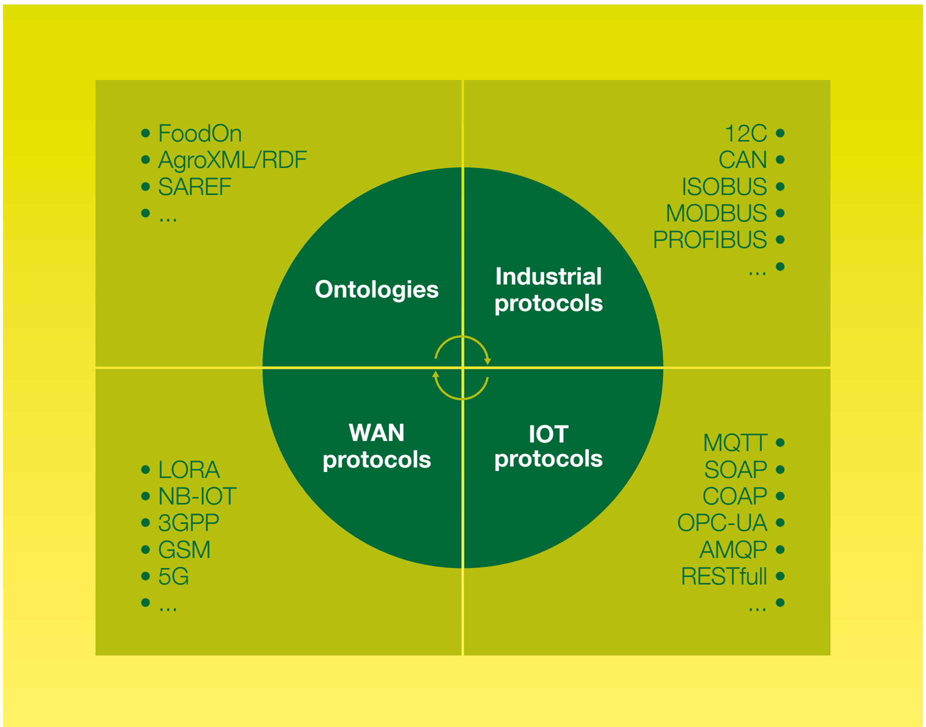

Figure 3. *Data-driven models. Source: Eurecat.*

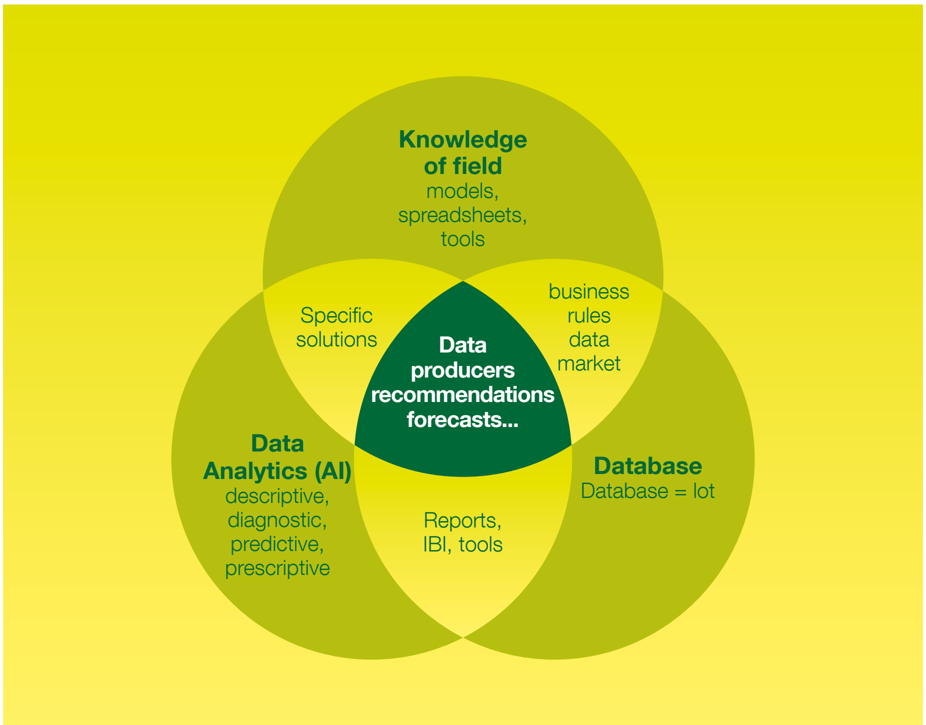

Figure 2. *Standards, ontologies and protocols related to the food sector and the rural environment. Source: Eurecat.*

04.03 From the farm to the table

The flow of information and knowledge arising from the application of digital concepts and interoperability will lead to a breakthrough in optimising the processes that comprehensively integrate production, processing, distribution and consumption in decision-making. Comprehensive management of the life cycle of food and ecosystems will prevent the unnecessary loss of qualities and properties, improve the experience of the end client and consumer, and preserve the environment.

Monitoring the consumer/citizen's experience and using this information to optimise management of the entire value chain will be essential to close the cycle. For example, the INTERACCIONA project has developed smart labels which are produced using printed electronics containing quality and temperature sensors. The circuit receives energy when a mobile device with NFC technology is placed close to it, and it monitors liquids packed in transparent containers. The solution helps link the entire agrifood value chain, from the farm to the table, optimises resource use according to demand, increases customer satisfaction, improves traceability, and is a step towards dynamic quality management, etc.

04.04 Effective use of information

The effective use of information generated by people, sensors and systems in combination with external data facilitates integrated farm management, and enables actions and reactions to take place more quickly and accurately. Farmers can use predictive data analytics to anticipate, prepare and optimise their decisions based on future scenarios.

The goal is to integrate predictive analytics and operational management that add value to data, and to extract the knowledge required to facilitate real-time decision-making.

Having the right digital skills, talent and profiles and an applied digital knowledge ecosystem will become increasingly important for the food sector and the rural environment.

The two areas where data analytics can be applied are: domain-specific practices (agronomic, veterinary, biological, environmental, etc.) and non-specific practices related to functional and support activities, such as planning purchases, resource management, sales optimisation, predictive maintenance, etc. Digital enabler technologies and data-driven models in particular are giving fresh impetus to improved integrated management by combining the two practices (Fig. 3).

The IoECrops project mentioned above is developing tools to support decision-making, which integrate both the application of data analytics when planning major agronomic operations, such as site preparation, sowing, fertilisation, irrigation and harvesting, with online support when carrying most of these operations, such as planting, harvesting and fertilising and irrigation. Other examples include the application of Artificial Intelligence and Big Data to optimising cured sausage dryers (Operational Groups 2017-021; and creating rankings of the best animals (cattle, pigs, etc.) for inclusion in batches based on business objectives (demonstration activities, Technology Transfer operation 01.02.01, advanced analytics on pig farms).

05. Conclusion

Although some applications have begun to be developed, data analytics techniques are still far removed from the everyday life of the agrifood world and the rural environment; they are consequently an opportunity that must be taken full advantage of.

The sector is facing a number of challenges, in which digital technologies will be a basic source of assistance. These challenges include: increased process efficiency, traceability and intelligent monitoring as far as the source of the products in the agrifood value chain, food safety, incorporation of the consumer experience, and reduced environmental impact in rural areas.

The sector will also have to deal with a new competitive environment, largely consisting of large groups and companies which are largely at an advanced stage of modernisation as a result of their major investments in new technologies and the professionalisation of their human capital. Participating in the digital technological revolution is therefore important for the economy and society as a whole, and for Catalonia's rural areas in particular. Being left behind in the digital revolution means lagging behind in optimising the processes that take place on a farm, which would lead to a loss of competitiveness that would force those farms out of the market within a few years.

Further reading

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