Eliot Herman

How did you spend your career?

I grew up in Boston, where I gravitated toward science from my earliest memories. Being a determined individual, I sought out places where I could further my scientific interests, including the Boston Science Museum, the historic Boston Library, and the Massachusetts Institute of Technology, where I participated in the Saturday high school program. In lectures and public events, seeing and interacting with famous and accomplished scientists was an inspiration.

As an undergraduate, I enrolled in the newly formed College of Creative Studies at the University of California (UC), Santa Barbara, which at the time was an experimental education program. A primary aspect of this program from the freshman year onward was that students conducted research and read primary literature to have a graduate student–type experience. For me this was an ideal environment; I could not only follow my interests in biology but also take courses, some advanced, in geology, chemistry, astronomy, and even nuclear engineering. In one UC Santa Barbara experience, I worked in a geology clean room where the recently returned Apollo moon rocks were being analyzed. This diverse exposure enabled my interests in art and photography that are still important aspects in my life. With too many interests, and without course limit restrictions to temper my enthusiasm, I all too quickly accumulated credits and graduated in the middle of my third year. I remained at UC Santa Barbara and was awarded a master's degree working with Beatrice Sweeney to finish up the algal research I began as an undergraduate.

I then moved to UC San Diego and completed my PhD with Maarten Chrispeels, which began my career in seed biology. I learned a great deal from Maarten, who has a terrific sense of what is important to do and how to accomplish it. I then held a postdoctoral position with Max Delbruck at Caltech, which ended when he passed away. My time at Caltech was amazing: Lee Hood' s lab, which neighbored Delbruck's, was inventing the future machines and software that empower molecular biology, and the Jet Propulsion Laboratory was flying Voyager past Saturn. I still vividly recall visiting with Max Delbruck in his home, both of us looking in wonderment at Saturn's ring structure and speculating on its mechanisms.

I moved on to UC Riverside to work with Leland (Lee) Shannon in the biochemistry department. In Lee's lab I became exposed to immunology tools, which he used to study seed lectins. I developed new approaches using electron microscopy to localize plant proteins, which later became an important tool of my research for many years. Lee used antibodies to study the relatedness of lectin proteins, and this formed foundational knowledge that was later critical to my interest in soybean allergens. Lee was busy with being graduate dean, and as his only postdoc I had tremendous freedom, which created a great training environment for me to move on to becoming an independent researcher. Anton Lang was on sabbatical at UC Riverside, and he encouraged me to publish a paper on the seed lectin concanavalin A in *Planta*. After I obtained my own research position and another *Planta* publication, Anton added me to the *Planta* editorial board, where I have served my entire career.

After my UC Riverside postdoctoral position, I was hired by USDA/ARS in Beltsville, Maryland, where I remained for 16 years. During that time, I developed my research programs in soybean allergens, oil bodies, and storage protein content. Working in the DC area, there were many opportunities for tangential assignments: I spent a year as an NSF program director with co–program management as the initial Arabidopsis genome grants were awarded and conducted; worked with the Environmental

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Protection Agency and on a biotechnology advisory board for the Advanced Technology Program of the Commerce Department's National Institute of Standards and Technology; served as a grant panel chair for the U.S.–Israel Binational Agricultural Research and Development Fund; and was a grant review panel member for NIH, NSF, DOE, and the Foreign Agricultural Service. I spent time at the Weizmann Institute in Israel and as a visiting professor at Tokyo Metropolitan University.

For several years I was part of a team that had radiation safety oversight for the entire USDA; radiation sources included not only ARS laboratory isotopes, but also other diverse sources such as Forest Service soil gauges and even the USDA–U.S. Customs and Border Protection airport x-ray scanners. This experience was quite a lesson in federal agency regulatory processes, especially navigating the paperwork when things did not go right. Congress mandated that the USDA administration develop a system for intramural research project review, and I served as the sole scientist member on that team. The system we developed for intramural project review is still being used more than 20 years later, a testament to the lasting impact of our work. During this time, I became an associate editor for the *Journal of Experimental Botany* and remained in that position for many years.

In 2001, Roger Beachy asked me to transfer to the Donald Danforth Plant Science Center as a USDA/ARS scientist. This position, created with an earmark by Senator Kit Bond (R-MO), made me one of the center's founding members. During my Danforth years, I was promoted to the federal civil service supergrade level and received the Plow Award, the USDA's highest recognition, for my work on soybean allergens. The real-world implications of my research were reported in public news forums, including the *New York Times*. During this time, I also worked at the U.S. Embassy in Stockholm with a temporary assignment representing the United States for the Foreign Agricultural Service. I visited with government agencies and private groups in the six Nordic and Baltic nations and discussed issues of biotechnology crops that are a key U.S. export. In 2008, I decided to take early retirement from USDA and transferred to being a non-USDA member of the Danforth Center.

During my time at the Danforth Center, I became a fellow of AAAS, a society I first joined as an undergraduate student, and a national fellow of the Explorers Club, a scientific exploration society initially founded to support polar exploration. In 2018, I finally stood on the North Pole, completing a goal dating from childhood.

In 2012, I was recruited by Brian Larkins to the University of Arizona, where I am currently a professor in the School of Plant Science and a member of the BIO5 Institute. One of the attractions of this position is being located on the medical school campus, which has provided me with cross-disciplinary research synergies with the medical faculty.

What do you consider your most important contributions to plant science?

Much of my career focused on improving soybean protein content and composition. My research program didn't start out in that direction. When I obtained my independent research position at USDA/ARS in Beltsville, I made the decision to not compete with existing seed storage protein labs that had prominent investigators. Instead, I decided to focus on how seeds accumulate oil. To investigate seed oil body ontology, we had to develop new tools, including polyclonal and then monoclonal antibodies, that could be used to isolate cDNAs from the then-new technology of gene expression libraries. These clones were sequenced and characterized using gel-based sequencing, and then used to isolate the corresponding genes from genomic libraries.

We produced monoclonal antibodies against the oil body membrane boundary proteins, but we also obtained strong antibodies against an unknown contaminating protein that did not match the abundant storage proteins. Using these latter antibodies, we cloned the corresponding cDNA and found that soybeans produce a member of the papain superfamily of cysteine proteases, this one with the unique feature of not possessing the active site cysteine residue. More interesting was the discovery that this protein matched the molecular weight of a band that appeared in the medical literature to be a major allergen of soybean.

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Using the papain-related antibody, I discovered this protein is the major immunodominant soybean allergen. Soybean allergy is one of the more significant human food allergies, and it has a broad impact because soybean is used in thousands of food items found in supermarkets and, notably, infant formula.

Identification of the major soybean allergenic protein led to collaborations with Rick Helm, a human neonatal allergist at the University of Arkansas Children's Hospital, and other colleagues who helped characterize infants' reaction to the allergen; it showed a broad, dominant response for intolerant infants. Having identified the soybean allergen, it seemed obvious that a null mutation could be useful to mitigate clinical soybean allergies. USDA houses the national soybean collection, and working with Ted Hymowitz at the University of Illinois, we screened a core diversity collection with antibodies but found no nulls. Further, the epitope map of the protein based on clinical serum samples showed multiple binding sites, revealing that a primary sequence mutant that eliminated a single site would not produce a null.

Techniques to transform soybean were just being developed, and in collaboration with Tony Kinney at the DuPont Experimental Station, we produced the first allergen null for a global crop. Although this by itself didn't make soybean a hypoallergenic crop (there are a number of other, less dominant allergens in soybean seeds), it was an important proof of concept that major allergens can be removed from food crops by biotechnology methods. Returning to the USDA national soybean collection and collaborating with Ted Hymowitz and Monica Schmidt, we used antibodies to screen every soybean accession, more than 16,000, and found one that is a null. Ted Hymowitz introgessed the mutant gene into a genetic stack containing previously identified nulls of two other antinutritional proteins, soybean lectin and Kunitz trypsin inhibitor.

For the past few years, in collaboration with Allan Schinkel and colleagues at Purdue University, we have been testing the allergen null progeny soybeans on a research line of swine that was inbred to be hypersensitive to soybean allergens; the piglets provide an experimental model for human infants. The results of these tests are leading us to new perspectives for understanding how the swine gut, and by implication the gut of any animal, including humans, interacts with bioreactive foods.

Another pioneering research project involving soybean seed biology arose after pursuing an unexpected result. I was collaborating with Tony Kinney at DuPont looking at storage protein synthesis in DuPont's first iteration of what would become a high oleic soybean seed. The transgenic seed displayed the desired oil phenotype, but unexpectedly was lacking one of the major storage proteins. After some investigation, we determined that the use of the β-conglycinin storage protein promoter in the construct used to create the desired oil trait was causing suppression of β-conglycinin protein synthesis.

What was fascinating about the seed was that it did not show a reduction in total protein, despite having one of its major storage proteins suppressed. Instead, it manifested a normal protein content dominated by the other storage protein, glycinin. We discovered what has become known as "proteome rebalancing"—that is, the seed accommodates to maintain its normal protein content by altering its protein composition. Continuing these studies, my group found we could exploit protein rebalancing to increase the yield of a foreign protein in soybean, thus making it a potential bioreactor that could enable cost-efficient production of biologics. We also showed that if we silenced both major soybean storage protein genes, which produce about two-thirds of the seed protein, the resulting seeds still maintain normal seed protein content by increasing the accumulation of otherwise minor proteins, including the major allergen, which increases more than tenfold. This seed proved to be a useful experimental system for gene discovery to elucidate the mechanism of proteome rebalancing.

Protein is a primary nutritional need for the growing human population, and soybean is already a primary source of plant protein for humans. By expressing modified genes reducing allergenic and antinutritional bioreactivity, we have created soybean seeds that produce more total protein without changing the seed's protein content and its biosafety. I am

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currently working with Brad Warner at Washington University Medical School and Monica Schmidt at the University of Arizona to develop a soybean bioreactor platform that produces biopharma compounds. We have produced human epidermal growth factor (EGF) in soybeans and formulated it into mock infant formula. The concept is to produce a bioactive infant formula to mitigate gut disorders, particularly for human neonatal necrotic endocolitis (NEC), a devastating disease that results in death for half of afflicted premature infants. This disease results from bacteria penetrating the intestinal wall, producing gangrene as the microbiome is initiated postpartum. If a bioactive formula could seal the intestinal tract before the advent of the disease, it would be prevented. Our studies have shown that the EGF-producing soybean is very effective at alleviating NEC in a mouse model. This product might also be leveraged for swine feed, where piglet loss because of gut disorder is important, thus potentially providing a large collateral market. I hope to merge the high-protein seed trait with low bioreactivity in order to optimize food and feed protein that will significantly contribute to global food security and sustainability.

When did you first become a member of ASPP/ASPB?

I first joined ASPP as a student when I was finishing up my master's degree at UC Santa Barbara. I attended my first ASPP meeting to make a presentation and look for possible advisers and PhD programs. I had decided I would attend graduate school to work in the plant and algae area, and ASPP represented both disciplines quite well, so this meeting was a good place to assess the state of the art and who was doing impactful research.

How did the Society impact your career, and what motivated you to become a Founding Member of the Legacy Society?

Many of my most important papers were published in *Plant Physiology* and *The Plant Cell*. The research on gene silencing of allergens and proteome rebalancing was published in ASPB journals. ASPB's journals and annual meetings have given my research national and international exposure and impact. Every day the news presents articles about future food, agriculture sustainability, and global challenges to the expanding human population. ASPB is an important part of the solution, and it needs to prosper to continue in its role. My contribution to the Legacy Society is my way of supporting its mission.

What important advice would you give to individuals at the start of their career in plant science?

Seek out creative and industrious people and learn from them, not only in your own specialty, but also in other sciences, including engineering, medicine, and the arts. Inspiration and synergy derive from disparate knowledge. My other admonition is to develop your own path and pursue it, drawing in collaborators and coworkers while redefining your own career into new disciplines as the years pass; never stop learning and synthesizing.

As an undergraduate at UC Santa Barbara's College of Creative Studies, I was required to conduct independent research in a sponsoring faculty member's laboratory. I chose to work with Beatrice Sweeney, who studied algal circadian rhythms. When I asked her if I could work in her laboratory, she said that of course I was welcome, but when I asked her what I might work on, she responded, "I don't know, but give it some thought, and when you have an idea we can talk about it." I have always taken this message to heart: we should always have our own ideas. I have had many great collaborations with inspiring scientists, including several members of the Legacy Society, but I have always pursued my own program and ideas as my primary career goal.

One of the joys of the scientific profession is the great scientists you can meet and work with. The global scientific community provides numerous experiences to meet, visit, and work with people from many nations. One of the privileges we have in our profession is to more broadly experience the world. As you pursue your own discipline and its details, continue to avail yourself of general journals, meetings of the broader scientific community, and knowledge far outside your expertise. If you do this, you will spend your life continuing to be awed by science.

Academic Family Tree
https://academictree.org/plantbio/tree.php?pid=799662