W1168: Environmental and Genetic Determinants of Seed Quality and Performance

The annual meeting of the W-1168 meeting was convened in Davis, CA on September 15 and 16, 2007. The goals of the meeting were two-fold, and as such, did not conform to the traditional presentations of state reports, but rather was geared to 1) participating in the success of the penultimate W-1168 goal of organizing an integrative seed science symposium, and 2) formally initiating the process that will lead to submission of a new project outline to over the period from October 2008 through 2013. Both goals were met.

Over the past three years, W-1168 members substantially contributed to the organization and presentation of the four-day symposium (September 17-20, 2007) "Translational Seed Biology: From Model Systems to Crop Improvement", hosted by the UC Davis Plant Sciences Department (see website for details: www.plantsciences.ucdavis.edu/ seedsymposium2007/). Invited speakers included W-1168 members, as did moderators, and most members attended this important milestone meeting. W-1168 developed guidelines for recognizing young investigators and their contributed posters, and awarded multi-author signed copies of the new book edited by Bradford & Nonogaki entitled ”Seed Development, Dormancy And Germination” as prizes at the symposium banquet. Over 300 scientists from more than 15 countries were in attendance, and the symposium was a demonstrated success.

The balance of the W-1168 meeting was devoted to discussion of future activities, including developing a revised project outline. The following text was developed from these discussions to set the tone for the project renewal:

“Seed quality is reduced by adverse environmental conditions during seed development, by innate biochemical mechanisms that delay or prevent germination, by the lack of seedling vigor, and by loss of viability in storage. The biochemical, physiological, genetic, and environmental processes influencing seed and seedling quality and performance are complex and vary by plant species, but likely share some common biological underpinnings. Biological processes in seeds need to be understood to reliably achieve stands of established plants that thrive for their intended end-uses. Seed costs are increasing and represent a substantial recurring investment to agricultural producers. A broad research portfolio is needed to bring sound scientific results to problems that impact the global competitiveness of the U.S. seed industry, food production, commercialization of advanced technologies, protection and restoration of environmentally sensitive habitats, and the deployment of non-traditional plant species for fuel and non-traditional uses.

Seeds are the foundation of agriculture. They are critical, strategic resources in commerce and civilization. High quality seeds are needed to produce food, often from plants bred for improved yield and nutritive value. Further, seed propagules are increasingly important to renew and rejuvenate degraded habitats, provide aesthetic and non-food products, and satisfy fiber and fuel needs. Seeds of weeds and invasive plants cause economic and environmental distress. Seeds are the most economical means to preserve genetic resources for the future. And seeds are the delivery system for improved products generated through genomics and biotechnology. This multistate project is unique; it focuses on seeds as inputs to natural and agricultural systems, particularly seed quality as it affects attainment of a high quality final product.

Seeds are the primary, ultimately the sole, entities for propagation of food, feed, fiber, bio-fuel, and ornamental plants. America produces copious quantities of seed to grow a vast array of plants whose natural and agro-ecological niches are exceptionally diverse, in environmental conditions that are not always favorable for their germination, emergence, establishment, and persistence. The underlying principles that influence successful plant propagation are biologically based, as are the solutions to overcoming problems that limit establishment of desirable species. Whether at the level of the individual seed, variety, field, habitat, or ecosystem, the needs for seed biology research transcend individual geographic regions. This multistate project has had, and will continue to have, an important role in capitalizing on research opportunities that successfully address the myriad biological processes that enhance seed performance. Many productive research collaborations have been initiated through this multistate project, and the wide array of seed biology areas of expertise among W-1168 participants synergistically stimulates new approaches leading to relevant new biological insights and fosters technical innovations applicable to the wide range of crops and species that comprise the work of multistate project group members.

Our stakeholders are those that produce and use seeds. These stakeholders need high quality seed to produce food, feed, fiber, bio-fuel, and other plant products, as well as validated information with which to produce high quality seeds. They include academic, commercial and government sector scientists, seed producers, agronomists, horticulturalists, land and natural resource managers, educators, extension agents, government agencies, and all industries that deliver seed to growers. Members of the W-1168 Multistate Project are educating the current and future generation of scientists and technicians that will form the core leadership in the U.S. seed industry in the future. The need is to maintain the high standard of seed quality and performance that is a hallmark of U.S. crop production, which has made the U.S. crop seed industry the recognized leader in the world with annual sales exceeding $5 billion annually, and to encourage adoption of similar standards and enhancements to other species with rising economic potential. Not all species respond equally to the breadth or intensity of available seed technologies, and research is needed to achieve the best balance of treatment cost and seed performance appropriate for the stakeholders' desired uses. The percentage of the total cost of producing a crop has become increasingly focused on the cost of the seed so that, in some crops, seed costs are now upward of one quarter of the total cost of producing a crop. Every farmer is sensitive to the need for rapid, uniform seedling emergence because it is the foundation on which stand establishment is based and potential yield is determined.

Renewed emphasis is being placed on maximizing the quality and performance of seeds to meet the demands of new technologies. For example, the physiological quality of seeds is of increasing importance in conservation tillage and revegetation programs, where seeds are often planted in hostile environments under adverse seedbed conditions. In these cases, establishment and survival of the seedlings is the most crucial step in the success of the entire enterprise. Rapid advances in biotechnology and genomics underscore the importance of maintaining all germplasm resources indefinitely into the future. These genetic resources, preserved in seeds, will provide the diversity upon which future advances in agricultural productivity will depend. Germplasm preservation assumes renewed importance since all genes are now potentially available for utilization in crop improvement. Seeds also deliver plant technology to the field. Farmers are required to invest greater capital in seeds that incorporate value added treatments such as priming, coating, optical sorting, or value-added traits. The benefits of these sophisticated technologies can best be utilized if seed performance is optimized.

Both foreign and domestic seed companies maintain production and research facilities at various locations throughout the U.S. due to the climatic diversity, the ability to produce high quality seed, skilled farmers who specialize in seed production, and the size of our domestic markets. Seeds are increasingly produced in one location and marketed in another. This interstate and global commerce requires a high quality product capable of withstanding the rigors of shipment and storage and performing reliably under a diverse range of field conditions. Meeting these demands requires cooperative research efforts in both production and utilization locations.

U.S. agriculture is the most competitive and productive agricultural industry in the world and is heavily dependent on the quality of the seeds on which it is based. Risk exposure to poor seed quality, even in the background of superior germplasm, is enormous and would result in disruptive economic and social consequences accompanying yield reductions such as fewer exports, higher food prices, or localized commodity shortages. The concept and provision of seed quality is well defined for most familiar agronomic and horticultural crops, but by no means optimized or evenly applied across species. Adoption of seed and seedling quality metrics is important for all utilized plant species. Since such metrics are necessarily species specific, research is needed at the species level, as well as at the cellular level where many genetic and environmentally responsive biological processes share common underpinnings but diverse effects. Exploiting traditional or non-traditional species for novel uses, such as those being developed for bio-fuels or high value oils, requires examination (or reexamination) of seed quality metrics to ensure growers and producers have the best chance of providing a high quality product to the consumer. Interruptions or inefficiencies in this supply chain have demonstrable economic consequences, and can be partially ameliorated by careful scientific attention to seed quality and performance. Loss of genetic resources and diversity through habitat destruction and supplanting traditional varieties and local species could have a long-term impact on the progress of plant improvement.

The unique biology of seeds as life in a suspended state and the specialized nature of the seed industry have given rise to Seed Biology as a distinct scientific and technical discipline. During the last three decades, this discipline has provided the American seed industry with the biological understanding and technical expertise needed to deliver a stable supply of the finest seeds to the U.S. agricultural industry and the world market. Most of the crops contributing to the annual U.S. agricultural productivity are grown from seeds, and the seed industry is a significant agricultural sector in its own right. In addition, exports of agricultural seeds are responsible for a positive balance of trade for the U.S.

There is a documented decline in the number of seed scientists graduating from land-grant universities, as well as a decline in the number of seed scientists charged with educating the next generation at these institutions. This is creating a gap of expertise in the seed industry and a declining capacity to meet this need. For instance, 44 seed science faculty in 16 land-grant institutions graduated 183 students between 1990 and 2000, but declining support resulted in only 35 students trained in seed science from 2000 to 2005, with a loss of nine faculty and three states with active seed science programs. With declining in-state programs, it is critical to view seed science research in a national context. The expertise of the state programs is also changing with an increasing focus on basic seed biology, as well as an increasing attention to non-crop plants in the environment. Preparation and delivery of high quality seed technology as a traditional focus has largely been successfully ceded to the dominant seed production industries; however, these industries also benefit from new approaches and research. The advantage of a multistate project is to integrate disparate activities and to leverage information gained from current state programs across the wide range of species and problems faced by seed producers and users nationwide. This multistate project serves as the only mechanism to unify seed science research across the U.S., bringing the national seed science expertise to bear on problems of local and regional significance.

This Regional Research Project was originally initiated in the Western Region over 35 years ago due to extensive seed production of horticultural, forage, and native species concentrated in this region. For example, seeds of cool-season grasses, carrots, beans, alfalfa, sweet corn, and cole crops are produced in the Pacific Northwest. Diverse vegetable and flower seeds as well as rice, wheat, hybrid sunflower, cotton, and clover seeds are grown in California and the Southwest. The importance of seed production extends beyond this geographical area, as the U.S. is a major world producer of cereal and oil seeds as well as forage, vegetable, and flower seeds. Seeds are produced throughout the U.S. and are utilized throughout the world. Soybeans, corn, and sunflower seeds are grown in the Midwest. Revegetation shrub and chaffy grass seeds are produced in the Great Plains states. Peanut, cotton, and fir tree seeds are produced in the Southeastern states. These examples of the diversity of seed production throughout the U.S., and the lack of any other regional projects devoted to seed biology or technology emphasize the role this project has played at the national level.

Despite the diversity of species and locations involved in this project, fundamental aspects of seed biology are common to all. For example, while some patterns of gene expression and the accumulation of storage products are shared across species, understanding these processes requires an array of examples, due to the diversity of mechanisms and adaptations possible. Measurement and enhancement of seed quality presents similar challenges and opportunities regardless of the species or location. It is precisely by examining seed biology from diverse perspectives, from the ecological to the molecular, that the entire biological picture becomes clearer and specific applications can be devised.

Developing solutions to these issues is central to the provision of an abundant supply of high quality seeds for successful stand establishment in agriculture. These issues are also complex, requiring unique skills, equipment and methodologies. Utilizing a multi-state effort by drawing on the expertise of specialized research scientists is the most efficient approach to addressing these issues on a national level. Despite recent advances in understanding the molecular biology of seeds, relatively little is known about how seeds germinate, why some seeds germinate better than others, why some seeds germinate before harvest, what causes dormancy, and why seeds die in storage. New fundamental knowledge about mechanisms underlying seed development, germinability, and storability is required to solve these challenges. Seed performance must be improved: (1) For the U.S. to maintain our global competitiveness as an exporter of seeds as propagules; (2) to help increase food production in the next century; and, (3) to take full advantage of advanced technology. A clearer understanding of how environmental factors affect seed performance in natural as well as agricultural ecosystems is needed to ensure the continued vitality of native plant populations and the productivity of cropping systems. Successfully completing the stated objectives will provide not only an increased understanding of the factors that influence seed biology, but also improved seed performance in the field.

We are using the latest technologies, and improving existing as well as developing new techniques to investigate the central questions of seed biology and seed delivery systems. To ensure that end users have an abundant supply of high quality seeds, this proposal has established three objectives:

1. Identify and characterize biophysical, biochemical, genetic and environmental factors regulating or influencing seed development, germination, vigor and dormancy.

2. Determine and model the biotic and abiotic factors affecting seed germination, seedling emergence and establishment of sustainable populations in natural and agro-ecological systems.

3. Develop, evaluate and transfer technologies to assess and improve seed and seedling quality, health, performance, utilization, and preservation.

These objectives are necessarily broad and reflect the diversity of stakeholder needs, the gaps in current knowledge that can be addressed by new technologies such as genomics, and the promise that proven and new technologies can yield practical solutions to complex seed biology issues relating to seed dormancy and germination, seedling vigor, and establishing or re-establishing high plant stands for all species in their respective applications. In most cases, the technical feasibility of the research procedures is proven as standard practice in the case of field-oriented research, or as an extension of established genetic, biochemical, and physiological principles. Results from genomic and proteomic approaches will likely yield new insights for practical application; however, there will likely be a time lag between discovery and adoption beyond the scope of this proposal.

Members from 11 states are working on projects that relate to Objective 1, five states' activities address issues relating to Objective 2, and nine states have technology transfer projects with major focus on Objective 3 goals, with primary attention to more than 25 distinct species as their model systems. These objectives are not mutually exclusive, but represent the continuum between basic and applied research in meeting seed user needs for the future. We are one of the longest running multistate working groups in the USDA, with origins in the late 1970s. Our members are internationally recognized authorities on seed science, with many demonstrated accomplishments including two major seed-oriented symposia in the last five years, dozens of books and book chapters, hundreds of peer reviewed journal articles, and deployment of a series of on-line educational courses. Within the present group, at least 30 collaborations have yielded demonstrated results, and many additional projects are ongoing and planned. It is highly likely that the future feasibility of achieving successful results through multistate collaboration is assured, given the prominence and productivity of the members of W-1168 in the recent past, as well as over the history of this multistate activity.

The projected impacts from completing this proposed work are as varied as the interests, issues, and species contributed by the members of the W-1168 multistate project. One major impact of the proposed work results from coordinated research results across species and applications, that is to generalize the innate biology of seeds as a first step to deploying improved technology to the end user. Progress on understanding the basic intrinsic mechanisms involved in seed development and limiting stand establishment is expected, as are the role(s) of specific genes, the environment, and their interactions. We expect results to increase efficiency and cost effectiveness of habitat restoration. Results will help to understand biological processes involved in seed dormancy and longevity, and germplasm preservation and the maintenance of species diversity. Significantly, transfer and development of seed technologies for the establishment of bio-fuel crops is essential for their widespread adoption, and progress is expected through collaborative efforts among members of this multistate project.

The primary biological purpose of seeds is to propagate the species by successfully completing germination and resuming plant growth. Native species have innate mechanisms that regulate their potential for germination, often delaying or timing germination to coincide with optimal conditions for growth. Domesticated crops have lost some, but not all, of these mechanisms, and there has generally been strong selection for rapid and uniform germination of crop seeds. Production of high quality seeds is fundamental to the success of U.S. agriculture. The breadth of W-1168 research is one of its strengths because seed biologists with diverse interests, ranging from molecular biology to ecology, can share their expertise. Multistate Research Project W-1168 provides an interdependent structure within which seed scientists across the U.S. can attain critical research objectives, focus and combine their efforts on projects of mutual interest to solve problems, discuss and critique results and hypotheses, and contribute to expanding scientific knowledge."

Other discussion:

A matrix was constructed (see p. 8 below) that reflects the individual seed science activities of each of the states participating in W-1168, as represented by members in attendance. Activities were divided as to Objective, Topic (broadly defined by focus of the individual program), Methods used, and Species employed. This list is not comprehensive, but is meant to highlight the diversity of the member's programs as well as to focus on the similarities that justify a multistate approach to problems addressable by seed science and technology. Of particular interest were a number of states involved in seed quality and stand establishment related to biofuel crops, and also the number of states involved in either habitat restoration or preservation (e.g. limiting invasive species spread).

The group identified on-going or planned collaborative projects between W-1168 members. For Objective 1, 15 projects were identified that have Multistate components. For Objective 2, five projects were enabled by Multistate collaborations, and for Objective 3, 10 projects have Multistate interactions.

In summary, this meeting was very productive in terms of information gathered and disseminated. Scientifically, the symposium was second to none in providing current, detailed perspectives across the whole range of seed biology topics. Administratively, the meeting set the stage for the next five years by highlighting current broad research activities of the W-1168 membership and solidifying research linkages between many members.

State / OBJECTIVES	CA	FL	IA	KY	LA	MI	OH	OR	TN	TX	VA	WA	NY	UT
Objective 1	X	X	X	X	X	X	X	X	X		X	X		X
Objective 2		X		X			X	X			X			X
Objective 3 TOPICS	X	X	X	X	X		X			X	X	X	X	X
Biofuels		x		X				X	X				X	
Desiccation tolerance				X	X							X		
Dormancy	X	X		X	X		X	X	X		X	X		X
Ecology		X		X	X									X
Emergence/establishment		X		X	X	X	X	X		X	X	X	X	X
Enhancement	X		X	X			X		X				X	
Genes	X			X		X		X	X		X	X		X
Germination	X	X		X	X	X	X	X	X	X		X		X
Hormone regulation	X			X				X	X	X		X		
Invasiveness							X							X
Oxidative stress	X			X	X	X					X			
Performance (broadly defined)				X	X			X		X			X	X
Restoration/endangered				X	X						X			X
Seed composition	X							X						
Seed development		X		X	X	X	X	X						
Seed health			X		X	X	X							
Seed structure	X			X							X			
Seed testing		X	X	X			X				X		X	
Seedling development						X				X	X			
Storage	X			X		X								
Stress			X	X	X	X				X		X		X
Transplant quality							X			X			X	
Vigor/viability METHODS	X	X	X	X	X	X	X	X			X		X	
Biochemistry	X		X	X	X			X				X		
Comparative physiology				X	X									X
Composition	X													
Computer technology			X	X			X			X				X
Education/extension	X	X	X				X	X					X	
Enzymology	X			X										
Field testing		X		X		X	X	X		X			X	
GC/MS				X	X									
Gene expression	X			X		X		X	X		X	X		X
Genetics	X	X	X	X		X		X			X	X		X
Health testing							X						X	
Microscopy	X	X		X		X					X		X	X
Physiology			X	X	X		X	X		X	X	X	X	
Priming	X	X		X			X		X	X				
Proteomics	X			X	X									
Tissue culture	X			X							X			

Transformation	X	X		X				X						
Vigor/viability testing SPECIES	X	X	X	X	X	X	X	X	X	X			X	
Arabidopsis				X				X			X	X		
Canola				X				X						
Carrot		X						X						
Endangered species				X										X
Invasive species							X							X
Lettuce	X	X					X							
Maize		X	X				X							
Native forbs		X		X							X			X
Native grasses		X		X			X		X				X	X
Orchids											X			
Pepper										X				
Phragmites							X							
Sneezeweed											X			
Sorghum	X													
Soybean			X	X			X							
Spartina					X									
Specialty crops	X	X	X				X	X		X	X		X	
Sugar beet						X								
Tomato	X			X			X	X		X	X		X	
Trees				X										
Turf grasses								X						
Watermelon Wheat			X								X	X		