Super Plants: Genetic Engineering Could Boost Plants Carbon-Capturing Ability

Scientists are working on super plants which will be used to decrease global carbon dioxide in our atmosphere and trap gigatons of the greenhouse gas

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1. Preface

1.1. What is our motivation to work on the topic?

The main reason is its importance for the future. We wanted to write about a topic which is up to date, interesting for our generation and for our future. It deals with a serious problem in our society which is the emission of CO2. Human activities like heating, transportation or production of electricity add about 9 gigatons of Carbon to the atmosphere yearly. Photosynthetic organisms on land and in the ocean absorb about half of it and let us humans deal with the rest of it. Everybody knows that global warming is enhanced by greenhouse gases and we need a solution to it. Therefore, it seemed interesting to do some research about plants which are highly efficient in capturing CO2 and find out how they work.
This could be a completely new tool to absorb new greenhouse gases and could reduce the amount of CO2 in the atmosphere.

1.2. What is especially interesting?

It's very notable that humans produce 9 gigatons of CO2 each year of which 100% could be captured with specialized plants. In order to obtain this plants various aspects, have to be covered. So we wanted to find out how do you get this super-efficient and world saving plants and how genetic engineering helps us to realize this idea.
The attraction to this subject definitely comes from the up-to-dateness and the presence of this problem in society. We were interested in the emission of greenhouse gases and when we searched for a suitable topic we stumbled across a very interesting article which dealt about bioengineered Tobacco plants with changed proteins which can take up more CO2 than the normal ones. This awoke our interest and we wanted to understand how they came up with the idea and how it works.

1.3. What are our questions with respects to the chosen topic?

As it is a topic which requires a large amount of background knowledge we have very much interesting questions and hope to find an answer to them, but here are the most important and central questions concerning our topic:

Are there already super carbon-capturing plants and what are their features and qualities?
Which results are expected by growing genetically changed plants?
Which would be the main issue in the process of transferring this idea to reality?
Which properties should such a plant have in order to accomplish its task?
How do this super plants work?
What progress was made with the application of super carbon-capturing plants?

2. Introduction

2.1. What is the context of the chosen topic? Are there any recent events?

The high emission of greenhouse gases in our atmosphere is worldwide known and a serious topic, having too much greenhouse gases results in polluted air and in the greenhouse effect (obviously) which causes global warming. (And global warming causes very much different problems like changed seasons, extreme weather, shifted climate zones, acidification of the sea, melt down of the poles etc...) This has even already lead to taking countermeasures to the emission of CO2 and start diverse projects in order to find a remedy to this problem. One of them are the super carbon-capturing plants which are created by genetic engineering.
The most important ones are the tobacco plants with RuBisCo.

2.2. What are Tobacco plants with bioengineered RuBisCo?

Tobacco plants with bioengineered RuBisCo are super plants that grow in an environment with a high carbon concentrations and can capture more carbon dioxide per enzyme than normal plants. The difference between the normal tobacco plants and the genetic modified ones is that the super tobacco plants have a more efficient RuBisCo enzyme that has been discovered in single celled blue-green algae (called cyanobacteria). This Tobacco plant with bioengineered RuBisCo is the first plant that can successfully capture more CO2 because of this version of the RuBisCo enzyme and is one of the biggest milestones in genetic engineering history of super plants.

Picture 1. (Picture of tobacco plant (Nicotiana) with bioengineered RuBisCo Enzymes

2.3. What is carbon capture?

Carbon capture is a process that captures the waste carbon dioxide and transports the waste into the roots of the plants. The climate-damaging effect of energy production from fossil fuels (coal, gas, oil) can be greatly reduced.

2.4. What is the recent scientific history?

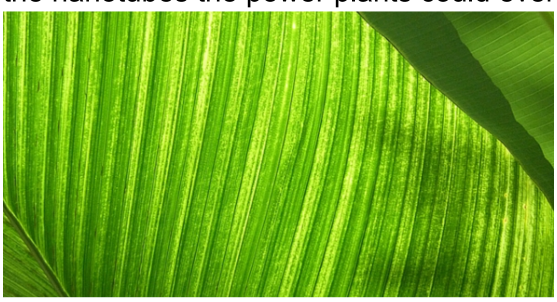
Realizing improvements to crop yield and resource use by boosting the catalysis of the photosynthetic CO2-fixing enzyme Rubisco has been a persistent challenge. Rubisco is a very inefficient enzyme that is produced in massive quantities by plants, making it the most abundant protein on earth. Scientists tried to make the enzyme more efficient by genetic engineering but failed several times. But a different type of Rubisco, that is much more effective, was discovered in single celled blue-green algae (called cyanobacteria) sadly scientists were never able to put that enzyme into other plants. In 2014, scientists accomplished to embed the effective type of Rubisco in a tobacco plant and created a tobacco plant that was able to capture more CO2 than the normal one. This was a big milestone and it gives the scientists hope for the future. Until now the genetic engineers haven't been able to embed the enzyme into another plant but we think they will manage to do so in the future.

2.5. Where and why is the capturing of CO2 by super plants used?

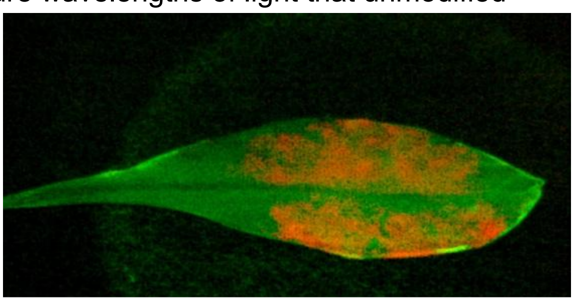
The idea of capturing more CO2 by super plants came up in North America for the first time. Many political and ecological reasons have forced industries, including the electric power sector, to move towards adopting greener technologies as CO2 has been recognized as a greenhouse gas (GHG), and therefore potentially harmful for the environment.
Because of having the highest CO2 emission on the world, the USA had to find some solutions to fight one of their biggest environmental problems. Not only the USA but also China, Europe, Australia and Japan followed the good sample, launched some new projects that would fight climate change more effectively and invested in research projects.

2.6. Are there alternative treatments?

There aren't many other treatments because only people from plant biology, the chemical engineering and nanotechnology community are working on this emerging field right now. But there are still some. Bionic 'watered' plants with dilution of carbon nanotubes is one example that is actually running in the US. The plant that was treated with the special dilution produces up to 30% more energy. Scientists predict that by altering the diameter of the nanotubes the power plants could even capture wavelengths of light that unmodified



Pictures 2. (Plant with system made out of nanowires and bacteria that can capture CO_2 emissions)



Picture 3. (Near infrared fluorescence of carbon nanotubes (orange) infiltrated inside leaves (green))

plants currently can't use, such as green light and ultraviolet.
Another treatment is being developed by the Lawrence Berkeley National Laboratory and the University of California. They have created a unique system in the plants - made out of nanowires and bacteria - that can capture CO2 emissions before they are vented into the atmosphere. Then, this brilliant idea converts CO2 and water into acetate, which are the main building blocks of photosynthesis. This is a very good and advanced system in the field of artificial photosynthesis.

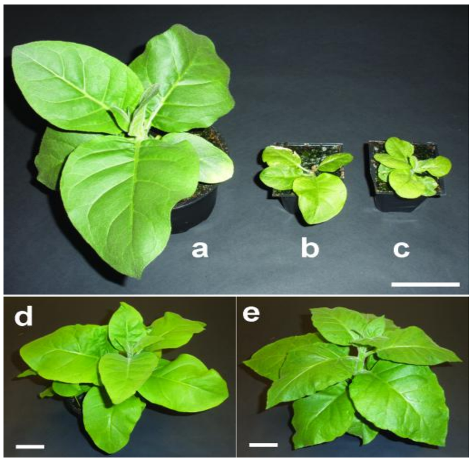
3. Description of engineering technique

3.1. Explanation of the applied technique including graphs and figures

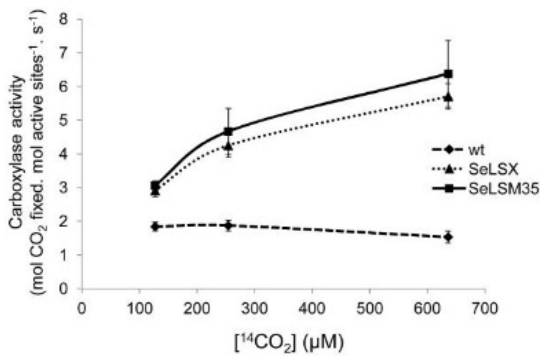
Rubisco (D-ribulose-1,5-bisphosphate carboxylase/oxygenase) is the number one enzyme (in organisms doing photosynthesis) processing CO2 from the atmosphere. But even being the most common, it's extremely inefficient. Therefore, scientists want to improve it in order to rise the efficiency of photosynthesis. The main problem in doing so, is the complexity of Rubisco which doesn't allow us to modify it or integrate the Rubisco from an algae (cyanobacteria, *Synechococcus elongatus*) which showed more efficiency in fixating CO2, in other plants.

Fortunately, it worked out to exchange the natural Rubisco of the tobacco plant with the Rubisco of the algae in modified tobacco plants where the new genes aren't integrated into the nuclear DNA but directly into the DNA of the chloroplast. The wild-type (a) plant and the modified ones are showed on figure 4. (Two types of *Synechococcus elongatus* Rubisco has been used: SeLSX(b/d) and SeLSM35(c/e)). In figure 5 the new DNA-elements (black) are added to the DNA-helix between the already existing DNA-elements. The enzyme even formed structures in the chloroplasts comparable with the ones formed in biogenesis in cyanobacteria as observable in figure 6.

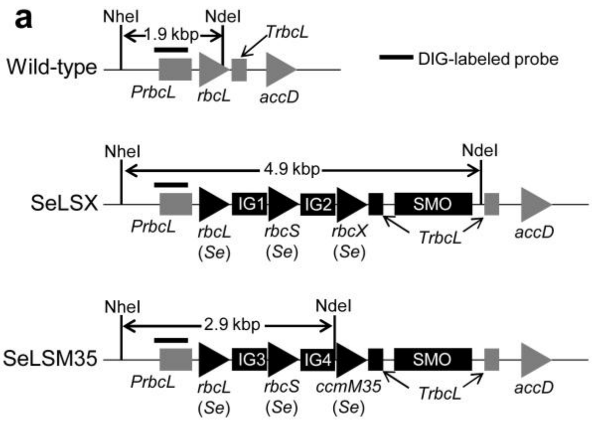
The plants showed higher rates of CO2 absorption than normal ones preserving all other functions. The graph in figure 7. shows that the modified plants absorb more moles of CO2 than the wild-type, this is caused by the integration of the Rubisco from the algae which is more efficient in absorbing CO2 than the wild-types rubisco. This are very bright news for the development of improved photosynthesis. It is even expected that some aspects of the cyanobacteria will possibly enhance crop yield.



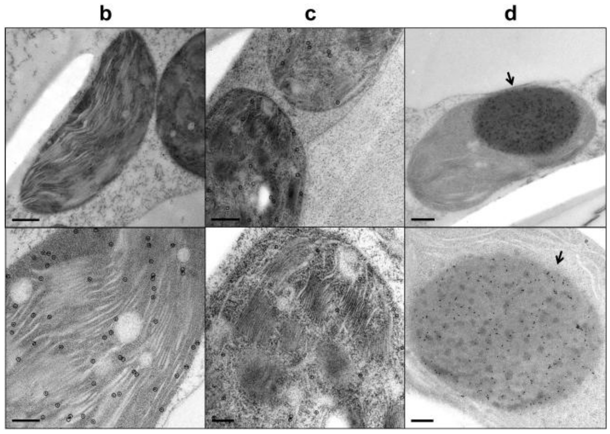
Picture 4. (Phenotype of the wild-type and transplastomic tobacco lines)



Picture 7. (Graph showing the efficiency of the treated plants compared to the wild-type)



Picture 5. (Integration of new DNA-elements into chloroplast DNA)



Picture 6. (Cross-section of the chloroplasts showing enzymes (Wild-type (b), SeLSX (c), SeLSM35 (d))

4. Documentation and pictures of research institutions

4.1. Interview with researchers and representatives of research institution

For the interview we got in touch with Tamara Zelikova a scientist from the AAAS Science and Technology Department of Energy to get some first-hand information the interview was held per e-mail, we requested for the interview on 5.4.2016 and got an answer back on 2.5.2016.

-How did the idea of transforming plants into super carbon-capturing plants come up?
Not sure about how this idea first came to life, but optimizing carbon capture for photosynthesis has been an important goal in agriculture. As photosynthesis becomes more efficient, especially for RuBISCO plants, agricultural yields go up and there has been a lot of research to make agricultural crops more productive.

-Is it possible to capture all CO_2 emissions produced by humans only by super plants?
The potential for plants to take up all the CO_2 is diminishing very quickly.

-Are there already super carbon-capturing plants on the world and what are their features and qualities?
Yes, as mentioned above, crops have been optimized for carbon capture and increased production. The key for carbon capture is the function of stomates (letting CO2 into the leaves and releasing O2 out) .C3 plants have lazy enzyme RuBISCO and it gets even lazier when it's hot and there isn't a lot of water (the future for many parts of our planet).

-Which techniques and processes in genetic engineering are applied to produce super carbon-capturing plants?
The same general domestication and selection process we have used for 100s of years in agriculture to grow crops is being in use today, but with more precise technology to select for very specific plant traits. We can now select for certain genes rather than general phenotypes (phenotypes are the result of certain genes being expressed).

-Which ideas have already worked out and which are upcoming ideas to make bioenergy crops even better?
Targeting very specific genes and splicing genes from some plant species into others to get certain desirable traits have worked and will continue to work in the future. The next frontier is understanding the microbiomes of plants (how microbes interact with plants to optimize production)

-Why don't we use machines in order to capture carbon and are there alternative treatments to reduce greenhouse gases?
This is an active and exciting area of research. There are scientists and engineers working on how to efficiently grab CO_2 from the atmosphere and use it for something. There are also researchers figuring out how to efficiently capture CO_2 from power plants and industrial plants. So – we are using machines to capture carbon, but at this time, the technologies are not as cheap as they need to be in order to have them widespread and in use everywhere.

-What was your motivation to work on this topic and what do you think is especially interesting about it?
My motivation was understanding how climate change impacts a very fundamental process of photosynthesis. Given the fact that the increase in CO_2 in the atmosphere is part of the problem, it is critical for us to understand what happens to carbon in the biosphere (what plants and microbes do with the carbon).

4.2. Conclusion of the Interview

In this interview we got some useful information from a person that is specialized in this topic. We learn from the interview that, optimizing carbon capture for photosynthesis has been a long goal in agriculture. The scientists are using a selection process with more advanced technology in order to select specific useful traits from plants. Future research steps will be to pick very specific genes from a desired plant, splice them and to put them into another one to get it working more efficiently. There are also very active researches for carbon capturing machines but as the technology is too expensive, they do not pay off yet in order to have them widespread and in use everywhere.

5. Discussion

5.1. What Progress was made up with the application of the chosen technique?

Because of the genius scientists that were able to introduce this efficient form of Rubisco into the common tobacco plants, we have more efficient tobacco plants that could grow in high carbon concentrations and could fix more carbon dioxide per unit of enzyme than the normal ones. Thanks to this results, common crops could be modified to soak up unprecedented levels of carbon dioxide, and perhaps lead to larger crop yields. Results from this experiment open the door to a new world of climate engineering and will be the reason for many new world-shaking results.

5.1. What are future research steps?

A goal is to improve the efficiency of the RuBisCo enzyme by genetic engineering even more than the single celled blue-green algae (called cyanobacteria) RuBisCo. Another step will be to include the modified RuBisCo enzyme in other plants more specialized plants (which also should have ideal genetic treats like much leaves and an extensive root system in order to store the carbon underground) beside the tobacco plants and maybe use this projection for artificial plants. This would lead to more potential super plants and would help us to reduce the amount of greenhouse gases in the atmosphere.

5.2. Discussion of ethical aspects

Advantages of the super plants are obviously the reduction of CO2 in our atmosphere and that leads to less polluted air and reduction of greenhouse effects which pretty much destroy slowly our planet. This is not only good for the scientists but for the whole population of the earth including other living species like animals. Even for the planet itself, if we stop global warming the poles stop melting, ocean stops acidifying etc.
Another aspect is that the plants become stronger and therefore probably are going to be able to provide better crop yields because of improved photosynthesis.
They carry following disadvantages with them, the high economical costs which have to be spent for the research process and there is not always a guarantee of success.

6. Summary

Super plants could be the remedy for the enormous consumption of carbon based fuels resulting in air pollution in today's society. If the scientists success to improve the photosynthesis of plants to a very high efficiency a very big problem concerning the whole world would be solved, global warming caused by greenhouse gases.
The aim is to capture the excess Carbon in the air and store it in the roots of the plants in order to bury it for millennia underground.
This research area is being mainly executed in the USA as in Europe (Germany and Britain). Unfortunately, scientists haven't been able to modify the protein (Rubisco) which is in charge of fixating the CO2 in order to raise its efficiency because of its complexity which developed over several millions of years.
But they were able to modify tobacco plants achieving more efficient absorption of CO2. This efficiency was obtained by the integration of a protein called Rubisco found in the algae *Synechococcus elongatus* which is way more efficient than the normal types of Rubisco which can be found in any plant. The new protein is placed directly into the DNA of the chloroplasts of the tobacco plant. The plants kept all their other functions.
Future plans are to pass this protein to other plants and not only tobacco plants and integrate the it in plants which optimally can capture carbon.
If we succeed to produce this plants, we will solve a big worldwide problem.
Another possible solution for the CO2 emissions could be the plants which get watered by nanotubes and also show higher efficiency in photosynthesis or the artificial photosynthesis being developed in California.

7. References

7.1 Websites

https://en.wikipedia.org/wiki/Effects_of_global_warming (28.4.2016)
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4176977/ (28.4.2016)
http://www.breakingbio.org/can-bioengineers-produce-plants-absorb-carbon-dioxide/ (29.4.2016)
http://www.independent.co.uk/life-style/gadgets-and-tech/bionic-plants-watered-with-carbon-nanotubes-could-create-living-sensors-lights-and-electronic-9199922.html (29.4.2016)
http://www.scientificamerican.com/article/genetic-modification-carbon-sequestration/ (29.4.2016)
http://environment.about.com/od/whatyoucando/a/best_trees.htm (30.4.2016)
https://en.wikipedia.org/wiki/Effects_of_global_warming (30.4.2016)
http://www.earthisland.org/journal/index.php/elist/eListRead/carbon_capture_technologies_that_could_help_fight_climate_change/ (30.4.2016)
http://www.popsci.com/environment/article/2009-06/installing-plastic-trees-help-environment (30.4.2016)
http://newscenter.lbl.gov/2010/10/26/next-carbon-capture-tool/ (30.4.2016)

7.2. *Pictures*

Cover: http://www.israeli-wine.org/2013/03/06/israeli-wine-from-the-inside/ (30.4.2016)
Picture 1. http://www.breakingbio.org/wp-content/uploads/bfi_thumb/Tobacco-that-absorbs-more-carbon-2xl1u2boe5fy4jj4cc191m.png (30.4.2016)
Picture 2. http://www.natureworldnews.com/articles/14178/20150417/artificial-photosynthesis-may-solve-carbon-emission-problem.htm (30.4.2016)
Picture 3. http://www.independent.co.uk/life-style/gadgets-and-tech/bionic-plants-watered-with-carbon-nanotubes-could-create-living-sensors-ligh (30.4.2016)
Picture 4: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4176977/ (30.4.2016)
Picture 5: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4176977/ (30.4.2016)
Picture 6: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4176977/ (30.4.2016)
Picture 7: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4176977/ (30.4.2016)