Abstract. Plant breeding is the process of creating genetically elite plants. It entails multidisciplinary research through which diverse technologies and knowledge are ‘translated’ into improved genetic types that enable production of more and better food, feed, fibers, fuel, raw materials, and countless valued-added products. Ramifications include our health, environment, social and economic stability, national security, energy independence, science and technology, i.e., our future. The scientific impact of plant breeding includes [1] discovery of new biological, agricultural and genetic phenomena, and/or their usefulness [2] development and/or establishment of new scientific knowledge and technologies; [3] ‘translation’ of scientific knowledge and technology into products that tangibly benefit US society; and [4] production of a capable and relevant scientific workforce. Our Nation’s level of investment in the applied, or so-called “conventional,” aspects of plant breeding is, however, in jeopardy. While significant funding and resources have been devoted to biotechnology and genomics-based plant biology programs during the last decade, funding of applied breeding, which largely translates the results of our ‘omics’ investments into products used by consumers, has diminished. To better capitalize on the ongoing revolution in molecular genetics and genomics, the US must re-invest in hands-on plant breeding and in the integrated education needed to produce professional plant breeding researchers and practitioners capable of assimilating advances in sciences and technology related to crop improvement. The need for applied breeding and capable plant breeders is mounting quickly domestically and internationally, as suggested by growing numbers of alarming media reports of insufficient availability, access, and affordability of food and other ag-derived necessities. Domestic advances in plant breeding research and education are needed to meet the six goals of the USDA’s Strategic Plan FY 2005 – 2010: 1) Enhance international competitiveness of US Agriculture; 2) Improve sustainability of rural farms; 3) Support increased rural economic opportunity and quality of life; 4) Enhance protection and safety of US agriculture and food supplies; 5) Improve US health and nutrition; and 6) Protect US natural resources and environment. Government comprehension, leadership and action are needed to establish a sustainable solution now, before it is too late.

Needs for Public and Scientific Awareness. Humans and most other animals are entirely dependent on plants, yet most US citizens are unaware of the profound ramifications of plants, plant breeding and breeding-related research in their daily lives. Over 98% of the US crops, managed forests and ornamentals result from plant breeding. The raw-product value of crops alone is about $100B/yr, and, of course, much higher in terms of economic impact, due to multiplier effects and the values of processed goods. Yet, consistent access to cheap groceries and store-bought products has left most US inhabitants with little cause to contemplate the importance of plants, much less plant breeding, or breeding-relevant sciences and technologies. The availability and affordability of countless items that we routinely don, consume and use, have blinded us to bigger issues, such as how essential plants are to the productivity of our economy, health, and environment, and the ever-present danger of social upheaval when shortages arise.

Given that most scientists also grew up and now live in urban areas, it is thus not surprising that they too have relatively little comprehension of the manners by which breeding programs advance, use and justify basic science and technology research. For example, the agricultural use of a new genetic trait, whether natural, induced, or man-made, usually requires that it be bred into existing or new elite-performing genetic types. Breeding and requisite seed increase typically require 5-6+ generations years, after which a few years of replicated trials at multiple representative locations are needed to firmly establish which, if any, of the best genetic products is acceptable as a “cultivar”. Given the monetary risks required for crop production, neither producers or insurers, large or small, can risk growing a new genetic type that has not been tested extensively. A single major weakness in a cultivar released for production can lead to a failed crop and a financial catastrophe for the producer’s family, and consumers in general.

Even though the economic, scientific and societal impact of plants and plant breeding remains huge, political leadership for securing necessary programmatic funding has been insufficient. This is due in part to the limited awareness of plants and plant breeding in the general population and most other scientists. Nonetheless, the needs for applied breeding and related research are both numerous and expanding, as exemplified by...
new crop diseases and pests (e.g., soybean rust, citrus greening, cotton root rot, wheat stem rust), the need for cost-effective biofuels, excessive trade imbalances, expanding acceptance of GMOs, and expanding consumption of non-GMO organic produce. Insightful action and US leadership are needed now, if we are to be able to breed the genetic types required for agricultural production this decade, and especially subsequent decades.

Past, Present & Future? In times not so long ago, the US rural-agrarian population was proportionately much larger, so the relevance and need of plant improvement were more widely understood. Though exact solutions were less than clear, the government established programs to stimulate integrated research, education, and extension, including applied research. Among the most important were Morrill Land Grant College Acts (1862, 1890), Hatch Act (1887) and Smith-Lever Act (1914). These programs led to phenomenal improvements in plant productivity and production, greatly increasing US disposable income. The resulting expansion of consumer spending helped drive US economic growth in all other sectors for more than 100 years, and continues today.

Fears of massive famine in the 1950s and 60s refocused attention on breeding at domestic and international scales. One result was the renowned "Green Revolution", which combined high-yielding plant genotypes with integrated cultural and economic strategies.

Success, abundance and fading cognizance have unfortunately led to complacency, and thus a steady decline of national investment in applied plant breeding over the last 20 years. This has seriously compromised even the strongest of university education programs. Public investment levels have waned, hands-on breeding programs have been reduced or dropped, production and testing of new genetic combinations has fallen, and the numbers of applied breeders trained has dropped (Guner and Wehner, 2003; Knight, 2003; Baenzigar, 2006).

International business, science, political, medical and news articles report disturbing shortages of food, increased commodity prices and even civic unrest, as the demands for plant-derived products continue to escalate and compete with each other. Given that natural resources are limited and increasingly stretched to their limits, the recent problems may portend of much more severe problems to come. Moreover, we are facing additional major challenges of water and fertilizer shortages, drought, salinity, erosion, heat, carbon-balance and other ecological concerns, economically stimulated increases in demand, high fuel costs, and food-biofuel competition. We are less prepared than we should be to use breeding to address these needs, due to a shortage of applied breeding programs, inadequate monetary support and a shortage of plant breeders with the requisite skills to translate “upstream” advances in the laboratory into new crops “downstream” to benefit humanity.

Stable, Multi-year Support. It is essential that support of core breeding program activities be sustained rather than sporadic. Short-term sporadic funding does not provide a sufficient basis for plant breeding or plant breeding education. Breeding requires multiple generations and thus years. In fact, high quality breeding and educational programs take decades to develop. The US and, indeed, the world must reinvigorate and be more consistent in maintenance of applied plant breeding. Loss of sustained support for applied breeding programs has already led to terminations or redirection toward other scientific disciplines, and undercut our ability to address national and regional needs.

The need for breeding and breeders cannot be dismissed, because our agricultural system requires both. Without consistent efforts to genetically ameliorate plants, modern agriculture would quickly succumb to the onslaught of constantly evolving pests and pathogens, such as wheat stem rust. Moreover, it would be unable to respond optimally to many other needs, such as more efficient water usage, improved heat tolerance, extraction of soil contaminants for land reclamation, enhanced nutrition, enhanced storage life, improved processing quality and the production of renewable biofuel feedstocks.

Complementarity of Biotechnolgy & Breeding.

Many of the potential plant-related benefits from modern biotechnologies rest on principle that they enable unique and/or faster genetic improvements. For instance, it is becoming increasingly feasible for a breeder with excellent plant performance data to genetically “dissect” observed variation for a given trait to identify those genomic regions with the greatest effects, and subsequently use the markers to select for/against desirable/undesirable genes and/or that collectively govern much of the variation...
in complexly inherited traits. The greatest bottlenecks in this process are obtaining good plant performance data, i.e., field research and related phenotype evaluation data, and having sufficient resources to couple those with high-throughput genomics. In virtually all cases however, the realization of such benefits require plant breeding. While there are situations for which genetic engineering offers solutions superior to those available from natural genetic variation, but once artificial genes are built, they must be incorporated into a recipient’s genome (transformed), shown to be stable and properly expressed, and bred it into agriculturally acceptable types. In other words, breeding is typically vital to usage of artificial genes, too.

Breeding as Part of the STEM Landscape. Lee and Dudley (2005) describe a plant breeder as the ultimate systems biologist. The associations between basic scientific research disciplines, STEM initiatives and contemporary plant breeding are extensive, generally bi-directional and synergistic, i.e., plant breeding leads to scientific and technical advances, and vice versa. Plant breeding research and practice entail detailed knowledge, experimental manipulation, and repeated observation of large numbers of genetically diverse plants at all stages of their life cycle, and in numerous environments. Being inherently multi-disciplinary, breeding-research teams often involve close working relationships between breeders and scientists with highly specialized training in STEM disciplines, such as taxonomy, phylogeny, reproductive biology, development, anatomy, physiology, biochemistry, pathology, entomology, nematology, genomics and bioinformatics, all aspects of genetics, genomics, statistics, biology, agricultural and process engineering, post-harvest physiology and processing, nutrition and medicine, business management, intellectual property management, and marketing.

Like many of our other technology-dependent industries, plant breeding requires a steady stream of students savvy in the STEM disciplines who will become “the next generation” of breeders. However, due to reduced funding and an aging populace, this system is also in jeopardy. In a survey conducted from 1995 to 2000, Guner and Wehner (2003) found that plant breeding students were trained at about 40 land-grant universities, about half at only six institutions. In reviewing this work, Bliss (2006) posed the question “Will the universities who have had strong programs in the past continue and make programmatic changes required for future breeding training?” Unfortunately, the answer to this remains uncertain.

The immersion of hands-on breeders, their colleagues, and their students into their individualized crop-specific worlds of natural and synthesized populations, agriculture, science and technology, is critical to the scientific discovery and scientific educational process. The hands-on work of breeding creates unique opportunities to identify unexpected results, new phenomena, biological constraints, technical bottlenecks, resource needs, knowledge gaps, and other opportunities ripe for new discoveries in STEM. As a metallurgist blends a superior alloy, plant breeder scientists and practitioners meld exceptional genetic end-products from related disciplines, e.g., pathology or biotechnology, into superior genetic packages that can agriculturally out-compete existing cultivars, i.e., they are the key translational “pipeline” and,
Indeed, a critical "lifeline" to a sustainable future.

**Funding – A Critical Need.** Historically, breeding has helped define targets for basic research, and vice versa. Plant breeding has also provided a means to utilize scientific and technological advances in the many disciplines, and helps economically and politically justify investments to conduct basic research. Now, however, US programmatic infrastructure for plant breeding is in deep trouble, due to decades of progressive redirection, diminution and elimination of programs that historically supported applied plant breeding and applied breeding research.

**Reliability and duration of funding.** Pursuit of high degrees of accountability and agility in funding new areas has contributed to the progressive reliance on short-term (1-5 years) competitive grants programs for funding research. While accountability and agility are very desirable, the inherently short-term and erratic nature of competitive funding are especially poorly suited to "core" elements of a breeding project, which require sustained, reliable support. Applied breeding projects are minimally 5-yr, and most often 7-10, and often >10-yr processes that require uninterrupted core support for supplies, facilities, personnel, machinery, fees, travel, and so on. Exclusive reliance on short-term funding mechanisms is thus not a viable option for a hands-on breeding program. Increased funding, including a mixture of sustained and competitive funding, however, could provide an optimal combination of attributes. Competitive funding mechanisms, for example, might be applied to educational and ad hoc breeding/research elements, i.e., supplementary and complementary to sustained core breeding program support.

**Research novelty versus utilization.** Currently, competitive grants programs for science and technology are targeted primarily at novelty, be it intellectual and/or experimental. This paradigm lends itself very well to “upstream” basic research, particularly with model organisms, especially those with short generation times. But the penchant placed on novelty precludes the funding of most applied breeding programs, because most applied breeding activities rely on extrapolated usage of a previously established facts or approaches to accomplish something of practical importance, irrespective of novelty. In many breeding programs, the greatest need is for cost-effective, and time-efficient “downstream” applied laboratory and field breeding methods. Technical and scientific novelty, per se, are not as important as usefulness. In fact, ideas and techniques that are the most portable across crops, and thus potentially the least novel, may be the most important, e.g., hybrid vigor, photoperiod insensitivity, early maturity, lodging resistance and thornlessness.

To support applied breeding research and education programs, the US needs to significantly ramp up its breeding investments, including [1] sustained support of core breeding programs, and [2] competitive and other forms of ad hoc project funding. The core programs must provide a stable framework for tackling major crop x environment needs across regions and states, and the competitive programs must target complementary and urgent ad hoc needs. While novelty is desirable, the greatest emphasis for applied breeding research should be on usefulness and bringing value to our society, i.e., the development of new crops and bio-based products to address our Nation’s increasing needs for balance-of-trade, food, feed, fiber, fuel and many other items.

**The need for leadership.**

Many plant breeding programs, expertise, germplasm and associated research resources have already been seriously weakened, and many others are at risk. Training the next generation of plant breeders and maintaining the public programs that conduct breeding work on the specialty crop (i.e. fruits and vegetables) is of particular concern. In some cases, the loss of a single breeding program can be devastating. Some are irreplaceable, and others will require decades or more, e.g., forest breeding, to replace. Further losses really are not an option, and action is needed. Given that our preponderantly urban population is largely unaware of our reliance on plants or plant breeding, strong government research program stewardship and leadership are needed to bolster and sustain programmatic support of hands-on US public plant breeding, and re-establish, monitor and even orchestrate breeding-compatible funding mechanisms.

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