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Abstract. Agriculture must adopt technological innovations to respond to the social demand of sustainable increase of food production. Among these innovations there will be a set of emerging biotechnologies that will contribute to respond to this demand and to reach additional goals like improving food quality and developing biological systems with enhanced resistance to diseases and environmental stresses in a global warming scenario. Our current knowledge on livestock genomes, and the development of computational biology, omics and gene editing technologies will provide novel tools to face agriculture challenges. The drivers of this novel green-"omics" biotechnological revolution should be the current and future students of the higher education systems, and therefore the implementation of programs to tackle these challenges and to improve the biotechnological skills and knowledge in their curricula will be essential to respond to agriculture needs. Also, a better understanding of agriculture market demands and of the complex process of products development should be included in agriculture curricula. Moreover, stronger interactions between higher education students and agriculture professionals and stakeholders will be required to fulfil the current gap between the education systems and the bio-economic sector. Additional efforts should be devoted to explain to the society the basis of agricultural production and the essential contribution of biotechnologies and other technological innovations in improving agricultural productivity, human life quality and social progress.

Keywords. Biotechnology– Higher education– Computational biology– Agriculture.

L'importance des biotechnologies dans les cursus agricoles

Résumé. *L'agriculture doit adopter les innovations technologiques afin de répondre à la demande sociale d'accroître la production alimentaire selon les principes de durabilité. Parmi ces innovations figureront une série de biotechnologies émergentes qui contribueront à couvrir ces besoins et à atteindre des finalités additionnelles telles que l'amélioration de la qualité des aliments et le développement de systèmes biologiques ayant une plus forte résistance aux maladies et aux conditions environnementales adverses dans un scénario de réchauffement global. Notre savoir actuel sur les génomes des animaux d'élevage, et le développement de la biologie computationnelle, des sciences omiques et des technologies d'édition de gènes constitueront de nouveaux outils pour affronter les défis de l'agriculture. Les moteurs de cette nouvelle révolution biotechnologique des omiques vertes devraient être les étudiants actuels et futurs des systèmes d'enseignement supérieur, et par conséquent la mise en place de programmes pour relever ces défis et pour améliorer les compétences et le savoir en biotechnologie dans les cursus sera un élément essentiel pour répondre aux besoins de l'agriculture. De même, une meilleure compréhension des demandes des marchés agricoles et du processus complexe de développement des produits devrait être intégrée dans les programmes d'études liés à l'agriculture. De plus, des interactions plus fortes entre les étudiants de l'enseignement supérieur et les professionnels et parties prenantes de l'agriculture sera nécessaire pour combler le fossé existant actuellement entre les systèmes d'enseignement et le secteur bio-économique. Des efforts additionnels devraient être faits pour expliquer à la société les fondements de la production agricole et la contribution essentielle des biotechnologies et des autres innovations technologiques à l'amélioration de la productivité agricole, de la qualité de la vie humaine et au progrès social.*

Mots-clés. *Biotechnologie – Enseignement supérieur – Biologie computationnelle – Agriculture.*

I – Introduction

Population experts anticipate the addition of another approximately 3 billion people to world population by mid-21st century. Food and Agriculture Organization of the United Nations (FAO) estimates that agriculture will need to produce about 70% more food than it currently does to fulfil the demands of this expanding population (FAO, 2009). The general consensus is that traditional crops and farming methods could not sustain that much productivity (Fedoroff *et al.*, 2010). Moreover, the dramatic increase in global food demand will growth together with an enhanced demand for feed, biomass and biomaterials. Also, agriculture must deal with decreasing natural resources and the negative effects of climate global warming, that will impact agricultural production, the changes in global demographic and the need for providing a sustainable, safe and secure food supply for human population. It should be a social priority to provide agriculture and forestry with the fundamental knowledge and tools to develop resource-efficient and stress resistant biosystems that will supply food, feed and other biobased raw-materials without compromising ecosystem services (Brookes and Barfoot, 2008).

Nonetheless, agriculture is a significant contributor to climate change. Agriculture and food production represent 40% of the total global industrial energy demand, while global agriculture represents 14% of total greenhouse gas emissions. Among the agriculture goals should be the improvement of the adaptive capacity of plants, animals and biological systems to biotic (new diseases and pests) and abiotic stresses, the conservation and use of biodiversity, and the implementation of measures at farm, forest and landscape level to mitigate specific stresses associated to global warming such as water scarcity, heat and highly saline soils. In addition, research must promote the sustainable management of soils, exploit the current advances in conservation agriculture and reduce greenhouse gas emissions from agriculture and forestry activities.

Recent reports of The World Bank on food security and crop yield emphasize the gains that can be made by bringing existing agronomic and food science technology to people without it, by exploring the genetic variability in our existing food crops and by developing more ecologically farming practices (Bellagio Meeting, 2007). This requires building local educational, technical and research capacities, food processing and storage capabilities, and other aspects of agribusiness, as well as rural transportation and water and communications infrastructure, but also involves addressing the regulatory issues that interfere with trade and inhibit the use of novel technologies, like biotechnologies. The private and public research sectors are doing significant efforts to implement and apply to breeding the conventional and more recent molecular technologies, as well as the genetic modification (GM), to adapt our existing food crops to increasing temperatures, decreased water availability in some places and flooding in others, rising salinity, and changing pathogen and insect threats (World Bank, 2008; Gregory *et al*., 2009). Biotechnology will be essential to respond to these novel breeding goals.

However, one potential barrier of applying biotechnologies to agriculture is the perception that society has currently of these technologies and the almost unique association of plant biotechnology with GM crops, as revealed by several social biotech surveys and barometers. For example, the seventh Eurobarometer survey on life sciences and biotechnology indicates that: (i) Europeans are mostly rather positive about biotechnology; (ii) Europeans feel that they lack basic information on important biotechnology issues; and (iii) all decisions on biotechnology should be rooted in sound science and take due account of ethical, health and environmental factors. The main conclusion of this study (Eurobarometer, 2010) is that Europeans citizens are in favour of responsible innovation with appropriate regulation to balance the market, but also that there is a major communication challenge that should be filled at the Education Systems. Notably, since 2005 Europeans have increased their confidence in doctors, scientists, the EU, national governments and industry, to do a good job in taking decisions on biotechnology issues. In the survey, 53% of respondents believe biotechnology will have a positive effect in the future (particularly in human health), and only 20% said that this effect might be negative. The survey also reveals important knowledge gaps, pointing to a need for more communication: a majority of respondents had never heard of some of the emerging biotech-associated areas such as nanotechnology (55%), bio/germoplasm banks (67%) and synthetic biology (83%). More importantly for agricultural innovation, the survey showed that a clear majority of Europeans (61%) remains opposes to GM food. There was strong opposition, with only 18% supporting animal cloning for food. However, there is cautious support for GM food applications, with 46% of respondents in favour and 38% opposite, but a clear majority of Europeans (61%, up from 57% in 2005) remains broadly opposed to GM food. There is a critical need to get beyond popular biases against the use of agricultural biotechnology and to develop forward-looking regulatory frameworks based on scientific evidence, as this perception could negatively impact the implementation of novel biotechnological tools for improving food and feed supply (Stein *et al*., 2009).

In this communication we describe our current view of the relevance of biotechnologies in the agriculture curricula of the current and future students of the higher education system. We also describe our own experience on implementing Biotechnology curricula at the Universidad Politécnica de Madrid (UPM), and present some of the results obtained in a survey carried out with Biotech undergraduate students, which intended to identify the specific skills that they consider should be added to their curricula. The survey data show that the Biotech curriculum students consider essential the improvement of their professional skills and their interaction with the productive sector for better career opportunities, and also that acquiring biotechnology knowledge will strength their professional succeed.

II – Materials and methods

In the frame of the Biotech2020 Initiative of the Biotechnology and Plant Biology Department from the Universidad Politécnica de Madrid, we performed a survey to identify the opinion of bachelor students demands for their curricula improvement. This survey consisted of a questionnaire to third-year students of Biotechnology Bachelor from the academic years 2013-2014 and 2014-2015. The questionnaire was done in a specific meeting and was followed by individual interviews by the Biotech2020 panel of experts. The respondents were students of any of the three different Biotechnologies specializations: Plant Biotechnology (n = 12), Computational Biotechnology (n = 11) and Health Biotechnology (n = 46). The questionnaire included several prioritizing questions aimed to identify putative gaps in students technical, scientific and professional formation, and to determine their current preferences for their future professional careers. Among the proposed answers to the main question ("what are the more relevant aspects that the student considered to improve his/her curricula") were the following: (i) scientific and biotechnical basic formation; (ii) practical training in biotech companies; (iii) legislation and business knowledge and skills; (iv) research and development practical training in Universities and Institutes; (v) postgraduate academic studies (Master and Doctorate); (vi) academic and professional mentoring and; and (vii) professional skills. The descriptive analysis and the graphical representations of the results were done based on the top ranked answers given by the students.

III – Results and discussion

1. Emerging biotechnologies in the agriculture higher education curricula

The application of novel technologies to agriculture to achieve a "sustainable intensification" is in the agenda of governments and international bodies (Gruskin, 2012). However, in parallel there is a global trend towards increased regulation of new technologies in agriculture, particularly biotechnologies. One of the reasons explaining this increasing regulation and developmental barriers is that agriculture and forestry are unique systems delivering commercial products but also wider non-marketed ecological and societal public goods. These manifold roles and the non-market value of agriculture and forestry livestock, including supporting the provision of important non-material benefits to society (landscapes and recreation) as well as of ecological goods and services, should be compatible with food and feed production.

The available **annotated genomes** of most livestock species and the decreasing price for sequencing offer unprecedented opportunities for advances in evolutionary biology, animal and crop breeding and even in the development of animal models for human diseases studies (Federoff, 2010; Gruskin, 2012). Technical developments in breeding, nutrition, and health in agriculture livestock (animal, crops and microorganisms) will contribute to increasing potential production and further efficiency and genetic gains. Molecular genetics tools are likely to have considerable impact, in particular marker assisted selection for traits that are difficult to measure, such as food and feed quality, resistance to disease and environmental stresses and improved fertilizers uptake.

The use of new technologies is occurring at fast pace, however with different level of advancement in the world, in particular for innovative breeding (**new plant breeding techniques)**. Genome editing or site-directed mutagenesis techniques as well as the use of epigenetics and gene silencing are already under experimentation in the public and private sectors (Lusser *et al*., 2012). Additional tools like synthetic promoters, “tunable” transcription factors, and the use of site-specific recombinases will also impact agriculture development. The potential to enable crop improvement by using methods such as the assembly and synthesis of large DNA molecules, plant transformation with linked multigenes and the generation of plant artificial chromosomes, could be consider as the first step from agriculture to synthetic biology. The first crops obtained through these new breeding techniques are close to commercialization, but only if the regulatory issues for the commercialization of these novel crop varieties are clearly established, the adoption of these techniques by breeders will definitively occur (Lusser *et al*., 2012; McDougall, 2011; Miller and Bradford, 2010; Stein *et al*., 2009).

A better understanding of the interaction of agricultural biosystems (crops, animals a microorganisms) with other organisms (beneficial or not) in the environment is essential to mitigate yield loses caused by disease, pests and weeds, and to exploit the beneficial interaction of crops and animals with their associated microorganism (**microbiomes**; Sessitsch and Mitter, 2015). The understanding of these interactions will benefit agriculture as some of these microbiomes could improve the nutrient uptake and the response of agricultural biosystems to biotic and abiotic stress, as it has been suggested to occurs in human (Hacquard *et al*., 2015). The design and generation of synthetic microbial communities for specific crops should be addressed and the specific biotechnologies associated and required for this type of innovation must be included in the agriculture curricula. Similarly, the soil and the microorganisms it contained must be considered as a biological system relevant for crop production, and therefore has to be studied using the new genomic and computational tools as a required step for its conservation and sustainable exploitation (Sessitsch and Mitter, 2015).

Biologists are joining the **big-data** club and developing the **computational biology (**Marx, 2013)**.** With the advent of high-throughput genomics, life scientists are starting to grapple with massive data sets, encountering challenges with handling, processing and moving information that were once the domain of astronomers and high-energy physicists. To build new understanding of physiological aspect of agriculture biosystems or even of natural ecosystems, scientists must be able to analyse oceans of new (big) data generated by genomic sequencing, imaging, and other advanced technology. Upper-level science and undergraduate and master students will need skills in writing computer programs, working with databases, and applying complex statistics and modelling to agriculture biosystems.

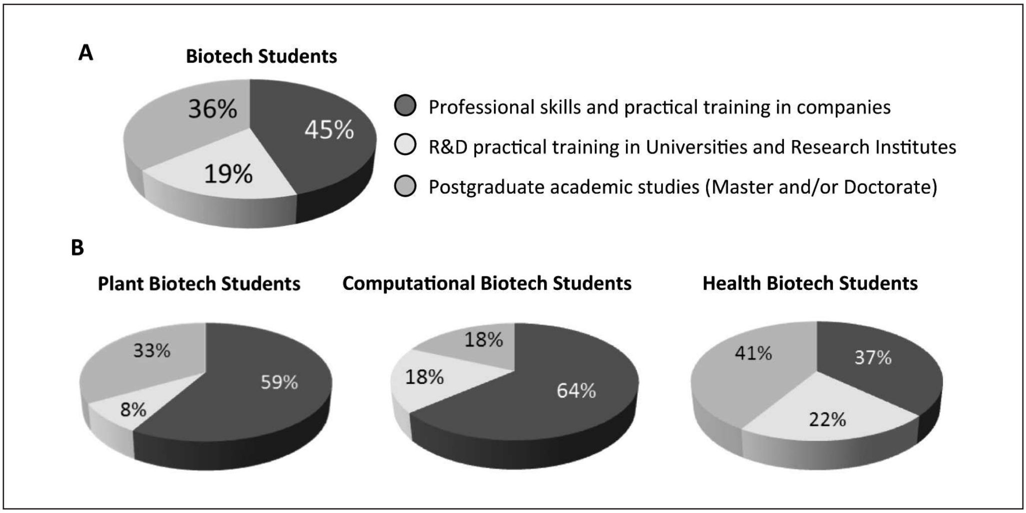

Fig. 1. Relevant knowledge and skills that the UPM Biotechnology Bachelor students considered have to be improved in their curricula for a competitive professional carrier.

Representation (in percentages) of the prioritized areas considered relevant for the UPM Biotechnology Bachelor students to improve their curricula in relation to their putative professional carrier. (**A)** Responses of all the students (n = 70), and **(B)** distribution of these responses in the different biotechnology specialization: plant, computational and health biotechnologies.

New research orientations are emerging in **behaviour science approaches** to agricultural development (World Bank, 2008). These new orientations are the product of both experience gained during the era that followed the Green Revolution and a response to changing goals in agricultural development that now place a greater emphasis on considerations of participation and equity. Use of ecological systems approaches to the study of farming systems is increasing. The importance of understanding traditional agriculture is becoming evident and technology development methodologies are beginning to simulate farm conditions at the research centres and to conduct experimental research on the farms. The appreciation of technology as a variable is leading to the development of alternative technologies adapted to different socio-natural situations. In this scenario biotechnologies could have significant contribution.

2. Moving biotechnologies and students out of academia into agriculture

The plethora of new concepts and biotechnologies indicated above should be included in the student agriculture curricula to respond to social and economic demands, but it might not be sufficient to respond to the professionals needs of future agriculture drivers, and to agriculture challenges (Langer, 2014). In the frame of the educational initiative program (EIP) BiotecH2020 (http://www.bit.etsia.upm.es/biotech2020.htm), we have carried out a survey among students from the Biotechnology Bachelor of the Universidad Politécnica de Madrid (UPM) to determine their perception about curricula needs. As shown in Fig. 1A, the students perception was mainly focused in three areas: (i) Professional skills and practical training in companies (45% of students); (ii) Postgraduate studies, that means further specific formation (36%); and (iii) R&D practical training in Universities and Research Institutes (19%). These data indicate that the students consider the acquisition of professional skills in companies and the specific formation (Master and PhD) in the biotech sector essential for their professional carrier. Of note, the percentage of the biotech students considering that the acquisition of professional skills in companies is important for their curricula is higher in those students enrolled in the Plant and Computational Biotechnology specialization than in the Health Biotech one (Fig. 1B). Notably, despite we have included a strong program of lab practical training and experimental Bachelor Thesis during the four years of the Biotechnology Grade, our perception, and that of the students, is that they would need to carry out more lab practices either in privates companies or public research institutes to acquire the professional expertise necessary for their professional future, especially for those students interested in biotechnology companies careers.

The BIotecH2020 EIP data also suggest that the students consider that they need to move biotechnologies out of the academia and into the industry. However, this remains a mystery to many scientists (Langer, 2014). What's more, knowledge of the commercial sector in academic circles can lag many years behind present business practice, especially when industry models are in constant evolution. Most life science researchers simply are not trained in the complexities of product commercialization (Langer, 2014; McDougall, 2011). In our opinion, properly educating more researchers to understand entrepreneurship and to have the skill needed to succeed in the commercial world is essential for translating discoveries into products, building companies and also providing the knowledgeable recruits that industry wants to hire. These needs are of special importance in the area of biotechnology (Langer, 2014).

The establishment of the undergraduate Biotechnology Program at the UPM was one of the strategic objectives included in the UPM BIOTECH Initiative launched in 2010 and aiming to provide biotechnology education skills to the students at earlier curricula steps to improve their knowledge and to increase their professional opportunities in the Biotech sector. This initiative was supported by the excellent results obtained with those students that have completed either the UPM Master and/or PhD Biotech Programs (Biotechnologies in Agricultural and Forestry (http://www.bit.etsia.upm.es/master_en.htm), and Biotechnology and Genetic Resources of Plants and Associated Microorganism; http://www.bit.etsia.upm.es/doctorado.htm). More than 90% of these students got a job in the first year after their completed their Master or PhD formation, and they had the opportunity to initiate their professional career in different departments (R&D, regulatory affairs, marketing, teaching, entrepreneurship, etc.) of either private or public bioeconomy entities, including those related with agriculture, food and biotechnology. This experience of more than 10 years further supports the professional competitive advantages of including biotechnologies in the Agriculture curricula.

In parallel to the BIOTECH Initiative, the UPM has tried to include Biotechnology formative programs in all life science-related curricula, including the Agriculture, Food and Forestry ones. However, the majority of the Biotech subjects in these curricula are optional and the number of students enrolled in these Biotech topics is far from optimal. In other Spanish Universities with Agriculture curricula we have found a similar situation. We consider that the lack of basic biotech knowledge and skills of the current Agriculture Bachelor students is unfortunate since we guess, based on our experience, that this formation would be required for their professional career development.

3. School Education systems: learning life science and understanding biotechnology

New educational approaches might be required to introduce biotechnology and biology at primary and high schools, and universities. In the current educational system, students are listening to lectures on photosynthesis, memorizing parts of the cell, and learning the terms of taxonomy, DNA and genetics, and biotechnologies (Bonde *et al*, 2014). While biological research is advancing at warp speed, amassing new insights and new data as the lines separating biology, chemistry, mathematics, and engineering dissolve and the fields converge.

Urge to take a new approach: in the place of courses based solely on lectures and memorization, schools and universities should incorporate the latest practices of biological research, engaging students with the opportunity to think and work like scientists on issues with real-world relevance. Thus, the students will feel that they're part of the science community, and that they're learning things that can be related to the real world. They should be challenged to *think.* The transformation of biology and biotechnology education from elementary school to universities, will be essential to support biotechnology, biomedicine, and other sectors that will be essential for 21st-century innovation and economic growth. Without that, the risk is that leadership of innovative countries in these fields will diminish, at great economic cost (Bonde *et al*, 2014).

IV – Conclusions

Biotechnology can make an enormous contribution to main agriculture goals such as reaching sustainable yield growth and providing food and feed for healthier life. Therefore, we consider that biotechnology must be a key subject in Agriculture Curricula Programmes. The Agriculture curricula should also consider that improving the professional skills and training of the students is essential to respond to agriculture and society needs and demands.

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