The Soybean Saga to Food and Climate Security

The game

The Soybean Saga to Climate and Food Security is a virtual reality immersive activity for Oculus. This activity consists of visiting four exhibits that cover different aspects of plant biology and agriculture with the Soybean as the main character and host. The first exhibit highlights aspects of plant reproduction and human usage. The second exhibit presents the relationship between the soybean and nitrogen-fixing bacteria. The third exhibit introduces the problem of pollution due to synthetic nitrogen. The last exhibit portrays research on soybean conducted at the Danforth Plant Science Center. As the player moves through the exhibits, the player has the option to collect soybean pods for points, watch videos and respond to questions.

The purpose of the game

Using the soybean as an example, the player will be able to learn about:

- plant science content on plant reproduction, the symbiotic relationship of roots with microbes, and the role of legumes in nitrogen fixation
- the importance of crops, such as soybeans, for human use
- real-world problems due to the use of agrochemicals (e.g. synthetic nitrogen) and how plants could contribute to more sustainable agricultural practices
- what scientists do in relation to plant and agricultural research

How to access the game

Before starting the game, the player should review the Quick Start guide to:

- adjust the headset
- get familiar with the controllers
- setup the playing area
- access the Soybean Saga game
- play the game

- maintain and care of the headsets
- be prepared for possible motion sickness

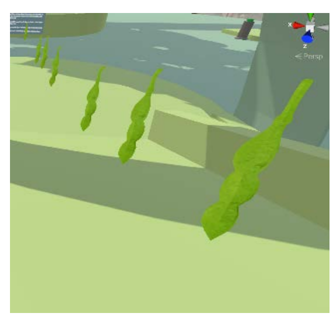
How to play the game

The Atrium

The game starts when the player arrives at a gate (arches) where there are instructions on how to move around and play the game. Most of the signs have a button on their side to hear Soybean narrate  their content.

The instructions' transcript includes the following content:

- *Before we begin, you should get used to the controls you will be using throughout this experience!*
- *Push the left joystick to move forward or back. Push the right joystick to change the direction you are facing.*
- *To press physical buttons, hold down the lower trigger (underneath your middle finger), on either hand to make a pointer finger, and then press the button down all the way to trigger the event!*
- *To interact with buttons on images or videos, point your right hand at the button and a pink laser will show up. To press the button, point the laser at the button and press the A button in the joystick!*
- *Collect the floating soybeans to increase your score! Across the Soybean Saga you will notice floating soybeans throughout your path. To collect them just walk through them and they will be automatically collected. To view your score for each level, hold down the left upper trigger with your pointer finger. Scores for all levels are recorded on the score chart near the exit button in the Atrium. See if you can collect all the soybeans and get 100% completion!!!*



The player arrives to the Atrium after passing the arches where there is the following welcoming sign:

WELCOME TO MY WOOOORLD! Who am I?!!! No other than a SOYBEAN PLANT! Why am I important? What are my special qualities? Well, I am a very important crop. Humans use me to produce hundreds of products related to human and animal food, oils, energy, and industry. Also, I am unique! I have nodules where I host bacteria. For what? Well, to find this answer you must visit one of the virtual rooms around this atrium. BUT WAIT, do not leave me yet!

At the Atrium, the player has the option to visit four exhibits in any order. The entrance to each exhibit consists of its title and a button that will allow the player to be teleported to the respective exhibit.

Inside the exhibit, there is another button to exit and return to the Atrium.

Questions for the students

At the end of the on this protocol, you will find a section with questions to ask the students about the content of the activity.

Student assessment of the virtual reality experience

At the end of the experience please ask your students to complete a survey about their experience playing the Soybean Saga at the following link:

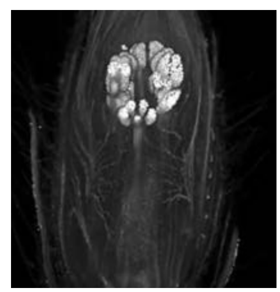
https://survey.iad1.qualtrics.com/jfe/form/SV_000GHx2jeVj64cK

Exhibit 1. How do I reproduce and be useful?

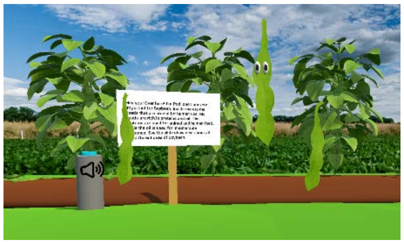
This exhibit presents content about the reproduction of the soybean and its usage by humans. In this exhibit the player has the option to watch videos of X-ray high resolution volume images of plant structures, generated at the imaging lab of the Danforth Center. The videos show close-ups of the soybean flower reproductive parts. The accompanying texts to the videos are:

- *In this video you can see on the top a bunch of white dots. These are pollen grains and contain the pollen, the male reproductive cells of the flower. These grains are held by the stigma, a structure at the top of the pistil. The pistil is like a cylinder that holds the pollen at the top and the ovaries at the bottom. The ovaries are the structures that contain the ovules, the female reproductive cells. Ahhh, too many technical words right!? Well, I invite you to see the other two videos which show you more details about these structures!*

- *In this video you can see the pollen grains in more detail. Within them you can see the pollen cells! Eventually the grains will break apart, the pollen will fly away, and some will land on the same flower or others. The pollen will make its way through the pistil to fertilize the ovules. This means that the ovules and pollen will get together and form a new cell. Through multiple cell divisions a seed will be formed. Isn't this cool? Yes, let's see the next video to see the ovules!*



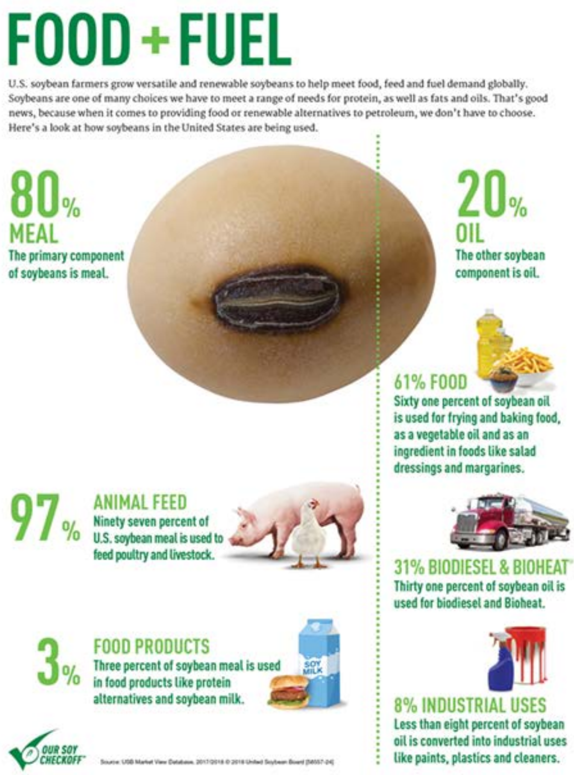
- *In this video you can see at the bottom the ovules, highlighted in pink. These ovules have already been fertilized by the pollen and seeds are developing within a pod. How many seeds do you see in the pod?*



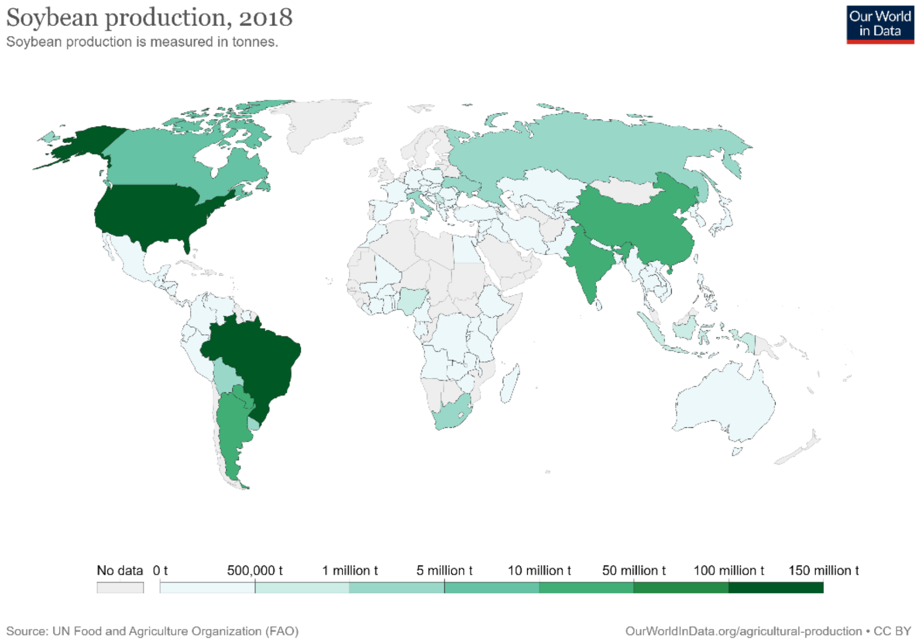
After the videos, there is a section displaying cartoons of soybean pods followed by a slide show that presents content on the different uses of soybeans.

- *Hey you! Over here! I'm Pod! And I am very important for Soybean. Inside me are the seeds that are crucial for human use. My seeds are rich in proteins and oil. The proteins are used for animal and human feed, while the oil is used for innumerable purposes. See the slide show next about all the different uses of Soybean.*
- *I am pretty cool, aren't I? Well, this is just the beginning. Click on this notebook to see how important I am for humans!*

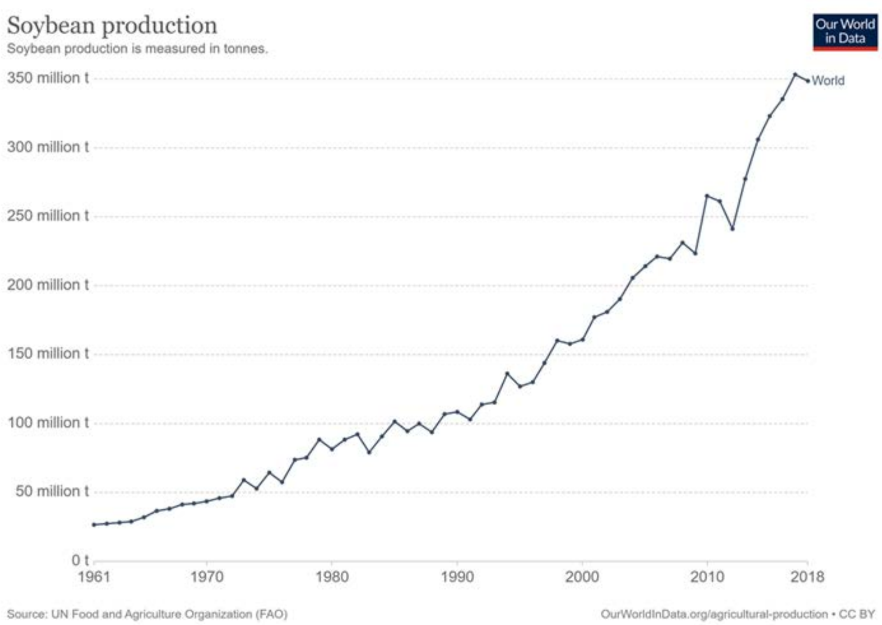
Below are the slides and transcripts presented in the notebook.



I am very popular among humans... see how important I am. They need me for their meals, to feed their animals, for biofuel, industry, etc., etc. In this infographic, you see that 80% of me is meal and the other 20% is oil. See how the meal and oil are used.

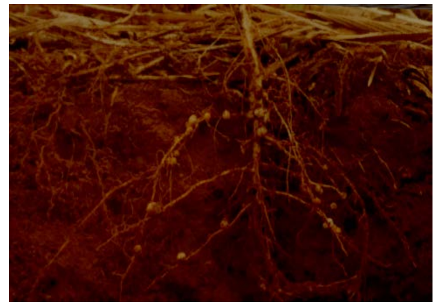


I am cultivated all around the world! The countries that have more area of farmland with me are the ones in the darkest green color. Which countries cultivate the most amount of soybean? A ton equals 1,000 kilograms or 2,000 pounds!



As more people are on the planet, they need more food for them and their animals, fuel sources, industry products, etc. Well, over the years, the amount of soybean production has increased due to these needs. In this graph, the production of soybeans is now seven times greater than in the 1960's!

Exhibit 2. Meet my friends the *Rhizobium japonicum* bacteria



This is an exhibit in an underground setting where the player can see videos and content about the symbiotic relationship of the soybean with soil bacteria and the role of this relationship to fix nitrogen.

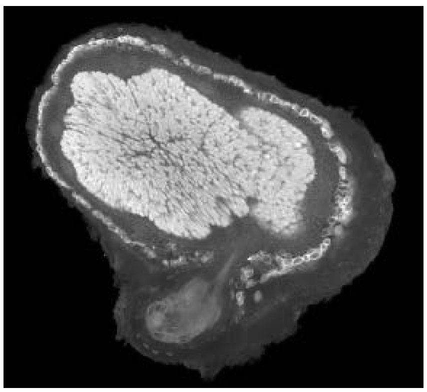
The following transcripts are presented in this exhibit:

- *I am a legume because I can fix nitrogen, yeah! … Haven't you heard of these words before? Allow me to explain. Let's start with nitrogen; this is a very important chemical element that plants need to make themselves. Yes, with nitrogen we can make proteins and parts of our DNA, so nitrogen helps make our cells. But there is a little problem… although the nitrogen is available in the atmosphere in large amounts, we can't use it… Here is where my friends the Bradyrhizobium japonicum bacteria come into play.*

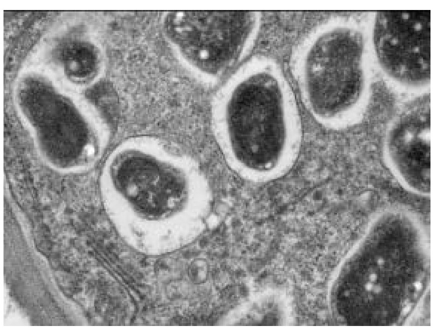
- *By the way, bacteria is plural and bacterium is singular. I have a symbiosis interaction with these bacteria. This means they help me, and I help them. Let me call these bacteria Bj…their name is too long. So Bj is found in the soil and love to live inside my roots because they can't make their own food, which I can provide.*

- *I give them carbon that is used by them as a source of energy and food to grow. I also provide shelter for them by making nodules. These are aggregations of cells where Bj can live. In return, Bj help me by converting the atmospheric nitrogen into organic compounds, particularly ammonia, that I can use to grow. Isn't this an excellent deal!? In addition, these organic compounds can be used by all plants not only legumes. Walk around to see more photos of our friendship!*

You see my roots and the nodules (the rounded structures), that is where Bj lives! The more nodules in my roots, the healthier I am!



See the video of a nodule. You can see the nice wall I create to host Bj. The gray grains are symbiosomes, which are structures that contain the bacteria. When a bacterium is living inside the nodule, it is called a bacteroid. The white glowing dots are the bacteroids.



With a powerful microscope you can see more details of my friends inside a nodule. The white circles are the symbiosomes that contain the bacteria. Remember, bacteria are single-cell organisms.

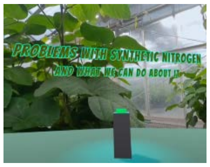


Exhibit 3. Problems with synthetic nitrogen and what we can do about it

In this exhibit the player is introduced to the problem of synthetic nitrogen as a major water pollutant. Synthetic nitrogen is used in large amounts as an agrochemical. Legumes, such as soybeans, fix nitrogen and thus can be used as an alternative to reduce the production and use of synthetic nitrogen.

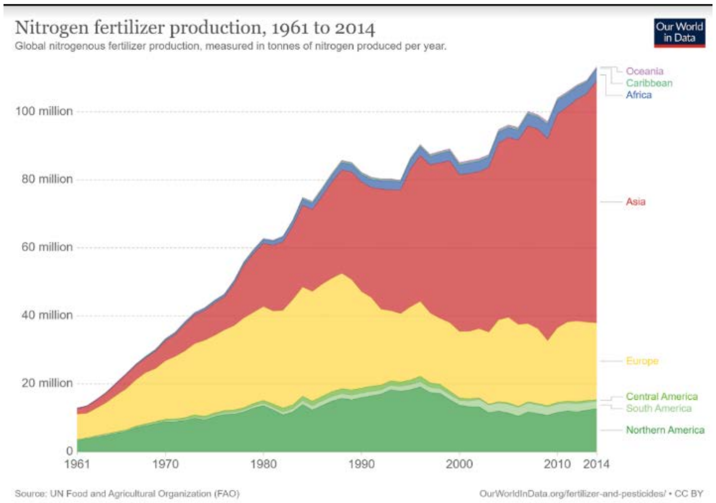
The first sign provides background information about this problem. By the sign, there is a molecule of nitrogen and popcorn. The player is invited to watch a short video at the end of the path.

- *Did you know, there are over 7.9 billion (2021) people on Earth! Farmers, scientists, landowners, and other workers collaborate to produce food for 7,874,965,825 humans and domesticated animals! This creates a large demand for food, so more land is cultivated and more fertilizers are needed. See the figure of nitrogen fertilizer production.*

- *Nitrogen is a crucial nutrient for plants, but they cannot take the natural form of nitrogen. So, scientists made synthetic nitrogen, which is made in a factory, to help produce more food. This sounds great, but there are some challenges…*

- *Nitrogen is very expensive to make! It needs a lot of fossil fuel for energy, it washes away due to rain and irrigation, and its over-application releases greenhouse gases! These ultimately affect food security and climate change. Let's watch a short video that tells this story!*

The following sign is a figure about the global increase in nitrogen fertilizer.



In the last sixty years, farmers have increased the amount of nitrogen fertilizer used in their fields. You can see how the nitrogen fertilizer production has increased from 20 million tonnes per year in the mid 1960s to more than 100 million tonnes per year by 2014.

The player continues through the path to a theater. The player can sit and watch a four-minute video about how legumes can help reduce the impact of pollution due to synthetic nitrogen. Watch the video at this link:

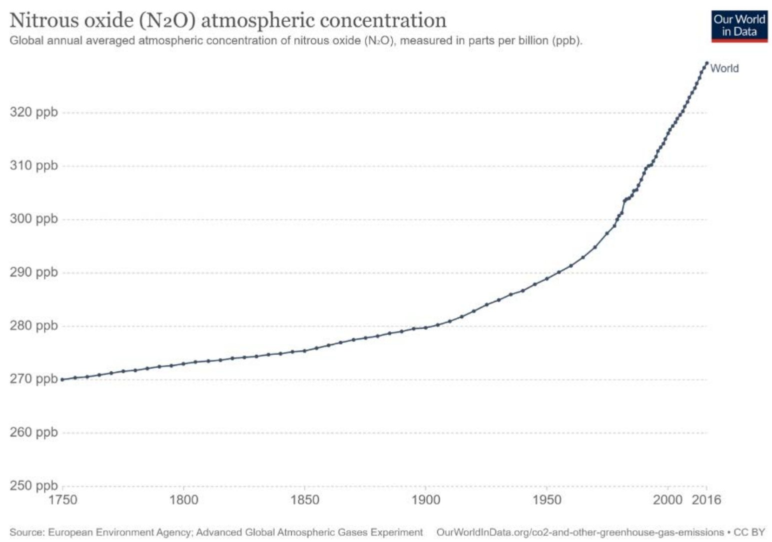
https://www.youtube.com/watch?v=A8qTRBc8Bws&t=3s.

The player continues through the path and sees another sign with the following text:

- *What a great movie! I really like to see the importance of microbes in this story. Too much synthetic nitrogen fertilizer stimulates soil microbes to feast on organic matter releasing nitrous oxide (N_2O) and carbon dioxide (CO_2) in the atmosphere! What is worse is that N_2O can persist for 100 years in the atmosphere and is 300 times more powerful than carbon dioxide (CO_2) in trapping heat, having a major impact on climate change!*

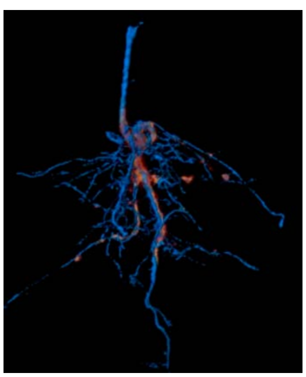
The Soybean Saga VR Activity Protocol

At the end of the path, the player enters a room. There are arrows that guide the player to the right to visit the exhibit. The first sign is a figure of the global increase of atmospheric nitrous oxide.



The greenhouse gas nitrous oxide has increased dramatically in the atmosphere from 270 parts per billion (ppb) to 320 ppb over the last 250 years.

The following sign explains the content of a video next to it:



What can we do to reduce emissions of greenhouse gases such as N_2O and CO_2 into the atmosphere and improve carbon sequestration to mitigate the impact of climate change? All of us can contribute in one way or another! I, for example, fix nitrogen that helps me grow, and I keep a lot of carbon in my body. Press the button here to see a video of the carbon that moves through my body.

The next sign transcript is:

Humans can use sustainable practices and emerging technologies to reduce the inputs of nitrogen fertilization. How? See some examples:

- *Precision agriculture allows farmers to apply the right amount of fertilizer in the right place and at the right time. This reduces extra nitrogen that would have been used* *by microbes to create more N_2O and helps plants and other organisms retain carbon in the soil.*

- *Sustainable agricultural practices such as no-till and cover crops retain more nutrients in the soil and avoid soil disturbance; this results in a reduction of N_2O and CO_2 in the atmosphere.*
- *Reductions in the consumption of meat and dairy products decrease the large extensions of land necessary to raise the animals.*
- *Limiting food waste that generates large amounts of greenhouse gases during food production and decomposition.*
- *Propose and support agricultural policy that favors optimization and reduction of fertilizer use as well as water protection legislation.*

The next sign transcript is:

What is the Danforth Center doing about this problem?

The Danforth Center recently established the Center for Subterranean Influences on the Nitrogen Cycle (SINC) to generate sustainable crops and systems to reduce the amount of chemical fertilizers, pesticides, water, and soil degradation in agriculture. It focuses on:

- *developing a technology platform to analyze key factors affecting use of nitrogen in the rhizosphere;*
- *understanding roles of microbes, soil, roots and environment on nitrogen uptake and usage;*
- *and accelerating testing and development of improved nitrogen-use varieties and biologicals.*

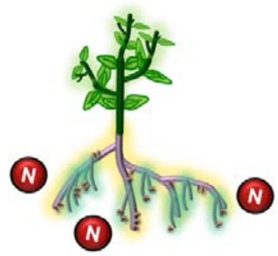
The next sign transcript is:

When there is too much nitrogen fertilizer in the soil, the plants do not need the help of Bj, remember my friends the Bradyrhizobium japonicum bacteria? This is baaaad, very bad because:

- *I am not motivated to secrete through my roots, flavonoids, which are chemicals that attract Bj, as well as many other microbes that like to live in my rhizosphere. The rhizosphere is the region of soil in the vicinity of the roots. Therefore, all those microbes die, and the microbial diversity of the soil is decreased. As more microbes* *live around my roots, there are more nutrients available and more protection from diseases!*

- *As less microbes live in the soil, more greenhouse gases are released into the atmosphere. Microbes help keep the carbon in the soil.*

Next sign:



See the differences in the presence of nodules where Bj lives with low and high levels of nitrogen fertilizer. Ryan DelPercio, a graduate student at the Donald Danforth Plant Science Center, is investigating how to improve nitrogen use efficiency in soybean by optimizing the soybeans nitrogen fixation process. In this way nodulation is continuous and excessive nitrogen use is minimized.

At the end of the exhibit the player can answer questions about the content of the exhibit by assigning blocks with percent values to options A, B or C on a table. Instructions to play are left of the table:

To pick up and move a block, hold down the lower trigger under your middle finger. Release the trigger after you place the block.

The questionnaire goes like this:

Assign the following % numbers, 30%, 87%, 78%, to the statements below:

A) ___% of nitrogen is in the air and unavailable to plants (Response: 78%)

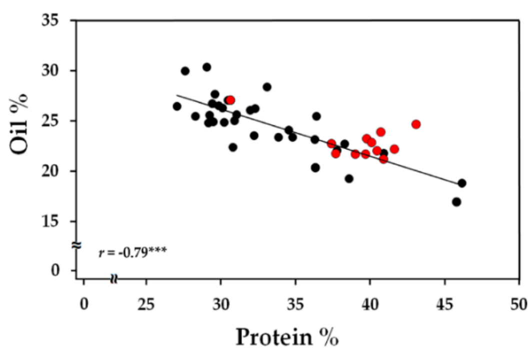
B) N_2O emissions into the atmosphere have leapt by ___% over the past four decades. (Response: 30%)

C) ___% of N2O emissions is due to agriculture. (Response: 87%).

Exhibit 4 – Research about me at the Danforth Plant Science Center

Meet my collaborator and friend Dr. Doug Allen, principal investigator at the Danforth Center. He is very interested in me because my seeds are usually 40% protein, 20% oil, and 40% other components.

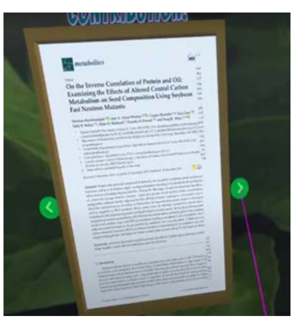
Since proteins and lipids are critical in healthy food—I am not talking about fast food! – Dr. Allen is investigating how can we change soybeans to offer seeds that have higher content of both. That will be very good to fight global hunger!



Dr. Allen and his team are checking the genes that turn on and off protein and oil production during seed development. His team found a negative correlation between oil and protein content among different varieties of me.

In this figure, each dot represents a variety of soybean. Varieties with higher oil content have lower protein content and vice versa.

Read an article about his scientific contributions!



"On the Inverse Correlation of Protein and Oil: Examining the Effects of Altered Central Carbon Metabolism on Seed Composition Using Soybean Fast Neutron Mutants". 2020. Kambhampati, Shrikaar, Jose A. Aznar-Moreno, Cooper Hostetler, Tara Caso, Sally R. Bailey, Allen H. Hubbard, Timothy P. Durrett, and Doug K. Allen. Metabolites 10(1): 18-33. https://doi.org/10.3390/metabo10010018

Although I am almost perfect…I can't produce high oil and protein content at the same time.

Dr. Allen's lab has been altering my genes, and they have been able to increase both protein and lipid content in my seeds. This means his research is contributing to improving plant productivity, helping with global challenges to feed a growing human population!

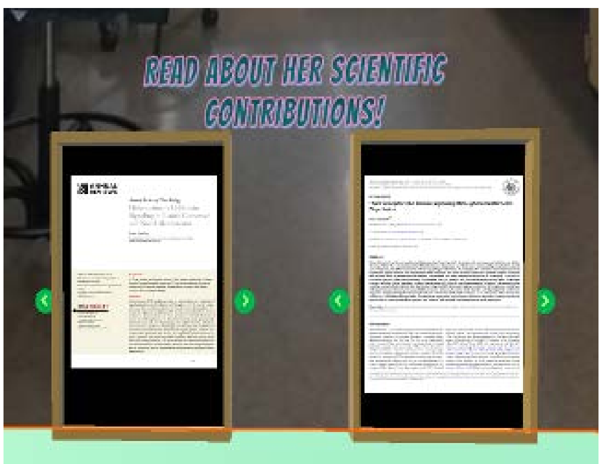
Learn about Dr. Sona Pandey on Floor 2!

After going up the stairs, you need to take an elevator.

Take the elevator to visit a molecular lab and learn about the projects that Dr. Sona Pandey and her collaborators are conducting to make a better crop!

Dr. Sona Pandey, another principal investigator at the Danforth Center, is another one of my scientist friends! Dr. Pandey's lab studies how plants sense and respond to various environmental stresses, for example high temperatures or drought, and optimize their growth and development to result in improved productivity.

Dr. Pandey and her teamwork with G proteins. These are signaling proteins that carry messages to cells triggering cell responses. For example, some G proteins promote formation of the nodules where I host Bj (Bradyrhizobium japonicum), and by helping host Bj, they thus are involved in plant yield.



G-proteins regulate many aspects of plant growth. This is the crystal structure of the alpha subunit of a G protein. Move around to see the structure from different angles.

Read about her scientific contributions!

"Heterotrimeric G-Protein Signaling in Plants: Conserved and Novel Mechanisms". 2019. Sona Pandey. Annual Review of Plant Biology 70 (1): 213-238. https://doi.org/10.1146/annurev-arplant-050718-100231

"Plant receptor-like kinase signaling through heterotrimeric G-proteins". 2020. Sona Pandey. Journal of Experimental Botany 71(5): 1742–1751. https://doi.org/10.1093/jxb/eraa016

The Soybean Saga to Food and Climate Security

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Game Developer and Designer	*Matt Medlin*
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Special Thanks
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Education Research and Outreach lab

USDA NIFA

Credits

Animations and videos

Soybean animations of x-ray images of flower, ovule, stigma, and nodule	*Keith Duncan, Danforth Center*
Crystal structure of the G alpha protein AtGPA1 from Arabidopsis thaliana	*Jones, J.C., Duffy, J.W., Machius, M., Temple, B.R.S., Dohlman, H.G., Jones, A.M.*
Understanding Our Soil: The Nitrogen Cycle, Fixers, and Fertilizer	*Jimi Sol*

Images

Soybean flower, roots, and fields	*United Soybean Board*
Greenhouse, laboratory, soybean plants	*Bill Stutz, Danforth Center*
Doug Allen, Sona Pandey	*Danforth Center*
Soybean root photo	*Lidian Miotto, accessed in NSF website*
Nodule microscopic view	*Louisa Howard*

Figures, diagrams, infographics

Soybean production 2018	*Our World in Data*
Soybean uses	*Iowa State University*
Soybean uses	*Our Soy Checkoff/USB Market View Database*
Soybean flowers	*Ryan DelPercio and Patricia Baldrich, Danforth Center and Margaret Franck, Cornell University*

Questions for the students

1. Describe three reasons why soybean is an important crop.

2. Explain what does it mean to be a legume like the soybean?

3. Explain the symbiotic relationship between the soybean and the *Bradyrhizobium japonicum* bacteria.

4. Explain one problem caused by synthetic nitrogen in agriculture.

5. Explain one sustainable practice or emergent technology that reduces nitrogen inputs in the soil. How does this practice or technology contribute to food security and or climate change adaptation?

6. Give one example of how the Donald Danforth Plant Science Center's research contributes to food security.