PLANT BREEDING FOR ORGANIC AGRICULTURE IN THE UNITED STATES: A NEW PARADIGM

By

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ABSTRACT

Organic farmers require improved varieties that have been adapted to their unique soils, nutrient inputs, management practices, and pest pressures. In addition to these biological specifications, organic breeding projects must also consider the cultural and economic influences that contribute to the organic farming movement. This dissertation describes the development, evaluation, and public release of an organic open-pollinated sweet corn variety. The variety was bred using a recurrent selection and participatory plant breeding (PPB) methodology, and released as a collaborative effort among breeders at the University of Wisconsin - Madison, the non-profit organization Organic Seed Alliance, and an organic farmer in Minnesota.

Three distinct analyses justify the methods used for this particular variety, and suggest models for future organic breeding projects. First, a synthesis of the histories of PPB and organic farming in the United States reveals the biological, cultural, and economic relevance of collaboration between organic farmers and public plant breeders. Second, field experiments evaluating the gains made from selection in this sweet corn variety, as well as a second open-pollinated sweet corn population, suggest the challenges of incorporating the multiple traits critical for organic growers. While significant linear trends were found among cycles of selection for quantitative and qualitative traits, further breeding is necessary to fully satisfy the requirements for a useful cultivar for organic growers. Third, a case study of the release and commercialization of this sweet corn variety highlight the need for policy changes to support new breeding collaborations and to ensure that varieties developed with public funds are widely accessible for use by both farmers and plant breeders. Ultimately, this sweet corn variety provides a successful example for the nascent organic seed sector, and contributes to the development of a new paradigm for plant breeding.

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Chapter 1

Introduction

In the summer of 2013, I found myself sitting in a field of organic sweet corn, two piles of half-eaten ears at my feet. During my five years as a graduate student in the sweet corn breeding program at the University of Wisconsin-Madison (UW), I had grown accustomed to the slight physical discomfort that comes from tasting countless ears of raw sweet corn. Usually the satisfaction of completing another cycle of evaluations, and the knowledge of being one step closer to a finished variety, made the discomfort tolerable. But this year was different, and my excitement completely overwhelmed any digestive concerns. I was with Bill Tracy, my advisor and sweet corn breeder at UW, and Scott Johnson, one of our organic farmer collaborators. That particular day, we were tasting sweet corn not to continue selecting and improving the variety, but to determine if it was ready to be released. As an open-pollinated (OP), outcrossing species, this sweet corn variety would never be perfect, and there would always be room for improvement. Indeed, the variable nature of an OP sweet corn was a critical aspect of this entire experiment. We had already determined that despite the mixture of red and yellow tassels, the differences in plant heights, and the range in eating maturity, the population we had been improving would be a welcome change for organic growers interested OP varieties. But we had yet to decisively answer the most important question: will consumers want to eat this sweet corn? We randomly harvested 200 ears from the field, and with each bite of an ear asked ourselves one question: “Do I want to continue to eat this entire ear of sweet corn?” If the answer was yes, the ear went into one pile, and if the answer was no, it went into another. We had agreed that 75% of the ears must land in the yes pile in order to release the variety. When the tasting was finished and the piles were counted, 84% were good enough to keep eating. A new variety was born.

Yet this accomplishment, taken alone, was not particularly noteworthy. Farmers and plant breeders, using the power of selection, have been doing as much for thousands of years. Plant breeding can be described as human directed selection in genetically variable plant populations, and requires a keen eye and years of hard work. But breeding also takes advantage of the remarkable genetic elasticity found in many plant species, enabling the continual adaptation of food and fiber crops to changing climates, disease and pest pressures, agricultural management systems, and taste preferences. For example, the sweet corn we were evaluating tasted nothing like the sweet corn varieties of 100 or even 50 years ago. Sweet corn (*Zea mays* L.) is based on the mutation of the *Sugary1* allele in maize, which affects starch production. The recessive form of this allele (*su1*) results in the accumulation of phytoglycogen at the expense of amylopectin, resulting in a wrinkled kernel with a creamy texture and slightly higher sugar content. Most modern sweet corn arose from the introgression of this mutation with Northern Flint maize varieties that developed in the northeastern United States (US) beginning in the 1800s (Revilla and Tracy 1995). Yet analysis of 57 *su1* accessions indicate that this mutation occurred independently in four other distinct locations in the US, Mexico and Peru (Tracy et al. 2006). At least three of these mutations occurred in pre-Columbian times, and were selected and improved by agriculturalists in those regions (2006). The sweet corn that we were evaluating uses a different endosperm mutant called *sugary enhancer1* (*se1*), which is one of seven endosperm mutants (in addition to *su1*) discovered in the 1950s-1970s (Marshall and Tracy 2003). When placed in a *su1* background, *se1* has the unique ability to accumulate high levels of sucrose and phytoglycogen simultaneously, giving the kernels a sweet flavor and creamy texture (Gonzales et al.1976).

This abbreviated history of sweet corn demonstrates that while farmers and breeders were able to identify and exploit a unique phenotypic trait long before there existed any concept of genetics, sweet corn breeding rapidly accelerated as a result of a series of modern scientific advances that began in the twentieth century. Plant breeding is a technology that is "supported by a strong body of science…that illuminates how the artifacts and techniques employed work, provides insight into the factors that constrain performance and provide clues as to the promising pathways toward improvement" (Nelson 2004, 458). The efficiency and precision with which plant breeders can improve a crop has occurred through scientific discoveries such as Mendel's experiments with the inheritance of traits in garden peas, Fisher's statistical models that provided the basis for quantitative genetics, Watson and Crick's identification of the double-helix structure of DNA, and the expanding field of molecular biology that has enabled the development of breeding tools such as tissue culture, double haploids, marker-assisted selection, and genetic modification. Using the knowledge generated in a wide range of scientific fields, from bioinformatics and biochemistry to plant physiology and plant pathology, plant breeders are continuously experimenting with new methods to develop better plants for farmers. In the process, farmers have largely relinquished their role as breeders, leaving the work to those formally trained in the discipline. There is little question that plant breeders have had some astounding successes. It is estimated that 56% of the dramatic yield increases of corn from 1930 to 1989 were the result of genetic improvements alone (Duvick 1992). The Green Revolution, credited with saving over a billion lives from starvation in the 1960s, was due to the high-yielding grain varieties developed by plant breeder and Nobel Prize winner Norman Borlaug and others.

Clearly, the influence of science on plant breeding is critical, but so too is the context within which plant breeding functions. As a technology, plant breeding does not exist in a vacuum, and the fate of any new variety is ultimately decided in a farmer's field. Due to the nature of her work, each farmer is situated in a specific physical space, identifiable by an exact set of GPS coordinates. Rooted in place, both the fields and the farmer are influenced by the surrounding interactions of geography, climate, economics, politics, and culture. A farmer's choice of what to plant on her land is not nearly as simple as picking varieties out of a seed catalog, but is informed by all of the complex interactions within which she operates. Plant breeders must be attuned to these influences, as attempting to understand these social interactions can be as important as understanding the genotype by environment interaction of any new plant variety. Which crops a farmer grows matters as much as why and how she grows it, and plant breeders have a responsibility to understand the multi-layered implications of any new variety they release.

Perhaps the most important contribution of the sustainable agriculture movement, of which organic farming provides one viable model, has been in creating a public discourse that considers these dynamic forces. No longer can we assess an acre of land simply by the number of bushels it produces, but we also must consider the greenhouse gasses emitted in the process, the quality of its soil and water, the surrounding wildlife habitat, the economic viability of those farming the land, and the nutritional health of those consuming its products. In the past, plant breeders have had the luxury of focusing on three critical plant traits: yield, yield, and yield. Organic plant breeding challenges this narrow perspective. One cannot effectively develop organically adapted varieties without understanding the biological, cultural, and economic influences on this particular agricultural system. Breeding for organics requires an awareness of the specific methods that farmers use to address soil fertility issues, pest pressures, and consumer preferences. It also requires an understanding of the social culture within which organic farmers operate, the breeding methods that are not allowed by organic certification standards, and the strong interest of farmers in OP varieties and involvement in the breeding process. Economic considerations factor heavily into breeding decisions, as the private organic seed sector is small, as is the market for organic seeds. These biological, social, and economic considerations certainly look different when breeding for conventional agriculture, but they are still present and must play a role in breeding decisions. However, the dominance of the conventional agricultural model makes them easier to ignore. Breeding for organic agriculture requires a broader perspective, and thus represents a new paradigm for plant breeding.

And so the true breeding value of our organic sweet corn variety lies not only in its genetics, but in its application of a participatory plant breeding (PPB) method that considers some of these biological, cultural and economic forces. Equally instructive is the example it provides of a collaborative release of a public cultivar that was developed and distributed in partnership with a public breeding program, a non-profit organization, organic farmers, and an organic seed company. This dissertation traces the development, evaluation, and public release of our organic OP sweet corn variety. While certain decisions and outcomes are unique to the specific actors (including the crop species) involved in this particular project, lessons learned can be instructive to future organic breeding projects. I attempt to distill these lessons through the following research questions: What are the cultural and economic incentives for organic farmers to engage with PPB? Are recurrent selection and PPB effective methods for improving an OP sweet corn population? What policy changes need to be implemented to fully support the collaborative breeding and release of public cultivars?

In Chapter 2, I explore the reasons why PPB has become a popular methodology for organic breeding projects in the US. From its roots in international development work, PPB has been shown to effectively address the significant genotype by environment interaction that can occur when conventionally bred varieties are grown in low-external input systems, such as some organic farms. In addition, however, the history of the organic farming movement in the US suggests the cultural relevance of engaging farmers in the breeding process. Finally, limited private investment in organic plant breeding necessitates the involvement of plant breeders at public institutions, further suggesting that PPB is an appropriate methodology for organic cultivar development.

In Chapter 3, I present the results from a series of field experiments used to evaluate the changes made to two OP sweet corn populations developed used recurrent selection and PPB. Organic growers face unique challenges when raising sweet corn, and benefit from varieties that maintain high eating quality, germinate consistently in cold soils, deter insect pests, and resist diseases. While significant linear trends were found among cycles of selection for quantitative and qualitative traits, further breeding is necessary to fully satisfy the requirements for a useful cultivar for organic growers.

Chapter 4 is a case study of the release of our organic OP sweet corn variety. In order to provide a context for the specific decisions made regarding the variety release, I analyze the intellectual property rights for plant cultivars, the Bayh-Dole Act of 1980, and the UW technology licensing office WARF (Wisconsin Alumni Research Foundation). While the commercialization of this variety represents just one potential model, it highlights the need for policy changes to support new breeding collaborations and to ensure that varieties developed with public funds are widely accessible, both for farmers and plant breeders.

Finally, in Chapter 5, I explain the significance of the name of our sweet corn variety, and provide perspectives on how this project can help inform future breeding for organic agriculture. Organic plant breeding is in its infancy, and just as the trajectory of plant breeding has followed a course of continual experimentation and advancement, it is our hope that others will improve the methods and the seeds that we have produced to create a more vibrant and robust organic seed sector.

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Chapter 2

Participatory Plant Breeding and Organic Agriculture in the United States

Abstract

Organic farmers require improved varieties that have been adapted to their unique soils, nutrient inputs, management practices, and pest pressures. One way to accomplish this is to breed varieties in the environment of intended use, such as directly on organic farms, and in collaboration with organic farmers. This method of breeding is a form of participatory plant breeding (PPB), and was originally created in order to meet the needs of small-scale farmers in developing countries. A robust body of literature supports the selection theory of PPB, which has become a prevalent methodology for organic breeding projects in the United States (US). Yet beyond the biological justifications, the history of the US organic farming movement highlights the cultural relevance of engaging organic farmers in the breeding process. Limited private investment in organic plant breeding necessitates the involvement of plant breeders at public institutions, further suggesting that PPB is an appropriate methodology for organic cultivar development.

Abbreviations

CGIAR	Consultative Group of International Agricultural Research
GM	Genetic modification
G x E	Genotype by environment
IPR	Intellectual property rights
LGU	Land grant university
NOP	National Organic Program
OP	Open-pollinated
PPB	Participatory plant breeding
PVS	Participatory varietal selection
US	United States of America
USDA	United States Department of Agriculture

2.1. Introduction

The 7th Organic Seed Growers Conference was held in Corvallis, Oregon in late January 2014. According to the organizers, this biennial event is the largest single gathering focused on organic seed in North America. The conference venue was at maximum capacity, and there was a palpable feeling of excitement in the air. New and innovative seed company displays filled the exhibit area, graduate students stood by posters explaining their latest research results, and experienced farmers shared their years of knowledge about on-farm breeding and seed production. Just as consumer demand for organic food continues to increase at an exponential rate, so too has interest from organic farmers in planting organic seed blossomed in recent years.

At the most literal level, organic seed in the United States (US) is seed that has been produced according to the organic production standards set forth by the United States Department of Agriculture's (USDA) National Organic Program (NOP). Seeds from most conventionally bred vegetable and crop varieties can be produced and certified as organic seed, with the exception of varieties developed using genetic modification (GM) and some forms of cell fusion. Certified organic seed, however, does not mean that the variety was bred organically, and thus may not contain the genetic traits that will enable it to thrive in organic management systems. Organic seed that has also been bred for improved performance under organic production can serve as an important tool to help farmers be successful in their fields. Indeed, research indicates that cultivars that perform well in conventional systems are not necessarily the best producers when grown in organic conditions (Murphy et al. 2007; Reid et al. 2010). In order for organic agriculture to continue to grow as a viable sector of the food system, varieties must be bred with adaptations to the unique soils, nutrient inputs, management practices and pest pressures found in organic farming systems.

But who will breed these new varieties and how will they do so? The conventional seed sector experienced a 1,300% real increase in research and development investments from 1960 to 1996 (Fernandez-Cornejo 2004). The result is a steady supply of new varieties adapted to conventional production systems each year. For the organic farming community, however, both external and self-imposed restrictions limit the resources available for investment in research and development for new varieties. As a result, the expansion of the conventional seed industry over the past 85 years does not provide an applicable model for expected growth in the nascent organic seed sector. Indeed, many organic advocates prefer very different models – ones that incorporate regionally adapted varieties, a diversity of seed companies, farmer engagement in the breeding process, and shared access to genetic resources.

At the 7th Organic Seed Growers Conference, public plant breeders, farmer breeders, organic seed industry representatives, and non-profit organizations presented their work on 20 specific organic breeding projects, 13 of which incorporated some aspect of participatory plant breeding (PPB) or participatory varietal selection (PVS) (Hubbard 2014). As the number of organic breeding projects increases, so too does the use of PPB. The following synthesis explores the reasons why PPB has become such a prevalent methodology for organic breeding in the US. From its roots in international development work, PPB has become formalized as a methodology by public breeders working in low-input systems in the developing world and low-external input systems such as organics in the developed world. But to fully understand its application for organics, it is also necessary to follow the history of the organic movement, and the cultural relevance of engaging farmers in the breeding process. Finally, this analysis shows that limited private investment in organic plant breeding necessitates the involvement of plant breeders at public institutions and provides fertile ground for this methodology to fully take root.

2.2. History of Participatory Plant Breeding

Plant breeding, as a practice, is as old as agriculture itself, with crops such as barley and emmer wheat domesticated by farmers approximately 10,000 years ago (Harlan 1992). Plant breeding, as a scientific discipline, can be traced more recently to the discovery in the early

1900s of Mendel's experiments on the inheritance of genetic traits. Plant breeding is a "science-based technology" that aims to deliver improved cultivars to farmers through selection in genetically variable plant populations (Tracy 2004, 26). PPB is just one of numerous methodologies that has been developed to achieve this goal. Specifically, PPB is a process in which farmers and formally trained breeders collaborate throughout various stages of the breeding process, often situating breeding plots in farmers' fields rather than on agricultural research stations, and selecting for agronomic and quality traits tailored to the farmers' specific requirements. PPB grew from critiques that began in the 1950s of the ineffectiveness of development projects aimed at introducing modern agriculture technologies to areas lacking these resources. For example, Apodaca (1952) explains the failed attempt of a USDA extension agent to replace the low-yielding traditional corn variety used by a farming community in New Mexico with a high-yielding hybrid, which was unacceptable because of its taste, texture and color. Interdisciplinary approaches such as Farming Systems Research and the Farmer-Back-To-Farmer model (among others) were created as an attempt to incorporate experimentation on farmers' fields throughout the research process, encouraging feedback from farmers at various stages of the project (Rhoades and Booth 1982; Jones and Wallace 1986). The theory behind these methods is that farmers are more likely to adopt new agricultural technologies (including new varieties) when they have actively participated in their development. This process is particularly relevant for resource poor farmers, especially in developing countries, whose diverse and complex needs are often underserved by agricultural innovations designed for larger commercial farms (Merrill-Sands et al. 1989).

Some suggest that these early methods of farmer engagement still treated farmers as mere research subjects, rather than true collaborators (van de Fliert and Braun 2002).

Nonetheless, they stood in stark contrast to the dominant model employed at international research centers such as the Consultative Group of International Agricultural Research (CGIAR), which were based on the structure of the public agricultural research system in the United States. Described as the “central source model” by Biggs (1990, 1481), the goal of these centers was to develop agricultural innovations that would reach the farmer only after being transmitted to national research systems and then extension agents. In this model, “there is an unambiguous, one-way progression in the research, extension and adoption process” (1990, 1481). The Green Revolution of the 1960s is perhaps the best example of this model, in which high yielding wheat and rice varieties were bred at international research centers in Mexico and the Philippines, promoted by national governments, and distributed by extension agents to farmers. While some farmers benefitted from these new varieties, those that were unable to adopt the new methods of seeding, fertilizing and irrigating that were required for high yields did not (Griffin 1972; Perkins 1997).

Despite this institutional culture, some public researchers at CGIAR centers were concerned that their work was not relevant for small-scale farmers and began to use interdisciplinary methods to better understand their needs. Social scientists, especially anthropologists, played a critical role in developing participatory research, a remarkable accomplishment given the dominant structure which viewed their work as “an extension type activity of limited relevance to a CGIAR center” (Thiele, van de Fliert, and Campilan 2001, 432). In the mid-1970s, the International Potato Center (CIP) in Peru was one of the first centers to actively promote the idea that farmer knowledge was as valuable as formal research to achieving its mission (Biggs 1990). Other centers that housed small groups of researchers using participatory methods included the International Center for Tropical Agriculture (CIAT) in

Colombia and the International Rice Research Institute (IRRI) in the Philippines (Chambers 1989).

By the early 1990s, a diverse group of national agricultural research stations, non-governmental organizations and farmers' organizations in developing countries were utilizing participatory research models with success. Trialing an array of advanced breeding lines on farmers' fields, with input from farmers on their preferences, was a straightforward application of this participatory process. Maurya (1989) and Ashby et al. (1989) give examples of farmers selecting adapted rice varieties in rain-fed upland areas of India and improved bush-bean and cassava varieties in Colombia, respectively. Using the term "participatory varietal selection," Sperling et al. (1993, 510) demonstrate that Rwandan bean farmers successfully identified superior bean varieties for their particular farms by evaluating on-station research trials. In addition, the farmer-selected varieties outperformed local mixtures 64-89% of the time, while the breeder-selected varieties did so only 34-53% of the time (1993). According to Walker (2006), the acronym PVS was first used for participatory varietal selection at a 1995 workshop hosted by Canada's International Development Research Center (IDRC), as was the acronym PPB. Witcombe et al. (1996, 450) describe both of these methods for the first time in the peer-reviewed literature, specifically referring to PPB as "a logical extension of participatory varietal selection," in which farmers are involved in the earliest stages of selection from segregating populations.

With a growing number of successful participatory projects, the CGIAR began to recognize the value of participatory research and formalized its commitment to this process with a systems-wide initiative on Participatory Research and Gender Analysis (PRGA) in 1996 (Thiele, van de Fliert, and Campilan 2001; van de Fliert and Braun 2002; Walker 2006). By

2000, a recommendation made to the CGIAR Technical Advisory Committee suggested "that PPB become an integral part of each CGIAR center's plant breeding program" (Vernooy 2003, 55).

PPB methodologies have now been thoroughly documented in the scientific literature, and vary significantly based on the project's resources and goals (Figure 2.1). All share a commitment to meaningfully involve farmers in the breeding process. PPB is often presented as a continuum of participation in which farmers can engage at various points of varietal development, such as setting breeding goals, making initial crosses, selecting among diverse progeny, evaluating experimental varieties, and distributing seeds (Morris and Bellon 2004). In addition, the distinction is usually made between "formal-led PPB," in which control of the project rests with scientists housed at public research institutions, and "farmer-led PPB," in which scientists play a more supportive role in the farmer's project (Sperling et al. 2001, 440). The selection environment can vary, with centralized PPB projects occurring on formal research stations while decentralized PPB projects take place in farmers' fields. Goals of PPB projects range from developing improved varieties, often for marginalized areas, to maintaining biodiversity, empowering disadvantaged groups (especially women), and/or reducing breeding costs and breeding timeframes (2001). After years of experimentation with the methodology, step-by-step guides to creating a PPB program can now be followed, such as Ceccarelli's (2012) comprehensive *Plant Breeding with Farmers: A Technical Manual*. Finally, there is no shortage of case studies documenting successful PPB projects in developing countries, and a growing number of examples from developed countries as well (see Ashby 2009 for a review).

2.3. Participatory Plant Breeding and Organic Agriculture

Given its success in producing improved varieties for marginalized farmers around the world, PPB has been proposed as a useful methodology for breeding adapted varieties for organic farming systems in developed countries (Murphy et al. 2005; Wolfe et al. 2008; Dawson, Murphy, and Jones 2008; Dawson et al. 2011). Similar to the situation of farmers in many developing countries, organic farmers often encounter heterogeneous environmental conditions, and lack suitable crop varieties due to minimal market influence with the larger conventional seed industry (Chiffoleau and Desclaux 2006). In addition, within organic farming systems a diversity of management practices are employed, potentially further stratifying variety performance between farms (Wolfe et al. 2008). According to Atlin, Cooper, and Bjørnstad (2001, 472), PPB programs are most effective when either "the targeted region has specific local requirements or when the cropping system differs greatly from that normally targeted by conventional programs." Both of these criteria apply to organic farming. With a strong focus on direct customer sales through farmers markets and Community Supported Agriculture (CSA), organic growers often have different quality requirements than their conventional counterparts (Dimitri and Greene 2002). Growing conditions on organic farms also can be vastly different than those found on high-input, conventional farms and breeding stations (Drinkwater et al. 1995; Bengtsson, Ahnstrom, and Weibull 2005). Organic on-farm PPB projects are becoming increasingly common, such as durum and bread wheat projects in France (Chiffoleau and Desclaux 2006; Dawson et al. 2011), vegetable breeding projects in the Northeastern United States (Mazourek et al. 2009; Mendum and Glenna 2010), and a broccoli breeding project in Oregon (Myers, McKenzie, and Voorrips 2012), to name just a few. In addition, the majority of these organic PPB projects involve breeders from the public sector.

Dawson, Murphy, and Jones (2008) provide a comprehensive literature review of the selection theory used to justify PPB for low-input systems in developing countries as well as low-external-input systems such as organic in developed countries. Much of the theoretical and experimental evidence can be attributed to the work of Salvatore Ceccarelli, who has been using PPB to successfully develop barley varieties since the 1990s at the CGIAR center in Syria, ICARDA (Ceccarelli 2014). In essence, selection schemes are most effective when the genetic correlation coefficient between the selection environment and the target environment are high, and the heritability of the traits under selection is also high. Centralized non-participatory breeding programs tend to increase heritability by reducing environmental variance through replicated trials repeated over multiple years and locations, and reducing the error variance by minimizing field heterogeneity through chemical fertilizers and pesticides. Yet these conditions differ greatly from those found on low-input and low-external-input farms, meaning that the correlation between the selection environment and the target environment is low. As a result, varieties respond differently in the different environments, an extreme example of an effect known as genotype by environment (G x E) interactions (Figure 2.2). Centralized non-participatory breeding program often attempt to minimize the effect of G x E by selecting varieties that are widely adapted through multiple environment testing. PPB allows for direct selection in the environment of intended use, actually exploiting G x E by intentionally choosing varieties that are best adapted to a specific location or production system.

In addition to the biological arguments for using PPB, practitioners also stress the value of PPB as democratizing the plant breeding process. To this point, Kloppenburg (1991, 535) states that “it is one thing to argue that the technical knowledge of resource poor farmers should be taken seriously precisely because they are resource poor and therefore not in a position to take advantage of the technologies that science has to offer. It is quite another thing to argue that farmers who do have the material and intellectual resources to make use of science-based technologies possess – in addition – knowledge that should be used to alter the way science develops and deploys these very technologies." Thus, despite the improved varieties that can arise when farmer knowledge is incorporated into the breeding process, PPB is often met with resistance from institutions because it opposes the traditional structure of public agricultural research. Of course, offering new research models is precisely part of PPB's value, beyond developing useful new varieties. All plant breeding methodologies must engage the farmer at some point. Yet this typically occurs at the very end stage of the breeding process, when a variety is released and will either find acceptance or rejection in a farmer's field. Through active farmer participation in the entire breeding process, PPB fundamentally changes the role of plant breeders. No longer is a breeder developing new varieties *for* farmers, but he/she is developing varieties *with* farmers. The power dynamic shifts considerably with the recognition that both breeder and farmer have equally valuable, yet critically different, perspectives to contribute to the process. Coming from the social science traditions of science and technology studies and actor-network theory, Chiffoleau and Desclaux (2006, 121) state that "PPB can be interpreted as an innovative socio-technical network" that encourages human and biological diversity by empowering otherwise silent actors. Mendum (2009, 7) goes even further by suggesting that "applying participatory plant breeding methods to a U.S. context could be understood as a radical act of democratization." As the history of the organic movement will show, these cultural implications of PPB justify its use for US organic agriculture as strongly as its biological relevance.

2.4. The Organic Farming Movement in the United States

The roots of organic agriculture in the US can be traced to Franklin Hiram (F.H.) King, a University of Wisconsin-Madison agricultural physicist and USDA chief of the Division of Soil Management. Disenchanted with the increasing dependence of US farmers on mineral fertilizers, King wrote *Farmers of Forty Centuries* (1911), in which he emphasizes the value of maintaining biologically rich soils based on his observations of indigenous agricultural societies in China, Korea, and Japan. While King's writing did not find much resonance in the US at the time, it did strongly influence Sir Albert Howard, an agricultural scientist from England. Howard spent 26 years directing agricultural research centers in India and developed a successful composting technique called the Indore Process. Like King, Howard greatly respected the peasant farmers with whom he worked, viewing them as the greatest teachers (Conford 2001). Upon his return to England in 1931, Howard gained the support of like-minded farmers, scientists, and writers by promulgating his theories of returning organic waste materials from plants and animals back to the soil in order to support the growth of vigorous plants, animals, and humans. Many organic farming practices that focus on maintaining soil structure are derived from Howard's theories, and as such he is often regarded as the founder of the organic movement (Conford 1988; Heckman 2006; Youngberg and DeMuth 2013).

In the US, the Dust Bowl of the 1930s served as a dramatic indication that a change in agricultural production techniques might be necessary, especially in regards to soil management. In the USDA's 1938 Yearbook of Agriculture, titled *Soils and Men,* Secretary of Agriculture Henry A. Wallace writes, "The social lesson of soil waste is that no man has the right to destroy soil even if he owns it in fee simple. The soil requires a duty of man which we have been slow to recognize" (USDA 1938, foreword). Yet it was the efforts of J.I. Rodale, an accountant and publisher from New York, who came across Howard's works in the 1940s and set in motion the US organic movement (Fromartz 2006). Rodale became an ardent supporter of Howard's theories about soil health and nutrient cycling, and dedicated the rest of his life to promoting what by then had become known as organic farming (credit for the term "organic" is given to Lord Northbourne in 1940) (Scofield 1986). In 1942, Rodale published his first edition of *Organic Farming and Gardening*, a magazine that continues to this day under the name *Organic Gardening*. Rodale also became a staunch critic of the use of pesticides in food production, citing not only their danger to human health but the likelihood of accelerating the evolution of pest resistances (Conford 2001). Rodale spread his ideas through the publication of numerous books and magazines, and established a research farm in Pennsylvania that manages long term farming system trials comparing conventional and organic production techniques. In so doing, Rodale inspired an entire generation of new organic farmers in the US (2001).

With increased access to inexpensive and effective fertilizers and pesticides after World War II, conventional farmers and agricultural scientists were more than a little reluctant to embrace the labor-intensive, low-external-input systems of organic agriculture (Kelly 1992). Some researchers at land grant universities (LGU) were openly hostile to the movement, including another University of Wisconsin-Madison soil scientist, Emil Truog, who thought that the avoidance of chemical fertilizers by organic farmers was "just pure bunkum" (1946, 317-318) and later referred to the organic movement as a "cult" (1963, 12). According to Youngberg and DeMuth (2013, 5), many agricultural scientists had grown up on farms similar to the mixed crop-livestock operations espoused by organic advocates, and their memories of long days of laborious work "collided with what they saw as little more than the romantic symbolism of organic farming." The authors go on to suggest that the researchers who held positions of authority at LGUs and within the USDA likely achieved their professional success by conducting "their own peer-reviewed research on the very same technologies now being criticized by (what appeared to be) non credentialed and overly zealous organic farmers" (2013, 6).

Yet despite Secretary of Agriculture Earl Butz's quip in 1971 that a switch to organic farming would require a decision about which 50 million Americans must starve, public opinion was changing regarding the current course of conventional agriculture (Treadwell, McKinney, and Creamer 2003). Rachel Carson's *Silent Spring* (1962) highlighted the potential harmful effects of unregulated pesticide use to humans, wildlife, and the environment. This increasing environmental awareness, coupled with Cesar Chavez's United Farm Workers Union revealing the dangerous conditions endured by migrant farm workers, inspired many to disengage from the industrial agriculture model by returning back to the land. But as veteran organic policy advocate Michael Sligh points out, the organic farming movement did not rest solely on the backs of environmentalists and social justice advocates who were abandoning the city life to try their hand at harvesting their own food. The growing influence of corporate agribusiness created an economic structure in which farm size needed to increase in order for farmers to stay competitive, thus forcing many out of business (Sligh 2002). As Sligh states, "part of what drove family farmers into organic farming was that conventional agriculture drove them out" (Fromartz 2006, 235).

Facing an absolute dearth of public research into effective organic farming systems, the growing number of organic farmers relied heavily on resources within their own community to discover and share effective production systems. According to the State of Organic Seed report (2011, 6), "it is no exaggeration to say that in the early decades of the organic movement there was a strong distrust of [the] Land Grant University system." Grassroots organizations such as the Maine Organic Farmers and Gardeners Association (MOFGA) and Natural Organic Farmers Association (later renamed the Northeast Organic Farming Association or NOFA) in Vermont were founded in 1971, with 35 grower support groups active in 28 states by the end of the decade (USDA Study Team on Organic Agriculture 1980). Organic farmers would congregate at annual regional gatherings, such MOFGA's Common Ground Fair, which began in 1977. In addition to Rodale's *Organic Farming and Gardening,* publications such as *Acres, U.S.A.* and *Mother Earth News* also began in the early 1970s and served an important function in disseminating useful information to organic farmers.

The USDA was also fielding an increasing number of requests for information regarding organic agriculture, and in 1980 released its *Report and Recommendations on Organic Farming* (1980). This report, the first of its kind undertaken by the USDA, was commissioned by Secretary of Agriculture Robert Bergland in part to determine the extent to which "organic systems might help to address the environmental, structural and financial problems that were now plaguing American agriculture" (Youngberg and DeMuth 2013, 7). The report's findings suggested that the agronomic and environmental benefits of organic farming justified increased research and support from the agricultural research community (2013). Yet a backlash from conventional agriculture led to a rejection of the report by the incoming Reagan administration, who quickly eliminated the USDA's newly established Organic Farming Coordinator position (2013).

In 1988, after multiple failed legislative attempts by Senator Leahy of Vermont and Representative Weaver of Oregon to implement the recommendations of the 1980 report, funds were directed to the USDA for the establishment of a competitive grants program for Low Input Sustainable Agriculture (LISA), which later became known as Sustainable Agriculture Research and Education (SARE). A notable aspect of this funding stream, still important for organic research today, is the inclusion of farmers and non-governmental organizations in the award process, indicating their continued influence and involvement in shaping the organic movement (Treadwell, McKinney, and Creamer 2003). Conspicuously absent from this program, however, is the term "organic", which policy makers believed was still too contentious. Yet the market for organic food continued to grow, and many organic advocates believed that a national certification standard would be beneficial for organic farmers and consumers. The Organic Foods Production Act was included in the 1990 Farm Bill with the purpose of defining the production standards for organic agriculture. After 12 years of intense deliberation, the NOP, housed within the USDA's Agricultural Marketing Service and advised by a 15-member group of organic representatives called the National Organic Standards Board (NOSB), established its Final Rule on organic agriculture in the United States in 2002.

Now with an official description of production practices defined by the USDA, the organic industry has grown at an unprecedented rate, generating over $31 billion dollars in sales in 2012 (Organic Trade Association 2013). Attitudes within academia have changed as well. A recent commentary in the journal *Science* states that "even in advanced economies, human well-being depends on looking after the soil. An intact, self-restoring soil ecosystem is essential, especially in times of climate stress" (Scholes and Scholes 2013, 565). While the article does not refer specifically to organic agriculture, this clearly is at the heart of the organic philosophy. True to its roots, organic farmers continue to have differing opinions about the speed with which the movement has grown and the decisions that have been made along the way, as well as the direction in which to chart its future course. Yet certainly the prevalence of organic food on most supermarket shelves today would not have been possible without the century long struggle of farmers, consumers, scientists, and policy advocates committed to promoting the organic movement.

Steeped in this history of self-reliance, organic farmers are eager to participate in the breeding of improved cultivars when faced with the prospect of limited varieties adapted for their systems. Having been compelled to develop effective on-farm systems without the assistance of public research from LGUs for so many years, organic farmers, rather than agricultural researchers, tend to be the experts in organic production. Most public plant breeders, on the other hand, have been trained in conventional agriculture systems and may have little knowledge of the varietal needs of organic farmers. PPB works as a breeding method for organic varieties in part because organic farmers share their knowledge with breeders regarding the biotic and abiotic pressures particular to their farming systems, as well as the nuances of their consumer markets. In exchange, the farmers have the opportunity to learn aspects of the science and art of plant breeding.

With this newly gained skill, organic farmers can further adapt the varieties that they are growing on their farms, even after the specific PPB collaboration has ended. This aspect of continual improvement helps to explain the prevalence of organic PPB projects that focus on developing open-pollinated (OP) varieties (Dillon and Hubbard 2011). Cross-pollinating OP varieties contain more genetic variability, compared to hybrids, allowing for on-going adaptations in response to environmental and human selection. In addition, seed form self-pollinating and cross-pollinating OP varieties can be saved from one year to the next, which allows the farmers (rather than the seed companies) to control the seed. This independence from external inputs has long been a value of organic farmers, as the history of the movement demonstrates. Other practical explanations also exist for the emphasis on OP varieties in PPB, including the large amount of land, labor, and capital required for hybrid development and seed production (Duvick 2009). Yet, especially as seed ownership has become an increasingly contentious issue, many organic farmers agree with the sentiment that "everyone should be able to breed vegetables on their own and save their own seeds at all times" (Mendum 2009, 153).

2.5. New Collaborations between Organic Farmers and Public Plant Breeders

In addition to the enthusiasm of organic farmers, public plant breeders are beginning to recognize the opportunity to develop improved varieties for organic farmers. In this context, the public sector includes breeders that are funded by federal and/or state appropriations, and may be based at federal research facilities, LGUs, or state agricultural experiment stations. Unfortunately, public plant breeding in the US is in crisis. Beginning with Frey's report (1996), a series of publications have documented the decline of public breeding programs, public breeding faculty positions, and government financial support over the past 20 years (Fuglie and Walker 2001; Heisey, Srinivasan, and Thirtle 2001; Sligh 2003; Guner and Wehner 2003; Gepts and Hancock 2006; Hancock and Stuber 2008). These ongoing budget cuts at the federal and state levels are part of a larger trend of stagnating public funds for agricultural research that has been occurring since the 1970s (Alston et al. 2010).

While public breeding programs are in decline, however, the private seed industry has grown at a staggering rate. With the advent of biotechnology in the 1990s, private seed companies began investing heavily in research and development, surpassing the amount spent in all other agricultural input sectors (Fuglie et al. 2011). By 2010, expenditures in seed and biotechnology research alone accounted for 45% of total private agricultural input investment (2011). This emphasis on research and development has been profitable for the private seed industry, with the value of the global seed market estimated at $47 billion in 2012 (McNabb 2013).

This growth is particularly remarkable given that recouping full research investments through seed sales is inherently difficult. As a living biological organism, planting a seed does not use it up. Instead, the seed will naturally reproduce itself, and at an exponential rate at that (one corn seed kernel will produce an ear with upwards of 300 kernels). With no assurance that a farmer will purchase new seed each year, private seed companies are likely to underinvest in research and product development – a classic case of market failure. Intellectual property rights (IPR) provide one remedy for this situation, and both biological and legal forms of IPR have been used to spur the growth of the seed sector. These include the development of hybrid cultivars beginning in the 1920s, the passage of the Plant Patent Act (PPA) of 1930 and the expanded Plant Variety Protection Act (PVPA) of 1970, the 1980 U.S. Supreme Court decision in *Diamond v. Chakrabarty* which ruled that living things are patentable subject matter, and finally the *Ex Parte Hibberd* decision by the U.S. Board of Patent Appeals and Interferences in 1985 to allow the granting of utility patents in conjunction with PPA and PVPA. These events have increasingly limited the ability of farmers and industry competitors to save, replant, and sell seeds (see Kloppenburg 2004 for a thorough history and analysis of the commodification of seed).

In addition, Fuglie and Toole (2014) suggest that the advances in recombinant DNA that led to GM varieties further incentivized significant private investment. This technology, in conjunction with strengthened IPR, allows seed companies to apply for utility patents on not just a new variety, but also the specific GM traits it contains, as well as the processes by which the traits are integrated. A single GM variety can incorporate as many as 40 different technologies, as in the now-famous case of GoldenRice™, with an accompanying licensing fee for each patent (Kryder, Kowalski, and Krattiger 2000). Monsanto, the industry leader, earned $11.7 billion in 2009 through not just seed sales, but the licensing of its GM traits to hundreds of firms, including its main competitors (The Economist 2009). These high licensing fees are ultimately passed on to the farmer, with seed costs that increased by approximately 50% (adjusted for inflation) for corn and soybeans between 2001 and 2010 (Fernandez-Cornejo et al. 2014).

The economic strength of the private seed industry begs the question of the role of public plant breeders in developing finished cultivars. According to the classic model of research policy espoused by Roosevelt's science advisor Vanevar Bush (1960), upstream basic scientific investigations leads to downstream technological advancements, and allows for separate yet complementary roles for public and private research. For example, a public breeder might screen exotic germplasm for a particular disease resistance, and then transfer the resulting improved material to a private breeder for introgression into a commercially viable finished variety. Critics have argued that this concept of a linear flow between basic science and applied technology is not nearly so distinct, and that assessing whether or not public and private sector research investments complement or compete with one another depends on the particular industry in question (Fuglie and Toole 2014). In the case of the private seed sector, research investments are directed towards a few high value conventional crops such as corn, soybeans, and cotton (Traxler cited in J. King, Toole, and Fuglie 2012). Even with strengthened IPR, minimal private money is spent on developing finished varieties of crops with lower economic returns, such as some small grains, perennial forages, and vegetables. These crops may generate less revenue because the seed is readily saved and replanted by farmers, the crop is not easily genetically modified, the value of the seed crop is minimal, or an unfavorable ratio exists between the cost of seed production and the market value of the seed. Yet a diversity of crop varieties is necessary in order to maintain a resilient agricultural system, and public plant breeders are well suited to address this public good by developing improved cultivars of these underutilized species.

Griliches (1958, 430) suggests that “to establish a case for public investment one must show that, in an area where social returns are high, private returns, because of the nature of the invention or of the relevant institutions, are not high enough relative to other private alternatives.” Breeding varieties for organic agriculture fits this description well, as the opportunity costs for a company catering to organic farmers are high in comparison to revenue generated by the conventional seed sector. Organic agriculture produces positive social outcomes by reducing some negative impacts of conventional farming practices. Numerous studies have shown that organic agriculture enhances plant and animal biodiversity, increases soil organic matter, and lowers soil nutrient runoff (Bengtsson, Ahnstrom, and Weibull 2005; Gomiero, Pimentel, and Paoletti 2011; Nemecek et al. 2011; Tuomisto et al. 2012). In order to enable more farmers to incorporate organic practices, however, new organic varieties of crops and vegetables must be developed. A small private organic seed sector does exist, but it is not sufficient to meet this need. Most seed companies catering to organic farmers tend to identify and sell varieties that, even though conventionally bred, will perform adequately in organic production systems. Fewer companies are breeding new varieties specifically adapted for organics. As the executive summary of the State of Organic Seed Report states, “challenges and needs loom large for expanding organic seed systems” (Dillon and Hubbard 2011).

This underinvestment is understandable, given that less than 1% of total farmland in the US is certified organic (USDA-NASS 2013). The small market limits the organic seed industry's growth potential, and limits the ability of individual companies to make sizeable investments in developing improved varieties for organic farmers. Yet even as the organic industry grows, other self-imposed limitations will further prevent the level of growth observed in the conventional private seed industry. While the organic seed industry does utilize some IPR strategies to recover research investments, such as hybrid seeds and PVPA certificates, the use of utility patents on organic varieties is not common. Utility patents for GM varieties enables high profit margins through restrictive licensing, but the prohibition of GM varieties for organic certification eliminates this income stream for the organic seed sector.

Perhaps more significantly, the organic community tends to view all forms of IPR critically, as there is a strong sentiment that seed is a common resource that should be shared collectively, rather than individually owned. Pervasive use of IPR by a company catering to organic growers may result in fewer customer sales, as the quality of a product is not always as important as the philosophy behind it. For example, the majority of Fedco Seeds customers, a company that has been providing seeds to organic growers since 1978, voted to drop all Seminis vegetable varieties from the Fedco seed catalog when Seminis was acquired by Monsanto in 2005 (Trueman 2009). While replacing the gaps left by the Seminis varieties was a challenge for the small seed company, Fedco sales doubled in the two years following their decision (2009). On the other hand, there is a willingness to experiment with new distribution models, as is demonstrated by the 2014 release of vegetable and crop varieties with an "Open Source Seed Pledge" that encourages growers to use the varieties in any way they like, as long as they do not protect the varieties (or their derivatives) with patents or restrictive licenses (J. Kloppenburg, personal communication, April 13, 2014). Of the initial 27 varieties released by small seed companies and public breeders with this pledge, 22 of the varieties were certified organic.

Given these private economic constraints, public plant breeders can play a crucial role in supporting the growth of the organic seed sector. With funding from federal and state governments, public plant breeders are not bound by the profit incentives of the private sector. Instead, they are able to focus on issues of food security, sustainability, public service, and education (Tracy 2004). Breeding for organic agriculture addresses these goals by supporting a more environmentally sustainable farming system that can produce food that is higher in antioxidants and lower in chemical residues (Baranksi et al. 2014). Public breeders have the flexibility to engage with organic farmers collaboratively, as equal partners in the breeding process, rather than as end consumers of their work. The new varieties that emerge from this breeding methodology help to increase the feasibility of farming more acres organically. The value of this work is rooted in its contribution to the public good, rather than its economic influence on a corporation's bottom line.

Breeding for organic agriculture has opened up new avenues of funding that public plant breeders can access to support PPB. An increasing amount of public grant programs are being earmarked for organic research as a result of tireless work of organic policy advocates. The State of Organic Seed Report (2011) shows that public funds supported 57 organic seed or organic breeding projects from 1996 - 2014, totaling almost $9 million, with the largest funding source coming from the USDA - National Institute of Food and Agriculture's (NIFA) Organic Agriculture Research and Extension Initiative (OREI). In addition, new funding streams from private foundations are increasing, such as the Seed Matters graduate student fellowships sponsored by the Clif Bar Family Foundation, as well as breeding grants from the Organic Farming Research Foundation (OFRF) and the Ceres Trust. These grants alone are not enough to totally revive public breeding in the United States, as longer-term funding is still required to adequately support breeding projects that can take 7-10 years to reach fruition (Mendum and Glenna 2010). Yet by emphasizing the role that public breeders can play in promoting more sustainable agricultural models, this may help to leverage larger funding streams in the future.

2.6. Conclusion

Plant breeding impacts people and societies because it determines the course of our agricultural future. Without appropriate varieties that are relevant for their systems, farmers cannot be successful and consumers suffer from either price increases or lack of food availability, or both. PPB is a useful methodology that has enabled breeders and farmers in the developing world to create varieties adapted to the marginal conditions of many subsistence farmers. PPB accomplishes this by taking advantage of G x E interaction, and selecting varieties directly in the environment of their intended use in order to achieve superior performance. Farmer participation is a crucial aspect of the methodology, as the farmer is best equipped to recognize the agronomic and quality traits that will enable the variety to be productive in his or her system.

As organic farming in the US has grown from outsider status to a more mainstream position in the agricultural sector, awareness of the need for organically adapted varieties has also grown. The selection theory that supports PPB as a useful methodology for small-scale farmers in the developing world applies similarly to organic farmers in the US, whose growing conditions vary significantly from conventional production, where most crop and vegetable varieties are currently bred. In addition, farmers do not need to be trained in quantitative genetic theory to actively contribute to PPB.

Yet organic agriculture and PPB share other important synergies as well. The history of the organic farming movement is one of farmer engagement in both the biological innovations necessary to cultivate a productive agroecological farming system and the political processes required to get official USDA recognition and support. Thus, farmer participation in breeding new varieties adapted for organic systems has strong cultural relevance within this community. Likewise, responding to the needs of farmers who are otherwise not being served by the conventional seed sector is a critical responsibility of public plant breeders. While this partnership may have been highly unlikely in the early years of the organic movement, new attitudes of collaboration among organic farmers and public agricultural researchers, coupled with new funding streams, are much more prevalent today. As agriculture confronts the pressing issues of climate change, an increasing global population, shrinking land availability, and limited natural resources, new models of sustainable farming are required. Organic agriculture continues to be one of the best examples of a viable alternative, with PPB offering a robust method for developing the improved varieties required for future growth of this sector.

Figure 2.1. Participatory plant breeding (PPB) methodologies: the project initiation, farmers' role in the breeding process, breeding location, and goals can vary depending on the unique set of participants involved and the resources available to them.

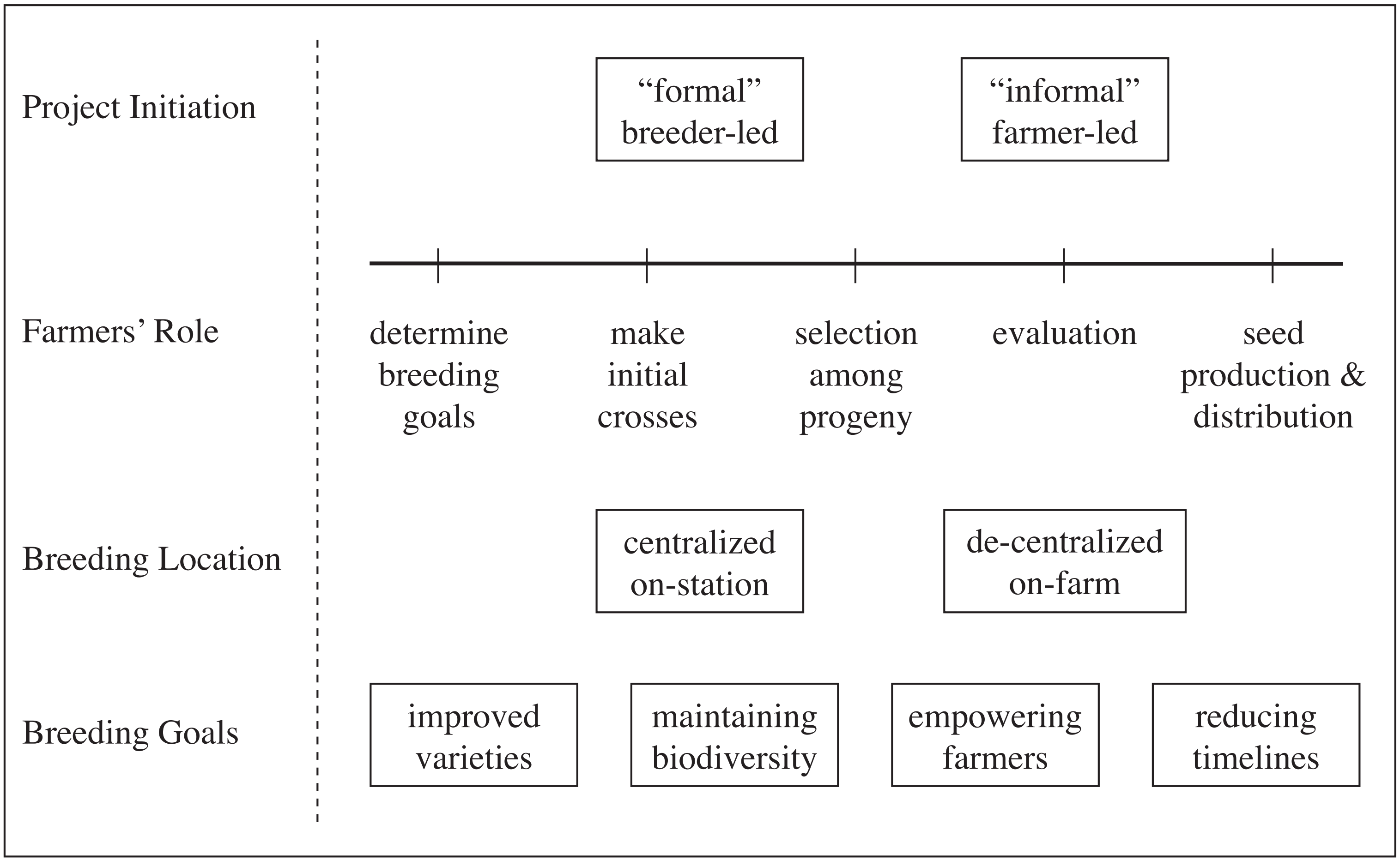
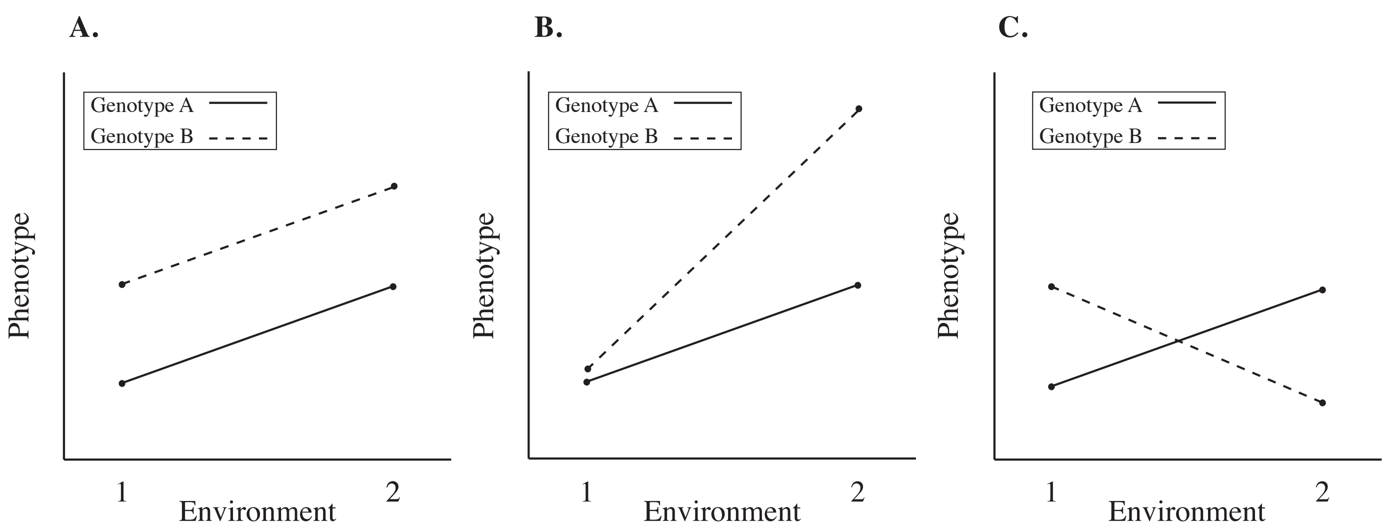


Figure 2.2. Three scenarios of genotype performance in two environments: **A.** Phenotypic values for genotypes A and B differ, but the relative difference in each environment remains the same, indicating no genotype by environment interaction. **B.** Both genotypes perform similarly in environment 1, but perform differently in environment 2, indicating a genotype by environment interaction. **C.** Genotypye A outperforms genotype B in one environment, but genotype B outperforms genotype A in the other environment, indicating an extreme genotype by environment interaction (Anholt and Mackay 2004).



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Chapter 3

Recurrent Selection and Participatory Plant Breeding for Improvement of Two Open-Pollinated Sweet Corn (*Zea mays* L.) Populations

Abstract
Organic growers face unique challenges when raising sweet corn, and benefit from varieties that maintain high eating quality, germinate consistently in cold soils, deter insect pests, and resist diseases. Genotype by environment rank changes can occur in the performance of cultivars grown on conventional and organic farms, yet few varieties have been bred specifically for organic systems. The objective of this experiment was to evaluate the changes made to open-pollinated sweet corn populations using recurrent selection and a participatory plant breeding (PPB) methodology. From 2008 to 2011, 4 cycles of two open-pollinated (OP) sugary-enhancer sweet corn populations were selected on a certified organic farm in Minnesota using a modified ear-to-row recurrent selection scheme. Selections were made in collaboration with an organic farmer, with selection criteria based on traits identified by the farmer. In 2012 and 2013, the population cycles were evaluated in a randomized complete block design in two certified organic locations in Wisconsin, with multiple replications in each environment. Replicated growth chamber experiments were also conducted to test germination rates across three seed production environments. Significant linear trends were found among cycles of selection for quantitative and qualitative traits, suggesting the changes were due to recurrent selection and PPB methodology for these populations. However, further improvement is necessary to satisfy the requirements for a useful cultivar for organic growers.

3.1. Introduction

As organic agriculture has grown in recent years, so too has an interest in breeding crop and vegetable varieties adapted specifically for organic farming systems. Varieties bred for conventional agriculture often perform differently when grown in organic systems (Murphy et al. 2007; Singh et al. 2009; Reid et al. 2010; Singh et al. 2011; Kamran et al. 2014). In addition to yield, organic farmers place a priority on crops that are disease and insect resistant, can compete with weeds, are adapted to intercropping and biologically diverse systems, and exhibit a positive yield response to organic fertility sources (Sooby et al. 2007). A survey of organic growers in the United States conducted in 2010 by the Organic Seed Alliance found that 83% agreed or strongly agreed with the statement, "varieties bred for organic system management are important to the overall success of organic agriculture" (Dillon and Hubbard 2011). Yet developing effective breeding strategies for organic agriculture is challenging. For cultivars in which the important traits under selection exhibit minimal genotype by environment interaction, indirect selection on conventional breeding stations may be the most efficient breeding method. When there is low genetic correlation between a genotype's performance on-station and on-farm, however, direct selection in organic conditions is preferred (Atlin et al. 2001). The diversity of cultural practices found on organic farms, especially regarding fertility practices and pest management, further complicate the choice of appropriate selection environments (Murphy et al. 2005). To date, no studies have been conducted to understand potential genotype x organic production system interactions (Horneburg and Myers 2012). Adding to the challenge, plant breeders who have been trained in conventional farming systems may be unaware of the most important traits for successful production in organic systems.

One strategy that has been used to breed varieties adapted to organic farming systems is participatory plant breeding (PPB) (Chiffoleau and Desclaux 2006; Mendum and Glenna 2010; Dawson et al. 2011; Myers et al. 2012). With this methodology, breeders and farmers work collaboratively throughout the breeding process, often making selections and evaluating progeny on organic farms. PPB was first described by name in the peer-reviewed literature in 1996, and was originally developed to breed useful varieties for small-scale farmers situated on marginalized land in developing countries (Witcombe et al. 1996). Advantages of PPB can include exploiting genotype by environment interactions by selecting superior lines in the target environment, involving farmers in the initial planning stages to facilitate development of varieties that suit their particular requirements, and, in the case of open-pollinated (OP) populations and diverse mixtures of self-pollinated pure-lines, allowing farmers to continually adapt and improve the variety (Dawson et al. 2008).

Initial examples of successful PPB projects tended to involve self-pollinating grain crops such as barley and rice, in part because of the relative ease with which these crops could be bred on-farm (Sthapit et al. 1996; Ceccarelli et al. 2000; Ceccarelli et al. 2003; Virk et al. 2003). After the initial crosses are made to generate variability in the breeding population, no further controlled pollinations are required in successive cycles of selection. Because the grain used for human and/or animal consumption is the same as the seed, participating farmers do not need to significantly alter their normal harvesting techniques to produce both a food crop and breeding seed for the next year. Examples of PPB projects with cross-pollinating grain crops, such as maize and sorghum, can also be found in the literature (Smith et al. 2001; Witcombe et al. 2003; vom Brocke et al. 2010). Cross-pollinating crops increase the complexity of the breeding scheme because selections are often made after fertilization has occurred, and unless the pollinations have been controlled by hand, pollen from both desirable and undesirable genotypes within the population contributes to the next cycle of selection. Selections made on half-sib progeny decrease the gain from selection made with each progressive cycle (Fehr 1987). PPB projects tend to focus almost exclusively on non-hybrid cultivars, with some exceptions such as a hybrid maize PPB experiment in southwest China (Li et al. 2013). In general, the large amount of labor and capital required to effectively breed and produce seed of hybrids is a limiting factor for PPB (Duvick 2009).

Organic PPB projects, while initially focusing on OP grain crops, have also increasingly explored the feasibility of improving OP vegetable crops (Hubbard 2014). Yet no examples are cited in the scientific literature testing the actual gains made from selection of an organic vegetable crop using a PPB methodology. A successful breeding project begins with the selection of high-quality parents, but minimal information may be available regarding the best cultivars for organic systems. When breeding on-farm, space limitations for trial plots and lack of homogeneity in field conditions can negatively affect the gains made from selection. These challenges may explain the lack of peer-reviewed literature in this discipline.

Sweet corn (*Zea mays* L.) is an example of a vegetable crop that, until recently, has not been bred for organic production systems. Organic sweet corn is grown for both the fresh and processing markets, and its narrow window of seasonal availability make it particularly attractive to consumers at direct sales venues such as farmers' markets (Diver et al. 2008). However, the field space and labor required to grow sweet corn organically deter many farmers from producing it (Local Season | Willy Street Co-op 2014). Controlling weeds is a significant challenge, as are insect and disease pressures, and the difficulty of achieving a uniform distribution of the high nitrogen requirements of sweet corn (Diver et al. 2008; Ulloa et al. 2010; Johnson et al. 2012). Breeding sweet corn for organic production could help to minimize some of these production issues.

The purpose of this study was to evaluate the gains made in two OP sugary-enhancer sweet corn populations, developed with a modified ear-to-row recurrent selection scheme and PPB. After the initial populations were developed, all breeding occurred on a certified organic farm in Minnesota from 2008 – 2011. The agronomic and quality traits under selection were those identified by the participating farmer as important to his organic sweet corn production system, and consistent with the general needs of organic farmers listed above.

3.2. Materials & Methods

3.2.1. Breeding History

Two sugary-enhancer sweet corn populations were developed at the University of Wisconsin's West Madison Agricultural Research Station (WMARS). The earlier maturing of the two populations, designated "early", was produced by crossing four publicly available sugary-enhancer sweet corn hybrids. Progeny were cross-pollinated by hand, followed by a cycle of self-pollination. The later maturing population, designated "late", was also produced by crossing four publicly available sugary-enhancer sweet corn hybrids. Progeny were alternately cross-pollinated by hand, followed by a cycle of self-pollination, for a total of four years of recombination. The early and late populations were maintained at approximately 150 plants per population, and share one common hybrid parent.

Beginning in 2008, each population underwent five cycles of a modified ear-to-row recurrent selection scheme (Table 3.1). The original ear-to-row procedure, developed by C.G. Hopkins (1899), involved planting a population in an isolated unreplicated plot, allowing the population to open pollinate, saving seed from the superior female parents, and replanting the selected half-sib families for further evaluation and selection. In the modified ear-to-row procedure used in this experiment, 136 ears from cycle 0 (C0) of the early population, and 92 ears from C0 of the late population were planted in unreplicated plots on a certified organic farm in Farmington, Minnesota. Prior to planting, Suståne (Cannon Falls, MN) 5-2-4 fertilizer was applied to the field at the rate of 667 kg ha^{-1}. Soil type is a Kanaranzi loam (fine-loamy, mixed mesic Typic Hapludoll). Twenty-five kernels from each ear were planted in single row plots, measuring 3.5 m long and 0.9 m wide. Alleys between plots were 0.9 m. At the V6 growth stage, plants were side-dressed with Suståne 5-2-4 fertilizer at the rate of 445 kg ha^{-1}. Initial weed flushes were controlled with a tractor-mounted cultivar, followed by hand weeding throughout the season.

Each plot was evaluated for germination by counting the total number of plants emerged. Plots were thinned at the V5 growth stage to a final density of 15 plants plot $^{-1}$. The breeders and farmer evaluated each open-pollinated row at the fresh eating stage (approximately 21 days after silk emergence) for the following traits: resistance to common rust (*Puccinia sorghi*), husk protection (amount of husk covering the ear tip), tip fill (complete kernel development extending to the tip of the ear), ear shape, kernel flavor, and kernel tenderness. All traits were identified by the farmer as important to his production system, and were evaluated on a 1-5 scale, with 5 as the best. Any rows that exhibited corn smut (*Ustilago maydis*) were immediately discarded. Flavor and tenderness ratings were weighted heaviest in selection, and no progeny rows with flavor and tenderness ratings below 3 were recombined. Unplanted remnant seeds from the best 11 ear rows from each population were planted in an off-season nursery in Chile, enabling two growing seasons in a single calendar year (one season for selection and the other for recombination). In Chile, plants were cross-pollinated by hand to create the next cycle of full-sib families. This procedure was repeated each year in both the early and late populations.

3.2.2. Evaluation Trials

Three separate experiments were conducted to evaluate the differences among populations and cycles of selection. The first experiment (EXP1) evaluated quantitative and qualitative plant and ear traits, and was conducted in 2012 and 2013 on certified organic land at WMARS and the University of Wisconsin's Arlington Agricultural Research Station (AARS). Soil type at both locations is a Plano silt loam (fine-silty, mixed mesic Typic Argiudoll). The experiment was arranged as a randomized complete block design (RCBD) with four replications per environment. Rows measured 3.5 m long and 0.8 m wide. Each plot consisted of four rows; alleys between plots were 0.9 m. Seed for cycles 0-3 (C0-C3) of the early and late population was produced at WMARS in 2011. Seed for cycle 4 (C4) of both populations was taken directly from the ears returning from the off-season nursery for use in 2012, and was produced at WMARS in 2012 for use in 2013.

In 2012, all cycles of the early and late populations were planted at WMARS on 18 May and at AARS on 23 May. In 2013, all cycles of the early and late populations were planted at WMARS on 16 May and at AARS on 03 June. Prior to planting, the 2012 and 2013 WMARS location was prepared with Suståne 8-2-4 fertilizer applied at the rate of 280 kg ha^{-1}. The 2012 AARS location was prepared with oganic poultry compost applied at the rate of 4,484 kg ha^{-1}. The 2013 AARS location was prepared with liquid dairy manure applied at the rate of 75 kl ha^{-1}. Initial weed flushes were controlled with a tractor-driven rotary hoe, followed by hand weeding throughout the season at all locations. All entries were planted at 30 kernels row^{-1} and evaluated for germination by counting total number of plants emerged. Plots were then thinned to the desired density of 15 plants row^{-1} (53,800 plants ha^{-1}) at the V5 leaf stage.

Morphological data were taken from the first five bordered plants in the left-center row of each plot. Flowering dates were recorded for all locations (except at AARS in 2012) and used as a predictor of fresh eating maturity. Silk emergence was recorded when fifty percent of the plants in the center two rows of a plot showed silk emergence from the husk. All calendar dates were converted to growing degree days (GDD), and calculated from planting date by subtracting 10°C from the average daily temperature, with minimum temperatures set no lower than 10°C, and maximum temperatures set no higher than 30°C. Plant height, ear height, and ear leaf width were measured post-anthesis. Plant height was measured as the distance from the soil surface to the tassel tip and ear height was measured as the distance from the soil surface to the ligule of the leaf subtending the uppermost ear. Ear leaf width was measured at the widest section of the leaf subtending the uppermost ear.

To evaluate ear characteristics, 10 ears from bordered plants in the left-center row were harvested at the fresh eating stage as determined by flowering dates. Five ears were husked, and data were collected on ear length, ear width, and number of kernel rows. Using a numeric rating scale of 1-5, with 5 as the best, the ears were further evaluated for their husk appearance, husk protection, tip fill (kernel development to end of ear), ear shape, and row configuration (Table 3.4). Five ears were tasted and evaluated for their flavor and tenderness. All plants in the right-center row were harvested, husked, and counted to determine the total number of marketable ears (ears measuring greater than 15 cm in length). Because flowering dates were not recorded in the 2012 AARS location, the ears in that environment were not evaluated for flavor and tenderness.

The second experiment (EXP2) for the evaluation of common rust (*P. sorghi*) resistance among the populations and cycles of selection was conducted adjacent to EXP1 in 2012 and 2013 at WMARS and AARS. All field preparations, row measurements, and seed sources were the same as EXP1. The experiment was arranged as a RCBD with three replications per environment. Each plot consisted of a single row of the population cycle entry, with one row of a common rust susceptible hybrid ('Sugar Buns' in 2012, 'Temptation' in 2013) bordering each entry to encourage an even distribution of secondary inoculum. All plants in plots and bordered rows were inoculated at the V8 to V10 leaf stage by filling whorls with a *P. sorghi* suspension (15 mg of urediniospores in 1l water with five drops of Tween 20 added to prevent clumping) using a back-pack sprayer (Chandler and Tracy 2007). Common rust susceptibility was assessed visually and assigned a severity rating of 1-5, with 5 as least susceptible, based on area of leaf tissue infected with pustules on the first five bordered plants.

The third set of experiments (EXP3) for the evaluation of germination was conducted in growth chambers at the Wisconsin Crop Improvement Association laboratory in Madison, WI. A warm germination (WG) test evaluated each entry under optimal conditions, a cold germination (CG) test evaluated each entry under cold temperature stress, and an infected-soil cold germination (ISCG) test evaluated each entry under cold temperature and soil pathogen stress. Seed for evaluation was produced in three environments at WMARS in 2011, 2012, and 2013. Ears were harvested a minimum of 40 days after hand-pollination, and dried to approximately 10% moisture with a forced air dryer at 35° C. Ears were hand-shelled, with damaged kernels discarded. Seed lots were maintained as balanced bulks and stored in a refrigerated room at 10° C in plastic containers to reduce fluctuations in seed moisture. C0-C3 of both populations were generated all three years, C4 of both populations was generated in 2012 and 2013 only. Entries from each seed production environment were arranged as a RCBD, with four replications per environment. In addition, four replications of the commercial hybrid ‘Temptation’ were included as a check.

For the WG test, two sheets of seed germination paper (Anchor Paper, Minneapolis, MN) were soaked in 20° C deionized (DI) water and laid flat. Fifty kernels of a single entry were equally distributed on the wet paper. Two additional sheets of seed germination paper were soaked and placed on top of the seeds. The four sheets of paper were rolled compactly to form a rag doll, and placed in a topless aluminum container. Once the container was filled (approximately 16 rag dolls each), a plastic sheet was secured over the top with a rubber band, and placed in a germination chamber set at 25° C for seven days. Evaluation consisted of counting normal, abnormal, and dead seedlings according to the Association of Official Seed Analyst, Inc. (AOSA) protocol (Association of Official Seed Analysts 2013). Percentages for each category were calculated as the number of kernels in each category divided by the total number planted.

Methods for the CG test were similar with a few exceptions. The rag dolls were prepared using DI water that had been cooled in a 10° C germination chamber to enable a consistent cold temperature stress for all entries from the beginning of the experiment. This temperature is slightly above the minimum temperature required for corn growth, but well below optimal conditions, and thus useful for evaluating cold stress on seedlings (Blacklow 1972). Once the aluminum containers were filled and covered with a plastic sheet, they were placed in a germination chamber set at 10° C for seven days, then transferred to a germination chamber set at 25° C for five days. Evaluation of germination was conducted in the same manner as the WG test.

Protocol for the ISCG test followed that of the CG test, with one significant difference. After the 50 kernels were distributed evenly on the wet germination paper, soil collected from fields previously planted to corn and containing corn pathogens was sprinkled over the kernels to sufficiently coat them, but not entirely cover each kernel. Two water soaked sheets were placed on top of the kernels and soil, and rolled together to form the rag doll. Evaluation for germination was conducted in the same manner as the WG and CG tests.

3.2.3. Data Analysis

Data analysis for all experiments was performed using the SAS 9.2 statistics package (SAS Institute, Cary, NC) and R version 3.0.3 (R Foundation for Statistical Computing, Vienna, Austria). For EXP1 and EXP2, environments and genotypes (cycles of selection in both populations) were evaluated as fixed effects, while replication within environment was considered random. Normality and equal variance tests were conducted on the entry residuals, with no deviations found. For all traits measured, an analysis of variance (ANOVA) was calculated on plot means using the SAS MIXED procedure. No significant ($p \leq 0.05$) genotype-by-environment interactions were found, with the exception of days to silking. Spearman rank correlations indicated differences in magnitude rather than rank, and entries were pooled across all environments. Entry means were compared using Fisher's protected least significant differences (LSD) at the $p \leq 0.05$ significance level. Orthogonal polynomial contrasts were performed to compare overall means between the early and late populations. A second ANOVA was calculated for each population, and cycles of selection were partitioned into linear and quadratic contrasts to test for trends in response to selection. Inference on statistical significance of linear and quadratic responses to selection was made based on F-tests of polynomial contrasts to increase the power to detect trends. Intercepts and polynomial coefficients were estimated based on population cycle means using the SAS REG procedure.

For EXP3, the WG, CG, and ISCG tests were analyzed separately, with genotypes analyzed as fixed effects, and seed production years and replications analyzed as random effects. Normality and equal variance tests were conducted on the entry residuals, with no deviations found. ANOVA was calculated on entry means using the SAS MIXED procedure. Spearman rank correlations were performed on significant ($p \leq 0.05$) genotype-by-seed production year interactions to test for changes in rank or magnitude. Non-significant correlation coefficients indicated that entries could not be pooled across seed production environments, and were analyzed separately. Entry means were compared using Fisher's protected least significant differences (LSD) at the $p \leq 0.05$ significance level. Linear and quadratic trends were analyzed using the same procedures as EXP1 and EXP2.

3.3. Results

3.3.1. EXP1: Quantitative and Qualitative Plant and Ear Traits

Significant differences were found between population means and/or among cycles of selection for all traits except for emergence percentage, number of marketable ears (Table 3.2), husk appearance, and tenderness (Table 3.3). In the late population, plants were significantly taller, ears were higher on the stalk, ear leaves were wider, and the maturity (measured by GDD to silking) was later, compared to the early population (Table 3.2). In the early population, plant height tended to decrease with successive cycles of selection, with a significant change from C0 at 162.2 cm to C4 at 138.9 cm. The late population plant height remained unchanged from C0-C3, then increased to 173.9 cm in C4. In the early population, ear height tended to decrease with successive cycles of selection, with a significant change from C0 at 48.3 cm to C4 at 42.0 cm. Ear height in the late population tended to increase, with a significant change from C0 at 52.3 cm and C4 at 58.6 cm. In the early population, ear leaf width decreased in C3, then increased slightly. There was no significant difference between C0 and C4. In the late population, ear leaf width tended to increase across cycles of selection, with a significant increase from 8.7 cm in C0 to 9.1 cm in C3. The early population became earlier from C0 at 589.2 GDD to C4 at 565.4 GDD. In the late population, maturity increased significantly from 605.4 GDD in C0 to 632.4 GDD in C4.

Ear length was significantly greater in the late population, with an overall population mean of 19.5 cm compared to 18.8 cm in the early population (Table 3.2). Ear length in the early population did not change significantly. Ear length in the late population increased steadily and significantly from 19.1 cm in C0 to 19.9 cm in C4. The early and late populations did not differ for average number of kernel rows (Table 3.2). In the early population, there was a significant difference between C1 at 14.7 kernel rows, and C3 (15.6) and C4 (15.5). In the late population, with 16.5 kernel rows, C4 had more rows than all other cycles.

The amount of husk covering the ear was rated on a 1-5 scale, with 5 as the best husk protection (Table 3.4). The overall mean of the late population, 3.8, was significantly greater than the early population mean, 2.9 (Table 3.3). Husk protection decreased significantly in the early population from a rating of 3.4 at C0 to a minimum of 2.5 at C3. Husk protection in the late population did not change significantly.

Tip fill is a measure of complete kernel development, and describes the kernel coverage at the ear tip. This trait was rated on a 1-5 scale, with 5 being a completely filled ear (Table 3.4). Tip fill was significantly better in the late population, with an overall mean rating of 3.5 compared to 2.8 in the early population (Table 3.3). This trait showed no significant differences among cycles of selection in the early population. In the late population, tip fill improved from 2.9 in C0 to 3.8 in C4.

Ear shape was rated on a 1-5 scale, with 5 being a perfectly cylindrical ear (Table 3.4). Ears were more cylindrical in the late population, with an overall mean rating of 3.7 compared to 3.3 in the early population (Table 3.3). Both populations tended to improve with successive cycles of selection, although the differences were not significant.

Row configuration was rated on a 1-5 scale, with 5 being the straightest rows (Table 3.4). Rows were straighter in the early population, with an overall mean rating of 3.3 compared to 3.0 in the late population (Table 3.3). Differences were not significant among cycles of selection in the early population. In the late population, rows become straighter from C0 at 2.6 to C2 at 3.3. C4 did not differ from C0 or C2.

Flavor was rated on a 1-5 scale, with 5 being the best. Flavor was significantly better in the early population, with an overall mean rating of 3.2 compared to 2.7 in the late population (Table 3.3). In the early population, improvement was observed with successive cycles of selection, from 2.8 at C0 to 3.6 at C4. In the late population, flavor improved significantly from C0 at 2.3 to C2 at 3.1. C4 did not differ from C0 or C2.

In the early population, positive linear responses to selection, as indicated by a significant linear coefficient, were observed for the flavor rating (0.2) and number of kernel rows (0.2) (Table 3.5). Negative linear responses were observed for plant height (-5.9 cm), ear height (-2.2 cm), days to silking (-6.6 GDD), ear length (-0.2 cm) and the husk protection rating (-0.2). A positive quadratic response was found for stand emergence (1.7%).

In the late population, positive linear responses to selection were found for plant height (1.5 cm), ear height (1.4 cm), ear leaf width (0.1 cm), days to silking (5.4 GDD), number of kernel rows (0.3 cm), the tip fill rating (0.2), and the tenderness rating (0.1) (Table 3.6). Positive quadratic responses were also found for plant height (1.3 cm) and number of kernel rows (0.2). The only negative response in the late population was the quadratic coefficient for the row configuration rating (-0.1).

3.3.2. EXP2: Common Rust Resistance

Common rust was visually rated on a 1-5 scale, with 5 as least susceptible, based on area of leaf tissue infected with pustules (Table 3.7). No significant differences were found among cycles of selection or between the early and late populations (Table 3.8).

3.3.3. EXP3: Warm Germination, Cold Germination, and Infected-Soil Cold Germination Tests

Results from the ANOVAs for each germination test showed that genotypes were not significant, but that genotype by seed production environment interactions were significant (Table 3.9). Non-significant Spearman correlation coefficients indicated that the interactions were due to changes in rank rather than magnitude (Table 3.10). Entry means could not be pooled across seed production environments, and seed production years 2012 and 2013 were analyzed separately. The 2011 seed production year was removed from the analysis because it did not contain cycle 4. Significant differences were found among cycles of selection and the commercial check variety for all germination tests separated by years (Table 3.11). Limited power in this analysis restricts the ability to draw meaningful conclusions from means separation, except perhaps to note that the commercial check ranked either first or second in germination rate for all tests in all years. Trends in linear and quadratic responses, partitioned by population, suggest that the early population exhibited either no change in germination rates with successive cycles, as in the case of the WG test in both years and the ISCG test in 2012, or a reduction in germination rates in the 2013 CG and ISCG tests (Table 3.12). While the 2012 CG test indicates an increase in germination rate with positive significant linear and quadratic coefficients (1.7 and 2.1, respectively), the low R^2 value explains only 37% of the variability. In the late population, all tests in both years indicate negative linear or quadratic trends, suggesting an overall reduction in germination rates with successive cycles of selection in this population (Table 3.13).

3.4. Discussion

The differences found among cycles of selection for quantitative and qualitative traits suggest the effectiveness of the modified recurrent selection and PPB methodology. However, some of the changes observed could also be caused by genetic drift, which are random changes in allele frequencies that can occur from one generation to the next, especially in small populations (Falconer and Mackay 1996). Genetic drift can be difficult to predict or quantify, although linear and quadratic trends may suggest that the changes observed result from direct or indirect selection. During selection of these populations, a strong emphasis was placed on improving the eating quality of both populations, as the participating farmer and breeders agreed that first and foremost, a new sweet corn variety must be enjoyable to eat. Sugary-enhancer sweet corn is based on a mutation of the *sugary enhancer1* (*se1*) allele, which has the unique ability among sweet corn mutants to accumulate high levels of sucrose and phytoglycogen simultaneously in a *sugary* (*su1*) background (Gonzales et al. 1976; Tracy 2000). As a result, sugary-enhancer sweet corn (*su1 se1*) maintains both the sweetness associated with the supersweet (*sh2*) varieties, and the creamy texture characteristic of traditional sugary (*su1*) sweet corn. While the genetics determining maximum sugary enhancer quality are not fully understood, it is clear that multiple recessive modifier genes contribute to high eating quality (Tracy 1997). The early population showed a significant linear response to direct selection for flavor improvement, while the late population exhibited a significant linear response to direct selection for tenderness.

The only other qualitative trait that showed a significant positive linear response to direct selection was the improvement of tip fill in the late population, an important trait for consumers. Husk protection showed a significant negative linear response to direct selection in the early population, while it remained unchanged in the late population with a high average rating of 3.8. Husk protection serves an important function for organic farmers because a long, tight husk extending beyond the ear can help deter the corn earworm (*Heliothis zea*) (Dicke and Jenkins 1945).

A number of quantitative traits, while not under direct selection, did respond linearly and, in some cases quadratically (Table 3.5 & 3.6). The changes observed in these traits could be a result of genetic linkage among traits, pleiotropy, or genetic drift such as inbreeding depression. While both populations were not significantly different from each other in C0, by C4 the late population was significantly taller, with a higher ear placement, wider ear leaves, and longer ears with more kernel rows compared to the early population. These agronomic qualities make the late population a better choice for an organic cultivar, as plant height and leaf width have been associated with weed suppression in sweet corn (Zystro et al. 2012), and larger ear size is generally preferred. Inbreeding depression tends to reduce plant height, ear size and days to maturity, suggesting that the early population may be suffering from this effect (Allard 1960).

Common rust is caused by the fungal pathogen *Puccinia sorghi* and produces reddish-brown pustules on the corn foliage. This plant disease can cause serious yield and quality reductions in the upper Midwest, and some level of resistance is crucial for organic growers (Tracy 2000). Significant differences were not observed among cycles of selection or between populations, which may be a result of the drought conditions in 2012 (Figures 3.1 & 3.2). The urediniospores that cause infection are wind-blown, and require at least 6 hours of 95% relative humidity or leaf wetness to germinate. The drought conditions of 2012 did not present a favorable environment for rust infection, and limited the robustness of the evaluation in that year. In the on-farm breeding plots, rust spores were not manually applied, and the selection pressure relied on natural occurrence of the pathogen. The lack of significant improvement between C0-C4 in the early and late populations suggest the utility of further selection for this trait in a rust disease nursery.

Cold soil germination is another critical issue, as organic growers cannot rely on fungicide seed treatments to assist with germination and may depend on early vigorous growth to outcompete weeds. The increased sugar and decreased carbohydrate ratio in the endosperm mutants of sweet corn lead to problems with germination, field emergence, and seedling vigor (Nass and Crane 1970; Wann 1980; Styer and Cantliffe 1984; Douglass et al. 1993). Multiple factors contribute to seed quality, including genetic background, environmental conditions, seed production, and pathogen susceptibility. The decreasing trends in cold germination and infect-soil cold germination experiments among cycle of selection (significant in the late population) is concerning but not surprising. There is a negative correlation between eating quality and germination. As eating quality increased among cycles of selection in both populations, it is likely that starch content decreased, which can lead to insufficient seedling energy reserves, especially in colder soils (Wann 1980; Styer and Cantliffe 1983). Initial selection of ears for cold tolerance in a cold germination chamber before field planting is recommended to improve this trait.

At least two limitations of the study suggest areas for further investigation. First, given the variability inherent in cross-pollinating OP populations, increasing the number of plants evaluated on a per plot basis will yield a more accurate representation of each population cycle. Second, while resource allocation is always a consideration, increasing the number of environments tested, particularly to include the selection environment, would potentially increase the statistical robustness and allow a comparison of performance between the selection and non-selection environments. Organic farming systems vary substantially, and given the slow process of building soil quality and structure with organic inputs, the number of years that a piece of land has been managed organically will greatly impact the health of the crop grown on it. The on-farm selection environment in this study has been in organic production for multiple decades, whereas the agricultural research station trial locations have been managed organically for ten years or less. This difference can cause improved crop performance in the selection environment in comparison to the trial locations.

This study indicates that progress can be made in developing OP sweet corn for organic growers using a modified ear-to-row recurrent selection scheme and on-farm PPB. While changes were observed in both populations, the late population exhibits promising traits including high eating quality, minimized tip blanking, good ear size and shape, and tall plants to help with weed competition. Yet further selection is necessary to improve traits that are critical for organic growers, including rust resistance, husk protection and cold soil germination.

Table 3.1. Breeding history of two sugary-enhancer sweet corn populations (early and late) developed by multiple generations of modified ear-to-row recurrent selection in Farmington, MN for improved performance in organic farming systems.

Population	Abbreviation	Breeding history
Early: Cycle 0	E0	Base population produced by crossing 4 publicly available sugary-enhancer sweet corn hybrids, followed by a cycle of inter-mating, then self-pollination.
Early: Cycle 1	E1	Based on the recombination of 11 ears selected in 2008 from 136 ear rows of E0.
Early: Cycle 2	E2	Based on the recombination of 13 ears selected in 2009 from 95 ear rows of E1.
Early: Cycle 3	E3	Based on the recombination of 13 ears selected in 2010 from 104 ear rows of E2.
Early: Cycle 4	E4	Based on the recombination of 12 ears selected in 2011 from 96 ear rows of E3.
Late: Cycle 0	L0	Base population produced by crossing 4 publicly available sugary-enhancer sweet corn hybrids, followed by 2 alternating cycles of inter-mating, then self-pollination.
Late: Cycle 1	L1	Based on the recombination of 11 ears selected in 2008 from 92 ear rows of L0.
Late: Cycle 2	L2	Based on the recombination of 12 ears selected in 2009 from 92 ear rows of L1.
Late: Cycle 3	L3	Based on the recombination of 12 ears selected in 2010 from 96 ear rows of L2.
Late: Cycle 4	L4	Based on the recombination of 12 ears selected in 2011 from 96 ear rows of L3.

Table 3.2. Means for quantitative plant and ear traits of cycles 0-4 from two sweet corn populations (early and late) grown in Arlington, WI and West Madison, WI in 2012 and 2013.

Entry	Plant Height	Ear Height	Ear Leaf Width	Emergence	Days to Silking†	Ear Length	Kernel Rows	Marketable Ears
	(cm)	(cm)	(cm)	(%)	(GDD)	(cm)	(average)	(average)
Early: Cycle 0	162.2	48.3	8.5	77.1	589.2	19.2	15.1	11.0
Early: Cycle 1	153.9	51.6	8.5	75.8	580.1	19.3	14.7	11.1
Early: Cycle 2	148.9	43.7	8.7	69.8	577.6	18.6	15.2	10.8
Early: Cycle 3	141.6	42.4	8.1	76.0	561.7	18.6	15.6	10.7
Early: Cycle 4	138.9	42.0	8.4	80.6	565.4	18.6	15.5	11.4
Late: Cycle 0	166.2	52.3	8.7	78.1	605.4	19.1	15.2	11.0
Late: Cycle 1	164.5	53.3	8.7	73.5	618.8	19.2	14.8	10.3
Late: Cycle 2	166.2	49.7	8.7	75.4	617.4	19.4	15.1	12.0
Late: Cycle 3	164.6	54.3	9.1	79.4	619.2	19.8	15.4	11.6
Late: Cycle 4	173.9	58.6	9.0	72.9	632.4	19.9	16.5	11.4
CV %	6.9	15.2	6.1	15.8	1.7	6.4	7.2	18.1
F-test ratio	18.2**	8.6**	4.9**	1.1ns	75.8**	2.9*	3.4**	1.0ns
LSD (0.05)	7.7	5.3	0.4	8.4ns	8.1	0.8	0.8	1.4ns
Orthogonal contrast of overall means between the early and late populations								
Early Population	149.1	45.6	8.4	75.9	574.8	18.8	15.2	11.0
Late Population	167.1	53.7	8.8	75.9	618.6	19.5	15.4	11.2
F-test ratio	107.9**	45.5**	26.1**	0.0ns	577.6**	10.0**	0.8ns	0.6ns

† Trait not evaluated in Arlington, WI in 2012.
*,** Significant at 0.05, 0.01 probability levels, respectively; ns = no significant differences.
LSD = Fisher's protected least significant difference, labeled "ns" if the F-test was not significant.
GDD = growing degree days in Celsius; CV % = Relative coefficient of variation.

Table 3.3. Means for qualitative ear traits rated on a 1-5 scale (5 is the best) of cycles 0-4 from two sweet corn populations (early and late) grown in Arlington, WI and West Madison, WI in 2012 and 2013.

Entry	Husk Appearance	Husk Protection	Tip Fill	Ear Shape	Row Configuration	Flavor†	Tenderness†
Early: Cycle 0	3.4	3.4	2.8	3.2	3.6	2.8	3.3
Early: Cycle 1	3.1	3.0	2.8	3.8	3.5	3.3	3.6
Early: Cycle 2	2.8	2.6	3.1	2.9	3.1	2.9	3.6
Early: Cycle 3	2.8	2.5	2.6	3.3	3.1	3.4	3.6
Early: Cycle 4	2.9	2.7	2.6	3.4	3.4	3.6	3.6
Late: Cycle 0	3.3	3.9	2.9	3.4	2.6	2.3	3.4
Late: Cycle 1	3.1	3.7	3.6	3.8	2.9	2.5	3.6
Late: Cycle 2	2.5	4.1	3.5	3.8	3.3	3.1	3.6
Late: Cycle 3	3.3	3.5	3.6	3.7	3.1	2.5	3.9
Late: Cycle 4	3.2	3.8	3.8	3.8	2.8	2.9	3.8
CV %	37.5	30.1	28.4	24.5	28.7	31.9	19.7
F-test ratio	1.0ns	5.4**	4.3**	2.0*	2.0*	2.3*	0.7ns
LSD (0.05)	0.8ns	0.7	0.6	0.6	0.6	0.8	0.6ns
Orthogonal contrast of overall means between the early and late populations							
Early Population	3.0	2.9	2.8	3.3	3.3	3.2	3.5
Late Population	3.1	3.8	3.5	3.7	3.0	2.7	3.7
F-test ratio	0.2ns	36.1**	25.7**	7.1**	7.4**	9.7**	1.1ns

† Trait not evaluated in Arlington, WI in 2012.
*,** Significant at 0.05, 0.01 probability levels, respectively; ns = no significant differences.
LSD = Fisher's protected least significant difference, labeled "ns" if the F-test was not significant.
CV % = Relative coefficient of variation.

Table 3.4. Qualitative ear trait rating scale used to evaluate cycles 0-4 from two sweet corn populations (early and late) grown in Arlington, WI and West Madison, WI in 2012 and 2013.

Rating	Husk Appearance	Husk Protection	Tip Fill	Ear Shape
5	Dark green color with long flag leaves	Very long, extending more than 7.5 cm beyond ear tip	Perfect, blunt ear tips	Perfectly cylindrical ear
4	Above average color and flag leaf length	Long, between 5.1-7.5 cm	Good ear tips	Ear tip slightly tapered
3	Average color and flag leaf length	Medium, between 2.5-5.0 cm	Top 1.2 cm of ear tip blank	Ear tip tapered
2	Pale color and, or short flag leaves	Short, less than 2.5 cm	Top 1.3-2.5 cm of ear tip blank	Ear tip strongly tapered
1	Pale or brown color and, or no flag leaves	Exposed ear tip	Top 2.6 cm or more of ear tip blank	Ear tip strongly tapered and, or curved

Rating	Row Configuration	Flavor	Tenderness
5	Perfect kernel rows	Excellent	Excellent
4	Above average kernel rows	Above average	Above average
3	Weak kernel spirals or row breaks	Average	Average
2	Most ears with some kernel spirals or row breaks	Below average	Below average
1	All ears with kernel spirals or row breaks	Poor	Poor

Table 3.5. Intercepts and significant linear and quadratic coefficients for response to selection among cycles 0-4 from the early sweet corn population grown in Arlington, WI and West Madison, WI in 2012 and 2013.

	Plant Height	**Ear Height**	**Emergence**	**Days to Silking†**	**Ear Length**	**Kernel Rows**	**Husk Protection**	**Flavor†**
Early Population	(cm)	(cm)	(%)	(GDD)	(cm)	(average)	(rating)	(rating)
Intercept	147.8	45.7	72.5	573.0	18.8	15.1	2.6	3.2
Linear coefficient	-5.9**	-2.2**	-	-6.6**	-0.2*	0.2*	-0.2*	0.2*
Quadratic coefficient	-	-	1.7*	-	-	-	-	-
R^2	0.99	0.68	0.76	0.89	0.73	0.89	0.99	0.70

† Trait not evaluated in Arlington, WI in 2012.
*,** Significant at 0.05, 0.01 probability levels, respectively; - = non-significance.
GDD = growing degree days in Celsius.

Table 3.6. Intercepts and significant linear and quadratic coefficients for response to selection among cycles 0-4 from the late sweet corn population grown in Arlington, WI and West Madison, WI in 2012 and 2013.

	Plant Height	**Ear Height**	**Ear Leaf Width**	**Days to Silking †**	**Row Configuration**	**Kernel Rows**	**Tip Fill**	**Tenderness†**
Late Population	(cm)	(cm)	(cm)	(GDD)	(rating)	(average)	(rating)	(rating)
Intercept	164.4	51.5	8.8	618.0	3.2	14.9	3.6	3.7
Linear coefficient	1.5*	1.4*	0.1*	5.4**	-	0.3**	0.2**	0.1*
Quadratic coefficient	1.3*	-	-	-	-0.1*	0.2**	-	-
R^2	0.80	0.81	0.58	0.81	0.95	0.99	0.84	0.83

† Trait not evaluated in Arlington, WI in 2012.
*,** Significant at 0.05, 0.01 probability levels, respectively; - = non-significance.
GDD = growing degree days in Celsius.

Table 3.7. Common rust (*Puccinia sorghi*) resistance rating scale used to evaluate cycles 0-4 from two sweet corn populations (early and late) grown in Arlington, WI and West Madison, WI in 2012 and 2013.

Rating	Rust Resistance
5	0-20% leaf area infected
4	21-40% leaf area infected
3	41-60% leaf area infected
2	61-80% leaf area infected
1	81-100% leaf area infected

Table 3.8. Means for common rust (*Puccinia sorghi*) resistance rated on a 1-5 scale (5 as least susceptible) of cycles 0-4 from two sweet corn populations (early and late) grown in Arlington, WI and West Madison, WI in 2012 and 2013.

Entry	**Rust Resistance**
Early: Cycle 0	3.3
Early: Cycle 1	3.3
Early: Cycle 2	3.8
Early: Cycle 3	3.6
Early: Cycle 4	3.9
Late: Cycle 0	3.8
Late: Cycle 1	3.3
Late: Cycle 2	4.0
Late: Cycle 3	3.7
Late: Cycle 4	3.7
CV %	27.9
F value	0.9ns
LSD (0.05)	0.8ns
Orthogonal Contrast of Population Means	
Early (C0-C5)	3.6
Late (C0-C5)	3.7
F ratio	0.4ns

*,** Significant at 0.05, 0.01 probability levels, respectively; ns = no significant differences.
LSD = Fisher's protected least significant difference, labeled "ns" if the F-test was not significant.
CV % = Relative coefficient of variation.

Table 3.9. Analysis of variance of percent germination for warm germination (WG), cold germination (CG), and infected-soil cold germination (ISCG) tests of a commercial check and cycles 0-4 from two sweet corn populations (early and late) grown in three seed production years (2011-2013) at the West Madison Agricultural Research Station in Madison, WI. Cycle 4 was grown in 2012 and 2013 only.

		Mean Squares		
Sources of Variation	df	WG (%)	CG (%)	ISCG (%)
Year	2	177.6*	862.4**	200.4**
Replication	9	58.1**	39.0	52.1
Genotype	10	516.3	392.1	652.7
Genotype x Year	18	621.9*	211.7**	376.5**
Error	84	16.9	36.3	43.6
CV %		4.4	7.2	8.9

*,** Significant at 0.05, 0.01 probability levels, respectively.
CV % = Relative coefficient of variation.

Table 3.10. Spearman correlation coefficients among means of percent germination that had significant genotype by seed production year interaction in the models for cold germination (CG), warm germination (WG), and infected-soil cold germination (ISCG) tests. Cycles 0-3 from two sweet corn populations (early and late) were grown at the West Madison Agricultural Research Station in Madison, WI from 2011-2013, cycle 4 was grown in 2012 and 2013 only.

	Germination Tests		
Seed Production Year Comparison	WG	CG	ISCG
2011 – 2012†	0.45ns	0.42ns	0.50ns
2011 – 2013†	0.38ns	0.50ns	0.17ns
2012 – 2013	0.0ns	0.11ns	0.33ns

† Comparison between cycles 0-3 only.
*,** Significant at 0.05, 0.01 probability levels, respectively.
ns = no significant differences.

Table 3.11. Means for percent germination in 2012 and 2013 for warm germination (WG), cold germination (CG), and infected-soil cold germination (ISCG) tests of cycles 0-4 from two sweet corn populations (early and late). All seed was produced at the West Madison Agricultural Research Station in Madison, WI.

Entry	WG 2012	WG 2013	CG 2012	CG 2013	ISCG 2012	ISCG 2013
	--------	--------	--------	%	--------	--------
Early: Cycle 0	87.7	94.4	87.9	71.5	83.4	70.2
Early: Cycle 1	84.9	92.8	71.9	89.4	52.0	79.1
Early: Cycle 2	87.5	94.5	79.0	77.9	73.3	56.2
Early: Cycle 3	94.5	93.9	91.0	75.1	89.0	62.1
Early: Cycle 4	86.5	96.5	86.9	60.8	76.4	60.5
Late: Cycle 0	89.0	93.5	92.5	92.0	91.3	82.3
Late: Cycle 1	90.5	96.5	79.4	83.1	72.6	78.8
Late: Cycle 2	97.5	91.0	92.0	73.1	85.8	79.5
Late: Cycle 3	88.0	93.2	81.5	68.4	69.6	58.8
Late: Cycle 4	88.0	86.9	77.1	76.0	62.5	79.4
Commercial Check	94.9	98.5	96.5	96.0	87.6	91.7
CV %	5.5	4.0	5.9	9.3	9.1	8.9
F value	2.7*	2.9*	9.6**	9.4**	13.1**	13.8**
LSD (0.05)	7.2	5.3	7.2	10.0	9.7	9.0

*,** Significant at 0.05, 0.01 probability levels, respectively; ns = no significant differences.
LSD = Fisher's protected least significant difference, labeled "ns" if the F-test was not significant.
CV % = Relative coefficient of variation.

Table 3.12. Intercepts and significant linear and quadratic coefficients for warm germination (WG), cold germination (CG), and infected-soil cold germination (ISCG) tests among cycles 0-4 from the early sweet corn population grown at the West Madison Agricultural Research Station in 2012 and 2013.

	WG 2012	WG 2013	CG 2012	CG 2013	ISCG 2012	ISCG 2013
Early Population	---		%		---	
Intercept	-	-	79.2	82.9	-	64.5
Linear coefficient	-	-	1.7**	-3.6**	-	-3.6*
Quadratic coefficient	-	-	2.1**	-4.0**	-	-
R^2	-	-	0.37	0.81	-	0.41

*,** Significant at 0.05, 0.01 probability levels, respectively; - = non-significance.

Table 3.13. Intercepts and significant linear and quadratic coefficients for warm germination (WG), cold germination (CG), and infected-soil cold germination (ISCG) tests among cycles 0-4 from the late sweet corn population grown at the West Madison Agricultural Research Station in 2012 and 2013.

	WG 2012	**WG 2013**	**CG 2012**	**CG 2013**	**ISCG 2012**	**ISCG 2013**
Early Population			---------------%	---------------		
Intercept	93.4	93.8	85.3	73.1	77.2	71.9
Linear coefficient	-	-1.7*	-2.9**	-4.7**	-6.1**	-2.6**
Quadratic coefficient	-1.4*	-	-	2.7*	-	1.9*
R^2	0.46	0.71	0.40	0.95	0.66	0.32

*,** Significant at 0.05, 0.01 probability levels, respectively; - = non-significance.

Figure 3.1. Celsius growing degree days accumulated over weekly intervals after planting in 2012 and 2013 at the Arlington Agricultural Research Station (AARS) and the West Madison Agricultural Research Station (WMARS) in Wisconsin.

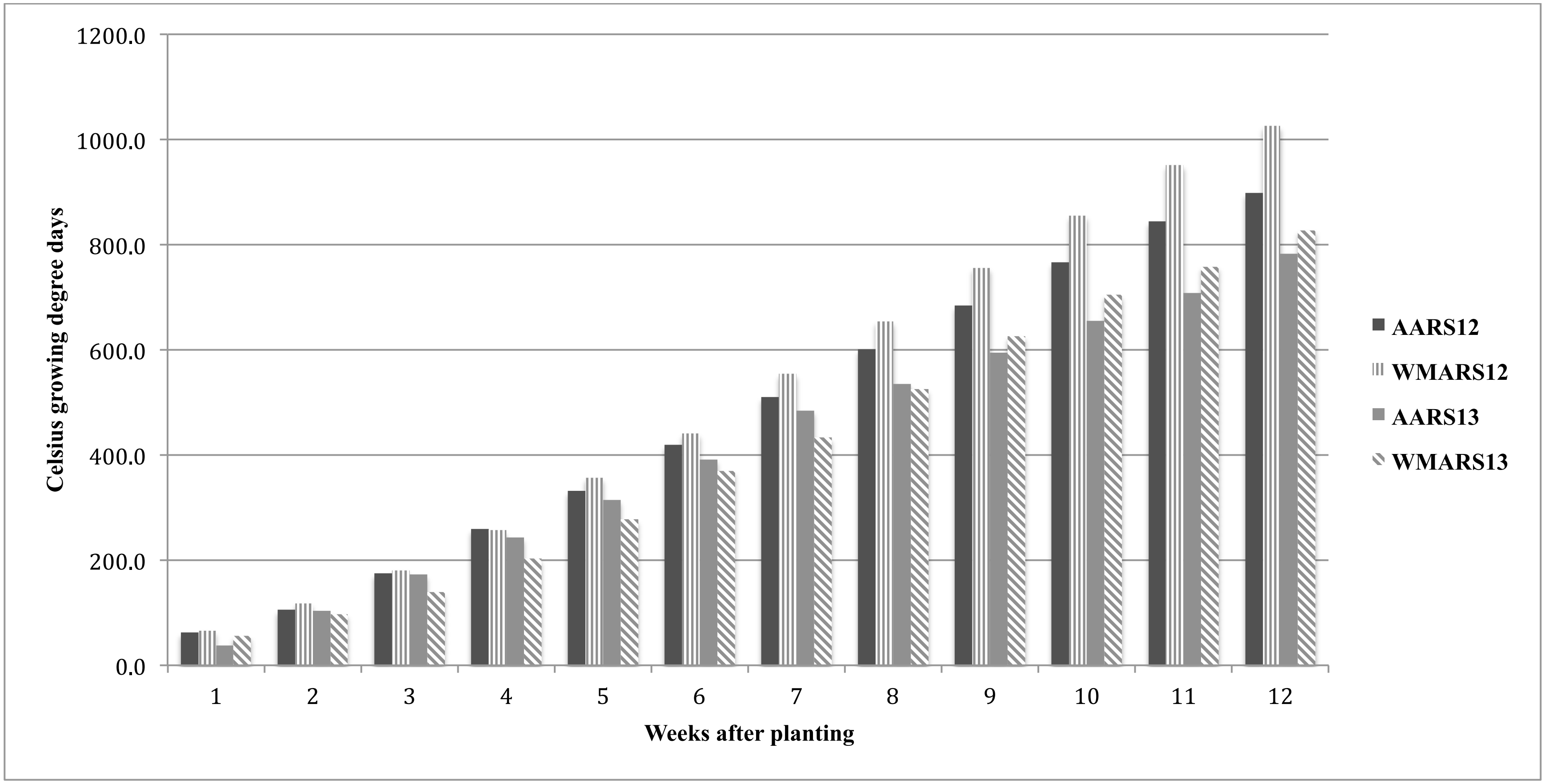
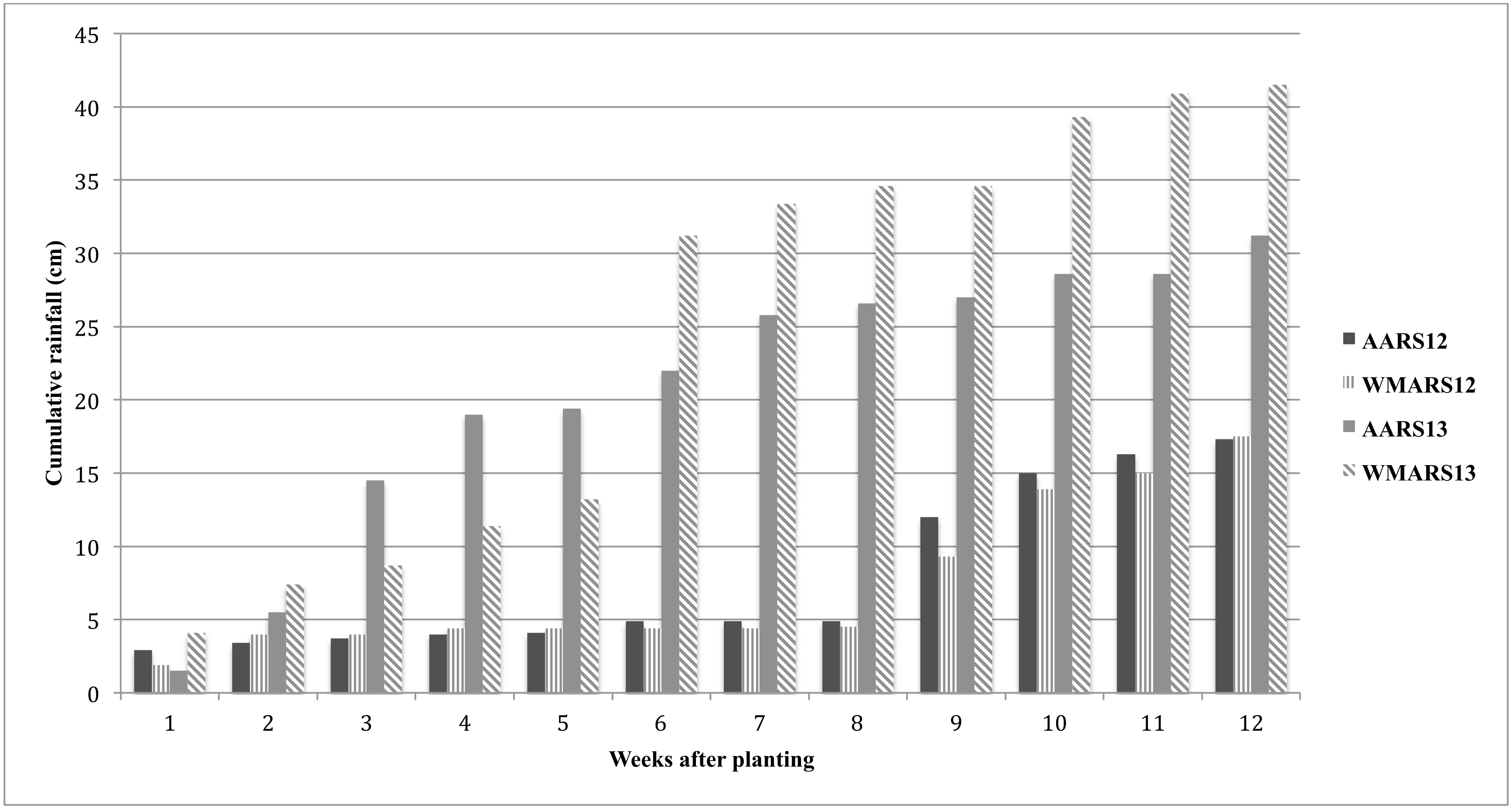


Figure 3.2. Rainfall accumulated over weekly intervals after planting in 2012 and 2013 at the Arlington Agricultural Research Station (AARS) and the West Madison Agricultural Research Station (WMARS) in Wisconsin.



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Chapter 4

Collaborative Release of an Organic Open-Pollinated Sweet Corn (*Zea mays* L.) Variety

Abstract
An increasing number of breeding projects for organic agriculture use a methodology called participatory plant breeding (PPB), in which farmers and professional breeders work collaboratively to develop improved varieties. As a relatively new breeding process in the United States, few examples exist of successful paths to commercialization of organic PPB varieties. PPB projects often rely on federal funding available to public breeders at land grant universities. As such, the resulting varieties are subject to ownership by the university's technology licensing office, a requirement of the Bayh-Dole Act of 1980, which can undermine the collaborative spirit in which the varieties are developed. In addition, unique specifications of varieties developed for organic farmers may require a more nuanced approach for their commercialization. This paper describes the release of an organic open-pollinated sweet corn (*Zea mays* L.) variety that was developed from 2008 – 2013, through a collaboration among breeders at the University of Wisconsin – Madison, the Organic Seed Alliance, and organic farmers in Minnesota. The commercialization of this variety represents just one potential model, but highlights the need for policy changes to support new breeding collaborations and to ensure that varieties developed with public funds are widely accessible, both for farmers and plant breeders.

Abbreviations

BDA	Bayh-Dole Act
HMS	High Mowing Organic Seeds
IPR	Intellectual property rights
OREI	Organic Research and Extension Initiative
OSA	Organic Seed Alliance
PPA	Plant Patent Act
PVP	Plant variety protection
TLO	Technology licensing office
UW	University of Wisconsin – Madison
WARF	Wisconsin Alumni Research Foundation
WFS	Wisconsin Foundation Seeds

4.1. Introduction

As interest in organic food has grown in recent years, so too has awareness of the value of breeding new vegetable and field crop varieties adapted for organic systems. In many cases, breeding projects for organic agriculture utilize a methodology called participatory plant breeding (PPB), in which formally-trained breeders and practically-trained farmers work together to set breeding goals, make selections, and develop useful varieties that fit the specific needs of the farmers. An example of this collaborative breeding effort is the development of an organic open-pollinated sweet corn (*Zea mays* L.) variety that took place from 2008 – 2013. Participants in the project (referred to as "the collaborators" throughout this paper) include a breeder and graduate students from the University of Wisconsin – Madison (UW), the non-profit organization Organic Seed Alliance (OSA), and an organic farmer in Minnesota. The project was initiated by interest from the farmer in developing an improved sugary-enhancer type sweet corn with good agronomics and high eating quality that performs well on his organic farm. Initial start-up funding came from a private foundation, followed by a large federal grant called the Northern Organic Vegetable Improvement Collaborative (NOVIC) funded through the Organic Agriculture Research and Extension Initiative (OREI) of the United States Department of Agriculture - National Institute of Food and Agriculture (USDA – NIFA).

Each summer, the collaborators convened at an organic farm in Minnesota to evaluate experimental populations and make selections among the most promising lines. The chosen rows were recombined in an off-season nursery and the resulting population grown again the following year for further selection, a method known as recurrent selection. While the breeding process underwent its share of difficulties, especially erratic and severe weather events during spring plantings and summer growing seasons, the real challenges began when the variety was ready to be released. PPB is a relatively new model of breeding, especially in industrialized countries such as the United States, and few finished varieties have been released. The path to commercialization can be complex, especially in regards to the issue of joint ownership by the collaborators. In addition, this sweet corn variety has the added complexities of necessitating particular seed production requirements due to its cross-pollinated biology and distinction as a non-genetically modified variety, as well as unique marketing requirements given the culture of the organic farming community and the sale of an open-pollinated variety among standard industry hybrids.

Due to the nature of the project and their intimate knowledge of the variety, the collaborators are arguably in the best position to understand the most appropriate pathway to commercialization. Yet because a variety can be protected with intellectual property rights (IPR), it is considered to be an invention and subject to the rules of the Bayh-Dole Act (BDA). According to this federal law, all university inventions that result from government-funded research must be disclosed to the participating university's technology licensing office (TLO). The university then has the right to claim ownership of the invention, seek appropriate IPR, and license the invention for commercial use. The practical implication of the BDA is that the Wisconsin Alumni Research Foundation (WARF), the TLO for UW, has the right to claim intellectual ownership of the sweet corn variety. WARF's control of the variety for commercialization purpose does not necessarily represent a negative outcome, but it does undermine the collective effort that enabled this variety to be developed. In addition, the standard procedure used to release other sweet corn lines developed at UW, in which the breeder has little or no involvement in seed production, does not incorporate the more nuanced approach required to effectively commercialize this particular variety.

This paper will explore the process by which the sweet corn variety was released and commercialized. It begins with background information on plant variety protections, the BDA, and WARF. Next, the details of the release are described, including the choice not to pursue

IPR, the utilization of Wisconsin Foundation Seeds (WFS) and an independent seed grower to produce the seed, and the negotiation of a limited exclusive contract with a commercial seed company that caters to organic growers. The commercialization of this sweet corn variety represents just one potential model for the release of an organic PPB variety in the United States. More importantly, however, this particular case study highlights the need for policy changes to support new breeding collaborations and to ensure that varieties developed with public funds are widely accessible.

4.2. Background Information

4.2.1. Plant Cultivars and Intellectual Property Rights

The past century has seen increasing proprietary protections placed on plant cultivars (also referred to as plant varieties). Plant cultivars are composed of self-replicating, living organisms, and present a challenge for seed companies and plant breeders wishing to recoup their investment in developing new varieties. It can take ten years or more to develop a new cultivar, requiring significant resources of land and labor, yet a new plant can produce copious amounts of seed in just one generation. In the United States, public law has been employed to address this issue, mainly in the form of patent-like protections. Four forms of public ordering IPR are available to protect new plant varieties: plant patents, plant variety protection (PVP) certificates, utility patents, and trade secrets. In 1930, Congress passed the Plant Patent Act (PPA), which allows for the protection of asexually propagated cultivars, such as many fruit trees and ornamental plants. Tubers, such as potatoes, and all sexually propagated species are specifically excluded from protection under the PPA. Administered by the United States Patent and Trade Office (USPTO), plant patents are granted to cultivars that are determined to be new and distinct, and give patent holders the right to exclude others from propagating and/or distributing the patented plant for 20 years. In 1970, Congress established the Plant Variety Protection Act (amended in 1994), which allows for the award of a certificate of protection for sexually propagated plants and tubers that are deemed novel, uniform and stable. Like a plant patent, protection is granted for 20 years. Yet there are a few important distinctions from the PPA. PVP is administered by the Agricultural Marketing Service (AMS) of the United States Department of Agriculture (USDA), not the patent office. PVP certificate holders are explicitly instructed to honor the research exemption, which allows anyone to perform research (including breeding) with the variety, and the farmers' exemption, which gives farmers the right to save and replant seed of the protected variety. In addition, a sample of the variety, including the inbred parents of a hybrid, must be placed in a public depository. The third form of IPR, the utility patent, is the strongest form of protection available under public law and has been available for use on plant cultivars since 1980, when the Supreme Court declared living organisms to be patentable subject matter in the *Diamond v. Chakrabarty* decision. Use of utility patents, even in conjunction with PVP certificates or plant patents, for plant varieties was specifically affirmed with the *Ex Parte Hibberd* decision of the U.S. Board of Patent Appeals and Interferences in 1985. Utility patents last for 20 years, are administered by the USPTO, and include no exemptions for use. A variety must meet the criteria of being useful, novel and non-obvious. Unlike plant patents and PVP certificates, which protect the plant variety as a whole, a utility patent can include multiple claims beyond the actual variety, including DNA sequences, specific plant traits, uses of the end product, and/or techniques used in the breeding process. These multiple claims significantly broaden the level of protection available with a utility patent.

A special case of IPR involves trade secrets, mainly applicable for inbred lines. Two inbred lines are crossed to create a hybrid variety, and it is the seed produced from this cross (rather than the inbred line itself) that is sold commercially. If the inbred line is not shared with other breeders, seed companies or farmers, it becomes a trade secret. Trade secrets are generally considered to offer weaker protection, compared to patents, as trade secret laws are written and arbitrated by individual states, rather than federally. While stealing a trade secret is illegal, it can be difficult to prove theft in court. No restrictions exist for competitors who attempt to "reverse engineer" a trade secret, although the statistical probability of developing the original parent inbred line by breeding out of a hybrid are exceedingly low. Thus, an inbred line that is well guarded by its owner can be a strong form of protection, as a trade secret can last indefinitely.

Once granted intellectual ownership of a plant variety, the "inventor" can access the typical benefits available to patent holders, such as charging monopoly prices, excluding or restricting others' use of the invention, and threatening legal action for patent infringement. These protections have helped to fuel significant economic growth in the private seed industry (Blair 1999; Fernandez-Cornejo 2004; Kloppenburg 2004; Stein 2005). The monopoly power that accompanies patent protection is compounded by the biological nature of cultivar development. Plant varieties are not de novo inventions, but rather an iterative process of biological improvements. As stated in the proceedings from a workshop on IPR organized by the Crop Science Society of America (Baenziger et al. 1993, 141), "living plant germplasm is unique and different from other types of IP for which patents can be obtained…Research for improvement of germplasm requires physical access to the germplasm itself, in contrast with most other types of IP where only the description is needed." The protection afforded by a utility patent enables a company to not only control the commercial distribution of a particular variety for 20 years, but also to restrict any further breeding work that could be performed on that variety for 20 years. The significant market power that accrues with patent protection of plant varieties enables the leading firms to gain an economic advantage over their competitors, while simultaneously building substantial barriers to entry for new firms by limiting access to useful germplasm necessary for cultivar improvement (Knight 2003; Leval 2004; Hancock and Clark 2009; Howard 2009; Kloppenburg 2013).

4.2.2. The Bayh-Dole Act

Plant breeding in the public sector has the potential to offset some of these monopolistic tendencies in the private sector by developing new varieties that can be made available with wider public access. Yet cultivars bred in the public sector and financed with public funds are subject to the rules of the BDA. Ultimately, lawyers in technology licensing offices (TLOs), rather than the public breeders themselves, have the final word on the type of intellectual property assigned to a variety. Removing plant breeders from the decision-making process can have important consequences for the fate of a variety, as will be explained below.

The BDA, officially known as the Patent and Trademark Law Amendments Act, has been the subject of controversy since its inception in 1980. Sponsored by Senators Birch Bayh and Bob Dole, the purpose of the original legislation was to promote the commercial development and utilization of inventions made with government-funded research by granting patent and licensing rights to government contractors. Lawmakers in support of the bill perceived federal ownership of patents as a disincentive for commercialization by industry, leading to research that was underutilized and thus, from their perspective, a waste of taxpayers' dollars. The assumption was not that patent and licensing rights (exclusive and non-exclusive) were detrimental to commercialization per se, rather that ownership rights should reside with the contracting firm or institution instead of the government. The BDA attempted to facilitate this title transfer by removing bureaucratic obstacles for contractors seeking patents on inventions, and creating incentives for researchers to cooperate in commercialization of inventions through profit sharing. The original BDA of 1980 conferred automatic ownership of inventions resulting from government-funded research, including patent and licensing rights, specifically with contractors categorized as small businesses and non-profit organizations (such as universities). The same privileges were extended to large businesses in a memorandum signed by President Reagan in 1983, and ratified by Congress in 1984.

While the BDA has implications for both for-profit and non-profit government contractors, intense debate has mainly surrounded its effect on university research. Supporters suggest that financial incentives created by the BDA have spurred increases in both basic and applied research, and that the start-up enterprises that have spun off from the commercialization of these innovations have contributed to job creation and economic growth (The Economist 2002; Thursby and Thursby 2011). Others argue that the effect of the BDA on academic research has been minimal, given that patenting by universities was already on the rise before 1980, new biomedical and biotechnology fields have greatly altered the patent landscape, and sweeping judicial changes have fostered a favorable environment for patent holders in general (Mowery et al. 2001; Jaffe and Lerner 2004; Rafferty 2008). Critics contend that the BDA has blurred the line between university research that is inspired by a culture of knowledge-sharing in service of the public good and private research that is motivated by profit margins, that exclusive licensing practices hinder scientific progress by limiting access to basic research tools, and that universities are mimicking corporations in their increasingly aggressive defense of patent and licensing rights (Eisenberg 1996; Press and Washburn 2000; Rai and Eisenberg 2003; Boettiger and Bennett 2006; Thursby and Thursby 2006).

As the debate over the effects of the BDA rages on, one unambiguous consequence has been the establishment of TLOs at research universities throughout the United States. According to the requirements of the law, a non-profit organization must still get approval from the granting federal agency for assignment of title rights (as was the case before the BDA), *unless* “such assignment is made to an organization which has as one of its primary functions the management of inventions” (35 U.S.C. § 202(c)(7)). In other words, a university cannot take advantage of the privileges bestowed by the BDA without an established TLO to manage its patents and licensing agreements. Indeed, after 1980, the number of TLOs at universities increased dramatically. According to the Association of University Technology Managers (1996), 25 TLOs existed in 1980, and by 1990 that number had grown to 200.

Yet this requirement highlights one of numerous paradoxes imbedded in the BDA. As explained by Eisenberg (1996), granting title rights to businesses (especially small businesses) was an acknowledgement that contracting firms are more effective than the federal government at commercializing inventions given their intimate knowledge of the invention, understanding of the nuances of their market, and capacity to develop the invention for production and sale. Research universities are more similar in structure to the federal government, however, compared to a business. Like the government, universities do not tend to have the resources to commercially produce a sellable commodity, and must still partner with industry in order to achieve this end. The TLO may be one mechanism to increase the university’s efficiency at bringing inventions to market, but the question remains as to why universities were granted patent rights at all? According to Mowery and Sampat (2005,122), “current research thus provides mixed support at best for a central assumption of the Bayh-Dole Act, i.e., the argument that patenting and licensing are necessary for the transfer and commercial development of university inventions."

4.2.3. Wisconsin Alumni Research Foundation

While never used as an argument to promote the passage of the BDA, increasing university revenue clearly has become the strongest motivator for the patenting and licensing policies of the TLOs (Jensen and Thursby 2001). Yet TLOs that are profiting from their patent holdings are the exception, rather than the rule. While the actual number of university patent filings has increased since the BDA, the relative importance and usefulness of university patents appears to have fallen, a suggestion that universities less experienced with patenting are pursuing patents with minimal effect (Henderson et al. 1998). A significant exception to this pattern is WARF.

Founded in 1925, WARF is one of the oldest TLOs in the country. It began when Harry Steenbock, a professor of biochemistry at UW, discovered that exposing certain fats to ultraviolet light induced the production of vitamin D. Steenbock recognized the health benefits and commercial applications of his work, particularly in the dairy industry. He believed that patenting the irradiation process would not only generate royalty money for the university, but would protect consumers from misleading health claims by unscrupulous firms, protect industry from patent owners charging excessive licensing fees, and protect Wisconsin's dairy industry by refusing to license the process to margarine producers (ensuring that the vitamin D content, and nutritional value, of milk would remain superior to margarine) (Apple 1989). Yet then, as now, the prospect of universities patenting their research was controversial both with-in and beyond the halls of academia, and the University of Wisconsin Board of Regents rejected Steenbock's offer of owning and patenting his work. Undaunted, Steenbock worked with a small group of alumni to establish WARF, an independent organization with the sole purpose of managing university patents and returning royalties to the UW research committee (1989).

WARF has been enormously successful and according to its website, "has earned more than $800 million in patent royalty revenues, paid more than $170 million to faculty and staff inventors and returned more than $1.25 billion to the university while also building an endowment that is now worth some $2 billion" ("Success Stories" 2014). WARF legal counsel testified in support of BDA, and its success is seen as an endorsement for the multiple benefits accrued when universities are allowed to patent their research. While some of WARF's patents have been unequivocally broadly useful and significant (such as the anticoagulant Warfarin and technologies used in magnetic resonance imaging), much of WARF's wealth is generated from an astute investment strategy that began in the 1930s. From 1928-1985, 76% of WARF's net income came from investments, while only 20% of its profits came from just 76 inventions that have produced income greater than their expenses (Schoenfeld 1986). Given WARF's ability to capitalize on Steenbock's early patents, its decades of experience in navigating academic and corporate cultures, and the shifting landscape of patentable technologies and litigation fees, Apple (1989, 394) suggests "it is not obvious that WARF's prosperity can be duplicated today."

WARF is one of only a handful of TLOs that generate significant income, with most TLOs earning $5 million or less while incurring substantial operating costs (Kenney and Patton 2009). WARF has been criticized for its aggressive pursuit of revenue through restrictive licensing policies, sometimes at the expense of enabling wide use of its inventions (Blumenstyk 2006). Yet WARF's financial success does allow it to take a nuanced approach in its interactions with inventors at UW. Schoenfeld (1986, 174) states that "implicit in the tasks of investing money, managing patents, and cultivating innovators and innovations is the task of developing staff expertise" to help ensure that inventions are dealt with appropriately. In addition, UW's unique policy of allowing researchers to own inventions that are not funded with federal money (or otherwise encumbered by grant restrictions) means that WARF has experience collaborating successfully with inventors, even when it does not own the invention (Kenney and Patton 2009). TLOs with fewer resources may not have the capacity to work with individual inventors to understand the unique circumstances surrounding a particular invention, and indeed are under no contractual obligation to do so (2009). As a result, these TLOs may be too eager to claim intellectual property, with the hope of generating licensing fees, which can prove detrimental to the commercialization and widespread use of the invention (Grimaldi et al. 2011).

The implication of IPR, the BDA, and TLOs for new plant varieties is that universities are now incentivized to protect and license cultivars developed in public breeding programs, rather than releasing them into the public domain.[1] For instance, according to Sidhu (2011, 199), the University of California is "a major contributor to the total number of plant patents filed each year." Carena (2013) traces the changing mechanisms of release for maize germplasm at North Dakota State University (NDSU). Until the 1980s, inbred lines and hybrid varieties were freely exchanged. With the BDA, seed distribution to farmers, seed companies, and other breeders became more restricted through MTAs and PVP certificates. Starting in 2009, with the hope of fully recovering royalties from its maize inbreds and hybrids, NDSU variety releases became exclusive to institutions such as foundation seed companies. As public breeding programs are encouraged to focus on crop types and private partnerships that will generate a sizeable return on

[1] Any variety that is either not protected with IPR, or for which IPR have expired, is considered to be in the public domain.

investment, they become limited in their scope of work, and tend to mimic the restrictive release policies of the private sector. With federal funding, public programs should have the flexibility to develop breeding priorities based on public needs, such as developing varieties that will increase agricultural sustainability or contribute to equity among farmers in under-served areas. Often this requires releasing varieties with minimal licensing requirements. For example, according to Howard's analysis (2009, 1281), "long-term sustainability requires that farmers and gardeners have the ability and means to produce food free from heavy reliance upon off-farm inputs," which includes the ability to save seeds and breed new varieties on-farm.

4.3. Organic Open-Pollinated Sweet Corn Release

In the midst of this increasingly restrictive IPR landscape, a PPB effort to develop an organic open-pollinated sweet corn variety took place from 2008 - 2013. Participants in the project include a breeder and graduate students from UW, the non-profit OSA, and an organic farmer in Minnesota. The project was initiated by interest from the farmer in developing an improved sugary-enhancer type sweet corn with good agronomics and high eating quality that performs well on his organic farm. Organic farmers have limited access to varieties that have been bred specifically for organic conditions (Dillon and Hubbard 2011). Organic advocates have successfully lobbied for public funding of organic breeding projects through OREI, in part because of the limited private investment in organic breeding. Although organic agriculture has been shown to have positive environmental impacts, compared to conventional agriculture, the amount of land devoted to organic agriculture is less than 1% of farmed acreage in the United States (Bengtsson et al. 2005; Gomiero et al. 2011; Nemecek et al. 2011; Tuomisto et al. 2012). Breeding requires significant financial resources, and the small market size of organic farmers leads to underinvestment by private firms, a classic example of an economic market failure. Public investment in organic breeding addresses this market failure by recognizing the value for agriculture when organic farmers have access to adapted cultivars, and by providing the financing to ensure that such breeding occurs.

Initial start-up funding came from a private foundation, followed by a large federal OREI grant from USDA-NIFA. Two populations, developed by the sweet corn breeding program at UW, were grown each summer on an organic farm in Minnesota. The collaborators evaluated each population for the qualities of interest identified by the farmer, and made selections among the most promising lines. By doing the selection on-farm, rather than on a conventional research station, and working directly with the organic farmer, the PPB methodology helps to ensure that the finished variety is specifically adapted to organic farming systems (Dawson et al. 2008). The best ears were recombined in an off-season nursery and the resulting population grown again the following year for further selection, a breeding method known as recurrent selection. With each successive cycle of selection, the collaborators were encouraged by the development of the populations, especially regarding the improved eating quality. In 2013, the collaborators agreed that one of the populations was ready to be released as a new open-pollinated sweet corn variety, selected on organic farms for traits important to organic growers.

With the release of this new sweet corn, the collaborators had four main goals. One was to identify a distribution mechanism that would allow sufficient entry into the market so that organic farmers across the US would have access to the variety. The second goal was to maintain the genetic integrity of the variety. The third goal was to ensure that, in coordination with the release of the variety, the collaborative breeding process used would be communicated so that other organic farmers and public breeders might be encouraged to engage in organic PPB.

The fourth goal was that, in the event of commercial success, royalties would be returned to the collaborators to support future organic breeding projects.

4.3.1. Intellectual Property Rights

In order to achieve their goals, the collaborators needed to have authority to make decisions about the variety, which was not assured because of the BDA and WARF's ability to claim IPR on the variety and commercialize it. The collaborators submitted an Invention Disclosure Report to WARF, with details about the variety for their review. After a representative from WARF met with the UW collaborators, WARF chose not to accept the variety for commercialization, citing that "WARF was not going to add much value to the technology transfer process as [the collaborators] seem to have a route to get it commercialized" (B. Werner, personal communication, November 22, 2013). Indeed, the collaborators had already begun planning how they intended to release the variety. In granting authority to the collaborators, WARF recognized that through their intimate knowledge of the variety and the organic farming community, the collaborators were in the best position to understand the most effective commercialization route. This epitomizes the "inventor ownership model" suggested by Kenney and Patton (2009, 1414) that "decentralizes the invention dissemination decision to those closest to the knowledge creation process and to the one[s] most likely to have the best information." However, it is important to note that WARF was under no obligation to relinquish control, and the collaborative process under which the variety was developed would have quickly come to an end if WARF had decided to claim ownership.

While WARF chose not to accept IPR for the variety, ownership of the variety did not automatically revert back to the collaborators. In accordance with the BDA, the funding agency

USDA-NIFA now maintained IPR. If the collaborators wanted to use IPR to protect the variety, they would have been obligated to petition USDA-NIFA. Instead, the collaborators had already agreed that they would not pursue IPR, and thus needed no special authority as “USDA-NIFA has no problem with inventors releasing the variety to the public and no permissions are needed” to do so (S. Castello, personal communication, April 14, 2014). In addition to the high cost of pursing a utility patent, the collaborators were ideologically opposed to the utility patent’s powerful restrictions on seed usage, especially regarding seed saving and breeding rights. A PVP certificate preserves such rights, however, and would allow the collaborators to control the sale of the seed to ensure that only the highest quality seed was in circulation. Yet there was concern that the organic community would respond negatively to the use of any IPR on a variety developed specifically for organics. For many organic farmers, organic is not just a farming method but a philosophy, and there is a strong sentiment within the community that seed is a common resource to be shared and protected by all, rather than individually owned (Mendum 2009). By not protecting the intellectual property of the variety, anyone purchasing the variety commercially will be free to do anything they chose with it, including saving seed, breeding a new variety, or even selling it.

Incidentally, after WARF and USDA-NIFA relinquished intellectual control of the variety, the UW legal department also reviewed the invention, mainly to ensure that no further contracts were being violated with its release. Through this process, it was discovered that initial funding for the breeding project was given by a private foundation, the Organic Farming Research Foundation (OFRF), accompanied by a contract stipulating that “all work funded wholly or in part by OFRF shall remain in the public domain” (B. Scowcroft, personal communication, November 14, 2008). This type of clause, which is becoming more common among private funders of organic research, highlights the organic community's resistance to any form of IPR. The language is vague in the contract, and it is unclear whether the finished variety being released was still subject to the terms of this contract. While such skepticism of the increasing constraints placed on seed varieties with IPR is warranted, a general prohibition against all forms of IPR fails to recognize the inherent differences between PVP certificates and patents. Ultimately, because the collaborators had elected to forego any form of intellectual property, they were not in violation of this initial contract from OFRF.

4.3.2. Seed Production

With the IPR decision settled, the collaborators' next concern was seed production. The standard procedure for the UW sweet corn breeding program, when entering into a contract with a commercial seed company, is to provide a small amount of breeder seed that the company is responsible for increasing to the level necessary for commercial production. Breeder seed is the seed that has been directly produced by the originator of the variety, and is presumed to have the highest level of genetic purity (Fehr 1987). In this instance, however, the collaborators were interested in managing their own seed production. As an open-pollinated outcrossing species, the population can shift significantly, and is especially susceptible to inbreeding depression, if the seed production is not executed properly. The collaborators had been working with this variety for five years, and were uniquely situated to identify unwanted plants to rogue during seed production. Another important consideration was isolation from other cornfields that might contaminate the variety with genetically modified organisms (GMO), which are prohibited by organic certification standards. The collaborators had identified an organic seed grower interested in producing the seed in a location outside of traditional sweet corn seed production, where risk of contamination would be minimal.

Yet just as the collaborators did not have intellectual ownership of the variety until it was granted to them, neither did they collectively have material ownership of the actual seeds. The breeder seed, which is stored at UW, is physical property of the university. Thus, the collaborators did not have the legal authority to contract with the organic grower for seed production, as they did not own the breeder seed. Fortunately, UW is one of a number of land grant universities that has maintained a foundation seed system. Wisconsin Foundation Seeds (WFS), an auxiliary program of the UW Agronomy Department, has been producing foundation, registered and certified seed since 1901. These various classes of seed are grown from breeder seed in accordance with standards set forth for the particular crop, and usually apply to field crops such as oats, wheat, and alfalfa. The seed is then sold either to certified seed producers or commercial companies. When seed production is not possible within the state of Wisconsin, WFS contracts with seed growers in the appropriate seed production region.

In the case of the sweet corn variety, WFS licensed foundation seed production to the organic seed grower identified by the collaborators. This arrangement allowed for the seed to be produced in accordance with the standards of the USDA National Organic Program, and thus certified organic. In addition, the UW collaborators had access to the seed production site to rogue unwanted plants and ensure the population was appropriately maintained. While the risk of GMO contamination can never be eliminated, the isolated location of the seed grower minimized the occurrence of unwanted transgenes.

4.3.3. Commercialization

After the contract seed production, OSA purchased the newly grown sweet corn seed from WFS. With this sale, OSA became the sole owner of the foundation seed, with the accompanying rights and responsibilities accorded to property ownership.[2] All of the collaborators agreed that OSA's ownership of the foundation seed was the preferred outcome, given that the stewardship of the variety fell within the mission of the organization, OSA's non-profit status afforded a level of liability protection, and the OSA infrastructure was best suited to manage the variety. The collaborators agreed that decisions regarding the variety would continue to be made collectively, and that any royalties generated by commercial sales would be used to support future organic breeding projects.

The final step in this process was to determine a distribution mechanism for the sweet corn seed. None of the collaborators had the capacity to effectively market and distribute this new sweet corn variety on their own. Instead, they identified commercial seed companies who sell seed to organic growers in the United States, and offered trial seed of the variety for these companies to grow. Three companies agreed to trial the new variety, and after evaluating its performance, one agreed to sell the variety through their seed catalogue. The company, High Mowing Organic Seeds (HMS), is a company in Vermont that caters to organic farmers and sells 100% organic seeds. HMS has a small in-house breeding program, but works extensively with public breeding programs and other seed companies to identify varieties suited for organic production systems.

HMS agreed to purchase the foundation seed from OSA, in addition to returning a royalty on seed sales, in exchange for a limited exclusive release. For three years, HMS would be the

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[2] UW still retains material property ownership of the breeder seed.

only seed company to receive seed from OSA for wholesale and retail sale. HMS insisted on this condition in order to justify their marketing expenses in promoting the new variety. After three years, however, OSA can provide seed to other companies interested in selling the variety, including small companies that may not have the capacity to sufficiently produce their own seed. Including this sunset clause with the exclusivity agreement was an important requirement for the collaborators, as their first goal is to distribute the variety as widely as possible.

Another aspect of the negotiation between HMS and OSA regarded the marketing of the variety. While HMS has an effective marketing mechanism through their seed catalogue, OSA also has a robust communications network. OSA and HMS agreed to coordinate on the marketing of the variety, including explaining the history of how the variety was developed and the benefits of breeders and farmers working together to develop improved organic varieties. In addition, as an open-pollinated variety, this sweet corn is entering a market class that has been dominated by hybrid varieties for at least 40 years. The variations in traits (such as maturity, plant height, and ear color), which are inherent in an open-pollinated, outcrossing species, are very different from the uniform hybrid sweet corn that farmers are used to growing. A coordinated effort to accurately market the variety ensures that this unique aspect of the variety is effectively communicated.

4.4. Reforming Public Policies to Support Public Cultivar Development

Public breeding programs play a critical role in developing useful varieties for cropping systems such as organic agriculture, which otherwise receive very little private investment. Indeed, without the support of a federal grant, this organic open-pollinated sweet corn would likely not have been bred, given the ease with which farmers can save open-pollinated seeds and the small number of organic sweet corn growers relative to conventional growers. In addition, the collaborative nature of the project, which involved participants from the public breeding sector, the non-profit sector, the commercial sector, the foundation seed system, and the organic farming community, is an unusual model for the private seed sector. Yet in exchange for the public funding that allowed this project to proceed, the collaborators were compelled to allow WARF to have the choice to retain intellectual ownership of the variety. WARF declined to do so, but this provides no assurance that other TLOs with differing approaches to plant variety protection may be as willing to cooperate with breeders. Because of WARF's leniency, the collaborators were allowed to achieve their goals for distribution of the variety, and to fully utilize the distinct, yet complimentary, resources that each individual collaborator contributed to the partnership. In order to promote not just organic PPB, but experimentation and innovation with new crops and breeding methods in service of the public good, significant changes need to be made to policies affecting public cultivar development.

First, cultivars developed with public funding should be excluded from utility patent protection. A finished cultivar is both a commercial end product, and a research tool for future breeding. While all forms of plant variety protection give the owner market control of the end product, the utility patent is the only form that also restricts access to the variety as a tool for further improvement. When public funds are used in the breeding process, other farmers and breeders deserve access to the variety for continued breeding. This research exemption does not diminish the market potential of a variety, as there is no empirical evidence to support the requirement of utility patents for the commercialization of publicly funded cultivars. In addition, the arguments in favor of strong patent protection do not make sense for public plant varieties. A central tenet of patent law is that "proprietary exclusivity is essential to innovation, either as an incentive to private investment or as a means of coordinating the exchange of information" (Hope 2008, 239). However, with publicly funded cultivars, the research and development has already been paid for, so this incentive is obsolete (Eisenberg 1996).

With a prohibition against utility patents, PVP certificates and plant patents (for asexual species) would remain as the strongest forms of IPR available for publicly funded cultivars.[3] Numerous studies show that the social returns to breeding programs can be very high, and it is appropriate that public funding contribute to an ethic of unencumbered germplasm exchange (Heisey et al. 2001). Indeed, a report in the journal Nature (Knight 2003, 569) suggests that the future of plant breeding in the public sector may depend on "making a concerted effort to break with the proprietary approach to intellectual property that is currently blighting the field." This sentiment applies not just to public cultivar development, but also to agricultural research in general. For example, an experimental effort to encourage sharing has been undertaken by leading public research institutions in the United States to freely exchange research tools in areas such as crop biotechnology called the Public Sector Intellectual Property Resource for Agriculture (PIPRA) (Atkinson et al. 2003).

Second, public cultivars should not be considered inventions that are subject to the BDA. Currently, inventions that qualify under the BDA include "any invention or discovery which is or may be patentable or otherwise protectable under Title 35 of the United States Code, or any novel variety of plant which is or may be protectable under the Plant Variety Protection Act" (35 C.F.R § 401.2(c)). This definition could easily be amended to exclude plant varieties. Authority would then be returned to the breeders, rather than the TLO, to determine the most

[3] The PPA was amended in 1998 to include a restriction on the use of "plant parts." It is unclear whether this includes gametes, which would restrict the use of patented cultivars in breeding. This has not been legally challenged, so a definitive decision has not been made (Hancock and Clark 2009).

appropriate route to commercialization. In instances where the breeders determine that protecting the cultivar with a PVP certificate or a plant patent is necessary, they would petition the granting agency for such rights. Otherwise, the variety would enter the public domain. This "inventor ownership model" has been shown to be successful at the University of Cambridge before policies similar to the BDA were implemented in the United Kingdom in 2001 (Kenney and Patton 2009). The TLO does not become obsolete, but instead is available to assist with commercialization at the request of the breeder. This "decentralized decision making allows for multiple paths to commercialization" and can potentially be more efficient that the current model under the BDA (2009, 1415).

Third, any royalties earned by public plant cultivars that have been commercially released should be returned to the breeding programs and the institutions that house them, rather than as personal profit. In general, public plant varieties tend not to generate significant income for universities. This is in part because the crops that do have a high profit margin are bred by the private sector (Traxler cited in King et al. 2012). An exception to this is the royalties generated from some high value fruit cultivars, such as strawberries. The University of California at Davis generated $4.5 million in licensing payments in 2013 for its patented strawberry varieties, with the public breeders personally receiving over $2 million, a portion of which was returned to the breeding program (Gordon 2014). While the BDA explicitly includes "a requirement that the contractor share royalties with the inventor" (35 U.S.C. § 202(c)(7)), keeping plant varieties outside of the BDA framework helps to ensure that varietal development is based on the public good rather than solely for financial returns.

Ultimately breeders, rather than TLOs, have the best understanding of the value of their new cultivar, the relevance of IPR, and the commercial seed companies most interested in marketing it. According to Hancock (2009, 46), "the value of relationships among breeders and users of the products…cannot be overemphasized in the licensing process." Beyond determining the most effective pathway to commercialization, increasing breeders' freedom to operate also allows for exploration of new mechanisms of cultivar distribution that are previously untested. The organic sweet corn release discussed here is one example. Another involves an experiment in applying an open source framework to plant varieties. The project, called the Open Source Seed Initiative, is based at UW and also has been supported by WARF (Miller 2014). A handful of public and private breeders, including a UW carrot breeder, have released varieties with an "Open Source Seed Pledge" that encourages complete freedom in seed usage and further breeding, as long as no further restrictions are applied with patents and licenses (Hamilton 2014). Such experiments are only possible when breeders are given full freedom to pursue breeding projects that are not motivated by financial returns, to engage in collaborations across institutional boundaries, and to explore alternative release mechanisms. With these new public policies in place, publicly financed breeding projects will be better positioned to develop the diverse set of varieties needed to promote healthy agricultural systems and farming communities.

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Chapter 5

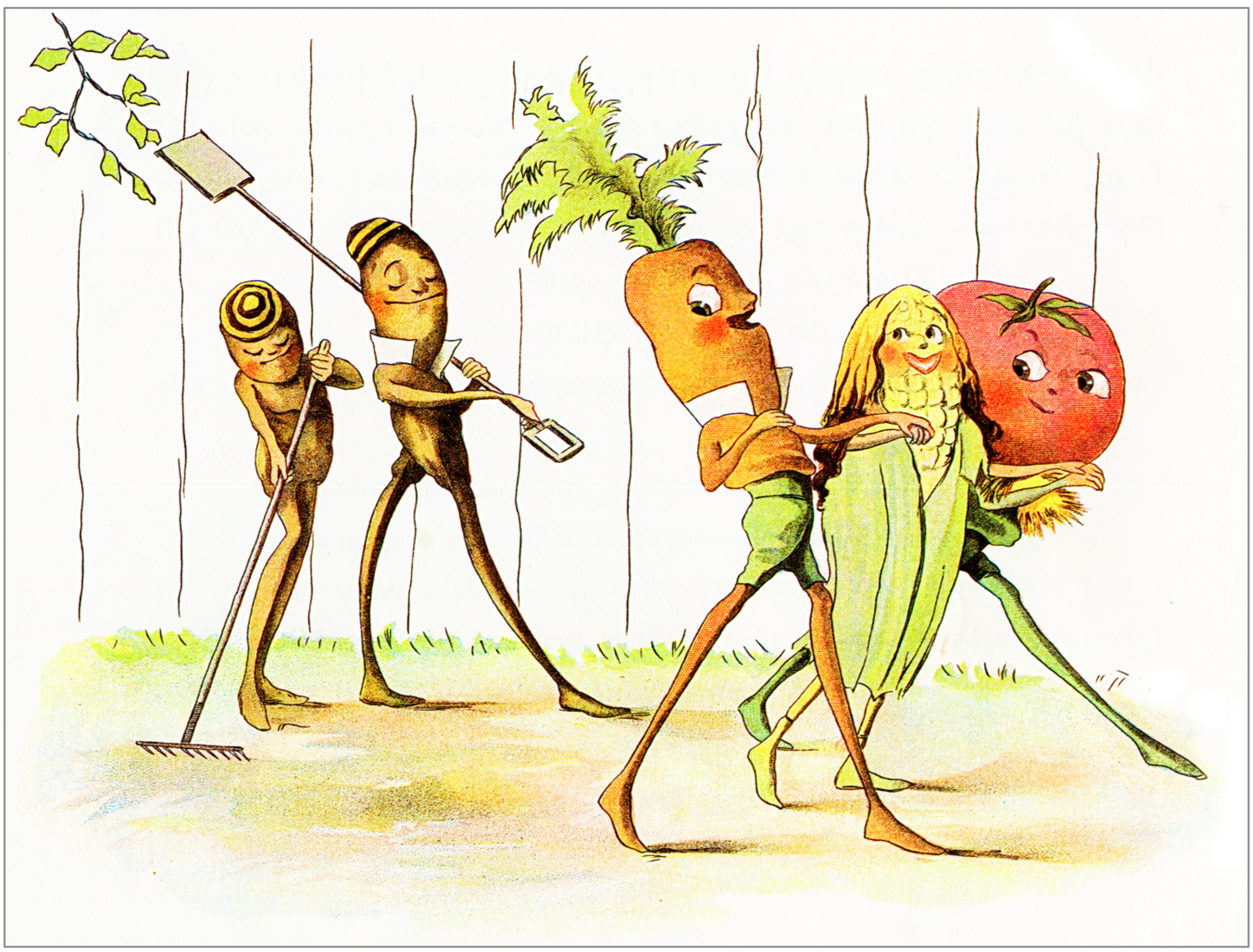
Conclusion

5.1. What's In A Name?

Long before the invention of the combine, the husking bee was perhaps the most popular social event that took place on countless American farms during the fall harvest. With the corn field full of dried ears that needed to be husked, what better way to get the work done than to invite the neighbors for an evening of dancing, drinking, and husking? Sometimes jugs of whiskey were hidden at the bottom of the corn pile to entice the huskers, or the party was divided into two groups as a competition to see which team could husk the fastest. But the best motivation for getting the work done was the prize given to anyone who discovered an ear of corn with all red kernels, called a pokeberry ear. The lucky finder of a pokeberry ear was given the privilege of choosing one person among the group to kiss.

As we pondered what name to give our new variety of sweet corn, we realized that the story of the husking bee captured the spirit of what we were trying to accomplish. The excitement of a husking bee depends on the variation found in open-pollinated corn varieties. If a husking bee were held today, it would be a dull party indeed, as there is no chance of finding a few red ears when the corn variety is a hybrid. The process of creating a hybrid leads to genetic uniformity among all of the plants, so that all ears are the same color, the same size, and the same maturity. The plant height is close to identical, all tassels are the same color, and even the leaves are positioned on the stalk at practically the same angle.

Our new open-pollinated sweet corn variety would be a perfect corn for the husking bee. The ears are bi-color, yet there is a chance of finding an all yellow ear, and an even smaller chance of uncovering an all white ear. This is because there is variation in the genetics of an open-pollinated population, and no two plants are identical. There is variation in ear size, ear shape, and ear color. Some tassels are yellow, while others are red. The plant height is not completely uniform. No two ears will even taste exactly the same, but hopefully most will taste good. Corn is a cross-pollinated crop, with pollen dispersal occurring with the wind. Every kernel on an ear of corn is fertilized by a grain of pollen that could potentially have come from a different plant. This diversity provides endless opportunity to continually adapt and improve the population. It is our hope that organic farmers will be able to successfully grow this variety, make selections according to their particular needs, save and share seeds, and continue to build on the work that we started. With the husking bee in mind, we chose to name our variety *Who Gets Kissed?*



(From: Upton, B. and F.K. Upton. 1897. *Vege-Men's Revenge.* London: Longmans, Green & Co.)

5.2. Perspectives for Future Organic Breeding Projects

This dissertation demonstrates that the real value of *Who Gets Kissed?* is greater than its open-pollinated genetics. It represents the successful application of a participatory plant breeding (PPB) methodology that addresses biological, cultural, and economic needs of organic farmers. As a multi-faceted breeding process that depends on relationships between not only breeders and plants, but between breeders and farmers, and between farmers and the land, PPB will not always be appropriate for every organic breeding project. But the synergies that can arise justify the extra time required to build relationships based on mutual respect and clear communication, and the logistical complications of moving breeding plots off of the research station and into farmer fields. With a culture of self-sufficiency, organic famers are eager participants in the development of improved organic varieties. As a farming system with proven environmental benefits, yet lacking resources from the private sector, public breeders are ideally suited to address this new breeding challenge.

As the experimental evaluation of two open-pollinated sweet corn populations indicates, the obstacles to developing improved organic varieties are not insignificant. Organic growers require a range of traits, including disease, pest, and weed resistances coupled with high quality flavor and appearance (in the case of vegetables). But progress can be made using breeding methods such as recurrent selection and PPB. In addition to evaluating finished varieties, the methods used to develop the varieties must be rigorously tested in order to gain information about the most effective systems for organic varietal improvement.

Organic plant breeding is in its infancy, and the development of useful varieties will require the creative and cooperative work of public and private plant breeders, organic farmer-breeders, organic seed producers, non-profit organizations, and private seed companies. Such new collaborations depend on more flexible policies for public cultivar releases that empower the breeders to make their own decisions regarding intellectual property rights and seed production. Public cultivars must always remain accessible for further breeding and improvement, and royalties should be used to support future breeding efforts.

The challenges for organic plant breeding also provide immense opportunities to create a vibrant organic seed sector. It is clear that the organic seed sector will follow a different path than has occurred in the conventional seed sector. Developing improved varieties for organic growers, with the right mix of complex traits, will not be easy. Farmer engagement with the breeding and distribution process will be critical, as will be the involvement and support of public breeding programs. Intellectual property rights will not generate the same level of wealth for private companies serving the organic market, due to cultural resistance and economic limitations. New methods for sharing germplasm, while adequately financing further breeding efforts, must be explored. Collaborations among breeders, farmers, seed producers, and seed companies will be critical. Yet through the process of finding creative solutions to these challenges, a new model for plant breeding can emerge.