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Ecotechnological solutions to satisfy current demands of forest products, a glance beyond the trees

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ABSTRACT

A significant increase in the demand for wood products, including timber, pulp and biofuels has exerted considerable pressure on the world's remaining natural forests. To expand the forest area by establishing forest plantations has been proposed as a way out to satisfy current and future demands, as well as to mitigate expected increases in atmospheric carbon. Specialized scientists in forestry and tree biotechnology advocate that humanity should rely on biotechnological solutions, particularly GM tree plantations, to achieve sustainable and more productive forest plantations. During the last decade, significant advances have occurred in both molecular methodologies and basic understanding of biotechnological processes associated with timber production. However, important sectors of civil society have showed reticence, even open opposition, towards these ecotechnological solutions. This article explores on the one hand the rationale of the academic sector in promoting biotechnological solutions to satisfy current demands of forest products and biofuels, and on the other, analyzes society's opposition towards these solutions. The academic sector needs to understand where the resistance towards the development and establishment of these highly innovative technologies stems. Scientists need to become better at framing the importance of scientific research to citizens, at eliciting public participation and fostering public dialogue about science.

1. Introduction

Humankind faces many challenges over the next few decades, but two of them emerge as critical issues: resources depletion and global environmental changes, both of which represent major threats to humanity (Barnosky et al., 2012; Rockström et al., 2009). Industrial extraction of biomass, mineral and fossil fuel resources, together with continental water and agricultural soils over use could lead to a collapse of key infrastructures and manufacturers, decline in food production and limits to local water access (Priora et al., 2012). Climate change, disruptions in nitrogen and phosphorous cycles, loss of biodiversity and ocean acidification in the forefront of the environmental crisis, remain major challenges for humanity in the next decades. Global forest ecosystems play a key role in tackling these challenges.

Forests store large quantities of carbon in vegetation and soil (Dixon et al., 1994), and through respiration and photosynthesis exchange carbon dioxide with the atmosphere. Hence, forests are a critical component of the global carbon cycle, and their response to environmental change and management remain as a key factor in determining the effects of climate change on global carbon balance (Houghton, 2005). In addition, forests are primary sources of ecosystems services, in terms of local food, water, biodiversity, recreation, and represent a major opportunity to mitigate the anticipated rise in atmospheric carbon over the next 50 years (Food and Agriculture Organization of the United Nations, 2015; Miura et al., 2015). Notwithstanding, it is openly acknowledged that urban and agricultural expansion, wood and biodiversity consumption, industrial mining and over use of water resources represent major menaces to forest conservation. Wood, as a commodity, is essential for timber, pulp, paper, and more recently as feedstock for biofuels and biomaterials (Häggman et al., 2013).

Despite their importance, world forest area has decreased to < 4 billion ha, about 30.3% of the terrestrial land area, with a net loss rate of 6.6 million ha per year between 2010 and 2015 (Food and Agriculture Organization of the United Nations, 2015). In 2011, wood global consumption was 3.0 billion m^3, about half of this amount was used for industrial purposes and half used as fuel (Food and Agriculture Organization of the United Nations, 2015). Both, wood and fuel consumptions have slightly increased in the last decades. The demand for forest products is accompanied by rapid deforestation. In an attempt to counter this problem, over 110 million ha have been subject to reforestation in the last 25 years, accounting for 7% of world's forest area (Food and Agriculture Organization of the United Nations, 2015).

Facing these scenarios, an ample set of technological initiatives has been suggested (Fenning et al., 2008; Somerville et al., 2010; Calmon

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et al., 2011). From a technological perspective, particularly wood consumption has enforced the need to develop new approaches for forest managements, this suggests that conventional silviculture techniques might not be sufficient to meet the required forest biomass productivity and ecosystem recovery (Fenning and Gershenzon, 2002).

These aspects become the argumentative platform for forestry engineers and scientists to generate a new frontier of research with the support of a growing private sector, in a long-term co-evolutionary process between humans and forests. Undoubtedly, this is a solid scientific warning on the need to preserve current forest and recover deforested areas to preserve ecosystem services. However biotech plantations, even though based on ecological principles, have incited an intense debate in the academic sector, local populations and society in general. This article explores the rationale of the academic sector promoting biotechnological solutions to satisfy current demands of forest products and biofuels, and analyzes societal responses in disagreement with this scientific approach. Societal choices, in a fast changing world, require a profound understanding amidst those sectors involved in the development and establishment of highly innovative technologies.

2. Eco-technological solutions for sustainable forestry

Specialized scientists in forestry and tree biotechnology consider that energy security (biofuel production), future demand of wood and fiber, and mitigation of expected atmosphere carbon increment in next decades will rely on science to provide the tools for sustainable and more productive forest plantations (Häggman et al., 2013; Harfouche et al., 2013; Hjälten and Axelsson, 2015; Näsholm et al., 2014). Fenning et al. (Fenning et al., 2008) suggested that in the future world forest could be classified in four categories: a group of forests with high biodiversity and carbon sequestration value conformed by natural forest close to pristine conditions; other forests under conservation figures due to their biodiversity interest and carbon sequestration potential capacity, but with some management of timber extraction; in developing countries, a third group conformed by small scale plots to provide local firewood and building materials; and the remaining needs of timber, biofuels, chemical products would be provided by plantations designed for that purpose, using highly selective exotic trees managed to maximize yield. This last category represents the main target in forestry scientific investigation, focusing on high-yielding and short-rotation plantations.

Notwithstanding the notable success in wood productivity obtained from conifers and eucalyptus plantations achieving over 20 fold natural forest biomass returns (Fenning et al., 2008), there is a wide consensus among forestry scientists on the need to go further by using biotechnological approaches (Häggman et al., 2013; Harfouche et al., 2013; Franklin et al., 2014). The main argument to develop new insights in forestry research, using molecular biology techniques, comes from the fact that this technique is more specific and is not hindered by the limitations of traditional breeding, related to the fact that trees have long breeding cycles (> 7–14 y), self incompatibility mechanisms and broad genetic and phenotypic diversity (Fenning and Gershenzon, 2002; Näsholm et al., 2014; Farnum et al., 2007). Therefore, research programs targeting on traits as early stem growth and form, disease resistance, water use efficiency or wood properties, associated with complex patterns of inheritance would be more efficient in terms of time, space and resources. This approach has been stimulated by the extraordinary progress obtained in recent years, based on the modification of physiological processes and associated genes, to improve tree biomass productivity, herbicide and disease resistance and enhanced root development (Dubouzet et al., 2013; Etchells et al., 2015).

Main research efforts have been addressed towards improved phenotypes in few species of trees already known in forestry. Domesticating forest trees has had two prime targets, better knowledge and potential manipulation of wood formation, and shortening juvenile period. Nevertheless, pesticides and herbicides tolerance, root formation, sterility, nitrogen and water use efficiencies, among others are features of current interest to obtain superior growth genetic trees.

Tree growth and crown architecture are key features to optimize solar radiation harvest that determines the gross input of carbon (biomass) to the plant (Franklin et al., 2014; Dubouzet et al., 2013). Part of the assimilated carbon is used for the maintenance of tissues and metabolism (leaf and fine roots turnover and respiration) and the remaining carbon is allocated to growth, reproduction and defense (Näsholm et al., 2014). Optimized tree architectural morphology and faster growth will facilitate higher light capture potential. Experience gained in agricultural crops suggests that manipulation of genes could contribute greatly to achieve these goals. Current subject of research encompass the modification of C_3 Rubisco (enzyme involved in atmospheric carbon fixation) to obtain higher catalytic rates, and the induction of over-expression of the biosynthetic genes associated to endogenous hormones as gibberellins, auxins or brassinosteroids. For instance, recent findings on cell division regulation showed that trees grew twofold faster than normal and formed more developed crowns, through the modification of two genes responsible for the rate of cell division in tree trunks (Etchells et al., 2015).

Increments in carbon allocation are shared between belowground and aboveground tree structures. Root formation could be promoted when vegetative propagation accelerates massive reproduction of trees. Cuttings of trees are susceptible to root, but plant rooting capabilities vary among the species. Enhanced root development can be achieved by modifying genes related to hormone biosynthesis as mentioned above, with tree growth. Experiences with the over-expression of genes from *Arabidopsis thaliana* in poplar have shown increments in root biomass in transgenic organisms under laboratory conditions (Harfouche et al., 2013).

Faster growing trees require more nutrients and water from soil to satisfy biomass demands. Molecular biology techniques allow engineered plants to maximize water and mineral nutrient uptake from rizosphere soil. This aspect is of particular relevance when considering plantations in environments with nutrient limitations. In natural ecosystems, nitrogen, phosphorus and less frequently potassium, can limit plant growth rate. Enzymes as glutamine synthetase, alanine amino transferase and glutamate dehydrogenese involved in the nitrogen acquisition mechanism, or phytase and potassium membranes transporters can be manipulated to maximize nutrient use efficiency. Recent findings have paved the way in this direction, obtaining more efficient use of nutrients (locally available or supplied) by trees and faster biomass accumulation rates, becoming a promising aspect in the search for optimal traits (Dubouzet et al., 2013).

Tree water demand is a major aspect to take into account to optimize crop yield. Seasonally environments with extended dry periods throughout the year reduce plant water potential, affecting conductance of CO_2 and therefore photosynthesis. Water-use efficiency of crops, the ratio between biomass production and water balance, becomes a key trait in seasonal ecosystems, but it is even more critical due to the acceleration of global climate change and unpredictable associated scenarios (Franklin et al., 2014). Approaches like the incorporation of the over-expression of an *Arabidopsis thaliana* protein kinase related to water-stress tolerance, or aquaporins proteins to facilitate water flow across cell membranes, among others, allow trees to overcome intermittent water stress during erratic rainy periods, and provide better abilities to extent the growing periods, hence increasing biomass accumulation (Näsholm et al., 2014; Dubouzet et al., 2013).

Mono-specific plantations, with nutrient-rich foliage under climate change scenarios are consider important triggers for herbivores to develop into pests. This might increase the risk of damage on plant tissue, representing a major threat to the sustainability of tree plantations (Hjälten and Axelsson, 2015). Expected consequences are reduced production, lower economic return, and unpredictable impacts on local ecosystems, therefore increments in the use of pesticides become a feasible response by managers. Genetic engineered trees focusing on