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Dedication: Kenneth J. Frey Oat Breeder, Educator, and Champion of Plant Breeding

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Plant Breeding Reviews, Volume 34 Edited by Jules Janick

I. INTRODUCTION

Kenneth J. Frey was born in a small midwestern farm during the Great Depression of the 1930s and became an outstanding oat breeder and an internationally known educator at Iowa State University. His conviction that the gene pool of cultivated oats had become too narrow to allow breeders to maximize the usefulness and value of the crop led him to explore different approaches to using related wild and weedy species in oat improvement. This research developed novel oat populations and intrigued many a student to study oats for their graduate research. He trained more than 100 students in the areas of plant genetic resources, introgression breeding, and breeding methods research. At one point in the 1970s, four out of five National Science Foundation fellows on the Iowa State University campus worked under Frey. The university's continued support for the oat breeding position was surely in part because of the students who emerged from his program. One might say that students were his main crop.

So widely were Frey's students placed that for many years at the peak of his career, he had more close professional contacts across public and private sector plant breeding in the United States than probably any other person. One result was the U.S. National Plant Breeding Study (NPBS) of 1994, a unique comprehensive summary of the human resources, crops, and breeding approaches in both public and private plant breeding (Frey 1997a). The NPBS has become a baseline resource for U.S. plant breeding policy setting. Together, the work of Frey's students and the impact of the NPBS are unique legacies, benefiting all crops and future generations.

Frey's use of wild species germplasm for crop improvement may exceed any other body of work on a self-pollinating species (J. Holland pers. commun.). Frey was convinced that cultivated oats had a narrow germplasm base in North America, based on historic information and on observation. He noted that useful resistance genes to crown rust (*Puccinia coronata*) from cultivated sources had been depleted by 1960 and that genetic improvement for yield in oats was slow compared to other crops (Frey 1992). This was of concern because the agriculture of the central midwestern plains of the United States needed a crop like oats. As a rotation crop with corn and soybeans, oats disrupt weed and pathogen life cycles and protect fields from soil erosion. Oats also leave a late-summer window of time that livestock producers need to spread manure on fields before the winter (J. Martin, pers. commun.). In practice, however, farmers also need productive, healthy oat varieties that bring a good price. Frey's work on germplasm development in oats was always focused around the dual goals of increasing crop health and productivity and of increasing crop value.

Breeders of other crops have used wild species resources for specific traits, such as disease resistance, but generally have concentrated on single traits introduced via backcrossing. Backcrossing minimizes the introduction of genes from a wild donor, other than at the target locus region. In contrast, Frey developed a number of broad-based populations incorporating large amounts of *Avena sterilis* germplasm to create enhanced breeding pools. This use of wild species for quantitative traits enhancement is rare in self-pollinating crop species (J. Holland 1997).

II. EARLY LIFE AND CAREER BEGINNINGS

K. J. Frey was born in Michigan on March 23, 1923. Although Frey's parents had only completed eighth grade, his family valued education, and he and his brother were encouraged to do well in school. Frey attended high school in Vermontville, Michigan, one of a class of 19 students. The school did have an ag major—that is, a series of classes in agriculture. There was talk of Ken going to college afterward, but there seemed little chance. The family had lost their farm due to foreclosure in 1933 and had to rent land to make a living. Frey's mother augmented their income by working in a retail store. However, young Ken applied to the state land-grant institution, Michigan State College (now Michigan State University), and was accepted. Tuition was $40 a quarter in those days, or $120 for an academic year (compared to over $10,000 for in-state tuition today). He recalls making ends meet, "... living in a rooming house with 13 other boys, where room and board were $5 a week. Breakfast was cinnamon rolls sent from home by my mother in the laundry bag. The landlady had compassion and made us boys coffee every morning." Ken earned his evening meal by working in the kitchen of a sorority house. During his first spring at school, Ken got a job hoeing weeds in Field Crops Department nurseries, for 25 cents an hour. This was, at the time, "a bonanza," as he described it later. By working 20 hours a week, he had $5, enough to pay for room and board. His second year working for the Farm Crops Department, he was paid 35 cents an hour, a significant raise. In the summers, he was able to save up $200 to $300, a sum large enough to help with expenses the next year. One way or another, he and his parents found a way to get him through college.

In the spring of his freshman year, a genetics class was assigned to all ag majors. Ken recalls that the professor, Dr. Hunt, made the subject fascinating. His research on dental caries in mice had developed two populations, one that never developed caries and the other so susceptible that the young were born with dental caries. As Ken later put it, "The students learned that with time and observation and statistics, one could select for almost anything; and—if it were simple enough—change it. There was no biochemistry in genetics in those days; the DNA story was just beginning and not widely known." During Ken's sophomore year, the assistant dean in the College of Agriculture, Dr. McGee, asked if he were interested in graduate school and introduced him to Dr. Eugene Down, a research professor who became his mentor and guide. From then on, Ken switched to working with plant breeders for jobs during the academic year.

Ken had met Ann Dunlap, his future wife, in his junior year. They both graduated from Michigan State in June 1944 and were married the following May. When Ken was deferred from the draft, Ann encouraged him: "Let's go to graduate school." They considered it a team project. While Ken studied and worked on his master's thesis at Michigan State, Ann worked at the Oldsmobile factory in Lansing making military equipment. As they recollected later, they considered that by working to help Ken get his degree, Ann was helping to build the basis for their future, when she would manage their home and raise their children. After Ken finished his master's degree with Dr. Down, they moved to Iowa State College (ISC), where he earned his PhD with Dr. George Sprague. Ann, too, worked, as a secretary for the ISC dean of engineering. Ken finished his doctorate at age 24, in 1948, and was offered a position at Michigan State with a salary of $4,200 a year—a fine salary for a new assistant professor in those days. Happy to be back in their home state, closer to the parents who had helped make his education possible, by 1952 Ken and Ann had two children and a new house. Then, at the 1952 annual meeting of the American Society of Agronomy, Dr. I. Johnson asked Ken to take a job back at Iowa State. (Notice the lesson of this tale, young readers: Attend your professional society meetings!) At the time, salaries at ISC were not competitive with those at Michigan State University, although this would change as visionary college presidents moved to change ISC to a university. But the job at Iowa would be 100% research, while the job at Michigan was 50% research and 50% undergraduate teaching. Ken had already discovered that he preferred, and was most effective, working with individual graduate students, something that made the ISC position "the" job, the one he had always wanted. A full-time research appointment would allow him to concentrate on what he most enjoyed. He and Ann considered the advantages of Ames, Iowa, as a place to raise a family and made another joint decision to seize the opportunity. The decision turned out to be the right one. Years later, Ken served a two-year term as interim dean but then returned by choice to the work he loved in full-time research and graduate education.

The move to ISC brought Ken Frey into an environment where other disciplines commonly interacted with plant breeding. He began a collaboration with plant pathologists Dr. J. Artie Browning and M. D. Simons and cytogeneticist Dr. K. Sadanaga that was to last for some 40 years, until his retirement in 1993. As a strategy to outwit the rapid evolution of crown rust strains, Frey and Browning first released multiline cultivars in two maturity groups that were available as certified seed in 1968 (Frey and Browning 1976a,b; Frey et al. 1971). These were controlled blends of several near-isogenic lines (Jensen 1952), each carrying resistance to a different strain of crown rust.

Based on his productive career developing innovative ways to provide durable resistance to oat diseases without the use of chemicals and his training of a bumper crop of plant breeding researchers, Frey was named a Charles F. Curtiss Distinguished Professor in Agriculture in 1970. He has continued to be associated with the ISU Agronomy Department as an emeritus professor. Appropriately, the Kenneth J. Frey Endowed Chair in Agronomy was established at Iowa State in 2007. Although not in oat breeding, the Frey chair position is focused, as was Frey's research, on developing new crop traits to bring added value for midwestern farmers. Thomas Lübberstedt serves as the first occupant of the Frey chair, a strategic position in this moment of an emerging bioeconomy that will call for many new plant traits.

III. RESEARCH

A. Multilines for Crop Protection

The multiline concept was first proposed by Jensen (1952) as a mixture of different but agronomically uniform pure lines. Such a cultivar would combine the favorable agronomic aspects of a uniform cultivar with resistance to rapidly changing pathogen populations. The rapid mutability of the oat crown rust pathogen and the depletion of major resistance genes made oats a good candidate for testing the multiline concept in practice (Frey 1992). With collaborators Browning and Simons, Frey developed and released the first multiline cultivars (Table 1.1), one early and one midseason (Frey and Browning 1976a,b; Frey et al. 1971, 1973, 1985). They backcrossed crown rust resistance genes from *Avena sativa* and the related wild species, *A. sterilis*, conferring resistance to various races into a common, agronomically superior

Table 1.1. Cultivars and germplasm released by K. J. Frey.

Name	Year	Citation
Bonkee Neal	1964, 1967	Knott, O.A., K.J. Frey, and A. J. Browning. 1963. Two new oat varieties for 1964 – Bonkee and Neal. Iowa State Univ. Ext. Pamphlet 297. Frey, K.J., J.A. Browning, and R.L. Grindeland. 1967a. Registration of Bonkee oats. Crop Sci. 7:168.
O'Brien	1967	Frey, K.J., J.A. Browning, and R.L. Grindeland. 1967b. A new variety. O'Brien oats. Iowa Farm Sci. 21:7–8.
Multiline E68 Multiline E69 Multiline E70	1971	Frey, K.J., J.A. Browning, and R.L. Grindeland. 1971b. Registration of multiline E68, multiline E69, and multiline E70 oat cultivars. Crop Sci. 11:939.
Multiline M68 Multiline M69 Multiline M70	1971	Frey, K.J., J.A. Browning, and R.L. Grindeland. 1971c. Registration of multiline M68, multiline M69, and multiline M70 oat cultivars. Crop Sci. 11:940.
Grundy	1972	Frey, K.J., and J.A. Browning. 1972. Registration of Grundy oats. Crop Sci. 12:256.
M isolines as parental lines	1973	Frey, K.J., and J.A. Browning. 1973. Registration of M (midseason) series of isolines of oats as parental lines. Reg. Nos. PL 1-10. Crop Sci. 13:291.
E isolines as parental lines	1973	Frey, K.J., and J.A. Browning. 1973. Registration of E (early) series of isolines of oats as parental lines. Reg. Nos. PL 11-23. Crop Sci. 13:291.
X117	1973	Frey, K.J., J.A. Browning, and R.L. Grindeland. 1973a. Registration of X117 oat germplasm. Crop Sci. 13:290.
Multiline E72 Multiline E73 Multiline E74	1976	Frey, K.J., and J.A. Browning. 1976. Registration of multiline E72, multiline E73, and multiline E74 oat cultivars. Crop Sci. 16:311–312.
Hamilton	1983	National Research Council. 1991. Managing Global Genetic Resources: The U.S. National Plant Genetic Resources System. National Academy of Sciences (K.J. Frey's description of Hamilton is cited on page 33 of this reference).
Multiline E76 Multiline E77	1985	Frey, K.J., J.A. Browning, and M.D. Simons. 1985. Registration of multiline E76 and multiline E77 oats. Crop Sci. 25:1125–1125.
H632-518 + 2 additional lines	1987	Simons, M.D., L.J. Michel, and K.J. Frey. 1987. Registration of 3 oat germplasm lines resistant to the crown rust fungus. Crop Sci. 27:369–369.
Webster	1988	Frey, K.J., M.D. Simons, L.J. Michel, J.P. Murphy, and J.A. Browning. 1988. Registration of Webster oat. Crop Sci. 28:374–375. Frey, K.J., M.D. Simons, L.J. Michel, J.P. Murphy, and J.A. Browning. 1988. Registration of Webster oat isolines as parental lines. Crop Sci. 28:386–387.

recurrent parent. The resulting isogenic lines were combined by mixing seed to form the multiline cultivars.

Frey (1982) described the features of multilines that affect the usefulness and durability of their resistance: Multiline varieties delay the buildup of inoculum during the course of epiphytotics by “spore trapping,” in which spores with particular virulence genes may reproduce on some isolines in the variety, but many spores will fall on resistant isoline hosts. This reduces the amount of diseased tissue over time and, consequently, reduces the amount of yield loss and quality damage suffered by the variety. Multilines theoretically should also maintain their levels of resistance longer than pure-line varieties because they exert stabilizing rather than directional selection on the pathogen populations. Although this claim would be difficult to verify experimentally, Frey (1982) noted that the resistance of the original multiline varieties had not decreased 13 years after their release. The major difficulty in developing multiline cultivars is the extensive backcrossing required, which tends to restrict yield potential of the variety to that of the recurrent parent. After five generations of backcrossing, the recurrent parent might be agronomically inferior to newly released cultivars developed by forward breeding. (This summary of Frey’s work on multilines is indebted to Holland 1997. Readers interested in learning more about the history of oat breeding—which in its early years is also the history of plant breeding—will enjoy Holland’s paper.)

The value of the trade-off between the stable resistance of a multiline versus potential yield increases will be situation specific. One of Browning’s students, Christopher Mundt, now at Oregon State University, has continued to develop the concept and practice of cereal crop multilines, working on rice with Chinese colleagues (Zhu et al. 2000, 2005). Mundt (2002) believes that practical difficulties associated with multilines often may be overestimated and that interest in multilines and other mixture types will increase as more work is done on designing agricultural systems specifically for sustainability.

B. Protein and Oil Content for Crop Value

Two sets of findings made it clear that *A. sterilis* possesses useful genes that do not exist in *A. sativa* and that they can be extracted from accessions that are not necessarily superior in expression for the trait of interest compared with *A. sativa* (Holland 1997). Cox and Frey (1985) demonstrated that the genes for high protein content in *A. sterilis* were different from, and complementary to, those in *A. sativa*. Thro and Frey (1985) demonstrated the same for genes for high grain oil content.

Frey and his students mated high-oil *A. sterilis* accessions to high *A. sativa* accessions, to combine genes for high oil. The interspecific crosses were then mated to agronomically superior *A. sativa* cultivars (Thro and Frey 1985). Through six cycles, thousands of F_2 plants from three-way crosses were field-selected for agronomic adaptation and cultivated seed type. Selections were evaluated for oil content, and lines with highest oil content were intermated. The process was repeated, and the second set of selections were mated to a different set of *A. sativa* cultivars. This population—twice selected first for agronomic type and only then selected for oil content, and with two sets of elite *A. sativa* parents—became the C_0 base population for recurrent selection for oil content (Branson and Frey 1989). Six cycles of recurrent selection for high oil content were completed on large populations of individual plants, with independent culling for agronomic type preceding oil content evaluation. Three more cycles continued at the rate of one per year (Frey 1992). Oil content increased at about 1% per cycle. By Cycle 6, the mean oil content of the population was 14.2% (Schipper and Frey 1991) and by Cycle 9 it was 15.8% (K.F. Frey to J. Holland, pers. commun.). Individual lines from the populations had oil contents as high as 16.3% in Cycle 5 (Schipper and Frey 1991) and 18.2% in Cycle 9 (K.F. Frey to J. Holland, pers. commun.). These levels exceed the highest oil content ever reported in either *Avena* species, 11.6% (Brown and Craddock 1972). The combining of complementary genes from the two species was successful, and the careful process of adapting the *A. sterilis* introgression lines before initiating selection (Branson and Frey 1989) was probably critical to the recovery of lines with high oil contents and competitive grain yields (Holland 1997).

Frey and Hammond (1975) suggested that oats with 17% groat oil content and favorable grain yield levels could compete economically as an oilseed crop, for example, in areas such as Scandinavia, where there are few productive oil crops (Björnstad et al. 1994). Oat oil has a very favorable fatty acid profile for human nutrition, high in linoleic acid and low in linolenic acid. In additional, the proportions of linolenic and palmitic acids are negatively phenotypically correlated with total oil content, a desirable relationship. Schipper et al. (1991) reported that the ratio of unsaturated to saturated fatty acids increased over cycles of selection for high oil content (Holland 1997).

Although introgression of wild germplasm ultimately should increase long-term progress by bringing in new variation, in the short run it will slow breeding progress, even dramatically, by introducing many traits unsuited to cultivated crops. Accelerating the breeding cycle is important in any program because it increases annual progress (i.e., genetic gain per year); and the ability to complete a cycle rapidly is especially important when working with wild species germplasm, because of the drag on genetic gain typical of early generations after crossing with wild germplasm. Frey formalized a method for a one-year breeding cycle in oats (Frey et al. 1988; J.L. Jannink, pers. commun.), consisting of a fall crossing program in the greenhouse to obtain S_0 seed from crosses among selected parents; generation advance and seed increase in the spring greenhouse; and summer field selection of $S_{0:1}$ lines for traits of interest to identify parents for the next cycle.

C. Selection Studies and Breeding Methods

Frey proposed the use of hill plots as an inexpensive alternative for evaluating large numbers of experimental lines for qualitative and quantitative traits (Frey 1965). Each hill plot was planted with 20 to 30 seeds and spaced 30 cm apart on a grid. The plots can be planted easily by hand or machine. Genetic correlations between hill plots and standard 4-row plots were 0.98 for grain yield and 0.96 for plant height and heading date. Frey's program used hill plots and the accelerated breeding method for long-term recurrent selection experiments to increase protein and oil content and to increase test weight and grain yield (Klein et al. 1993), beta-glucan content, and adaptation (K.F. Frey to J. Holland, pers. commun.). Because hill plots require few seeds per entry and numerous plots can be planted with ease in small areas, they have been used in recurrent selection of oats both at Iowa State University and at the University of Minnesota (Pomeranke and Stuthman 1992).

Frey had a career-long interest in the effects and usefulness of contrasting selection environments and, in particular, in whether separate breeding programs were required to obtain genotypes that excel in low-input or suboptimal environments. Atlin and Frey (1989) proposed a method for identifying situations in which selection in low-input environments should produce the best varieties for those environments. Using genetic correlations between yields in low- and high-input environments, they found that separate breeding programs often were indicated, but that no general recommendation was possible. They recommended that decisions to initiate a breeding program specifically for and in low-input or suboptimal environments could be made objectively based on detection of genes conferring special adaptation in that environment (i.e., low genetic correlation between performance in low and high environments) and demonstrated accuracy of selection (i.e., demonstrated ability to assess the true worth of breeding lines in the low-input environment). This interest was followed up in a set of papers with Holland, Bjørnstad, et al. (2000, 2002), using oats to test if recurrent selection could improve a single population's adaptation to diverse environments simultaneously. Working with high- (Idaho) and lower-yielding (Iowa and Norway) environments, they were able to increase genetic correlation of yields in different environments as well as yields both within and across locations.

In an extreme example, Cox, Cox, and Frey (1987) looked at genetic variances within three barley cultivars after six generations of selfed propagation in two greenhouse environments: fertile soil versus infertile sand. Through the first five generations, genetic variances for grain and biomass yield, as measured in a field experiment, were insignificant between treatments. However, in Generation 6, six of 63 variances for Generation 6 families-within-Generation 5 families were significant. Five of the six significant variances occurred in the sand group. The authors surmised that the large genetic variance values perhaps resulted from stress-induced mutation, "the effects of which were below the threshold of detection in the earlier generations. Eventually, heritable changes in genes affecting replication and processing of nucleic acids themselves may have accumulated so that mutation in Generation 5 occurred at a higher, detectable level in some families." Although this was an unusual suggestion at the time, the authors would not be surprised at recent findings in *Arabidopsis* that although most genomic and transcriptome variation between genotypes is silent at the phenotypic level, a few hot spots unlock major phenotypic variation across environments (Fu et al. 2009). Fu et al. noted that further research is needed to clarify whether these hot spots are fragile to stress (such as growth in sand) and thus possibly important in adaptation to changing environments.

IV. GRADUATE EDUCATOR

Ken Frey was proudest of his students, whom he liked to describe as each being different in some way. In all, he trained 75 doctoral students, as many as 40 more at the master's degree level, and worked with over 20 postdoctorals and visiting scientists from other countries. Most Frey graduate students were from the United States and Australia, but a number were from Egypt, Nigeria, Ireland, and Mexico. Many conducted portions of their thesis research at international agricultural research centers of the Consultative Group on International Agricultural Research (CGIAR) system, particularly the International Center for Research in the Semi-Arid Tropics, in India. Frey students now hold research positions in both the public and private sector in the United States, Australia, and the CGIAR. They work in all aspects of plant breeding, including genetic resources, germplasm development, variety development, quantitative genetics research, and public and private sector program management. They are active in horticultural as well as agronomic crops, in production systems from transgenic to organic, and in civil service for agriculture.

In practice, the Iowa State graduate students working on oats formed a single multidisciplinary group across professors, and included graduate students focusing on oat pathology research with Drs. Browning and Simons. The oat group (Fig. 1.1) also became a focus for students interested in plant genetic resources per se, a topic on which there was, at that time, no separate program of study.

Notably, Frey gave early opportunities to women students. In the mid-1970s, women were few among graduate students in agricultural science, and were typically international students with the United States Agency for International Development or private funding. But fully half of the dozen U.S. graduate students in the Iowa State oat project at that time were women. Frey's openness to women students was pragmatic and based on an application of good plant breeding theory: Accepting women into the oat project doubled the effective population size for selecting students, which would increase the probability of finding good plant breeders.

Fig 1.1. Ken Frey with the Iowa State "oat crew" on a summer afternoon in 1979. From left to right, standing: George Patrick and Ron Skrdla (technicians); Kim Fawcett, Paul Murphy, Ted Lund, Jimi Adegoke (holding a shock of oats), Stan Cox, Jane Scott (now West), Karen Kuenzel (now Moldenhauer), and Dan Rodgers (all graduate students). On the ground in front: K. J. Frey and Ann Marie Thro (graduate student). Frey students in 1979 who are not in the photo are Paul Gibson, Larry Robertson, Mark Millard, and Bruce McBratney. Photographer not recorded.

In addition to training graduate students one on one in the United States, Frey reached many more students with his excitement about use of wild relatives in plant breeding, recurrent selection in self-pollinating crops, selection environments, and other aspects of plant breeding through frequent invited lectures at universities in Sweden and Egypt, at the agricultural research station at Novi-Sad in what was then Yugoslavia, and at the International Atomic Energy Agency in Vienna.

V. CHAMPION OF PLANT BREEDING: THE NATIONAL PLANT BREEDING STUDY

A. The Study

Shortly before Ken Frey retired to emeritus professor status, Dr. J. Preston Jones, national program leader for agronomy in the Cooperative States Research Education and Extension Service (CSREES, now NIFA, the National Institute for Food and Agriculture) in the U.S. Department of Agriculture (USDA) encouraged him to consider serving in Washington as a national program leader for plant breeding. Although Frey decided to remain in Ames, Jones and Frey were awarded a small grant of CSREES end-of-year funds for a National Plant Breeding Study (NPBS), the first comprehensive study of resources invested in plant breeding by all sectors, public and private. Earlier, Kalton et al. (1989) had looked at numbers of master's and doctoral degrees but had not directly studied indicators of resources invested.

The NPBS (Frey 1997a,b, 1998, 2000) was a seminal study, laying a comprehensive base of data at a time (1996) when plant breeding was fully mature after a century of development. Study respondents included "just about everybody." Frey had worked with so many plant breeders that those in the private sector trusted his guarantee that their data contributed for the study would never be released in an identifiable form. He was probably the only individual who could have obtained the response he did: 100% response for the public sector and 97.5% for the private sector. Years later, when the NPBS was updated (NPBS II) (Traxler et al. 2004), Frey was already in his "second retirement," and NPBS II was able to obtain comprehensive data only for the public sector.

The NPBS data showed an annual decline of 2.5 scientist-years in the state agricultural experiment stations, for each year for the five years 1990 to 1994, or a net loss of 12.5 positions. During the same interval, private sector investment increased by 32 scientist-years annually, net 160 additional positions (Frey 1997a). What struck Frey the most from the NPBS data was how many crops lacked adequate plant breeding investment to make them of optimal value to farmers and consumers. For various reasons, these crops were not suited for a private sector enterprise to make enough profit to be viable. Seeking a way to encourage public sector investment in such crops, Frey proposed a series of NPBS conferences and an expert panel (Frey 1997a, 1998), funded by a small grant from USDA's Economic Research Service. Primary recommendations from the NPBS panel (Frey 2000) included developing significant public support for:

- Breeding for crops such as fruits, vegetables, nuts, noncommodity cereals and legumes, and others (i.e., investment in breeding crops beyond the major commodities)
- Broadening the genetic base of crops (also known as germplasm enhancement)
- Breeding and developing new crops
- Integrating genomics and biotechnology with plant breeding
- Educating and training future breeders.

An additional recommendation from the NPBS was:

- Increased attention to public-private interfaces and cooperation in plant breeding.

B. Influence

In early 2001, the USDA Advisory Committee on Agricultural Biotechnology (ACAB), appointed by then-Secretary of Agriculture Dan Glickman to represent the diversity of views on biotechnology, invited Frey to present the NPBS findings. ACAB subsequently submitted a report to the secretary recommending support for public plant breeding (Cook et al. 2001, The Future of Public Plant Breeding Programs: Principles and Roles for the 21st Century; web posting expired, available from this author). The report was the only consensus reached by ACAB. Its status as sole consensus point may have given the report the potential to command significant attention, had it not been for the date (August 2001) it was submitted.

A month later, the World Trade Center was attacked, and federal government attention was directed to immediate security needs. For reasons that are now history, the ACAB report and its recommendations were essentially forgotten. But before the year's end, CSREES provided a small grant to Auburn University to lead an update of the NPBS (Traxler et al. 2004). This "NPBS II" study documented further decline in public sector crop breeding. In spite of valued collaboration from many in the private sector, the NPBS II team was unable to obtain comprehensive data for that sector: a sign of changing times and a new generation of personnel who did not know Ken Frey. The information provided—and not provided—by NPBS II had the effect of focusing renewed attention on the original NPBS data and recommendations.

Since then, NPBS has been part of the motivation and justification for a cumulative growth in activity in support of plant breeding. Activities that can be traced to NPBS influence, or use its data, include:

- *The Plant Breeding Coordinating Committee (PBCC).* This state/federal multistate project includes agronomic, forest, and horticultural crops and plant breeders from all sectors, with elected officers and long-term strategic goals to analyze and communicate contributions of plant breeding to public welfare; form partnerships with groups that benefit from plant breeding; and communicate critical needs for maintaining strength in plant breeding (Hancock and Stuber 2007).
- *Seeds and Breeds (S&B),* an independent membership group of nonprofit groups, small-scale private sector breeders, and producers working in organic and/or local foods agriculture. For S&B, germplasm enhancement and specialty crops breeding are priority research needs (Duvick 2003; Sligh and Lauffler 2003; Tracy 2003). S&B and the PBCC differ in complementary ways in their interactions with decision makers who affect research policy and allocate resources. Many members of both groups are also members of professional societies, creating a web of synergies to increase awareness of the situation described by the NPBS and to realize its recommendations.
- "*Plant Breeding and the Public Sector: Who Will Train Plant Breeders in the U.S. and Around the World?*" This workshop, organized by Michigan State University (Hancock 2006), was unique for its graduate student leadership and the detail in which it explored possible forms of public-private collaboration and practical strategies for providing the needed breadth of education within the normal duration of an MS or PhD program.
- "*Training the Next Generation of Plant Breeders.*" This well-attended 2008 symposium was sponsored by the Crop Science Society of America's Crop Breeding Division (H. Ohm, http://a-c-s.confex.com/crops/2008am/webprogram/Session4301.html).
- *The American Seed Research Summit, "Strategic Research, Education And Policy Goals For Seed And Crop Improvement"* (American Seed Research Foundation, American Seed Trade Association and

National Council of Commercial Plant Breeders 2008). This summit was born from the private sector's experience that decline in public plant breeding programs leads to a shortfall in high-quality young professionals. The Seed Summit's top recommendations were: to strengthen public and private partnerships and to coordinate and engage seed industry stakeholders to support stable funding for education and research. At this writing, private companies including Pioneer/DuPont and Monsanto are providing graduate fellowships for plant breeding education (e.g., www.monsanto.com/responsibility/youth_education.asp; www.monsanto.com/responsibility/sustainable-ag/produce_more/beachell_borlaug/default.asp; Anon., CNN Money 2007).

Such a diversity of activities, each one highlighting the importance of plant breeding, is effective in the context of agricultural policy making in the United States. The different approaches allow maximum opportunities for communication with the entities that influence, make, and implement decisions. The credibility of the different groups rests in no small part on their common support for a set of core recommendations, based on data. Like the NPBS itself, they represent a comprehensive range of crops, production systems, and economic sectors in agriculture—broad coverage that probably has been a factor in their persistence and effectiveness.

C. Outcomes

A number of recommendations originally articulated by the NPBS are being taken up. Although it is not possible to assign credit with certainty, the NPBS and its "progeny" groups and events almost certainly played a role. Since 2008, growing world attention to food security has been an important factor in increased attention to plant breeding. Equipped by NPBS-initiated assessment, plant breeders are better prepared to direct the increased attention into research and capacity investments that will be constructive for the long term.

As of this writing, Congress has authorized and funded several programs, particularly in USDA's National Institute of Food and Agriculture (www.nifa.usda.gov/; click on "Grants") that accept proposals that include plant breeding research and education. Just as one example, a multistate project for oat genomics and breeding competed successfully for a 2009 grant from USDA NIFA's Agriculture and Food Research Initiative (AFRI) program (Jackson 2009). It seems fitting that oats, Ken Frey's crop and, in fact, one of the first crops to receive attention from breeders after Mendel's work was rediscovered (Holland 1997), will receive funding for the development of contemporary molecular tools for breeding.

Despite encouraging developments for plant breeding, many high-quality projects and important objectives cannot be funded. Existing grant programs must stretch limited funds to cover many other areas. For example, at this writing, actual funding appropriated for AFRI ($262 million for 2010, up from $201 million in 2009) does not approach the $700 million authorized (i.e., allowed to be appropriated) by the 2008 farm bill. Working with about a third of its intended funding, AFRI must cover some 40 or more different biological and social subject areas, ranging from microbes to watersheds. Hatch Act funds have increased somewhat in 2009 and 2010, to $207 and $215 million, respectively (see tables at www.nifa.usda.gov/about/offices/budget.html), but their future is debated. Whatever the outcome, maintaining the continuity required to achieve maximum long-term progress and impact from investment in breeding programs is a perennial question.

Resolving these issues in a way that provides optimal public benefit from plant breeding—given all the other demands on public sector science and technology—is work for the next generation of plant-breeding champions. Thanks to Ken Frey's foresight, they will find data, structure, and precedent to support their participation in the national science policy dialogue.

VI. THE MAN

Dr. Ken Frey is generally a very reserved and private person. He was admired and respected by his students, who were grateful for his support and for the many research and professional opportunities he provided. Over the years, the many directions taken by his research produced many different populations and breeding questions, such that there were not only many possible projects for a new student but also a range of duration and level of difficulty. Frey almost always judged correctly in matching research projects with a student's interest and ability. He always had a few extra questions in the back of his mind for students' special projects. One result was that many of his students graduated with multiple publications in addition to their theses, something that was unusual for plant-breeding graduate students at that time. His many visiting professorships and other activities created numerous open doors for his students. He enjoyed helping students find the right opportunity and recommending them.

"Mind over matter" is a phrase Ken Frey often used to exhort a grad student, when the combined demands of research and study seemed too much. It always came in hearty tones, and with a smile. In retrospect, it is characteristic of him. It perhaps derives from the formative experiences of his own early life on a farm, the influence of his parents with whom he worked to be able to attend college, his experience as a college student and student worker during the Great Depression, and his early career days when his wife, Ann Frey, also worked outside the home, to help them get started. Nothing worthwhile came easy; hard work was the way forward. He considered himself fortunate to live in a country where it is possible for individuals to benefit from the value of their work and was an example, to his students, of what could be achieved.

Clearly a belief in the importance of individual effort was conveyed within the Frey family to the next generation as well. All three of Ken and Ann's children became professionals in fields requiring rigorous preparation: Terry, a professor of virology and associate department head at Georgia State University; Karen, a nurse-practitioner who leads the genetic diseases program of a major health insurance company; and Kevin, a professor of music and humanities at San Jose Community College.

Frey often worked long hours and expected that his students would work as long as required to do a good job in their research and classwork commitments. He regularly left the office at the end of the official workday, and did much of his writing and lecture preparation at home. It was important to him that students have privacy and not feel pressure to work late for the wrong reason, that is, to be seen by their professor!

In spite of his own full career, Frey's office door was always open during the day for student questions. When he retired, the young researcher who followed him in the oat breeding position described him in terms that any Frey student would readily recognize: "He was very generous to me when I started, opening up his program to me, explaining the materials, and always being available for consultation. But he was also very careful to let me run the program how I wanted" (J. Holland, pers. commun., 2009).

VII. AWARDS AND HONORS

The many honors received by Ken Frey include Fellow of American Association for the Advancement of Science (AAAS) (1960); Fellow of American Society of Agronomy (ASA) (1963); C.F. Curtis Distinguished Professorship in Agriculture (1970); Japanese Society for Promotion of Science (1981); Iowa Academy of Science (1983); and CSSA (1985);

Fulbright Scholar, Australia (1968) and Yugoslavia (1977); Genetics and Breeding Award, National Council of Commercial Plant Breeders (1982); Dekalb-Pfizer Crop Science Distinguished Career Award (1986); Governor's (Iowa) Science Medal (1989); and the Henry A. Wallace Award for Distinguished Service to Agriculture (1990).

As the Iowa State oat breeder, Ken Frey served on the North Central Oat Technical Committee (chair, 1954–56; board of directors, 1952–58). He served his national colleagues as president of the Crop Science Society of America for 1980 and 1981 and of the Agronomy Society of America for 1983 to 1984; as associate editor of *Crop Science*, 1964 to 1968; and as a long-serving member of the editorial boards of the *Journal of Plant Breeding* and the *Egyptian Journal of Genetics and Cytology*.

Dr. Frey was an invited visiting professor at the University of Minnesota, USA (1967); University of Gottingen, West Germany (1972)' University of Novi-Sad, Yugoslavia (1977); University of Alexandria, Egypt (1977); and Agricultural University of Norway (1994).

He organized two international Plant Breeding Symposia (1965 and 1979), which led to the First International Crop Science Congress, of which he was the president (1989). He has lectured in plant breeding throughout the world, was a frequently invited plenary speaker at international meetings, and served on numerous research review panels.

In 2005, 13 years after Ken Frey retired to become emeritus professor, a gift from an anonymous donor established two endowed chairs in the Iowa State Agronomy Department. The names of the chairs were decided by the faculty, who chose to name one of them for Kenneth Frey. To Dr. Frey, the fact that the names for the endowed chairs were chosen by the faculty—that is, by his peers and successors—was a special honor.

VIII. EPILOGUE

Kenneth Frey's research increased the speed and lowered the cost of the oat breeding cycle and used related wild species to develop broad-based, adapted oat germplasm with high oil and protein. His collaborative work with plant pathologists J. A. Browning and M. D. Simons to demonstrate the value of the multiline cultivar theory is being revisited far beyond Iowa as a sustainable approach to crop protection. His students are working today in many different crops and many different venues, public and private. His most lasting contribution may be the National Plant Breeding Study, which sowed the seeds of a sustained, constructive, broad effort to increase awareness and support for the public benefits of a robust plant-breeding capacity.

ACKNOWLEDGMENTS

The material on Kenneth Frey's early life comes from several interviews with him during 2009. The draft took its form during exchanges with J. Holland and J.-L. Jannink, who followed Frey in sequence as oat breeders at Iowa State; and oat breeders A. Björnstat of Norway and D. Stuthman of Minnesota: all indispensible contributors of information and perspective. R. V. Thro, mother of Ann Marie Tho, took a special interest in this manuscript. Additional insights and comments were provided by many former Frey graduate students.

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