Public Service in Support of Crop Improvement Methods

Basic or applied; curiosity-driven or problem-solving; ivory tower or practical; these are some of the terms used to describe a supposed dichotomy between types of research objectives. However, at UC Davis and other public land-grant institutions, the guiding principle is “both/and” not “either/or.” In the Seed Biotechnology Center (SBC), we practice this in our research projects, which span from the molecular to the ecological levels and from fundamental biology to problem-solving applications. We also practice it in our public service activities, where we are a science-based source of information on the development and application of new and innovative scientific discoveries to solve real agricultural problems. This is embodied in the mission statements of the SBC and of our partner organization Seed Central — to bring science to market faster for agricultural and consumer benefit.

An example of this is the recent development through basic research of methods to “edit” DNA and make precise changes to modify or introduce beneficial traits into plants and animals. A colleague at UC Davis (Alison van Eenennaam) and her collaborators used these methods to recreate a known hornless trait in dairy cows, which would eliminate the need to painfully dehorn calves. Similar specific modifications of existing genes could enable new disease resistances in crop varieties without resorting to wide crosses to wild relatives that require years of backcrossing to solve the unwanted traits. Several approaches have demonstrated improved drought and salinity tolerance in crops by transferring or modifying single genes. However, in most of these cases, despite having the improved plants in hand, researchers must embark on a decade-long process to attempt to reproduce the same plants using much more cumbersome and slower breeding processes solely to permit commercialization without the expensive regulatory requirements and stigmatizing label required for products developed using these new, efficient breeding methods.

The next two years are an extremely critical time for the future of agriculture. The availability of new, more targeted and more efficient methods to modify genomes (e.g., CRISPR) has triggered reevaluation of the current federal system regulating the products of biotechnology in plants and animals. In 1992, when the initial principles for such regulation were described, it was supposed to be the product itself, not the process by which it was produced, that was to determine regulatory oversight process. However, that was never implemented in practice, and regulatory requirements are determined primarily by what methods were used to create the final product, not by the trait itself, although some traits require review by multiple regulatory agencies (USDA, FDA, EPA). In July 2016, a new federal GMO labeling law was enacted that will require labels on foods produced using certain genetic modification techniques, but not others. As the rules for implementation of this law are developed and implemented by 2018, the determination of which techniques will require labeling and which will not has enormous consequences for the ability of breeders to provide genetic solutions to agricultural production problems and reduce environmental impacts. It is essential that agricultural scientists and breeders provide input into this process, document the positive record of plant breeding (regardless of the methods used), and move toward a regulatory system that protects public safety but does not stifle innovation and progress.

In this effort, the SBC is working closely with groups such as the American Seed Trade Association and BIO to provide documentation of the benefits and safety of the screening and testing procedures that are standard in plant breeding and specifically what risk analyses and regulations would be relevant and appropriate for new breeding methods. In addition, the SBC also submits our own independent comments to USDA-APHIS, EPA and FDA when public input is solicited on regulatory matters. While the current regulatory system has enabled some crops (corn, cotton, soybeans, canola) to be improved using biotechnology methods, California’s major crops have not benefitted as yet. We will submit science-based and fully documented comments to the current reviews by FDA and USDA of their regulatory stances toward gene editing methods and revision of the current regulatory schemes for both plants and animals.
It is opportune to note that the iPhone was introduced only 10 years ago, while crops developed using biotechnology have been grown safely in fields for more than 20 years. In contrast to the myriad of advances that have occurred to enhance mobile devices, crop biotechnology has been limited to only a few significant traits and crops. CRISPR is the cell phone of biology, opening opportunities that we can hardly imagine, but which in 10 years could be revolutionary in feeding more than 9 billion people sustainably and addressing the challenges of climate change. Or, it could be bottled up under outdated regulatory regimes and misleading criticism that have largely stifled both innovation and application in agriculture. In contrast to the creativity and inventiveness fueled by public/private partnerships and access to markets that drive Silicon Valley, restrictive regulatory regimes and market hurdles have handicapped both public and private efforts to utilize scientific advances to more rapidly improve crops. The SBC will continue its public efforts to encourage science-based and rational oversight that assesses risks and informs the public without creating unnecessary hurdles that stymie innovation.

Kent J. Bradford, Director
Seed Biotechnology Center
University of California, Davis

2http://sbc.ucdavis.edu/News/Publications_534/#Regulatory
The University of California, Davis (UC Davis) Plant Breeding Academy (PBA) has been offered since 2006 with classes in the USA, Europe, Africa and Asia. To date, the program has trained more than 230 breeders, 80% of which are from the private seed industry. The PBA is a postgraduate program that teaches the fundamentals of plant breeding, genetics and statistics through lectures, discussion, and field trips to public and private breeding programs. The program maintains its core curriculum in addition to upgrades that address the most recent developments in plant breeding theory and practice.

The core instructors include internationally recognized experts in plant breeding and seed technology: Kent Bradford, Allen Van Deynze, Rale Gjuric (all UC Davis), Rita Mumm (University of Illinois), Todd Wehner (North Carolina State University), Iago Hale (University of New Hampshire), Bruce Walsh (University of Arizona), Idy van Leeuwen (BreedWise) and Alexandra Tomerius (AIB). They are supported by a number of guest lecturers from the private industry and academia.

### PBA Highlights in 2016

**UC Davis PBA Class V graduates**

The UC Davis PBA Class V held its fifth session in February and final session (and graduation) in June, both in Davis, California. Over the last two years during the six sessions, sixteen participants in this class spent more than 300 hours in classes, workshops and the field. The graduation ceremony in June included a special celebration to recognize the PBA’s tenth anniversary. Special guests and alumni joined the event, which also recognized Dr. Todd Wehner as a founding instructor who has been with the Academy for ten years teaching in the US, Asia and African courses.

**Davis PBA Class V course participants included:**

- Marta Baptista, Driscoll’s Strawberry Associates, USA
- Ray Cowley, DuPont Pioneer, Australia
- Ryan Eadry, Halls Plant Farm, USA
- Pieter (PJ) Fourie, Hygrotech, South Africa
- Ezequiel Gallegos, Nunhems, Mexico
- Evan Gillis, DL Seeds, Canada
- Lluvia Gutierrez, Driscoll’s Strawberry Associates, USA
- Marilyn Hino, East-West Seed Co., Philippines
- Sean Keyworth, HM.Clause, USA
- Jace Knight, Dixon Seed, Inc., USA
- John Larse, Larse Farms, Inc., USA
- Jeff Mansiere, Bayer CropScience, Canada
- Curtis Van Laecke, Horizon Seeds Canada, Inc., Canada
- Eric Willard, RJ Reynolds Tobacco Co., USA
- Josh Williamson, Nunhems/Bayer, USA
UC Davis PBA Class VI starts

UC Davis PBA Class VI held its first session in September in Davis, California. The class core curriculum maintained upgrades from previous classes while adding modules to address the most recent development in plant breeding theory and practice. Core instructors were supported by a number of guest lecturers from private industry and academia.

Davis PBA Class VI course participants include:
Parag Agarwal, VNR Seeds Pvt. Ltd., India
Michael Courtney, Shamrock Seed (Vilmorin/Limagrain), USA
Aman Dayal, Dayal Seeds, India
Erin Gerdes, Nuseed, USA
Manoj Kumar Kabdal, Pioneer, India
Ryan McMillen, Rijk Zwaan, USA
Bear Reel, C.W. Hemp, USA
Kelly Stanton, Enza Zaden, USA
Donato Titolo, Dow AgroSciences, USA
Amit Vachher-Gnanathurai, Coastal Seed Co./Grownwell Coop, USA
Katriona Vigueras, Bayer, USA
Hong Jen (Victor) Wang, Sakata Seed America, USA
Carlos Manuel Xico, Bejo, Guatamala
Akira Yokofuji, Snow Brand Seed Co., Japan

European PBA Class IV continues

The fourth class of the UC Davis European PBA (EPBA) completed three sessions in 2016: Angers, France in March; Gatersleben, Germany in June; and Gent, Belgium in October. During these and the remaining two sessions to be held in Almeria, Spain and at UC Davis, this class will spend more than 300 hours in classes, workshops and the field, to complete this premium professional certification program.

Europe PBA Class IV course participants include:
Remy Adriaensen, Bayer CropScience, Belgium
Solène Crépellièrre, Syngenta, France
Grégory Lavric, KWS Momont, France
Alessandra Lillo, Driscoll’s Genetics, UK
Przemyslaw Matysik, Hodowla Roslin Strzelce, Poland
Nina Muellers, KWS SAAT SE, Germany
Michal Rokicki, Poznanska Hodowla Roslin, Poland
Adam Sitarzki, Driscoll’s Genetics, Poland
Erik Van der Biezen, Bayer CropScience, Belgium
Arie Vana, Enza Zaden, Spain

UC Davis PBA partners with Limagrain Academy

A special plant breeding training course delivered in August was organized as a collaborative effort between the UC Davis PBA and Limagrain Academy. Thirty-one Limagrain breeders based in China, India, Israel, Japan, Thailand and Vietnam attended the one-week course in Bangkok, Thailand. PBA core instructors included Rale Gjuric (UC Davis) and Todd Wehner (North Carolina State University).
Africa PBA Class II graduates

In June and November, the African PBA (AIPBA) and World Agroforestry Centre (ICRAF) welcomed Class II to Nairobi, Kenya for the second and third 2-week sessions of the 6-week continuing education program. This class represented professionals from 16 nations and 26 institutions throughout Africa. Instructors included experts from academia and industry professionals including Rale Gjuric (UC Davis), Iago Hale (University of New Hampshire), Rita Mumm (University of Illinois), Bruce Walsh (University of Arizona), Todd Wehner (North Carolina State University), Allen Van Deynze (UC Davis) and Kent Bradford (UC Davis). Special topics were covered by Darshna Vyas (LGC), Oswald Crasta (DowAgrosciences), Alex Lipka (University of Illinois), Nasser Yao (BecA/ILRI), Ramni Jamnadass, Prasad Hendre (ICRAF), and Damaris Odeny (ICRISAT) and were complemented with several discussions at local breeding programs such as CIMMYT and the Coffee Research Institute of Kenya. Local support for the AIPBA was provided by The World Agroforestry Centre director Tony Simons with logistical support from Imelda Ingumba and Mehmood Hassan. Logistical support at the SBC was provided by Sue DiTomaso and Sally Mohr.

Over five years, the AIPBA aims to train 150 of the top African plant breeders in the latest plant breeding strategies, including population improvement, quantitative genetics, selection theory, objective phenotyping and application of genomics to plant breeding. The goal is enhance the ability of Africans to provide nutritious food to reduce stunting due to malnutrition. This program was organized in collaboration with The African Union New Partnership for Africa’s Development (NEPAD) Agency and the African Orphan Crops Consortium.

In 2016, the AIPBA gratefully received financial support from AGRA (Alliance for a Green Revolution in Africa) that will be utilized to fund 15 students in the current class and 15 in the next AIPBA class. Furthermore, AIPBA instructor and African Orphan Crop Consortium Steering Committee member Allen Van Deynze gratefully accepted a gift from Jon and Terase Curtis, who provided funding to support one student in the course.

Africa PBA Class II course participants included:
Abush Tesfaye Abebe, Ethiopian Institute of Agricultural Research, Ethiopia
Enoch Gbénato Achigan Dako, Horticulture and Genetics Unit/ Faculty of Agronomic Sciences/University of Abomey-Calavi, Benin
Patrick Adébola, Agricultural Research Council, South Africa
Richard Akinwale, Obafemi Awolowo University, ILE-IFE, Nigeria
Wassu Mohammed Ali, Haramaya University, Ethiopia
Charles Amadi, National Root Crops Research Institute Umudike, Nigeria
Gladys Amoding, NARO/National Semi-Arid Resources Research Institute, Uganda
Emmanuel Chamba, CSIR-Savanna Agricultural Research Institute, Ghana
Charity Chidzanga, Scientific and Industrial Research and Development Center (SIRDC), Zimbabwe
Nicholas Denwar, CSIR-Savanna Agricultural Research Institute, Ghana
Mathews Dida, Maseno University, Kenya
Abe Gerrano, Agricultural Research Council-Vegetable and Ornamental Plant Institute, South Africa
Samson Gwali, National Forestry Resources Research Institute, Uganda
Innocent Habarurema, Rwanda Agriculture Board (RAB), Rwanda
Mainassara Habibou, INRAN/CERRA-KOLLO, Niger
Gemecuh Keneni, Ethiopian Institute of Agricultural Research, Ethiopia
Konan Jean Louis Konan, National Agronomic Research Center (CNRA), Côte d’Ivoire
Josephine Therese Makueti, World Agroforestry Centre West & Central Africa, Cameroon
Sydney Mavengahama, Agricultural Research Council, South Africa
Memory Mazarire, Crop Breeding Institute, Zimbabwe
Kiddo Mtunda, Sugarcane Research Institute-Kibaha, Tanzania
Charles Mutimaamba, Crop Breeding Institute / Dept. of Research & Specialist Services, Zimbabwe
Fulgence Nyongabo, Institut des Sciences Agronomiques du Burundi (ISABU), Burundi
Daniel Nyadanu, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Dowiya Benjamin Nzawele, Institut National pour l’Etude et la Recherche Agronomiques (INERA), DR Congo
Pascal P. Okwiri Ojwang, Egerton University, Kenya
Happiness Oselebe, Ebonyi State University, Abakaliki, Nigeria
Lawrent Pungulani, Chitedze Research Station, Malawi
Julia Sibiya, African Centre for Crop Improvement, University of KwaZulu-Natal, South Africa

African Orphan Crops Consortium
The African Orphan Crops Consortium’s (AOCC) objectives are to improve the nutrition, productivity and climatic adaptability of some of Africa’s most important indigenous food crops to decrease the malnutrition and stunting that is rife among the continent’s rural children. The AOCC (see www.africanorphancrops.org for annual reports) has begun by investing in training Africa’s top breeders to integrate modern tools and strategies into their plant breeding programs. It jumpstarts breeding programs in African crops by sequencing a base genome for 101 African crops and defining the genetic diversity of 100 genotypes selected to represent local landraces, lines with favorable nutritional and productivity traits and a broad sampling of genetic diversity for these crops. Importantly, all the information and lines are made publicly available. In 2016, the AOCC worked on 29 reference genomes, eight of which are expected to be released in 2017. It continued to work on defining the genes for 50 crops through the Illumina Greater Good Initiative and collecting samples for resequencing. New partners include Wageningen University and AGRA. The new website describes each of the crops, AOCC partners and network, as well as some graduate profiles. An unforeseen consequence of the AOCC’s Plant Breeding Academy is development of a professional cohort of plant breeders working together across the continent. For example, Dr. Firew Mekbib of Haramaya University Ethiopia is amplifying AOCC’s resources by training PhDs to work on 38 indigenous crops. Similarly, an AfPBA cohort has acquired a €1.5 M grant to train 40 graduate students to work on ten additional orphan crops from five countries. Grants leveraging AOCC resources to date total over $10M.
Significant contributions by AOCC partners

- **Alliance for a Green Revolution in Africa (AGRA) (Westlands, Kenya)** is an organization supported by the Bill and Melinda Gates and the Rockefeller Foundations, which supports the AOCC in many ways.
- **Agricultural Research Council (ARC) (Pretoria, South Africa)** supports the AOCC with sequencing of the genes (transcriptomes) for the AOCC.
- **Biosciences eastern and central Africa-International Livestock Research Institute (BecA-ILRI) (Nairobi, Kenya)** is a shared agricultural research and biosciences platform providing laboratory services to African and international scientists conducting research on African agricultural challenges. It provides the AOCC with lab and project support, training of breeders, and the curation of germplasm used by the AOCC.
- **BGI (Shenzhen, China)** is one of the world’s leading sequencing organizations. It is involved in sequencing, annotating, assembling and curating many of the 101 African orphan crop genomes.
- **Food and Agriculture Organization (FAO) (Rome, Italy)** supports development for the AOCC.
- **Google (Mountain View, CA, USA)** provides rapid transfer of AOCC data worldwide using cloud space.
- **Illumina Inc. (San Diego, CA, USA)** develops technology and kits for use in genetic research and has provided the AOCC with reagents to sequence the gene complement of 50 species.
- **Cyverse (Tucson, AZ, USA)** is a collaborative that has developed a cyber infrastructure for data-intensive biology driven by high-throughput sequencing, phenotypic and environmental datasets, and has helped the AOCC with analysis and curation of sequence and genotype data.
- **LGC (Hoddesdon, UK)** is an international life sciences measurement and testing company, providing reference materials, genomics solutions and analytical testing products and services; it has provided genotyping services for AOCC plant breeders.
- **Mars, Incorporated (McLean, VA, USA)** is one of the world’s largest privately-owned food companies; it has provided over $2 million for the African PBA, scholarships for breeding programs and support for AOCC lab personnel.
- **New Partnership for Africa’s Development (NEPAD) (Midrand, South Africa)** has provided administrative, logistical and political support for the AOCC.
- **Thermo Fisher Scientific (Waltham, MA, USA)** helps companies and organizations solve their research challenges; It has donated four Proton sequencers and four Chef Stations and reagents for African orphan crop lines.
- **UNICEF (New York, NY, USA)** supports the development of the AOCC.
- **University of California at Davis (CA, USA)**, one of the world’s leading agricultural universities, manages the African PBA and supports the AOCC laboratory.
- **VIB and Plant Systems Biology at the University of Ghent (Ghent, Belgium)** is a non-profit research institute in the life sciences with 1,200 scientists conducting strategic basic research on the molecular mechanisms; It has helped the AOCC with bioinformatics and annotation of plant genomes.
- **Wageningen University (Wageningen, The Netherlands)** is a world-leading agricultural university working closely with the AOCC to define the nutritional value of African crops and breeding lines.
- **World AgroForestry Centre ICRAF (Nairobi, Kenya)** hosts the AOCC lab and the African PBA’s lab and helps manage its data.
- **World Wildlife Federation (Washington DC, USA)** has worked with the AOCC since its inception, helping with initiation and vision.
Additional SBC Educational Courses

Seed Business 101℠

This one-week program is designed to expose participants to the five functional areas of a seed company: research and development, production, operations, sales and marketing and administration. The course content is delivered in a very interactive way by creating a virtual seed company and case studies for each functional area. The program provides those new to the seed industry a broad understanding of the major aspects of a seed company’s operations and cross-departmental knowledge of best practices for profitability. The class is taught by widely respected industry executives with additional help of experts participating as guest speakers. Starting in 2012, two distinct programs are offered, one focusing on field crops and the other on horticultural crops. More than 400 participants have completed this course since 2010.

Four Seed Business 101 courses were offered in 2016

Horticulture — February, Chiang Mai, Thailand
This course included students from Thailand, India, Japan, France, Philippines, Korea, China, Tanzania, and the USA. The SBC recognizes Chia Tai Co. Ltd., East-West Seed and HM.Clause Thailand as joint sponsors of the course. Their hospitality was key to the success of this session.
Field Crops — September, Durham, North Carolina, USA
Field Crops — December, Chicago, Illinois, USA
Horticulture — December, Davis, California, USA

Seed Production

This 3 day course is designed to enhance participants’ knowledge of the underlying biology of seed production and the key roles of bees and other insect pollinators, how to manage seed crops from agronomic, quality control, and genetic integrity standpoints, and how to meet new challenges through seed production research.

Attracting over 50 participants, this course was offered on February 2 – 5, 2016 at UC Davis. It was taught in an interactive format by Drs. Greg Welbaum, Kent Bradford, and Rale Gjuric and industry expert, Mike Pereira, along with other important guest lectures.
Program Management for Plant Breeders

This course’s objective is to enhance the management skills of professional scientists who are leading and directing plant breeding and laboratory programs in modern agricultural research and development programs of agribusiness companies and the public sector.

Here are a few course topics that were presented in Program Management for Plant Breeders:

- Understanding where your plant breeding or research program fits in the overall strategy of the organization. Establishing a vision and goal for your program and defining your key strategies and capacities.
- Comprehending the financial aspects of your program. Managing budgets, expenses, capital projects and period reporting. Reading and understanding a financial statement and managing your resources within the goals of your organization.
- Leading and managing people towards a common goal. Learning the principles of effective hiring, retention, evaluation, promotion, training, mentorship and motivation. Handling difficult situations using conflict resolution. Dealing with and embracing change and creating a culture of innovation.
- Creating effective and efficient programs. Understanding the principles of work flow, scheduling, safety, and legal compliance. Learning issues surrounding intellectual property and contracts, treaties and agreements.

Twenty-five breeders and researchers representing public and private organizations from the USA, France, Mexico, Turkey, Canada, Costa Rica and Taiwan participated in the third offering of this course, held in Davis, CA on September 20 — 22, 2016. Lead instructors were Fred Bliss, Tom Francis and Rale Gjuric. Participants included UC Davis PhD student Kay Watt, the recipient of the Larry Teuber Memorial Scholarship award (see photo above).

Breeding with Genomics

The course is aimed at professionals who are directly or indirectly involved in plant breeding and germplasm improvement. It offers a valuable opportunity for breeders who are already using these tools to expand their knowledge of new strategies and technologies and for laboratory personnel to appreciate how the marker data that they generate are applied in breeding programs. Included is a hands-on workshop on marker application in breeding programs, with R, the Integrated Breeding Platform and BLUPS software support.

Breeding in Genomics was offered in Davis, California on February 16 — 18, 2016. In attendance at this seventh course offering were 33 students coming from the US, Canada, Mexico, Turkey, Taiwan and France.
Advancements in Plant Breeding, Trial Design and Analysis

The Institute of Field and Vegetable Crops Novi Sad (IFVCNS), in collaboration with UC Davis PBA, developed and delivered a customized course to address the advancements in plant breeding, experimental design and analysis. This course was aimed at professionals involved in plant breeding and germplasm improvement.

Thirty plant breeders and scientists from Austria, Belgium, Bulgaria, Croatia, Germany, Holland, Italy, Moldova, Norway, Romania, South Africa, Serbia and Switzerland attended the course in Novi Sad, Serbia, on September 27-29, 2016.

OUTREACH AND PUBLIC SERVICE

Solanaceae Genomics Conference

In 2016, the SBC hosted the Solanaceae Genomics conference at UC Davis. This 5-day international conference brought together 360 students and scientists from private and public organizations across six continents to discuss the latest developments in genomics and their application to plant breeding in solanaceous crops. The conference included 14 sessions from genetic diversity, high throughput phenotyping, systems biology to breeding. Four workshops focused on integrating students and diversity by having graduate student speakers and co-chairs in each session. Five tours highlighted plant breeding programs and agriculture locally. Several video interviews with participants (available at http://seedworld.com/2016-solanaceae-conference-giant-views-interviews/) illustrated the importance of research in agriculture. The local organizing committee included Allen Van Deynze, Ann Powell, Sue DiTomaso, Julie Tillman with support from Rebeca Madrigal, Sally Mohr, Joy Patterson, Amanda Saichaie and Kathy Esparza.
UC Davis Student Farm

As part of two grants, the SBC is working closely with the UC Davis Student Farm, Mark Van Horn, Raoul Adamchak and Carol Hillhouse to entice K-12 children to plant sciences. Diversity in 40 lines of *Capsicum* (*Capsicum annum*, *C. baccatum*, *C. chinense*, *C. pubescens*, *C. frutescens*) and *Lycianthes* were planted in the Student Farm’s garden. Similarly 40 carrots of diverse colors, tastes and shapes were planted. Programs were developed to engage a wide audience: UC Davis undergraduates; Student Farm volunteers, interns, staff, and affiliates; and elementary, middle, and high school students. Approximately, 1,600 children visit the student farm per year and about one-half participate in educational activities, including *Understanding the Origins and Genetic Diversity in the Solanaceae* seminar and the *Okra and Chile Festival*. A film on pepper breeding was created by students and is available at PlantBreeding.ucdavis.edu. This work was funded by the National Science Foundation Specialty Crops Research Initiative.

Seed Central

**Seed Central/Food Central**

UC Davis is a world leader in seed, plant and agricultural sciences. While the influence of UC Davis extends throughout the USA and far beyond, the approximately 100 seed and seed-related companies clustered near UC Davis benefit greatly from its proximity. Established in 2010 as an initiative of the UC Davis SBC and SeedQuest, Seed Central/Food Central (SC) facilitates communication, networking and research collaboration between UC Davis and the surrounding seed and ag biotech industry. Seed Central now has 44 company and organization members (11 joining in the past year) from the global seed and food industry. New members include several startups focused on ag and food, overseas seed companies, and The Morningstar Company.

Seed Central offers regular networking events with featured guest speakers in Davis (nine per year) and Salinas (two per year). Since SC’s creation in 2010, attendance at these events has continued to grow with a total of over 1,800 participants from over 340 companies and organizations from California, the U.S. and overseas. In January, SC hosted the very successful *Roundtable on Women in the Seed Industry*. Additionally, SC teamed up with the UC Davis Office of Research to present at each event one of the start-ups housed at the HM-Clause incubator. Seed Central also introduced in September *Conversations*...
in 3D, where featured guests engage in interview-style conversation in lieu of a traditional Powerpoint presentation. In Salinas, SC’s October event facilitated networking between researchers from UC Davis and USDA ARS, UC Cooperative Extension specialists and Farm Advisors, the Grower-Shipper Association of Central California, professors, administrators and students from Hartnell College, California State University Monterey Bay, UC Santa Cruz, and Aggie Ambassadors.

2016 Seed Central/Food Central Forum Presenters and Topics

SPECIAL SESSION featuring Cutting Edge Technologies
- Kristi Spittle and Kristin Mars, Pacific Biosciences of California, Inc.
- Ai Oikawa, Co-Founder & Managing Director, Afingen
- Diane Wu & Poornima Parameswaran, Founders, Trace Genomics, Inc.
- Paul Gepts, Professor of Plant Sciences and Geneticist/Breeder, UC Davis | Grain Legume Breeding in California and East Africa: Contrasting Endeavors
- Phyllis Himmel, Director, Collaboration for Plant Pathogen Strain Identification (CPPSI), UC Davis | The Collaboration for Plant Pathogen Strain Identification
- Michael Gumina, Global CEO, RiceTec Inc. | Hybrid Rice: A Global Perspective
- Steven J. Knapp, Professor and Director of the Strawberry Breeding Program, UC Davis | The UC Davis Strawberry Breeding Program: Reformation and Expansion
- Diane Barrett, Fruit and Vegetable Products Specialist, Food Science & Technology, UC Davis | 20+ Years of Processing Tomato Research in the Barrett Lab: The Condensed Version

SPECIAL SESSION featuring Light and Lighting Technologies
- Michael Siminovitch (Moderator), Director of the California Lighting Technology Center (CLTC), Professor of Design, and Associate Director of the Energy Efficiency Center, UC Davis
- Melanie Yelton, Director of Research, LumiGrow, Inc.
- Heiner Lieth, Professor / Extension Specialist, Plant Sciences, UC Davis | Development of New Soilless Crop Production Technologies
- Clark Lagarias, Professor of Biochemistry, Department of Molecular and Cellular Biology, UC Davis | Light Regulated Development in Plants
- Daniel Morash, Founder, California Safe Soil, LLC | Conversation in 3D, with Ed Lewis, Associate Dean, College of Agricultural & Environmental Sciences/Professor, Department of Entomology and Nematology, UC Davis
- Gia Fazio, Director of Project Planning, Arcadia Biosciences | Conversation in 3D, with Sarah Dohle, Plant Biology Graduate Student (PhD), UC Davis
- Mike Lassner, Biotechnology Consultant and Advisor | Conversation in 3D, with Richard Michelmore, Director of the UC Davis Genome Center and Professor, Departments of Plant Sciences; Molecular and Cellular Biology; and Microbiology and Immunology, UC Davis

Collaborative Research (CoRe) Laboratory

Concept development continued for the Collaborative Research (CoRe) Laboratory, a research facility on campus that would provide laboratory and administrative space for companies, house sponsored research projects, provide access to shared infrastructure, equipment and service programs, and contain space for start-up ventures. The SC team worked with campus’ Design and Construction Management unit to develop plans for such a building that could be located adjacent to the Plant Reproductive Biology building where the SBC is housed. The concept has been approved pending development of a business plan for extramural funding for construction and operation of the CoRe Laboratory. It is envisioned that companies/tenants would collectively pay for the building construction over a 10-year period and outfit the individual spaces to their own specifications. Interest has recently been expressed by a local development firm that could facilitate progress on the project. If the CoRe Lab could be of value to you, contact the SBC or SC.
Seed Central Student Programs

In addition to connecting UC Davis research with industry, SC’s other important focus is to connect UC Davis students with potential mentors and employers by offering a number of activities that give students an opportunity to become engaged with the seed industry. Toward this end, students can attend networking events, field trips to seed, ag biotech and food companies, and professional development workshops. Seed Central hosted two field trips in 2016: Bayer CropScience in West Sacramento, CA and Arcadia Biosciences in Davis, CA. Seed Central also offers students a mentorship program connecting them with professionals, an annual Grand Prize Internship, professional shadowing days, career development workshops, and assistance in finding internships and permanent employment. In 2016 SC offered its sixth and seventh workshops: Communication Skills with Carl Winter (Director of the FoodSafe Program and Extension Food Toxicologist, UC Davis) and Networking and LinkedIn with Cynthia Goldberg (Program Coordinator at UC Davis Internship and Career Center).

Discover Series

The Discover Series (DS) introduces UC Davis science and scientists to seed, ag biotech and food companies. Now in its second year, the DS allows the integration of basic and applied research that will not fit into established SC events. As a part of the DS, member companies are invited to UC Davis once a year to meet newly hired faculty. Three times a year, members are invited to hear short presentations by scientists who pursue basic research that has potential to translate into applied research. Nine UC Davis researchers delivered DS research presentations to members in 2016.

2016 DISCOVERY SERIES Presenters

- Tom Gordon, Dept. of Plant Pathology, UC Davis | Genetic Resistance to Disease
- Johan Leveau, Dept. of Plant Pathology, UC Davis | The Health Triangle: Soil and Root Microbiota of Processing Tomato
- Lynn Epstein, Dept. of Plant Pathology, UC Davis | Fusarium Yellows on Celery: Understanding the Biology and Towards Controlling the Disease
- Luca Comai, Dept. of Plant Biology, UC Davis | Chromosome Manipulations for Efficient Breeding
- Anne Britt, Dept. of Plant Biology, UC Davis | In vivo Generation of Haploids Through Non-Transgenic Modification of Centromere Function
- Ioannis Stergiopoulos, Dept. of Plant Pathology, UC Davis | Molecular Mechanisms of Fungal Pathogenesis on Plants: From Systems Biology to Translational Research
- Gail M. Bornhorst, Dept. of Food Science and Technology, UC Davis | Engineering Aspects of Gastric Digestion
- S.P. Dinesh-Kumar, Dept. of Plant Biology, UC Davis | Plant-Microbe Interactions
- Siobhan Brady, Dept. of Plant Biology, UC Davis | Root Development at Cell Type Resolution

Corporate Affiliates Partnership Program

Our Corporate Affiliate Partnership Program (CAPP), called the Plant & Seed Sciences Partnership Program (PSSPP) is coordinated by the SBC within the College of Agricultural and Environmental Sciences at UC Davis. CAPP is an established university model to facilitate research agreements and interactions between stakeholders, SC members, and the university, and has remained vibrant since its inception in 2012, facilitating over $3 million in collaborative research funding.
The Vegetable Research and Development Forum

The Vegetable Research and Development (Veg R&D) Forum is an occasional meeting of the research managers of vegetable seed companies with breeding activities for the North American market. The purpose is to enable discussion amongst research managers of long-term, pre-competitive research topics and research-related policy issues of importance to the North American vegetable seed industry, with invited participation by other relevant specialists such as university scientists, technology providers to the seed industry, and members of the downstream agriculture & food industries. The Second Veg R&D Forum was held in November, paving the way for new research consortia in the area of seed vigor, plant health, seed crop pollination, and new plant breeding techniques.

2016 Veg R&D Forum Presenters
- Kent Bradford, Dept. of Plant Sciences, UC Davis | New Research on Seed Vigor
- Phyllis Himmel, Director, Collaboration for Plant Pathogen Strain identification (CPPSI) and Bryce Falk, Dept. of Plant Pathology, UC Davis | Project to Identify and Pool Information About Newly Emerging Disease Strains and Races
- Neal Williams, Dept. of Entomology, UC Davis | Using Wild Bees for the Pollination of Seed Crops
- Richard Michelmore, Depts. of Plant Sciences; Molecular and Cellular Biology; and Microbiology and Immunology, UC Davis | New Opportunities for Plant Improvement
- Anne Britt, Dept. of Plant Biology, UC Davis | Haploid Induction Through Single Amino Acid Substitutions in CENH3 Histone Fold Protein
- Isabelle Henry, Dept. of Plant Biology, UC Davis | A Tool for Functional Genomics? The Case of Bud Burst

The Vegetable Research and Development Forum

Principal Investigator: Diane Barrett
Title: Sensory Description of Cooked Onions
Sponsors: Enza Zaden, Bayer CropScience

Principal Investigator: Anne Britt
Title: Tomato Haploid Induction via Transgenic Mutation of CENH
Sponsors: Rijk Zwaan, Hortgenics, Syngenta Seed

Principal Investigator: Luca Comai
Title: Haploid Induction in Tomato through the CENH3 Effect
Sponsors: Rijk Zwaan, Syngenta Seed, East-West Seed

Principal Investigator: Luca Comai
Title: Efficient, High-throughput Reverse (and Forward) Genetics System for Tomato Using an Optimized TILLING Population
Sponsors: Rijk Zwaan, Bayer CropScience, Enza Zaden

Principal Investigator: Richard Michelmore
Title: BGDGP (Bremia Genomic Diversity Project)
Sponsors: Rijk Zwaan, Enza Zaden

Principal Investigator: Richard Michelmore
Title: ILGC (International Lettuce Genomics Consortium)

Principal Investigator: Allen Van Deynze
Title: Defining the Genetic Determinants of Fruit Size and Shape in Pepper
Sponsors: Rijk Zwaan, Enza Zaden
Collaboration for Plant Pathogen Strain Identification (CPPSI)

The CPPSI mission is to build a science-based system for standardizing the identification of plant pathogen strains and races using sets of plant host differentials, reference plant pathogen strains and instructional white papers. These hosts, pathogen strains and white papers are collectively referred to as Reference Materials.

Production of reference materials are under way for pepper TSWV, tomato TSWV, watermelon Fusarium wilt and lettuce downy mildew. Drafts of the associated white papers are also in development. Fall 2017 is targeted for making these reference materials available through www.cppsi.org. Watermelon Fusarium wilt has been a more challenging system to work with and should be available in early 2018. The lettuce downy mildew reference materials are being developed in collaboration with the International Bremia Evaluation Board (IBEB) and Richard Michelmore (UC Davis).

The CPPSI Advisory Council approved the proposed development of Harmores 3 reference materials in June. Harmores 3 is a 2-year strain and resistance harmonization effort between the EU registration organizations, EU seed companies and CPPSI. Members of CPPSI are helping to identify the official differentiating hosts and reference strains for melon powdery mildew and Fusarium wilt as well as tomato root knot nematode & Fusarium wilt through comparative testing and differential host set development.

With the support of the Advisory Council, we have expanded the responsibilities of CPPSI to include additional projects that support the CPPSI mission. CPPSI members are participating in the International Seed Federation (ISF) Disease Resistance Terminology Working Group to revise the ISF Disease Resistance Terminology document. The document serves as a guide for making claims of disease resistance in commercial varieties by the vegetable seed industry. CPPSI is also participating in the Harmores 3 project to help define and select differentiating hosts that help identify pathogen strains. CPPSI will soon facilitate the distribution of ISHI reference materials and is helping ISHI develop a distribution system for North America. We are also developing a website to pool resources and information on emerging diseases.

The CPPSI Business Plan is being updated to reflect the successful launch and establishment of CPPSI at the UC Davis SBC in 2015, outline the activities that make up the expanded CPPSI responsibilities and to identify the steps towards long-term sustainability of the CPPSI initiative.

The CPPSI director and members of the working group meet with the CPPSI Advisory Council twice a year to review progress and set direction for the coming year. The CPPSI Advisory Council is comprised of representatives from founding CPPSI members. CPPSI appreciates the continued support from our founding members: Bayer Crop Sciences, HM.Clause, Monsanto, Sakata Seed America, Syngenta, Enza Zaden and Rijk Zwaan.
The Kent J. Bradford Endowment

Establishment of the Kent J. Bradford Endowed Chair in Seed Science will provide support for a faculty member at UC Davis who would be focused on seed biology and technology and serve as the director of the Seed Biotechnology Center. An endowment will ensure that the seed industry’s needs for academic research, education and public service can continue to be met. For more information or to contribute to our goal, contact Christine Schmidt at cmschmidt@ucdavis.edu.

Still growing strong!
In 2016, we were delighted to receive gifts to the endowment from Rijk Zwaan, Sakata Seed America and Enza Zaden. Their generous gifts are very important to the growth of the campaign. We will continue to add new gifts in 2017.

Thank you to our generous endowment supporters in 2016!

SBC Awards and Presentations

During the American Seed Trade Association’s Corn & Sorghum Seed Expo in Chicago, the National Council of Commercial Plant Breeders recognized Allen Van Deynze with the Public Plant Breeding Award. This award is given to a person who has made outstanding basic contributions to the advancement of plant breeding and genetics in the public sector.

Each year the SBC staff makes numerous presentations for diverse groups to discuss various topics related to seeds, biotechnology and agricultural research.

Following are some examples from 2016:

Presentations and Posters: Allen Van Deynze

- African Orphan Crops Consortium: A Global Partnership to Address Food and Nutritional Requirements in Africa through Genomics Applications
Presentations and Posters, Allen Van Deynze (continued)

- Van Deynze, A.E. Plant breeding at UC Davis. Chinese delegation, Davis, CA, April, 2016
- Van Deynze, A.E. Plant breeding at UC Davis. Woolman High School, Davis, CA, April, 2016
- Van Deynze, A.E., and Shapiro, H. Growing Africa out of stunting, hunger & malnutrition

Presentations: Kent Bradford

- Seed drying and the dry chain. Rockefeller Center, Bellagio, Italy, April 12, 2016
- Seed Biotechnology Center and recent research on seed quality. Invited seminar, Limagrain Vegetable Seeds, Chappes, France, May 9, 2016
- MicroRNA-based mechanisms connecting seed dormancy and flowering times in lettuce and Arabidopsis, and application of bulked segregant analysis by genome sequencing to identify causal genes underlying mutation-induced traits. Invited seminar, HM.Clause, Bohalle, France, May 13, 2016
- Genetic and molecular mechanisms regulating both seed dormancy and flowering. Invited seminar, John Innes Centre, Norwich, U.K. May 23, 2016
- Genetic and molecular mechanisms regulating both seed dormancy and flowering. Invited seminar, University of Birmingham, Birmingham, U.K. May 26, 2016
- DELAY OF GERMINATION1 (DOG1) regulates both seed dormancy and flowering time through microRNA pathways, with Huo, H., and Wei, S. 5th Workshop on the Molecular Aspects of Seed Dormancy and Germination, International Society for Seed Science, Vancouver, CA, May 31 - June 4, 2016
- Biotechnology and agricultural sustainability. Invited speaker, International Conference on Sustainable Agriculture in Pakistan, University of Agriculture, Faisalabad, Pakistan, November 19, 2016
• **Seed technology for farmer prosperity and food security.** Keynote Address, Pakistan Seed Congress-Seed Security for Sustainable Agriculture, University of Agriculture, Faisalabad, Pakistan, November 21, 2016

• **Dry chain technology for preserving seed quality.** Invited presentation, Pakistan Seed Congress-Seed Security for Sustainable Agriculture, University of Agriculture, Faisalabad, Pakistan, November 22, 2016

• **Genetic and molecular mechanisms regulating both seed dormancy and flowering.** Invited seminar, University of Agriculture, Faisalabad, Pakistan, November 24, 2016

**Presentations: Rale Gjuric**

• **Canola Performance Trials: Update, data quality and prediction ability.** Canola Discovery Forum, sponsored by Canola Council of Canada. Winnipeg, MB, Canada, October 26, 2016

**Board and Committee Service Advisory Council**

The SBC Advisory Council announced expansion of its membership. The SBC is grateful for their sage advice and support.

- Phil Ashcraft, Verdant Partners
- Charlie Brummer, UC Davis Plant Breeding Center
- Jovan Djordjevic, Bayer CropScience Vege. Seeds
- Rick Falconer, Rijk Zwaan
- Dan Gardner, S&W Seed Co.
- George Gough, Monsanto
- Gary Hudson, Hudson & Associates, Inc.
- Matthew Johnston, HM.Clause
- Francois Korn, SeedQuest
- John Palmer, California Crop Improvement Assn.
- Betsy Peterson, California Seed Assn.
- Howard-Yana Shapiro, Mars, Incorporated
- Chip Sundstrom, FJS Consulting
- Mary Wadsworth, J.G. Boswell Company
- Chris Zanobini, California Seed Assn.
- Jeff Zischke, Sakata Seed America

**Upcoming Conferences and Meetings**

During 2016 the SBC was busy planning for these large conferences. Venues were selected, programs started to be developed and venues and other arrangements were made. Save the dates for the following SBC hosted events:

- **National Association of Plant Breeders Conference** August 7 — 10, 2017, UC Davis, CA. USA
- **International Society for Seed Science Conference** September 10 — 14, 2017, Monterey, CA. USA
- **Cucurbitaceae Conference** November 11 — 16, 2018, UC Davis, CA. USA

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**SBC in the News**

Media and news highlights featuring SBC

SBC.ucdavis.edu/News/SBC_in_the_News/
Update from the UC Davis Plant Breeding Center

The Plant Breeding Center (PBC) at UC Davis coordinates and expands plant breeding teaching and research on campus. The PBC is focused on training graduate students to be well rounded, with experience in field-based breeding evaluation and techniques, supplemented with an understanding of and facility with modern genomics and phenotyping technologies. The PBC is working with the Graduate Group in Horticulture and Agronomy to develop a clear plant breeding coursework track and is currently devising a Graduate Academic Certificate in Plant Breeding. The PBC plans seminars and field trips to supplement plant breeding coursework by giving students real-world examples of the types of work available in both public and private sectors. They also secure funding to expand field-based plant breeding education and prepare graduate students for employment.

In 2015 the PBC obtained a nearly $1 million grant from the USDA-NIFA Organic Research and Education Initiative (OREI) to train students to create and conduct actual breeding programs and develop cultivars for organic vegetable production. This project became known as the Student Collaborative Organic Plant Breeding Education (SCOPE) project. In 2016, the SCOPE project grew to include a for-credit weekly seminar for both undergraduate and graduate students and began offering internship credit for undergraduate students. The PBC hosted a successful SCOPE Field Day to show off the first selections each team is making and to invite more students from interdisciplinary fields to join.

As part of the SCOPE project, the PBC is working with the Organic Seed Alliance and organic growers across California to set priorities and eventually trial new germplasm on-farm. As the project progresses, growers will evaluate germplasm and participate in breeding varieties that have the most desirable traits. Current plans include new varieties of tomato, pepper, common bean, and lima bean, with additional crops added in the future. To see more about the SCOPE project, visit: orei.faculty.ucdavis.edu.

The PBC will be hosting the National Association of Plant Breeders Annual Meeting from August 7-10, 2017 in Davis, CA. Organizers are pleased to announce that the Honorable Secretary of Agriculture for California, Karen Ross will be a keynote speaker to kick off the conference. Tours on Monday, August 7th will include bean and grape breeding programs at UC Davis and breeding cucurbits at Syngenta Vegetable Seeds. A second tour on Thursday, August 10th will include a trip to several industry facilities in Salinas and surrounding areas, including Driscoll’s. Visit NAPB2017.ucdavis.edu to learn more.

In order to continue training in field-based breeding and expand the scope of its public breeding projects across crops, the PBC is fostering collaborations with the seed and nursery industry, commodity groups, and non-profit organization partners who are interested in either providing in-kind support to breeding programs or in directly funding research, including graduate student stipends, on a particular crop. The PBC’s website can be found at plantbreeding.ucdavis.edu.
RESEARCH

The California Coffee Genome

Coffee is the second most traded commodity in the world, yet there is very little research in plant breeding and certainly not plant genomics. With an epidemic of coffee rust destroying 55% of the crop in Central America, the world is now paying attention. SBC researchers, including Kevin Stoffel and Amanda Hulse-Kemp, partnered with UC Davis researchers Juan Medrano and Dario Cantu to sequence the coffee genome using the latest technologies. The SBC also partnered with California farmer and entrepreneur Jay Ruskey, of Good Land Organics in Goleta, CA, the northernmost coffee plantation in the world. Mr. Ruskey has established coffee production in Southern California to the order of 15,000 trees. Researchers collected DNA and RNA from a single tree from the Geisha variety growing at Good Land Organics, one of the most prized varieties in the world for its unique flavor. Its genome was sequenced using Pacific Biosciences SMRT technology coupled with Dovetail Genomics. The annotation was conducted with Computomics Inc. It was the first Coffea arabica genome made available to the public (in Jan 2017). The group also showed that current varieties being grown in Central and South America have very little genetic diversity. This project exemplifies the Land Grant mission to work directly with farmers to develop new technologies to benefit consumers. The work was funded by Suntory, Inc. and in-kind contributions from Pacific BioSciences and Good Land Organics.

Cotton

Improvement of transformation efficiency in cotton

The advent of gene editing technologies such as CRISPR/Cas9 can dramatically increase our ability to tailor phenotypes and determine gene functions for crop improvement. This requires an efficient regeneration system that is currently limiting in cotton. In an effort to enable functional genomics and gene editing in cotton, the SBC is collaborating with David Tricoli (UC Davis, Ralph M. Parsons Foundation Plant Transformation Facility) and David Stelly (Texas A&M) to screen a novel source of germplasm for regeneration capacity and transformation efficiency. Transformation efficiency in cotton is poor and limited to a few genotypes which has limited genetic diversity in breeding. A complex population of recombinant inbred lines derived form 11 cotton parents was obtained from David Fang and Jonnie Jenkins, USDA/ARS. This population provides unique recombinants that may respond to transformation protocols better than the now commercially irrelevant few lines currently being used, such as Coker 312. The hope is also to develop protocols that are more amenable to transformation across lines to maintain genetic diversity in breeding pools. In 2016, 125 of these lines, including their parents, were tested in culture with three protocols for transformation. A single line has been identified to date that responds well and can be transformed. The final data and remaining lines are being evaluated in 2017.

The second goal of these experiments is to develop gene-edited lines that can induce haploid plants in cotton. Once doubled, these pure-breeding lines can dramatically increase the efficiency of cotton breeding and genetic studies. The SBC is translating research developed in Arabidopsis in the Simon Chan lab (UC Davis) to cotton. Chan identified a specific chromosomal protein (CenH3) that can be modified to simplify the development of haploid plants. The SBC is taking a multipronged approach to develop a haploid inducer for cotton by incorporating the latest technologies. This research is being supported by Cotton Incorporated.
Lettuce

Novel regulatory mechanism links seed dormancy and flowering times in lettuce

Postdoctoral scholar Heqiang Huo and visiting scientist Shouhui Wei working in the Bradford Lab discovered that a gene previously known to be involved in regulating seed dormancy (termed DELAY OF GERMINATION1 or DOG1) is also involved in regulating seed thermoinhibition in lettuce and Arabidopsis. In addition, DOG1 also influenced flowering times, as had been observed in ecological experiments, but without a clear mechanism. Huo demonstrated that the effects on both seed dormancy and flowering involved microRNAs (small, 21-nucleotide RNA molecules) that target specific transcripts for degradation. Thus, the same underlying molecular regulatory system is involved in transducing environmental effects on both seed dormancy and flowering. This study (see Publications section, page 28) was supported by the National Science Foundation, USDA-National Institute of Food and Agriculture, the China Scholarship Council and Natural Science Foundation of China, and Rijk Zwaan B.V.

Identification of mutations affecting lettuce seed thermoinhibition by genomic sequencing

Postdoctoral scholar Heqiang Huo of the Bradford Lab also collaborated with the Luca Comai Lab in the UC Davis Genome Center to test a new strategy to identify mutations affecting seed germination. Scientists at Rijk Zwaan induced mutations in lettuce and selected lines that resulted in germination at higher temperatures. Using a method called bulked segregant analysis (BSA) combined with whole genome sequencing enabled efficient identification of the mutated gene that affected germination. This project demonstrated that BSA by sequencing is feasible for identifying specific induced mutations with a clear phenotype, even in plants with a large genome. This work (see Publications section, page 28) was supported by Rijk Zwaan B.V.

Genetic analyses of lettuce seed germination and flowering

Germination of lettuce (Lactuca sativa) seeds is delayed or inhibited when planted at warm temperatures, leading to delays or failures in seedling emergence and resulting in yield losses and higher costs. Working with a mapping population derived from a primitive L. sativa accession (PI251246), Fei-Yian Yoong (PhD student) in the Bradford Lab identified a gene involved in the action of ethylene (ETHYLENE RESPONSE FACTOR 1 or ERF1) as a likely candidate to be associated with germination thermotolerance (see Publications section, page 28). Further work with this population by Mohan Niroula, a PhD student in the Bradford Lab, showed that the same gene was responsible for the effects of maternal environment during seed development on this thermoinhibition phenomenon. Thus, it appears that maternal environmental conditions act in some way through this gene to determine subsequent seed germination responses to temperature. This may enable more consistent seed performance independent of the location of seed production. Niroula also identified a new QTL for flowering time in this same population. This locus on chromosome 7 may act through a phytochrome-encoding gene. Working with a different mapping population (Salinas x US96UC23), Niroula also identified a QTL associated with the ability of seeds of some lettuce genotypes to germinate in the dark. Interestingly, two conserved DNA variants were identified at this locus, each present in both cultivated and primitive (Lactuca serriola) genotypes, that were associated with the ability of seeds to germinate in the dark. This work was supported by the Western Regional Seed Physiology Research Group, a voluntary collaboration of seed and seed technology companies (Ball Horticultural, Bejo Zaden, Chia-Tai, East-West Seeds, Enza Zaden, Germain’s Technology Group, HM.Clause, INCOTEC, Bayer-Nunhems USA, Rhino Research, Rijk Zwaan, Sakata Seed America, Seed Dynamics and Syngenta).
**Pepper**

**Defining genetic resistance to late blight and the basis of fruit shape**

In an effort to develop acceptable bell pepper breeding lines conferring stable genetic resistance to late blight, *Phytophthora capsici*, the SBC has been working for the last 6 years on determining the genetic basis of resistance to the pathogen as well as the basis for fruit size and shape. In many species, primary sources of disease resistance come from unadapted landraces or wild relatives, bringing in many undesirable traits. In 2016, QTL analyses on multiyear data revealed the complexity of the traits, including defining QTL and candidate genes on chromosomes 5 and 10 for resistance to late blight. Analyses also determined the genetics of fruit shape, leaf shape, anthocyanin and pubescence in fruit. QTL regions were examined for candidate genes using the genomic sequence and potential genes were identified. This work was conducted by Jareerat Chunthawodtiporn, who described the research in her PhD thesis. Her first paper was accepted in *Plant Genome*. This work was supported in-kind by Enza Zaden B.V. and Rijk Zwaan B.V., the UC Davis Plant Sciences Department and a fellowship to PhD candidate Jareerat Chunthawodtiporn from the Government of Thailand.

**Leveraging population structure to define genetic loci for fruit quality**

SBC researcher Theresa Hill has used a novel method to identify genetic loci using structured small populations in pepper. By comparing blocky, nonpungent peppers to nonblocky, pungent type peppers with 1000s of DNA markers, it was shown that even with 40 individuals, genetic loci (thus candidate genes) associated with traits differentiating these two groups can be identified efficiently. It was shown that loci for fruit shape and pungency (capsaicin synthesis) can be identified. This was verified using nested biparental populations segregating for fruit shape and also populations segregating for pungency (see above). By summarizing the literature and analyses of the above populations, Dr. Hill identified QTL syntenic to those found in tomato, but also several novel QTL for fruit shape. Candidate genes are being verified using mutation analyses. Robust DNA markers have been made available for these loci. This work has been published in *Plant Genome* journal in 2017. This work was supported by Enza Zaden B.V and Rijk Zwaan B.V.

**Determining the basis of plant regeneration in pepper**

Doubled-haploid plants provide simpler genetics and can make breeding programs more efficient. Although anther culture can be used in pepper, there is a large variation in the response in different genotypes from production of no haploid embryos to production of 100s per culture. The SBC assayed a large RIL population to correlate genotypes with phenotype with the goal of identifying genes regulating embryogenesis and regeneration that may confer genotype specificity to anther culture in pepper. Several QTL and potential candidate genes have been identified for this important trait by a team including Theresa Hill, Tui Ray (Research Associate) and Alddo Chaverni (undergraduate student). This work was supported by Rijk Zwaan B.V. and a UC Discovery grant.

**Understanding the basis of color in pepper**

The SBC partnered with Ilan Paran (Volcani Institute, Israel) to identify the determinants of dark green fruit color in pepper. Initial research by Paran showed that at least two chromosomal regions control this trait. After publishing that the gene CaGLK was responsible for the locus on chromosome 10, the team received funding to define the genes on chromosome 1. Field trials, metabolic profiles, Bulked Segregant Sequencing...
analyses and expression analysis are being employed in this project. Candidate genes are currently being verified by SBC researcher Kevin Stoffel using expression in tomato and mutation analyses in pepper. A Binational Agricultural and Research and Development (BARD) grant was obtained to define candidate genes and interactions with this gene and the QTL found on chromosome 1 by Paran’s group.

Breeding for beet curly top virus resistance

The SBC is working with Robert Gilbertson (Department of Plant Pathology, UC Davis) and Jose Luna-Ruiz (Universidad Autonoma de Aguascalientes, Mexico) to screen a population of wild peppers (C. annuum var glabriusculum) for resistance to beet curly top virus. To date, several resistant sources have been identified. They have been transferred to jalapeno-type peppers for release and genetic studies. This project is funded by a National Science Foundation fellowship to PhD candidate Randi Jimenez and the Department of Plant Sciences, UC Davis.

Introducing new technologies for sequencing of plants and a (much) better pepper genome

The SBC partnered with 10X Genomics (San Francisco, CA, USA) to evaluate their technology to sequence and assemble plant genomes. 10X Genomics cost-effectively combines physical mapping and sequencing of genomes for about 5 to 10% of the cost of other current technologies. The SBC was the first to show that 10X Genomics technology can efficiently sequence and assemble the complex pepper genome (3.5 billion base pairs). The work was done in 2 months and presented in May and September at international conferences. The order of the DNA was verified using four high-density genetic maps, and pseudomolecules were created. The results showed that 10X Genomics technology was far superior when compared to the current four pepper genomes created using Illumina’s technology, where large gaps were found the genomes, especially in areas near centromeres with low recombination. These areas represent over 1/2 of the pepper genome. 10X Genomics analyses also defined both haplotypes in heterozygous regions. As a result, genome structure not accessible in the past can be efficiently defined. For example, the 2.5 kb deletion found in the pun1 gene in nonpungent types was clearly defined in the hybrid plant sequenced. Analyses of the datasets were done by SBC’s Kevin Stoffel, Amanda Hulse-Kemp and Theresa Hill, and Dr. Shamoni Maheshwari from UC Davis. The work was contributed in-kind by 10X Genomics with funding from Rijk Zwaan B.V. and Enza Zaden.

Designing a pepper for mechanical harvesting

Mechanical harvesting of pepper is a goal for the industry due to increasing costs and reduced availability of labor. As in tomato, both harvesters and breeding varieties amenable to mechanical harvesting are required. There are no shortage of designs for harvesters. Of the 60+ designs for pepper, three companies now produce harvesters used for pepper. Although this has been achieved largely in ripe paprika types, green jalapeno and other chiles for salsa and pickling are still a challenge to harvest. The two traits essential are to be able to destem the fruit from the pedicel or peduncle and uniform ripening. While screening wild germplasm from Mexico, the SBC identified a unique accession that destems well and has good pericarp thickness, traits that are usually found in repulsion. Several breeding populations were created to transfer these unique traits to Jalapeno and now blocky types, by measuring the force to destem. Innovations were made on how to measure the torque required to break the stem. Selections have outperformed the best jalapeno hybrids for destemming in replicated trials. With the procurement of additional research funding, the next step will be to test these populations with mechanical harvesters. Theresa Hill and visiting graduate student Vincenzo Cassibba from Italy worked on this program with partial support from HM.Clause.

Understanding the basis of color in pepper (continued)
Understanding the Origin of Peppers

The centers of genetic diversity and phylogeny for Capsicum species are not well defined. In collaboration with Lynn Bohs (University of Utah), Sandra Knapp (British Museum of Natural History, London), Gloria Barboza (National University of Córdoba, Argentina) and Ellen Dean (UC Davis), the SBC is defining the phylogeny of the up to 40 Capsicum species and 200 Lycianthes species, its closest relative. The project involves collections and taxonomic treatments for each genus; defining the phylogenies at the DNA level using exome capture and sequencing of 2400 genes; and disseminating on the Solanaceae Source database. This work is funded by the National Science Foundation and the Museum of National History, London.

Seed Physiology and Technology

Seed respiratory patterns during germination

As we reported last year, the Bradford Lab has been testing the capabilities of an instrument, the Astec Q2 (www.astec-global.com), that can measure the respiratory (oxygen consumption) patterns of individual seeds during germination. Seeds begin to respire almost immediately after imbibition of water and their subsequent respiratory patterns are closely associated with seed vigor. SBC researcher Pedro Bello developed new ways to analyze this data that enable modeling of seed respiration in response to temperature, water, respiratory inhibitors, aging and priming. He also developed methods to analyze these data to reveal the characteristics of blended lots that contain multiple seed populations. Collaborative studies with seed technology companies indicate that this method may be useful as a seed vigor test while reducing labor costs associated with repeated observations of germination over time. This research (see Publications section, page 28) was supported by a consortium of seed and seed technology companies (Astec Global, Bejo Zaden, INCOTEC, Rhino Research, Rijk Zwaan, SESvanderHave and Syngenta) and by AgInnovation USA.

Metabolomics of seed germination

The Bradford Lab partnered with Dominique Ardura (PhD student) and Oliver Fiehn of the West Coast Metabolomics Center at UC Davis to analyze changes in the small metabolites and lipids that occur during seed germination or dormancy. Ardura sampled lettuce seeds at various times after imbibition and quantified the amounts of several hundred metabolites. Changes in small molecules (e.g., metabolic intermediates), phospholipids and triglycerides (storage lipids) were associated with different stages of germination under optimal conditions. These patterns in metabolites are altered by elevated temperature or the hormone abscisic acid during imbibition. This project was supported by the American Seed Research Foundation.
Seed Storage

The Dry Chain: Seed drying and storage strategies for humid regions

Seeds lose viability rapidly in high humidity and warm temperatures, which prevail throughout the humid tropics. A novel method for seed drying using desiccant Drying Beads® enables drying of seeds to safe storage moisture contents even in rainy climates. When combined with hermetic storage containers, the seeds also are protected from damage due to molds, insects and rodents. As mold growth is prevented, accumulation of aflatoxin in storage is also prevented. We call this combination of drying upon harvest and subsequent waterproof packaging the “Dry Chain”, in analogy to the “Cold Chain” of continuous refrigerated storage used to preserve fresh produce. Kent Bradford participates in a project led by Johan Van Asbrouck of Rhino Research in Thailand, the inventor of this technology, and funded by the U.S. Agency for International Development (USAID) through the Horticulture Innovation Lab based at UC Davis. Van Asbrouck is conducting a scale-up project that is implementing this drying and storage methodology with seed companies in Bangladesh. In addition, we are working with colleagues at UC Davis to extend this approach to the drying and storage of many California commodities. For more information, see www.drychain.org and www.dryingbeads.org.

Spider Plant

Collaborative breeding program for Spider Plant

As a development of the African Orphan Crops Consortium, the SBC is a collaborator on a program led by Dr. Enoch Achigan Dako, University of Abomey-Calavi, Benin on participatory breeding of Spider Plant (Cleome gynandra) for resilience to climate and improved nutrition. Other collaborators include Eric Schranz, Wageningen University, The Netherlands; Edgar Deguenon, Hortitech Development, Benin; Andreas Ebert, AVDRC, the World Vegetable Center; and Patrick Mandu, KENRIK, Centre for Biodiversity, National Museums of Kenya, Nairobi, Kenya. Spider Plant is a vegetable eaten as “spinach” in most countries in Africa. It is a C4 plant adapted to several environments including drought stressed areas. It is highly nutritious and a rich source of micronutrients and vitamins. It is eaten steamed or mixed into many dishes. The SBC extended the above research to Davis by testing 46 landraces from Asia and Africa. Many accessions performed well in Davis, yielding well after 3 cuttings and exhibiting a variety of flavors. This project is funded by the Dutch foundation NWO-WOTRO Science for Global Development and the Department of Plant Sciences, UC Davis.

Spinach

Sequencing of the spinach genome

Spinach production in California has increased steadily with the introduction of fresh market baby leaf products in the 1990s. This has also been accompanied by an increase in incidence of disease, including Peronospora effusa (downy mildew), Fusarium wilt and Verticillium wilt. To develop molecular tools to address the challenges in controlling these pathogens, the SBC is utilizing the UC Davis Corporate Affiliates Partnership Program (see page 14) to partner with a consortium of Seed Central members and BGI to sequence the genome of spinach. Consortium members
include Rijk Zwaan, PopVriend, Syngenta, Enza Zaden, Nunhems, Sakata Seed America and American Takii. In 2016, the SBC completed sequencing and assembly of the spinach genome in partnership with BGI using Illumina technology and Pacific Biosciences SMRT technology including annotation and anchoring to a genetic map. A second phase of the project includes refinement of the order of genes, sequencing of 192 lines and further annotation. This work is being conducted by SBC’s Amanda Hulse-Kemp (now USDA/ARS) and Hamid Ashrafi (now faculty at North Carolina State University); Massimo Iorrizzo (North Carolina State University) and Lieven Sterck and Yves Nav de Peer (University of Ghent, Belgium). We expect to publish the genome in 2017.

**Sampling genetic diversity in spinach**

To leverage work above, the SBC is in the process of sequencing the genetic diversity in 1500 candidate genes for disease resistance, horticultural traits and reduced uptake of cadmium. This work is funded by the California Seed Association (Spinach Research Committee).

**Breeding for resistance to downy mildew and low uptake to cadmium**

Allen Van Deynze is co-leading a breeding program with Charlie Brummer (Director, UC Davis Plant Breeding Center) in spinach focusing on developing broad genetic resistance to downy mildew in baby spinach. Julian Osorio-Marin is the plant breeder implementing the program in collaboration with Steve Koikes (UC ANR) and Steve Klostermann (USDA/ARS) from Salinas. The program has developed 30 populations to screen in the field in Salinas for resistance. It is also developing rapid assay screening in growth chambers. Additionally, Rachel Frank-Greenhut, a masters student, is screening 500 lines for low uptake of cadmium in spinach, a problem in some growing areas in California. Ms. Frank-Greenhut is also genotyping the population with candidate genes and making crosses to introgress the trait into advanced lines. This program is funded the California Leafy Greens Board with in-kind support by USDA/ARS.

**The SBC Research Team**

Alfred Huo, Allen Van Deynze, Amanda Hulse-Kemp, Cris Heitmann, Dominique Ardura, Jareerat Chunthawodtiporn, Kent Bradford, Kevin Stoffel, Mohan Niroula, Pedro Bello, Prasad Hendre, Randi Jimenez, Shuangshuang Liu, Theresa Hill, Vincenzo Cassibba and Zhi Li.

**SBC recognizes Dr. Ann Powell**

Dr. Ann Powell, Professional Researcher with the Department of Plant Sciences and Program Director for Seed Central, fully retired in December 2016. Ann completed her PhD in Biochemistry at the University of Washington and after holding several post-doctoral and research associate positions, began her UC Davis career in 1991. Her primary research interests focused on biochemical and molecular investigations of fruit development, ripening and quality, particularly of tomato. She worked closely with Drs. Alan Bennett and John Labavitch at UC Davis to understand the role of plant cell wall modifications in fruit softening and resistance to postharvest diseases with the intention of developing varieties with improved quality characteristics and postharvest storage life. Her group identified a gene in tomato that could potentially increase the sugar content (and dry matter yield) of processing tomatoes. Ann contributed her expertise in cell biology, biochemistry, molecular biology and genomics to a diversity of other projects with multiple collaborators as well. She was an important contributor to the Plant Reproductive Biology community. Ann retired from her full-time research position in 2014, but continued to contribute to Seed Central by organizing research collaborations and networking sessions. In addition, she was an essential and active leader in the development and implementation of the 2016 Solanaceae Conference. She moved to Washington, D.C. to serve as a Program Director at the National Science Foundation and enjoy being closer to her children and grandchildren. We will miss you, Ann, and appreciate your contributions to UC Davis, the SBC and Seed Central!
Scientific Publications by SBC Researchers

SBC Team

Allen Van Deynze
Research Director

Joy Patterson
Program Representative

Julie Tillman
Program Representative

Kent Bradford
Director

Phyllis Himmel
CPPSI Director

Rale Gjuric
Education Director

Rebeca Madrigal
Program Representative

Sally Mohr
Program Representative

Susan DiTomaso
Associate Director
PARTNERSHIPS FOR THE FUTURE

Charting the future of agriculture research

A message from Andy LaVigne

We find ourselves entering a time like no other in the history of the plant sciences. And from the standpoint of the American seed industry, we find ourselves on the threshold of monumental increases in the evolution of plant breeding. It is truly because of institutions like the UC Davis Seed Biotechnology Center (SBC), and other land grant institutions across this great nation, that we are able to stand here today and see the awesome opportunities that lie ahead for our industry.

The breakthroughs we have experienced in plant biology, genetics, bioinformatics, physiology, genome mapping, agronomy and more, have all played keys roles in the advancements we are seeing employed in the education and research programs across the U.S. and around the world. New and innovative research collaborations between our land grant institutions and private companies, between foundations and global research institutions, and even between colleges and high school students doing science fair projects; we are seeing more support and interest in addressing the many challenges facing our global society.

The plant breeding community has embarked on a major effort to drive the policy initiatives that will impact the future opportunities for developing and employing the ever-evolving techniques used by breeders. An agriculture and food coalition has been formed to provide leadership around how the U.S. government, as well as governments around the world, will address evolving breeding techniques that fall under the umbrella of gene editing, such as CRiSPR-Cas9. Clear and science-based policy will enable researchers across the spectrum to employ these techniques to maximize the potential that lies in plant families and to continue to develop new, innovative techniques in the future. The plant sciences have to be able to continue to evolve and it is imperative that we do not allow misguided policies to stifle that evolution.

In collaboration with the SBC, and several other land grant institutions, the American Seed Trade Association (ASTA) is working to provide extensive information about the evolution of plant breeding, emphasizing the rapid change in the plant science over the last number of decades. Helping people better understand how the science has changed; what those changes mean to developing new varieties; and how breeding techniques are changing as this new information is made available. The involvement of the public plant science and breeding community is key to helping drive this education and outreach process. Communicating how the science has evolved and explaining how the developed information will be employed in the breeding process will resonate very positively in the public and policy arenas when coming from representatives from the public and private breeding communities.

As we have seen over the past 20 years, the general public, policy makers and elected officials have a limited understanding of science in general and the use of technology overall in agriculture. It is absolutely incumbent on the agriculture and research community as a whole to ensure that innovation is not stifled by uninformed or ill-informed individuals who don’t believe agriculture should employ advanced technology in the pursuit to constantly improve the methods used to address the challenges facing agriculture and food production in the coming years.

The relationship that the UC Davis SBC has developed with their counterparts at other land grant institutions and the private sector has been invaluable to our efforts over the years. Their leadership has enabled ASTA to increase funding for the National Plant Germplasm System, ratify the International Treaty on Plant Genetic Resources, and garner additional support for plant breeding programs across the public land grant system and within USDA.
These relationships are going to be even more important in the future. Pressure on the funding mechanisms at the state and federal level will continue to stress the agriculture research structure in the future. It is vital that all levels of the agriculture community take the time to communicate the importance of agriculture research and development, and ultimately the employment of discoveries into use in farmers’ operations. Any time an opportunity arises – local Rotary Club meeting; talking to a seatmate on a flight; giving a presentation to a child’s class; talking to teachers in a local school – to talk about the wonders of plant breeding, and the science that supports those miracles, we have to take that opportunity. Don’t pass it up, because someone else may take that opportunity and you may not like how they talk about what you do for a living!

Over my time at ASTA, I have had the great fortune of visiting many of our land grant institutions across the U.S. I continue to marvel at the excitement I have seen in the young men and women involved in the plant sciences at those institutions. They realize that they are part of an evolution that will impact so many parts of our lives by employing the knowledge of their predecessors, professors, peers and themselves to address the agricultural, food, natural resources, global warming issues that confront us today and in the future. I applaud the SBC for taking such a strong, active role in driving that future to ensure their current and future students, as well as researchers, professors, farmers and many others, can be part of a vibrant and EVOLVING plant science world.

Andrew W. “Andy” LaVigne
President & CEO
American Seed Trade Association

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