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Current Opinion in Biotechnology

Can plant biotechnology help in solving our food and energy shortage in the future?

Editorial overview

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Current Opinion in Biotechnology 2011, **22**:1–4

0958-1669/$ – see front matter

DOI 10.1016/j.copbio.2011.01.007

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Miguel Blázquez received his PhD in 1995 from the Autonomous University of Madrid, working in the regulation of glycolytic flux in yeast. He then joined the Salk Institute (La Jolla, CA) as a PostDoc in Detlef Weigel's laboratory, where he studied the interplay between hormones and environmental signals in the control of flowering time. He is now a staff researcher of the Spanish Research Council at the Institute of Plant Molecular and Cell Biology (IBMCP) in Valencia, Spain, studying the molecular mechanisms that underlie plasticity in plant development.

World population has grown from 2 billion during the Second World War to 7 billion in the twenty first century. The fast growth of the human race creates new problems. In the future we anticipate shortage in water and food supply. Moreover, the industrial world creates environmental pollution due to heavy usage of fossil based energy.

An important goal in plant science is to improve the production of food and find new resources for renewable energy. Biotechnology provides new tools for improving food quality, increasing crop yields and finding new resources for energy production.

In the past few years, advances in both our understanding of plant genomes and the functional analysis of key regulators of many physiological processes have been profound. In this issue of *Current Opinion in Biotechnology*, progress in several selected areas of plant biotechnology has been compiled. On the basis of these, there is no doubt that plant biotechnology will contribute to building a sustainable economy by providing renewable sources of food, feed, energy and so on, all with a minimum impact on the environment.

Methods for the increase of crop yield have been highly successful in the past years. However, an assurance of food availability does not depend only on the quantity of food but also on its nutritional quality. The nutritional quality of food is a major problem in poor countries. Vitamin A deficiency is estimated to affect approximately one-third of children under the age of five around the world. It is estimated to claim the lives of 670,000 children under five annually. Approximately 500,000 children in developing countries become blind each year owing to vitamin A deficiency. Genetic engineering can tackle the problem of vitamin deficiencies in basic food. In recent years a combinatorial transformation method has been developed which allows the insertion of genes controlling entire biosynthesis pathways into plants. Such developments enable the production of provitamin A in corn and rice plants. The uses of genetic engineering together with conventional breeding allowed the development of crop plants with elevated carotenoid content. However, it is highly unlikely that such crops will be seen in the market due to political issues. The political dimension of genetically modified crops is usually negative. The media, public and politics feed each other with mis-information about the risks of using genetically modified crops. The first review deals with ways to develop plants with improved nutrient content and the environmental safety of these genetically modified plants, as well as the political issues that have been arising with the development of such genetically modified plants [1].

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Modifying the biosynthesis pathway of carotenoids may influence other biosynthetic pathways in plants. The metabolic network in plants is very complex compared to other organisms. Apart from primary metabolism, plants also synthesize a vast range of specialized metabolites. Primary metabolites include universal building blocks of sugar, amino acids, nucleotides, lipids and energy sources. Secondary metabolites play a key role in maintaining plant fitness. Unlike primary metabolites, absence of secondary metabolites does not result in immediate death, but rather in long-term impairment of the organism's survivability. Secondary metabolites are often restricted to a narrow set of species and they often play an important role in plant defense. The major secondary metabolite classes produced by plants are: phenolic compounds, terpenoids and alkaloids. In the second paper the regulation between primary metabolism and secondary metabolism in plants is reviewed. Regulations of the expression of genes encoding various metabolism associated transcription factors has shown that similar transcription factors can simultaneously regulate genes involved in the synthesis of primary and secondary metabolites. Identifying such transcription factors will aid in the improvement of various plant traits [2].

In an industrialized world food allergies are a growing concern. The concern of food allergies is not limited to human consumption. There is a growing sensitivity to food allergies in livestock that are being fed with synthetic food. Major plant food sources such as wheat and soybean are cited as a major source for food allergies. Additional plants crops such as peanuts, tree nuts, sesame and sunflower are considered as sources for food allergies. Preventing possibly life-threatening allergic responses is a significant medical issue and critical issue in the food industry. The review in this issue describes ways to identify allergenic proteins. It also describes ways to generate transgenic plants producing allergen-reduced or allergen-null food. The complexity of the allergy issue may influence the approval of new transgenic plants that enter the human food chain [3].

The rapid increases in fossil energy cost have led to increasing interest in alternative energy resources. This issue of *Current Opinion in Biotechnology* contains two reviews dealing with issues related to food and renewable energy. Vegetable oils consist of energy-dense triacylglycerols that are composed of three fatty acids bound to a glycerol backbone. Vegetable oils are used in preparation margarines, salad oils and fried foods. With the need for new energy sources, triacylglycerols are attractive for biodiesel production. Biotechnology offers a number of solutions to meet the growing need for vegetable oils and vegetable oils with modified composition of fatty acids. Once the critical enzymes in the biosynthetic pathway of oilseeds have been discovered, it opens the avenue for biotechnology to change the amount and composition of vegetable oils. Manipulation of seed oil can be achieved by modifying the amount of different enzymes in the biosynthetic pathway. Metabolic engineering will provide important tools for increasing and modifying fatty acid composition in vegetable oils. Plant biotechnology will provide the tools to generate new crops with modified oil composition in non-food crop plants [4].

The production of renewable fuels from biomass is an evasive goal. Burned wood was used in the past for heating and as a fuel for transportation. Modern society needs to consume energy in the form of liquid or gas. Therefore, we need to develop new ways to produce fuel form plants. Enzymes are being used to deconstruct and ferment the plant cell wall to produce biofuels. However, this process is still inefficient. Analyzing the enzymes that degrade cellulose will open new avenues to create an efficient enzymatic process that can degrade cellulose to produce biofuels. The instant review describes deferent approaches to design enzymes and to screen for improved enzymes that decompose the plant cell wall. These enzymes will enable industrial processes for the production of renewable fuels [5].

Biotechnology-oriented research with Arabidopsis: think small, win big

The adoption of Arabidopsis as a model organism in plant biology laboratories has resulted in a tremendous advance in our comprehension of plant physiology and development, with an impact only comparable to the combination of Drosophila and *Caenorhabditis elegans* studies upon animal biology. Moreover, during the past ten years, the plant community has had access to the invaluable resource of the complete Arabidopsis genome sequence and the corresponding tools devised for its analysis [6]. As a result, we can now describe with certain detail the molecular mechanisms that underlie a number of processes, and even point to the pathways through which these mechanisms have evolved in different species.

Given this success in the generation of basic knowledge, a relevant question has logically arisen, which is partly shared by plant biologists and plant biotechnologists. How much more effort should be allocated to Arabidopsis, compared to other species? From the point of view of a plant biologist, the answer is not clearcut: on one hand, several important issues such as the evolution of plant development, or the study of secondary metabolism cannot clearly be tackled only with Arabidopsis and require the application of the molecular tools designed for Arabidopsis to the analysis of other species. On the other hand, a large investment in systems biology approaches in Arabidopsis may render a more precise and integrated view of a plant's life. From a biotechnologist's point of view, the larger effort should be placed in resolving the most pressing needs of society in the short

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term, which requires a shift of the resources towards the study of more agronomically important crops. However, this view is also balanced by the realization that intelligent manipulation of plant physiology must be preceded by extensive knowledge of the processes of interest, and this is achieved much faster with model organisms.

In this issue, we have aimed at critically assessing the contribution of Arabidopsis studies to Biotechnology, and we have therefore selected a few topics that illustrate how basic knowledge of generated with this weed can been translated into biotechnological applications, even in areas for which Arabidopsis might not be considered the most appropriate model organism.

A requisite for Arabidopsis studies to be considered useful in crop biotechnology is the possibility of building predictive models that allow fine manipulation of important traits. The availability of large datasets, including genomic sequence information for a number of plant species, as well as transcriptomic, metabolomic, and epigenomic data in Arabidopsis needs to be transformed into intelligible coordinates in a real-world plant biology framework, forming a network with functional meaning. The review by Ferrier et al. in this issue (pages...) sheds light into the inference of gene regulatory networks illustrating the success achieved when multiple experimental approaches are combined, and indicating the limitations for the application of current models to crops.

Starch is one of the golden molecules from a biotechnological perspective. Besides its nutritional value, it presents a large portfolio of applications in the food industry [7], and also as a major source of ethanol in the biofuels industry [8]. In this regard, any advance that allows the efficient manipulation of the starch form accumulated in the plant, its amount, or its degradation into sugars, is a priority. The review by Santelia and Zeeman in this issue (pages...) summarizes recent developments in Arabidopsis research on starch synthesis and the influence of transient phosphorylation of the glucan in starch breakdown. Although this information has not been effectively converted into a biotechnological breakthrough yet, the review conveys the message that the complexity of the whole process requires an additional effort just setting the grounds for further uses, and provides an optimistic perspective for the directed synthesis of novel starches.

Hand selection of plant varieties over the centuries has allowed the adaptation to local environments of cereals and other plants used as food and forage crops. However, we now face newer challenges, such as the expansion of cultivated areas to less fertile fields, or the adaptation of crops to a globally changing climate. Research on Arabidopsis has identified a number of signaling pathways involved in the regulation of the response of individual plants to extreme changes in temperature and water availability. Chew and Halliday (pages...) point out the conservation of several key elements for this response in Arabidopsis among higher plants, and review the modification of stress resistance achieved through the precise manipulation of these networks in wheat and other crops. Interestingly, this review also highlights the use of phenological and molecular models both to understand the complexity in any given response, and also to forecast crop yield under stress.

Arabidopsis does not tuberize. This single statement should be enough to redirect biotechnology research on tuberization to other plants, especially *Solanum tuberosum*. A similar conflict arises in the study of the formation of fleshy fruits –such as those in tomato plants, citrus trees, and others, so different from the dry pods of brassicaceae. Certainly, the differentiation of certain tissues in these organs, or the synthesis of pigments and volatiles through secondary metabolism is species-specific. However, the signaling pathway that controls tuberization in potato plants shares much of its topology and key elements with the regulation of flowering time, both in potato, rice, and Arabidopsis, as stressed by Abelenda et al. in this issue (pages...). In fact, this example illustrates how plants have recruited basic signaling modules for the control of diverse physiological and developmental processes, differing only in the way that they are triggered, or the identity of the molecular targets at the output of the pathway.

An equivalent surprise is the wealth of information on wood formation that has been generated with Arabidopsis. Wood is generated by secondary growth of plant vasculature. When grown under short days, the Arabidopsis hypocotyl undergoes increased secondary growth and develops both vascular and cork cambiums, making it resemble the trunk of woody species such as poplar [9]. All available evidence points to the conservation of molecular mechanisms between trees and herbaceous plants during vascular development, and the review by Zhang et al in this issue (pages...) describes how the physical properties of wood can be altered by targetted misexpression in trees of key elements identified through Arabidopsis research programs. However, it's important to remark that Arabidopsis does not form parenchyma rays therefore limiting its usefulness in studying genes involved in wood formation [10]. Thus in order to fully evaluate gene function in wood development it is important to conduct studies in a true wood species such as poplar.

Beyond the examples of the impact of Arabidopsis research upon crop biotechnology, a general assumption is that advances in plant biology mostly fall behind those made with animal models. However, there is a growing list of discoveries made with Arabidopsis that have direct implications in human health [11], including the recent finding in Arabidopsis that nucleosome positioning throughout the genome determines DNA methylation

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pattern, and that this phenomenon is found in humans too [12]. The review by Xu and Møller in this issue (pages. . .) highlights the use of Arabidopsis in the molecular disection of three neurological disorders: Friedreich's ataxia, and Alzheimer's and Parkinson's diseases. For instance, lesions in DJ-1/PARK7 protein have been associated with Parkinson's diesease, and the biochemical function of the DJ-1/PARK7 protein in Arabidopsis is conserved. This has opened the possibility to study the process at the biochemical level in a versatile model organism, and has led to a link between the diesease and reactive oxygen species.

In 1959, Volkswagen launched one of the most acclaimed advertising campaigns in the 20th century, persuading post-war US customers to ''Think small'' and appreciate the benefits of their Beetle [13,14]. Paraphrasing their ads, ''our little *weed* [car] isn't so much of a novelty any more'', but that's only because we are already used to its advantages, not because it has lost its glare.

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