Elizabeth Vierling

How did you spend your career?

I find plants fascinating and fabulously beautiful, from the microscopic to the macroscopic level. This led me to major in botany as an undergraduate at the University of Michigan, and I got hooked on research working in a lab in Freiburg, Germany, during my junior year abroad. A brief year as a technician at Northwestern University, helping with research on *Agrobacterium,* resulted in my staying in Chicago to pursue a PhD in biology at the University of Chicago. My dissertation involved investigating the biogenesis of photosystem I—chloroplasts were definitely my first great love in plant biology.

When I completed my degree in 1982, molecular biology was exploding, and I was excited to be invited to join Joe L. Key's lab at the University of Georgia as a postdoc. Joe's lab was a fabulous place to do research. Georgia was a hub for plant molecular biologists. Joe provided unconditional support to pursue one's research interests, and I was surrounded by talented graduate students and postdocs. Joe even allowed me to continue studying chloroplasts in a lab that mostly worked with etiolated soybeans! I was able to develop my interest in the molecular response of chloroplasts to heat stress, and within a month of joining the Biochemistry Department at the University of Arizona in Tucson as an assistant professor, I landed an NSF grant to expand my work on the biochemistry of small heat shock proteins (sHSPs).

The Biochemistry Department in Tucson was a perfect place to launch my independent career. Early on I participated in multiple ASPP/ASPB activities, being part of the *Plant Physiology* editorial board, serving on the ASPP Executive Committee, and selecting authors for a volume of the *Annual Review of Plant Physiology and Plant Molecular Biology* (the unwieldy name at that time). The International Plant Molecular Biology Meeting was held in Tucson in 1991, and I served on the organizing committee, making sure participants would have access to enough water!

I developed my research program with funding from NIH (for 28 years), expanding out from chloroplast sHSPs to homologues in the cytosol and to the Hsp101 protein disaggregase with funding from DOE. I progressed to tenure (I submitted my tenure package and headed off on an African tenting safari), motherhood, and full professor status, and then in 2009 I was made a regents professor, the highest rank at the university. Along the way, my group ventured into isolating *Arabidopsis thaliana* mutants defective in heat tolerance (supported by USDA), resulting in totally new research directions, including how nitric oxide homeostasis impacts growth and fertility and the control of mitochondrial gene expression and respiration (with NSF support).

From 2008 to 2010, I chose to take a position as a rotating program officer in the Division of Molecular and Cellular Biosciences at NSF. I lived in Arlington, Virginia, and commuted monthly across the country to work with people in my Tucson lab. It was a great experience and put me closer to my family on the East Coast. Unexpectedly during that time, I was recruited to the Biochemistry & Molecular Biology Department at the University of Massachusetts Amherst. So I bid Arizona goodbye after 25 years and arrived in Amherst in time to experience a record January blizzard. My first purchase was a snow shovel, a necessary piece of exercise equipment in Massachusetts. At UMass, where I am now a distinguished professor, I rebuilt my lab with postdocs, grad students, and undergraduates, and I continue to enjoy winter. In Amherst I have also expanded my outreach to the local K–12 schools, supplying them with plant "growth racks" and summer funding for teachers to develop a plant-based curriculum. Hundreds of students in Amherst are now doing experiments every year involving plant growth.

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I have especially taken advantage of four full-year sabbaticals, first at the Whitehead Institute at the Massachusetts Institute of Technology with Gerry Fink; then in The Netherlands with Martin Koornneef; then at the Max Planck Institute of Molecular Plant Physiology in Golm, Germany; and most recently on a jaunt around the world with stays in China, Australia, and Oxford. I highly recommend taking opportunities like this, which are unique to an academic position. Collaborations across the world have been wonderfully enriching and expanded my research program in interesting and productive ways.

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

My first contribution came from my dissertation research, which demonstrated that chlorophyll binding proteins are synthesized in the dark but not assembled or stable in the absence of chlorophyll biosynthesis. This was recognized as an important feature in the control of chloroplast development. In Joe Key's lab, I got sucked into the first experiments on the plant heat shock response. By focusing on the effects of heat stress on chloroplasts, I recognized that chloroplasts likely have homologues of bacterial HSPs, and I identified chloroplast-localized Hsp70s. However, in addition, by translating mRNA from control and heat-stressed plants and then performing in vitro chloroplast protein import, I discovered that plants produce novel small proteins targeted to chloroplasts in response to stress.

Further studies of these sHSPs and their biochemistry launched my independent career. We went on to determine that sHSP homologues are also present in mitochondria and the endoplasmic reticulum, reflecting an expansion of this conserved protein family in the plant lineage. Cytosolic sHSP homologues proved more tractable biochemically, and through the work of talented students and postdocs, we were able to show that these proteins can prevent irreversible heat-induced denaturation of heat-labile proteins and, with the addition of adenosine triphosphate, can facilitate refolding of inactive proteins and other chaperones (Hsp70 and Hsp101). An exciting breakthrough was solving the crystal structure of a dodecameric sHSP from wheat in 2001, in collaboration with colleagues in the United Kingdom. This structure provided a foundation for further developing the model for how these proteins act as chaperones. Our studies with plant sHSPs have directed this research field for all eukaryotes.

More recently we have turned our focus to testing the chaperone model for sHSPs in vivo, gaining evidence that the cytosolic proteins participate in protecting translation. We are now developing CRISPR mutants of whole, specific sHSP families in Arabidopsis for genetic analysis of these conserved stress proteins, and we hope to continue our contributions to this field.

Independent lines of research have developed from isolating mutants of Arabidopsis that cannot acclimate to high temperature stress. The first mutant that came out of this screen was null for Hsp101, a chaperone and protein disaggregase. This was the first genetic evidence that a specific HSP is required for heat tolerance, and the *hsp101* mutant remains the gold standard control in labs around the world for tests of heat tolerance. Another mutant we isolated was defective in eIF5B, and our analysis of the *eif5b* heat stress phenotype revealed that rapid recovery of translation is essential for recovery from heat stress. Mutants in the enzyme S-nitrosoglutathione reductase (GSNOR) also came out of our screen. GSNOR catalyzes the catabolism of S-nitrosoglutathione (GSNO), the major form of nitric oxide (NO) in cells, and thus GSNOR is critical to NO homeostasis. *gsnor* mutants are not only heat sensitive but also defective in root growth, pathogen resistance, and fertility. Studies of GSNOR are now yielding novel insights into the roles of NO in fertility and protein nitrosation, which I view as new, significant contributions to plant biology.

Finally, we are very excited to have identified a mutation in mitochondrial transcription termination factor 18 (mTERF18) as a suppressor of the heat sensitivity of *hsp101*. This *hsp101* bypass-suppressor mutant represented the first mutation of a mitochondria-targeted mTERF in plants. Heat tolerance of *mterf18* likely results from reduced reactive oxygen species production, and the phenotype genetically separated the relative contribution of protein disaggregation and refolding by Hsp101 from the damage due to reactive oxygen species

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during heat stress. I anticipate our continued studies of *mterf18* and its importance to mitochondrial metabolism will be another major contribution to plant science. There is lots still to discover!

When did you become a member of ASPP/ASPB?

I became a member of ASPP/ASPB in 1977, when I was just a second-year graduate student performing research in the Charles Reid Barnes Botanical Laboratory with Randall S. Alberte at the University of Chicago. Sadly, along with its wonderful collections greenhouse, this old brick building has long since been replaced by a multistory medical research building. Little did I know in 1977 that the president of ASPP that year was Joe L. Key, who would become my postdoctoral adviser. I don't know if it was at that meeting or a subsequent one that I gave a short talk in a session with Rick Vierstra, who follows me alphabetically in every society and meeting directory. My adviser introduced me to colleagues from both his postdoctoral and graduate student days, and many of those connections became part of a network of individuals who have supported me throughout my career.

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

I am passionate about plants and continually frustrated that research in basic plant biology is underfunded and underappreciated. It is also not surprising that many people have lost sight of the origin of their food and the critical roles plants play in all of life. I view ASPB as a major force in promoting the importance of plant research and education. The Society also advanced my early career with multiple opportunities for which I remain extremely grateful. ASPB journals and the Annual Review promote quality research, and the annual meeting has given me many chances to present my work and expand my network in science, not to mention reconnect with friends and colleagues. ASPB provides me with a scientific home, and I didn't have to think twice about becoming a Founding Member of the Legacy Society.

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

In any career, it is important to pursue whatever you are most passionate about. Don't let yourself get sidetracked by what may appear to be the most wonderful experimental system or the coolest new technique. Those things will all change with time. Follow the questions that most intrigue you, and find the best system and best techniques to address them—or better yet, invent what you need to answer them. Change your approach when the questions require it.

Interact and collaborate with others—this makes science more fun, and it expands your perspective, often leading to the best science. Network at every possible opportunity, no matter how hard it may seem; you never know when a connection will turn into an opportunity or a great friendship. Be your own worst critic, but don't be afraid of self-promotion. Hone your speaking and writing skills—they will propel you to a higher level, regardless of what you finally end up doing. Explore your career options, remembering that the best career for you is the one that inspires you.

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