AN ABSTRACT OF THE THESIS OF

Laurie R. McKenzie for the degree of Master of Science in Horticulture presented on March 6, 2013

Title: Breeding an Open Pollinated Broccoli for Organic Production Systems Using Participatory Methods

Abstract Approved:

James R. Myers

Organic agriculture is an important and growing sector of U.S. and world food production. Consumers are increasingly aware of and interested in the production practices and impacts associated with agriculture and as such, are showing a preference for sustainably produced, raised, and harvested foods. In order to continue to meet the growing demand for organic produce, organic growers need cultivars that are optimally adapted to organic and low input conditions.

Quality seed is the foundation of any functional and stable farming system. Unfortunately the lack of organically bred and produced seed is hindering the continued growth and success of organic farming. Meeting the needs of the organic sector has been a challenge for the seed industry; it is an industry that often doesn't understand the specific and unique requirements associated with the diversity of environmental and market demands of organic systems. However, organic farmers and the organic food systems they supply, require a robust organic seed system that is appropriately adapted to regional agronomic challenges and market needs, meets standards and regulations, and encompasses the social and ecological values of organic agriculture.

One plausible approach to meeting the cultivar and seed needs of organic and low input production systems is through the use of participatory plant breeding (PPB). PPB is a collaborative approach for identifying and developing genetically diverse plant

material and varieties involving partnerships among formal sector breeders and researchers, farmers, extension agents, educators, and end users. Participatory plant breeding fundamentally changes the way that formal breeding programs and farmers manage germplasm and plant genetic resources. Typically, formal breeding programs restrict access to germplasm and breeding materials and only supply farmers with finished varieties. In PPB, farmers are involved in the early stages of creation and evaluation of germplasm and breeding material, and stay engaged with the breeding process until new varieties are created.

PPB is an excellent model for breeding specifically for organic systems because organic systems in developed countries have many similarities to low-input agricultural systems in the developing world. Some of these parallels include heterogeneous growing environments, a wide range of end uses and marketing strategies, lack of suitably adapted and/or derived varieties, lack of attention from the formal seed sector, and a reduced reliance on synthetic inputs (compared to conventional systems). Breeding for organic systems is a relatively young field and breeders in the formal sector do not have a good handle on what traits are important for robust production under organic conditions. Thus the opportunity to meld farmers' experience and knowledge with breeders' expertise is an effective way to breed for organic production systems.

The purpose of this project was to investigate and explore the opportunities and challenges of organic plant breeding using participatory research methods. This research had three goals: 1) to develop an open pollinated broccoli with contemporary quality traits for organic production systems using participatory strategies; 2) to compare broccoli selections made by formally trained plant breeders and farmer breeders; and 3) to capture the stories and experiences of the formal breeders and farmer breeders involved with this broccoli material in order to contribute to the growing wealth of knowledge on collaborative and organic breeding work.

The Oregon State University Vegetable Breeding Program made significant progress towards decreasing the variability of the broccoli project material through three successive years of modified half-sibling selections. Evaluations and selections were based more strongly on quality traits rather than soley on production traits such as yield. Although progress was incremental and statistically verified in only three out of the fifteen quality traits, we observed trends in the data indicating progress towards an increasingly uniform, stable, and reliable open pollinated broccoli with specific adaptation for organic production systems.

There were very few differences between broccoli materials developed by formally trained plant breeders and farmer breeders. This was especially true for the three cultivars developed in the Pacific Northwest (PNW) (one in Washington and two in Oregon). The 'East Coast' population, which had been collaboratively selected by formal and farmer breeders in New York, expressed significantly distinct differences from the PNW materials. When the farmer breeder and formal breeder materials were pooled together and compared to pooled check cultivars they expressed significant differences for nearly all traits across all years. This demonstrated that all of the collaboratively developed open pollinated materials are distinctly different from the F_1 hybrids currently available.

Our work has demonstrated a few of the myriad of positive outcomes achievable with the use of participatory plant breeding for organic production systems. The participatory nature of this project resulted in increased confidence and feelings of empowerment for all involved. Both farmers and breeders felt their involvement was socially beneficial and widened their networking and seed community circles. The farmer-bred cultivar 'Solstice' is now available as a result of Jonathan Spero's work, and a cultivar tentatively named 'Benton' is about to be released for sale through Oregon State University.

Our results agree with previous study findings that formal and farmer breeder selections are often not distinctly different; thus providing evidence for continuing to support the involvement and education of farmers in plant breeding, especially in reference to organic production systems. This study demonstrates the potential of collaboratively developed and farmer-bred cultivars to become viable and vibrant open pollinated alternatives to the current open pollinated cultivars on the market today.

Breeding an Open Pollinated Broccoli for Organic Production Systems Using Participatory Methods

by
Laurie R. McKenzie

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Laurie R. McKenzie, Author

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Breeding an Open Pollinated Broccoli for Organic Production Systems Using Participatory Methods

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Chapter One: Introduction and Literature Review

The Organic Issue

Organic agriculture is an important and growing sector of U.S. and world food production. The organic industry now accounts for 5% of all agricultural production in the U.S. and represents a multi-billion dollar market; consumers spent 26.7 billion dollars on organic food and beverages in 2010 (Organic Trade Association, 2013). Consumers are increasingly aware of and interested in the production practices and impacts associated with agriculture and as such, are showing a preference for sustainably produced, raised, and harvested foods. This trend is likely driven by the perception that organic and other sustainably produced foods are more nutritious and have a reduced environmental footprint compared to conventional agriculture. In response, sales and production are increasing in all areas of organic agriculture; between 2002 and 2008 certified organic cropland in the U.S grew at an average annual rate of 15% (Organic Trade Association, 2013).

In order to continue to meet the growing demand for organic produce, organic growers need cultivars that are optimally adapted to organic and low input conditions. Meeting the needs of the organic sector has been a challenge for the seed industry; it is an industry that often doesn't understand the specific and unique challenges associated with the diversity of environmental and market demands of organic systems. Organic agriculture represents only a very small piece of overall production and is often considered too much of a niche market for serious investment by the seed industry (Lammerts van Bueren and Myers, 2012; Osman et al., 2008). Many large seed companies also lack the skills, knowledge, and equipment to facilitate organic specific breeding and seed production.

Quality seed is the foundation of any functional and stable farming system. Unfortunately the lack of organically bred and produced seed is hindering the continued growth and success of organic farming (Dillon and Hubbard, 2011). In comparison to farmers producing in conventional systems where there are more options to manipulate the growing environment, organic farmers rely more heavily on the genetic approaches inherent in the cultivars they use, as well as biodiversity in the landscape to cope with many of the daily challenges they face in the field (Dawson and Goldringer, 2012). Organic farmers and the organic food systems they supply rely on a robust organic seed system that is appropriately adapted to regional agronomic challenges and market needs, meets standards and regulations, and encompasses the social and ecological values of organic agriculture. Unfortunately current organic seed production systems are not meeting the needs of organic agriculture (Dillon and Hubbard, 2011).

Although the National Organic Program (NOP) standards stipulate the use of organic seed for organic production, they allow for the use of untreated, non-organic seeds when an equivalent organically produced cultivar is not commercially available. This is problematic for the organic community because conventional seed production makes use of inorganic chemicals and inputs, the use of which is in direct conflict with the principles of organic agriculture.

This has resulted in an inadequate supply of organically produced seed and cultivars developed specifically for organic production (Dillon and Hubbard, 2011). Most cultivars currently used in organic agriculture have been developed in conventional breeding programs (Lammerts van Bueren and Myers, 2012). Although selected for traits considered important for organic farming, these cultivars have been developed under highly uniform, controlled conditions maintained with an array of chemical pest protectants, herbicides, and fast-releasing fertilizers. These conditions are not representative of organic environments that rely on few chemical inputs and soil fertility regimes based on manure, composts, and soil building crop rotations. Many organic farmers struggle to obtain culitvars with reliable and robust performance under organic conditions. Additionally, seed availability has become increasingly unpredictable as the seed industry continues to consolidate, cultivars are discontinued, and crop genetic variability become inaccessible by patents and other forms of intellectual property protection (Dillon and Hubbard, 2011; Lammerts van Bueren and Myers, 2012). The needs of the organic farming community are pushed aside and left unaddressed as cultivar development and seed production is increasingly focused on technology heavy methods such as genetic engineering that are unacceptable for organic production.

The belief that the best cultivars have optimal performance independent of production system has long dominated the plant breeding industry. Most breeding efforts in the last 50 years have targeted broadly adapted cultivars with stable performance over a wide range of environments. However, this belief that the production system control afforded by readily available fertilizers and chemical herbicides and pesticides provides an optimal genetic selection environment is being questioned by recent research results. Breeders have assumed that controlling environmental variation would result in increased genetic expression, allowing for optimal selection progress. Recent findings indicate that hertitabilities are similar (Reid et al, 2009), and in some cases higher, in organic environments (Goldstein et al., 2012). If this is indeed the case then it is worth making efforts to incorporate decentralized, direct selection in the target environment into breeding programs for optimal efficacy.

Traditionally, the goal of formal breeding programs has been to produce broadly adapted cultivars that perform well over a wide range in both space and time (Ceccarelli and Grando, 1997; Vlachostergios and Roupakias, 2008). Producing few, broadly adapted cultivars allows seed companies and public breeding programs to meet the needs of a large segment of the market while effectively recouping research and development costs. This is particularly true for vegetable production where manipulation of the growing environment is used to create similar growing conditions even when regionally separated and quite diverse climatically. This model is best suited to similar environments with limited variability; broadly adapted cultivars do well in high input systems such as conventional systems where field similarity can be-achieved through the use of synthetic and chemical inputs and analagous management practices.

Recent research by Dawson et al. (2008) suggests that broadly adapted cultivars may actually be narrowly adapted to environments that are adjusted to similar conditions with fertilizers, herbicides, and pesticides. Thus these cultivars may lack the resiliance needed for adaptation to the system variability inherent in organic production environments.

Another commonly held belief is that organic agriculture is less productive than conventional agriculture. One problem with studies that support this idea is that they have been conducted with cultivars that were developed under high-yielding conventional conditions (Murphy et al., 2007). Several studies provide evidence for genotype crossover interaction between conventional, high-input and organic, low-input environments that indicates that the best performers in each system are not the same (Ceccarelli and Grando, 1997; Vlachostergios and Roupakias, 2008; Przystalski, 2008; Reid et al., 2009). Murphy et. al. (2007) showed that when early stage breeding material was trialed in side by side conventional and organic environments, the top performing lines in each system were not always the same. There was some overlap, indicating broadly adapted material, as well as material that clearly segregated depending on environment. As a result, the material with greatest potential for strong performance in organic and low input systems may be discarded in early generations when lines are selected in a non-target environment. These findings corroborate earlier work by Ceccarelli (1997) and Reid et al. (2009), who demonstrated that when selections were made in the target environment, there were greater differences among selections.

When breeding material is selected within conventional and organic environments, there are large differences in agronomically important traits other than yield for the two systems (Reid et al., 2009; Murphy et al., 2007; Drinkwater et al., 1995). For instance, fast-acting fertilizers provide immediately available nutrients in conventional systems whereas organic systems rely on composts, manures, and soil residues whose availability is dependent on temperature and soil biological activity. As such, it can be very challenging to match crop nutrient demand with supply in an organic system (Dawson et al., 2008a; Jones et al., 2010). Unmet nutrient demand can substantially reduce crop yield compared to high input, conventional systems. (e.g., 5-47% reduction in cereals, Przystalski et al., 2008; 44% reduction in lentils, Vlachostergios and Roupakias, 2008). Traits such as root architecture that facilitate exploration and exploitation of soil resources and interaction with soil microorganisms that contribute to nutrient acquisition and use efficiency are of greater importance in organic systems. Other important traits include: ability to compete with and suppress weeds, pest and disease resistance, and abiotic stress tolerance. Although stress, disease, and pest resistance are important to all farming systems, many of these traits have not received adequate attention nor been a high priority of conventional breeding programs. In addition, pest and disease complexes may differ between conventional and organic environments. The incorporation of these traits into breeding programs will benefit all farmers as we make progress towards a more sustainable agriculture less reliant on high inputs of fast-acting fertilizers and chemical crop protectants (Lammerts Van Bueren et al., 2002).

There is a current and progressively demonstrated need for increased organic breeding and seed production (Osman et al., 2008; Murphy et al., 2007; Reid et al., 2009; Lammerts van Bueren et al., 2011). Without dedicated resources, research, and increased attention to the specific needs of organic production systems, organic farmers will be forced to continue operating with sub-optimal varieties that hinder the full expression and capability of organic agriculture. A strong, robust organic seed industry will contribute to increased organic product quality, increased organic acreage, and provide a diversified income stream for organic farmers, all of which serves to strengthen the organic industry.

Participatory Plant Breeding

As previously discussed, modern conventional agriculture and plant breeding techniques mostly benefit farmers in high-input and high yielding environments that use chemical fertilizers and crop protectants. Although there is a significant amount of international breeding work targeted to low yielding environments, spill-over benefits from formal crop improvement programs have been limited in resource poor and low input farming (Almekinders and Elings, 2001; Ceccarelli and Grando, 1997 and 2007; Vernooy, 2003). Many low input and resource poor farmers around the world either choose not to use, or cannot afford, such inputs to alter their systems to provide the growing conditions these modern varieties need to reach their full potential. Concerns over water and soil degradation associated with chemical use and decrease in crop biodiversity associated with conventional plant breeding are also issues for many farmers (Ceccarelli, 2006; Ceccarelli and Grando, 2007; Vernooy 2003). It is imperative that we find a way to meet the needs of low input and organic farmers in an ecologically and socially responsible manner.

The issue of crop biodiversity decline is somewhat contentious. The common wisdom has been that there has been an erosion of genetic diversity with modern breeding efforts (Fowler and Mooney, 1990). However, recent research on tomato suggests that modern varieties are more genetically diverse than landraces and heirloom varieties (Sim et al., 2012). The increase may be the result of introgression of disease resistances and other traits from related wild species into cultivated tomato. A meta-analysis of crop biodiversity found that during the 20th century, there have been no significant changes in crop biodiversity (Wouw et al., 2010). However this analysis focused predominately on cereals rather than vegetables, and whether it is directly applicable to vegetable crops is unknown. These works suggest that although crop biodiversity may not be actively declining, the intra-crop diversity is (likely) increasing due to modern selection and breeding work. In addition, this does not address the question of the loss of cultivars (due both to neglect and seed industry consolidation). While genetic diversity may be retained, unique assemblages of genes are being lost.

One plausible approach to meeting the needs of organic and low input production systems is the use of participatory plant breeding (PPB). PPB is a collaborative approach for identifying and developing genetically diverse plant material and varieties involving partnerships among formal sector breeders and researchers, farmers, extension agents, educators, and end users. Those who work with PPB models seek to integrate and appreciate the unique and valuable knowledge of everyone involved (Vernooy, 2003). Participatory plant breeding advocates and users believe that the power and creativity of stakeholder cooperation is more useful and effective than working alone.

According to Almekinders and Elings (2001), the strategy of PPB projects is to insert useful genetic diversity into local systems and build on farmers' capacity to exchange and select seed. These projects are often more about serving the farmers and the farming communities than they are the interests of the research institutions or seed companies. Introducing new genetic material and diversity into the organic sector through PPB projects would be enormously beneficial. PPB may be able to provide a breadth of materials to meet many of the needs and challenges of organic production systems. Research has shown that genetically diverse materials may be more suitable for heterogeneous environments because they have an increased buffering capacity and potential for adaptation (Almekinders and Elings, 2001). Breeding diversity into crops is insurance against pest, disease, and environmental failure. Allocating plant resources to pest and disease resistance and environmental buffering comes at a cost, which is often expressed in reduced yields. Although increased genetic diversity can reduce yields and lessen uniformity, it can be an effective and efficient breeding strategy for organic systems. PPB has been proven to increase local crop biodiversity (Ceccarelli and Grando, 2007; Vernooy, 2003). In a time and a country where the number of available crop cultivars is decreasing due to continual consolidation in the seed industry, this may be one of the most valuable contributions PPB can make to the agricultural sector.

Participatory plant breeding is aimed at most effectively meeting the needs of farmers who work in marginal and high stress environments, and with low input systems (Almekinders and Elings, 2007; Ceccarelli and Grando, 1997 and 2007). PPB is a relatively young phenomenon in the United States where access to and availability of "prime" growing land is much more prevalent than in developing countries where PPB has historically been of greatest use and benefit. Organic production is sometimes conflated with low input farming, and the two do share many attributes. The following four traits can be used to characterize organic and low input farming:

1. *Diverse and heterogeneous growing environments* that employ a vast array of fertility and crop protectant strategies that are not easily standardized;
2. *Wide range of end use and marketing strategies/outlets* including direct marketing (farm stand and farmers' market sales), wholesale distributing, Community Supported Agriculture programs, restaurant and grocery store accounts;
3. *A lack of suitably adapted and derived varieties* with reliable and robust performance under low input and organic conditions;
4. *Lack of attention from the formal seed sector*, which considers the organic and low input community a small and insufficiently profitable niche market (Desclaux et al., 2012).

Participatory plant breeding fundamentally changes the way that germplasm and plant genetic resources are managed by formal breeding programs and farmers. Typically, formal breeding programs restrict access to germplasm and breeding materials and only supply farmers with finished varieties. In PPB, farmers are involved in the early stages of creation and evaluation of germplasm and breeding material, and stay engaged with the breeding process until new varieties are created (Ceccarelli and

Grando, 1997). The range of goals that can exist within PPB programs is quite wide and according to Sperling et al. (2001) these include but not limited to:

> "… production gains; enhancing biodiversity and germplasm conservation; effective targeting of user needs (developing adapted germplasm for especially disadvantaged user groups (e.g. women, poor farmers); making breeding programs more cost-efficient, particularly through decentralization of programs which target more niches; capacity building and knowledge generation for farming communities and the formal research and development sectors; empowerment, particularly of farming communities; institutional and organizational innovation; breeding program and seed policy modifications for expansion and institutionalization of PPB."

The application of PPB models can produce a wide range of outcomes depending on the project goals and who the stakeholders are.

There is a wide range of agroecological environments that could potentially be served by PPB: from those that are primarily subsistence-based and highly unstable where farmers' crop choices are governed by their own preferences and available, adaptable material, to highly controlled systems where crop production is highly stable and primarily driven by consumer demand and commercial processor needs (Sperling et al., 2001). PPB programs are also being implemented in intermediate areas where the agroecological-climatic stresses are less severe. In these cases meeting quality concerns of the end users is usually defined as the paramount challenge (Weltzien et al., 2000). This indicates that PPB can be used to help farmers meet the quality demands and preferences of their markets while simultaneously adapting varieties to their local climate and unique growing conditions. Other benefits to using PPB in low stress environments include: increasing intra-crop varietal diversity in what have become relatively uniform farming areas, and creating opportunities for farmers to gain greater control over their breeding process and seed supply (Vernooy, 2003).

There are a variety of ways in which PPB projects are structured to meet end goals. Farmer participation can usefully occur at various times, depending on the crop, parent materials, target environment, researcher ability to assimilate farmer criteria, farmer capacity to handle different types of materials, traits of interest, scale of the breeding program, and volume of materials to be screened. Often the stages and ways in which farmers and researchers participate change and evolve over the lifetime of the project, especially as the understanding of each other's skills and priorities increase (Sperling et al., 2001). Equal contribution of individual knowledge is critical to the life and success of any PPB project (Dawson et al, 2008). In order for projects to be considered truly participatory, farmers need to be involved in making key decisions alongside breeders rather than acting only as suppliers of labor, space, and materials. As is true of any breeding work, the general progression of most PPB projects is as follows:

1. *Setting breeding goals*: It is important for all participants (farmers, breeders, researchers, end users) to discuss from the very beginning the explicit primary and secondary goals, and to agree on what outcomes the program is aiming for.
2. *Generation (or acquisition) of variation*: This is usually best done by breeders and/or researchers as they have access to a greater range of germplasm than farmers and have the skills and resources to generate genetic variability.
3. *Selection in segregating populations*: Farmers, breeders, and researchers collaboratively select a number of target environments for grow outs and make selections. Farmers and breeders make both joint and individual selections in all environments. The best selections are used for further cycles of selection and recombination (Ceccarelli and Grando, 2007)
4. *Variety testing and characterization*: Conducted at an advanced stage when selections have been made and material is close to release. Farmer and breeder involvement can vary widely in this phase.

5. *Interaction with seed systems (release, popularization/marketing/diffusion, seed production, distribution):* In this stage it is important that farmer contributions to the breeding process be recognized when finished materials are released and be included in any form of intellectual and/or property rights. (Vernooy, 2003)

PPB is a way to overcome the limitations of conventional breeding by offering farmers the possibility to choose, in their own environment, cultivars that best suit their needs and conditions (Ceccarelli and Grando, 2007).

PPB is an excellent model for breeding specifically for organic systems. Breeding for organic systems is a relatively young field and breeders in the formal sector do not have a good understanding of what traits are important for robust production under organic conditions (Lammerts van Bueren and Myers, 2012). Thus the opportunity to meld farmers' experience and knowledge with breeders' expertise is an effective way to breed for organic production systems.

The synergetic benefits of collaboration are also highly socially valuable to all participants. Not only does involving farmers early on in the breeding process keep the work relevant and effective, it also fosters creativity, community, innovation, and companionship. Strengthening the organization of farmers increases their capacity to experiment and innovate and creates direct connections to the formal sector, which allow farmers greater access to the agendas of the formal agricultural research system (Vernooy, 2003).

PPB projects are in their infancy in the United States and are therefore still highly variable in terms of their outcomes. It is difficult to link the degree of participation and the roles performed by researchers and farmers with specific outcomes (Sperling et al., 2001). However, the numerous PPB projects worldwide and in the United States clearly indicates that they are enjoying successful outcomes and meeting the demands of farmers, breeders, and consumers.

PPB work is not without challenges. One major challenge of PPB is incorporating the large number of potential target environments. These target environments differ widely by climate, farming objectives, access to inputs, and market opportunities, meaning that often a large number of selection sites will be needed, especially in low input environments where farm to farm and site to site variability is high (Ceccarelli and Grando, 2007). This can strain budgets, necessitate added travel time among sites, and increase monitoring and collaborative time commitments. Another challenge is maintaining effective communication between farmers and breeders to ensure continuity, timing, and accuracy of evaluations and selections.

Some objections to PPB include the sentiment that if plant breeders do their jobs properly there is no need for PPB, that seed companies are not capable of handling the multitude of varieties that come out of PPB projects, and that PPB varieties do not meet the requirements for varietal release (Ceccarelli, 2006). In response, it is necessary to reiterate that conventional breeding has been very successful for favorable environments and where inputs have been used to modify the environment to create advantageous crop conditions, but has been less successful in meeting the needs of low input (and organic) environments. Formal breeders and researchers only minimally understand the complex ecology of organic systems; incorporating farmer knowledge into the breeding process will result in a more comprehensive knowledge about these systems in order to maximize breeding efficacy (Desclaux et al., 2012).

The objection that seed companies will have difficulty dealing with the diversity inherent in and among PPB varieties implies that the needs of the seed companies are more important than the needs of farmers and consumers. This may indeed be difficult for large seed companies, but will be a welcome addition to many smaller seed companies. Incorporating a diversity of regional and small-lot cultivars into regional and small-scale seed companies has been embraced by many growers and seed producers at regional NOVIC meetings (Morton, Still, Spero pers. comm., 2011 and 2012). A vibrant and functional seed industry must be built and maintained on a broad foundation of genetic diversity and stay closely aligned to farmers' needs.

As to the third objection, many successful PPB projects have demonstrated that it is possible for participatory projects to generate quality data and varieties that are comparable, and sometimes superior, to conventional breeding programs. In addition to producing data on important agronomic traits, PPB projects generate information on farmers' preferences, which serves to make the process of variety release and dissemination more efficient and effective (Ceccarelli, 2006). Although PPB projects usually strive to create varieties that are more genetically heterogeneous than most modern varieties, it is possible to do so while maintaining the stability and uniformity necessary for release. Like conventional breeding, PPB is flexible and can be used to produce varieties with variable genetic structures such as pure lines and hybrids (Ceccarelli, 2006).

Thus, the most frequent objections to PPB are unfounded; they tend to ignore the fact that farmers have modified crops for millennia, domesticating wild species, exchanging seed, and introducing new crops and new varieties into production. In the process they have accumulated a wealth of knowledge that modern science tends to ignore. PPB is one way or recognizing farmers' skills while merging them with modern science (Ceccarelli and Grando, 2007). The collaborative nature and valuing of multiple kinds of knowledge inherent in PPB work is strongly aligned with the values and philosophy of organic agriculture. PPB has the potential to be of enormous benefit to the continued work to strengthen and expand the organic breeding and seed industry.

The purpose of this project was to investigate and explore the opportunities and challenges of organic plant breeding using participatory research methods. We believe that developing varieties and producing seeds under organic conditions and incorporating farmer preferences and selections into the breeding process will lead to a stronger and more productive organic agriculture community. Breeding varieties to withstand the stresses and challenges in organic growing environments will benefit not only the organic sector, it will provide valuable and useful crop (and genetic) biodiversity to the greater agricultural community and contribute to many forms of vibrant and viable sustainable agriculture far into the future. This research had three goals that are examined in the next three chapters: to develop an open-pollinated broccoli with contemporary quality traits for organic production systems using participatory strategies; to compare and contrast broccoli selections made by formally trained plant breeders and farmer breeders; and to capture the stories and experiences of the formal breeders and farmer breeders involved with this broccoli material in order to contribute to the growing wealth of knowledge on collaborative and organic breeding work.

Chapter Two: Oregon State University Organic Broccoli Project

Introduction

Organic agriculture has not yet realized its full yield potential due to poorly adapted and selected cultivars that do not have optimum performance in organic systems. The organic sector requires cultivars that are adapted to organic conditions in order to improve yield stability and quality (Lammerts van Bueren et al., 2002). Once the unique conditions inherent in alternative and low-input systems such as organic are met, these systems will be better equipped to realize their full potential as high-yielding, viable alternatives to conventional agriculture (Murphy et al., 2007).

Most of the literature addressing the sub-optimal crop performance of organic systems focuses primarily on production traits such as yield with less attention given to quality traits. For broccoli in particular this has resulted in cultivars that are almost entirely F_1 hybrids with big, dense heads and uniform maturity that allows for single cut harvests but lack important quality characteristics for organic systems. Successful performance in organic systems is often based on a broad spectrum of both quality and production traits. Because we believe that crop quality is often more important than total yield and quantity for organic markets, we focused our work developing an open pollinated broccoli cultivar for organic systems on a suite of important, farmer identified, quality traits. We also paid attention to important production traits and made a conscious effort to enhance and maximize yield (potential) for our material.

Organic agriculture is commonly criticized as low yielding. A recent meta-analysis of the crop yield gap between conventional and organic systems conducted by Ponti et al. (2011) found that on average, organic systems yield 80% of conventional systems. However they calculated a rather large standard deviation of 21%, indicating that it is currently both possible and realistic to achieve comparable yields under organic conditions. There are many studies that present conflicting evidence on this topic, although it is generally accepted that conventional systems out-yield organic ones.

There may be several reasons for this current yield gap. Work by Lotter (2003) found that organic research has received only a fraction of the time and resources that has been dedicated to conventional systems. This lack of research investment began approximately 50 years ago and with time has become more apparent. The ratio of public funding dedicated to genomics vs. organic seed and plant breeding research was 70:1 between 2002 and 2005 (Dillon, 2013). According to research by Mader et al. (2002), the sub-optimal performance of organic systems is potentially attributable to six main factors including: 1) Disproportionately less funding, research, and support than conventional due to the small market share that it represents, 2) Lack of scientific understanding of the ecological complexity and diversity inherent in organic systems, 3) Biased comparison trials that rely on varieties developed for conventional systems, 4) Lack of interest in, or perceived need for, organic specific plant breeding work, 5) The National Organic Program (NOP) provision allowing for continued use and production of untreated non-organic seed, 6) Low correlation between conventional and organic production systems, and the inefficiency of indirect selection for optimal genetic gain in relation to organic system productivity. Research has demonstrated marked potential yield increases with dedicated resources and specific investments in breeding for organic production systems.

The selection environment is another key piece contributing to the current yield gap of organic systems. A five-year study conducted by Murphy et al. (2007) at Washington State University has shown that yields for wheat breeding material in paired organic and conventional locations have highly significant ($p<0.001$) genotype x environment (GxE) interactions. This research also showed no correlation for yield rankings for four of five locations between the two systems, indicating that the best performing varieties in one system were not the best in the other. They concluded that direct selection in organic systems resulted in 5-31% higher yields than yields resulting from indirect selection in conventional systems (Murphy et al., 2007), direct selection was more effective and efficient for traits with low heritabilities that are strongly influenced by GxE, such as yield, than indirect selection. Indirect selection was found to be effective for traits with high heritabilities that show little GxE interaction, which aligns with findings from other research as well (Goldstein et al., 2012). Although indirect selection can be effectively applied to breeding for organic systems for some traits, there is increasingly wide agreement that separate breeding systems are justified if the goal is to optimize yields and production in organic systems (Osman et al., 2008; Goldstein et al., 2012).

There is debate about whether heritabilities are lower in organic systems and thus gains from direct selection would be more difficult to achieve. Recent research results have shown that heritability estimates can be statistically similar in both organic and conventional systems, or even higher in organic systems (Reid et al. 2009; Goldstein et al., 2012). Results from the spring wheat study by Reid et al. (2009) suggest that genetic gain may not differ between the two systems but that it would be more difficult to predict under organic conditions. It is generally assumed that the dynamic and sometimes stressful conditions in organic systems would make selection difficult by masking the genetic variability and thus reduce heritabilities. Reid et al. (2009) also concluded that breeding within organic systems will be beneficial and produce positive results and genetic gains, but will likely result in lower genetic gains compared to conventionally managed land for some traits. They found that optimally managed research stations were useful for selection of highly heritable qualitative traits such as grain color, size, texture, and maturity, but not suitable for quantitative traits, such as yield, that are affected by GxE interactions. If heritabilities are comparable under organic and conventional selection environments, as has been documented by the work of Goldstein et al. (2012) with maize, then direct selection in the target environment is in fact more efficient and effective than indirect selection under conventional conditions (Messmer et al., 2012). Organic varieties and breeding materials need to be flexible and robust in order to thrive in variable environmental conditions, which is likely controlled by a complex set of traits that may not be easily genetically selectable in conventional systems.

It is very difficult to achieve optimal growing conditions in organically managed systems. Organic systems depend on biologically dynamic fertility regimes in which nutrient availabiliy is influenced by climate, and where timing resource delivery during critical stages in crop development is dependent on factors that are largely uncontrollable. Conventional systems use chemical crop protectants and tools to rapidly achieve the best possible conditions which increases the probabilty of achieving optimal yields. In contrast it can take many years to build up to stable and reliable organic field conditions that promote optimal crop expression. Thus it is important to develop materials and varieties with the genetic elasticity for high productivity under variable conditions for organic production systems (Dawson and Goldringer, 2012).

Cultivar choice can have a large effect on the success of a variety within a system. For example, the previously mentioned spring wheat study by Reid et al. (2009) used a randomly mated F_6 population to compare yield and many agronomically important traits between organic and conventional environments. They found that traits of importance in organic systems may not be the same as in conventional systems, and that weed pressure in particular had a noticeably large negative effect on organic yields; reducing yields up to 50% of that in conventional systems when no traits other than weed biomass differed between the two systems. They noted that semi-dwarfing varieties, which are very popular for conventional production, would be less suited for organic systems because they have very little weed suppressive ability. Although selection for some traits will be universal between the two systems, the complex ecology of organic systems requires a broad spectrum of unique traits to meet the challenges of organic management.

There are many issues surrounding the organic breeding conversation, but for every issue in the conversation, there also seems to be a desire for solutions on a local and institutional level. In an attempt to address the above issues and meet the needs of organic growers in the Pacific Northwest, the Oregon State University (OSU) vegetable breeding program (VBP) engaged in a long-term, collaborative breeding project. Broccoli was chosen as a model crop for this project because it was an area of expertise for the OSU VBP and it lends well to mass selection techniques, which are fairly simple and easily accessible to farmers. Most currently available broccoli varieties are F_1 hybrids. Although many of these cultivars perform well in organic systems, the seed is often expensive and not conducive to direct seeding or seed saving. In an effort to provide an open-pollinated (OP), open source broccoli cultivar with quality characteristics comparable to contemporary F_1 hybrids, the OSU VBP has engaged multiple researchers, plant breeders, and many organic farmers in the Northern Organic Vegetable Improvement Collaborative (NOVIC, 2013) project. The hypothesis of this research was that by using participatory plant breeding methods, the OSU VBP could develop an open pollinated broccoli cultivar with contemporary horticultural traits adapted to organic production systems.

Materials and Methods

Broccoli Population Development

The broccoli project began in 1997 with the creation of a diverse breeding population from a random mating of six contemporary F_1 hybrid varieties (Arcadia, Barbados, Decathlon, Excelsior, San Miguel, and Shogun) and 17 inbred lines that had been developed through the OSU VBP. This was followed by four years of random mating without selection within a conventional system at OSU in order to maximize recombination and genetic diversity within the population.

Population improvement was carried out over the next seven years (2001–2007) with farmer participation using a divergent-convergent scheme. Each season, participating organic farmers (ranging from one to seven depending on the year) and the VBP would select for the traits of head size, plant vigor, freedom from diseases, and heat tolerance. These selections were then allowed to randomly mate and produce seed. Farmers returned a portion of their seed to the OSU VBP where seed from all sources was blended and aliquots sent back out, this process being repeated yearly (Figure 1). Initially, the project was not intended for organic production systems, but when the farmer participation component was added in 2001 it became apparent that the material had potential benefits for organic systems. In 2004, research production at OSU was moved to transitional ground to facilitate selection and eventual variety development within an organic system. OSU production and selection sites were moved onto certified organic ground in 2008.

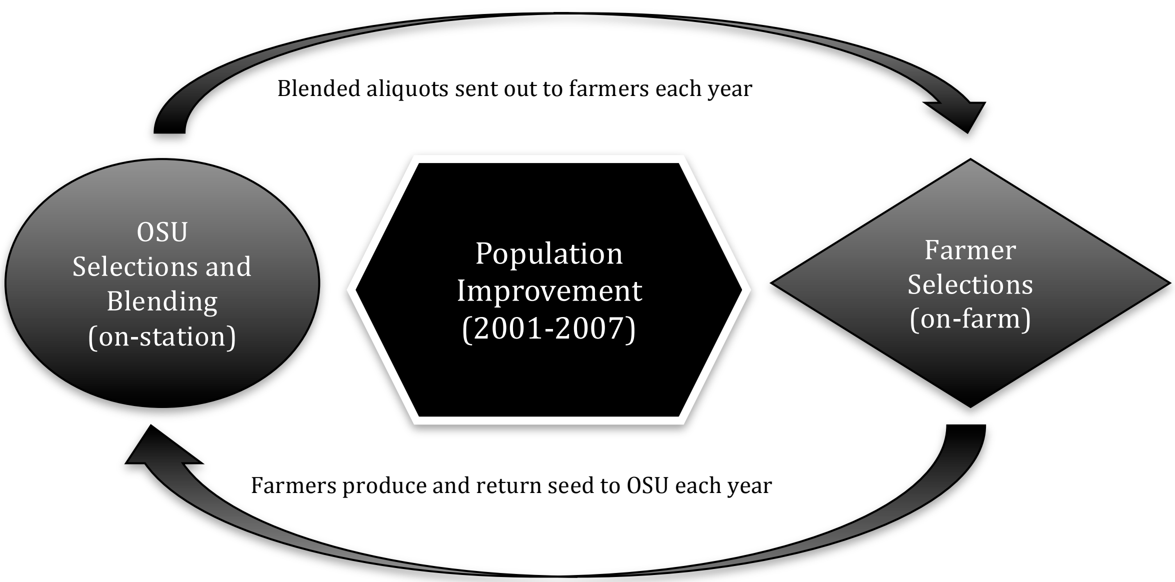

Figure 2.1. Divergent-convergent breeding scheme for broccoli population improvement in the OSU VBP (2001-2007)

In 2008, the OSU program shifted from population improvement to variety development and stopped incorporating selections made by farmers (Table 1). The NOVIC project was established in 2009 and absorbed the broccoli project. This allowed for the establishment of a graduate student position to carry out the variety development. For the three years of this study a combination of half-sibling and modified ear-to-row breeding schemes were used to maximize genetic gain from selection(s). During the third field season a comparative trial to assess selection progress was included. This allowed for a side-by-side comparison of selections made in 2009, 2010, and 2011.

Table 2.1. Flow of OSU VBP broccoli breeding activities

Time Period	Activities
1997	Population origin
1997-2000	Random mating without selection for genetic recombination
2001-2008	Population Improvement involving farmer participation through convergent-divergent shuttle breeding
2001-Current	Parallel independent farmer-breeder on-farm selection and variety development
2009-Current	Variety Development at OSU, continued development of farmer-breeder varieties

OSU Vegetable Breeding Program Broccoli Variety Development

Research sites were located at the Oregon State University Lewis Brown Horticultural Farm near Corvallis, Oregon at latitude N44.551579 and longitude W123.218023. This farm is located near the Willamette River on alluvial Chehalis silty clay loam soils at 69 masl. All growing sites were on certified organic ground established in about 2005 and 2009. During 2011 an additional selection and production site was located at the Oregon State University Vegetable Research Farm near Corvallis, Oregon at latitude N44.572856 and longitude W123.242562. There was no certified organic ground available at the Vegetable Research Farm so the study site was located on a plot of land that had been in cover crops without chemical inputs for at least the three previous years and met the criteria for organic transitional ground.

Year One – 2010

Protocols and criteria for evaluation were based on the NOVIC variety trial protocols (NOVIC, 2013), available field space, and discussions with Dr. Myers (endowed professor of Horticulture at OSU). Forty-five half-sibling broccoli families were seeded in the greenhouse into 50 cell trays on April 6th, 7th, and 8th. The planting medium was an "organic" potting soil from Sun Gro Horticulture. At three weeks, transplants were fertilized with foliar applications of fish emulsion (5-2-2) obtained from Wilts Farm (certified organic) in Corvallis, OR. A 3.75% solution was applied six times at two to three day intervals beginning 21 days after seeding.

Transplants were grown in a glass house where daytime temperatures were maintained around 26.7°C/80°F (no higher than 32.2°C/90°F) and minimum night time temperatures were 12.8°C/55°F. On May 7th plants were moved outside to a lath house and hardened off for 17 days before transplanting. Transplants were planted into certified organic ground at the Lewis Brown Horticultural Farm on the 24th of May in a randomized complete block design with three replications. Families were planted to single row plots of 20 plants with 30.5 cm (12 in) within and 76.2 cm (30in) between row spacing to best approximate the planting density of typical organic farming practices.

Corvallis Municipal Compost (approved for organic use) was applied at a rate of 37.8 m^3/ha (20 yd^3/acre) before transplanting. Directly after planting, plots were fertilized with OMRI approved feathermeal (12-0-0) at a rate of approximately 780 kg/ha (697 lb/acre) using an Allis-Chambers G-tractor with a John Blue applicator. Fertilizer was double banded.

Severe flea beetle pressure necessitated five applications of Pyganic EC 1.4 (EPA regulation # 1021-1771, manufactured by McLaughlin Gormley King Co.) during the growing season. The initial application was done on June 15th using a boom sprayer at a rate of 2.8 ml/l (0.36 oz/gal). Subsequent sprays were done on July 29th, August 3rd, 5th, and 10th using a handgun sprayer at a rate of 8.3 ml/l (1.07 oz/gal).

Comprehensive evaluations were taken during peak maturity. All families were ranked on a 1-5 scale for a combination of desirable characteristics (such as ideal head and bead size, head shape, color, and firmness, plant architecture and vigor, and freedom from disease), with 1 representing the least desirable and 5 the most desirable set of characteristics. Observational notes were also taken on each plot. Rankings were averaged over replications and families were sorted from highest to lowest. Rankings were paired with field notes to determine the desirable families to carry forward into 2011. Ninety-four single plant selections (SPS) were made from the 24 best families. Selection intensity was 3.5% among families and 6.5% within families. Fifty of these SPS produced seed, which was harvested and moved forward into 2011 as individual families.

Year Two - 2011

The 50 half-sibling families selected in 2010 were grown as transplants in the manner previously described. The Sun Gro potting soil was replaced with a certified organic planting mix obtained from Gathering Together Farm. Families were seeded on the 11th of April and moved outside to harden off on May 6th. Transplants received one application of fish fertilizer (in same manner as 2010) on May 6th.

Transplants were planted in two locations due to concern over potential for losses to flea beetle damage: the Lewis Brown Horticulture Research Farm on May 23rd and the OSU Vegetable Research Farm on May 13th. Both fields were fertilized with Corvallis Municipal Compost (approved for organic use) at a rate of 57 m^3/ha (30 yd^3/acre) before transplanting. Families were planted in complete randomized block designs with three replications at both locations. Plots were 4.6 meters (15 ft) long and planted on 30.5cm (12 in) within and 76.2 cm (30 in) between row spacing.

Directly after transplanting plots were double-banded with granular Nutri-Rich fertilizer (8-2-4) at a rate of 855 kg/ha (763 lb/acre). Nutri-Rich (OMRI approved, Stutzman Farms) is derived from a combination of dried poultry waste, blood meal, feather meal, and potassium sulfate. All plots were covered with Agribon AG-15 gauge row cover after transplanting and fertilization for flea beetle protection. Row cover was removed when plants were beginning to show signs of head development.

Due to insufficient row cover material, a section of the field at Lewis Brown was left uncovered for 11 days. During that time Pyganic EC 1.4 was applied on June 10th and 16th to the exposed plants with a backpack sprayer at a rate of 8.6 ml/l (1.1 oz/gal). Pyganic was again applied on August 19th to all plots during seed set and development to prevent seed loss to flea beetle feeding (same application rate). No Pyganic was used at the Vegetable Research Farm study site.

Comprehensive evaluations were taken at peak physiological maturity at both locations as described for 2010. The Lewis Brown farm presented a much more ideal growing environment and subsequently plants were much healthier and more vigorous at that location. Ten families ranked in the top 20 at both locations so these lines were carried forward into 2012. Using field notes and maturity data from both locations, another 11 families with superior performance were also carried forward for 2012 (total of 21 families selected). Families were deemed sufficiently uniform to move into a hybrid selection scheme where all plants meeting quality requirements within a family were bulked across replications. Within each family an average of 12 plants were selected for pollination and seed production. Selection intensity at the Lewis Brown farm was 12.6% (284 plants selected); it was 10.0% at the OSU Vegetable Research farm (226 plants selected). Seed from all plants within each family were bulked together to form the 21 families used for the 2012 season.

Year Three - 2012

One tablespoon of seed (approximately 4, 000 seeds) from each of the 21 families selected at each location in 2011 was combined to make up the planting stock for 2012. Families were seeded on April 18th and grown in the same manner described above. No fish fertilizer was applied in 2012. Transplants were moved outside to harden off on May 10th and planted out into the field at the Lewis Brown farm on May 21st. Field design was a randomized complete block with three replications. Plots were 16.5 meters (54 ft) long with 36 plants on 45.7 cm (18 in) within and 76.2 cm (30 in) between row spacing. The plot spacing was altered compared to previous years to accommodate other trials in the field and increase design efficiency.

All plots were fertilized with Nutri-Rich double-banded in the row directly after transplanting as in 2011. Due to weather and equipment constraints, compost was not applied to the field pre-planting. All plots were protected with row cover directly after fertlizer application. Pyganic EC 1. was applied on August 20th and 28th to combat flea beetle feeding during seed set and development using a backpack sprayer at a rate of 7.8 ml/l (1oz/gal).

Comprehensive evaluations were done at peak maturity. Rankings and selections were done as described in 2011. Fifteen families were selected for continued research and development. An average of 18 plants/family were selected for a total of 274 selections and a selection intensity of 12%.

An additional trial was planted in 2012 to allow for side-by-side comparisons of selections made in 2009, 2010, and 2011 and assessment of breeding progress. Planting stock for each year was created from a bulk mix of all selections and seed harvested in a given year (i.e. seed from each SPS made in 2009 was bulked in equal parts to make up the planting stock for that year). Transplants were grown, planted and managed in the same manner as described above. Measurements and ratings were recorded for all of the previously described traits. Traits were measured at peak maturity and taken on five plants/plot.

Data Analysis

Data obtained from the side-by-side trial in 2012 was analysed to assess selection and breeding progress between 2009 and 2011. Normality was graphically assessed with Q-Q plots for all data. Data was analyzed using SAS statistical software to run a PROC GLM Analysis of Variance (ANOVA). All possible pairwise combinations among least square means were evaluated using t-tests. The model for this analysis was:

Response (y) = Selection Year + Replication + Error

The null hypothesis for this analysis was that trait means would be equal for all years. We decided to use a 0.1 probability level for significance in order to effectively visualize trends and differences in this highly variable breeding material.

Results and Discussion

For the comparison of selections made from the OSU breeding material in 2009, 2010, and 2011, significant difference of note were discovered for the following traits: head height, exsertion, bead size, and head size (Table 2.2). Bead size was significantly smaller in 2011 than 2010, and highly significantly smaller ($P<0.001$) than 2009. Head height and exsertion both expressed significant decreases over time. Head size significantly decreased from 2010 to 2011. Trends for increasing variance over time were noted for the following traits: canopy and head height, exsertion, trimming, firmness, and harvest index. Trends for decreasing variance over time were noted for the following traits: bead size, head color, heat stress, and head size.

Table 2.2. Summary of trait means and variance for comparison of yearly selections from broccoli breeding material grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. Selection years are compared to '2011' for mean separation significance.

Selection Year	Days to Harvest	Hollow Stems (%)	Young Heads^y (%)	Prime Heads^y (%)	Over Mature Heads^y (%)	Canopy Height (cm)	Head Height (cm)		Exsertion^x (%)		Trimming^w (1-5)
					Mean						
2009	57	2	1	45	54	58	53	+	91	+	4.5
2010	57	2	0	44	53	59	53	+	90	+	4.5
2011	57	2	0	44	56	58	49		85		4.3
					Variance						
2009	--	0.0	3.0	121.3	122.3	29.0	25.0		36.9		0.4
2010	--	0.1	0.0	151.0	52.0	26.0	29.9		36.7		0.6
2011	--	0.1	0.0	0.0	0.0	54.7	34.0		111.5		1.1

+Indicates significance at the 0.1 P level. [z]Days to harvest were calculated from transplant to harvest; [y]% young, prime, and over mature heads were calculated from counts of all the plants in a plot; [x]exsertion calculated by dividing head height by canopy height; trimming 1=excessive trimming needed and 5=minimal trimming needed

Table 2.2 Continued

Selection Year	Bead Size[v] (1-5)		Firmness[u] (1-5)	Head Color[t] (1-5)	Heat Stress[s] (1-5)	Head Size (cm)		Head Weight (gm)	Biomass[r] (gm)	Harvest Index[q] (%)
					Mean					
2009	2.7	***	4.0	4.0	4.60	11.0		162.4	787.4	21
2010	2.3	*	4.2	4.0	4.70	11.6	+	180.0	870.6	21
2011	1.7		3.8	4.2	4.70	10.0		159.2	791.1	20
					Variance					
2009	0.8		0.4	0.8	0.5	4.4		1452.7	11882.1	8.6
2010	0.4		0.6	0.8	0.4	4.9		1141.9	30460.7	8.2
2011	0.4		0.6	0.5	0.2	1.8		1435.9	19894.4	14.9

+, *, **, *** Indicate significance at the 0.1, 0.05, 0.01, and 0.001 P levels, respectively. [v]for bead size 1=coarse and 5=very fine; [u]firmness 1=very loose and 5=very firm; [t]head color 1=light green and 5=dark blue-green/purple; [s]heat stress 1=unmarketable head and 5=no noticeable damage; [r]biomass was a measurement of all above ground plant matter; [q]harvest index was calculated by dividing head weight by biomass.

The data obtained from the trial comparing selection years was extremely variable. A large part of the variation is probably attributable to environmental variability and the complexity of conducting agricultural research in a naturally dynamic environment. It is possible we could have decreased the variability in our results by conducting the trial in more than one location, increasing the replications and/or number of samples taken from each replicate, and or repeating the trial over a number of years.

We emphasized evaluation of quality traits rather than production traits in this study. Our selections were based on these quality traits, with the understanding that stable and reliable quality in fresh market vegetables is often paramount to production mass in organic production systems. However, yield is often more easily influenced (and optimized) by cultural and management practices than by gains from breeding and selection. It is possible that by focusing our attention on quality rather than production traits caused us to miss observable gains from our selections.

It is also distinctly possible that the qualities we focused on are related to less than ideal production traits. An example of this is head weight and exsertion; as exsertion increases, head weight decreases (Baggett et al., 1995). As the plant allocates resources to extend the stem and crown high up into the canopy, the less photosynthate it has to form a dense, heavy head. Therefore as we select for increased exsertion we are also unconsciously selecting for lighter weight heads. That said, we were not ignoring important production traits in our selections: we made our selections based on an array of both quality and production traits, working to increase quality traits while simultaneously retaining (and hopefully increasing) production traits as well.

We worked to decrease the variation in the breeding material within our population. Being an open-pollinated population means that the material will inherently contain a fairly high degree of genetic variability. Our intention was to develop a broccoli cultivar with a balance of genetic diversity, to allow for specific adaptation and environmental resiliency, and acceptable uniformity in contemporary production traits. Declines in variances associated with bead size, head color, and head size emerged from the data, indicating that our selections were trending towards decreasing the variability in the population. Although this trial does not indicate that we made directly significant, noticeable changes in other quality traits, trends from this data suggest that with further research and replication gains from selection could become more apparent.

Chapter Three: Population Comparison

Introduction

Due to the many successes of providing new and improved varieties for low-input agriculture around the world where successful production relies on complex combinations of traits and integrating growers' preferences into the breeding process, participatory plant breeding (PPB) presents an excellent model for breeding specifically for organic systems (Desclaux et al., 2012). Breeding for organic systems is a relatively young field and breeders in the formal sector do not have a good understanding of what traits are important for vigorous production under organic conditions (Lammerts van Bueren and Myers, 2012). Incorporating farmer selections into the breeding process is an important aspect of participatory strategies; melding farmers' experience and knowledge with breeders' expertise will strengthen the efficacy of breeding for organic production systems. This chapter will take a closer look at how farmer and formal breeder selections result in cultivar similarities and differences.

A key reason for incorporating participatory strategies into breeding programs is for increased efficiency. It is very difficult, if not impossible, for breeders to anticipate farmers' preferences (Almekinders and Elings, 2001). Without farmer input and a comprehensive understanding of the challenges unique to organic production environments, formal plant breeders and researchers run the risk of orienting their work towards outcomes that may not best serve the interests of the organic community.

The synergetic benefits of collaboration are also socially valuable to all participants. Not only does involving farmers early on in the breeding process keep the work relevant and effective, it also fosters creativity, community, innovation, and companionship. Participatory work strengthens the organization of farmers and increases their capacity to experiment and innovate. It also creates direct connections between farmers and the formal sector, which gives farmers greater access to the agendas of the agricultural research system (Vernooy, 2003).

Participatory barley breeding work in Syria has demonstrated that farmers are highly capable selectors of cultivars (Ceccarelli et al., 2000). Farmers involved with this project were found to be capable of handling large numbers of entries and developing their own scoring methods for taking multiple observations during the growing season. It was concluded from this work that although the selection criteria used by farmer and breeder selections were nearly identical, the results of their selections were somewhat variable. Farmers selected more strongly for specific adaptation and incorporated a greater degree of diversity into their selections compared to formal breeders. Farmers were slightly more efficient at identifying the highest yielding entries on their farms and on research stations located in low rainfall areas, whereas selections by breeders were more efficient on research stations located in high rainfall areas. This provides compelling evidence for involving farmers in plant breeding; they are decidedly proficient at selecting for important agronomic traits that directly result in direct cultivar improvements. This work has proven that there is much to gain, and nothing to lose, in implementing decentralized, participatory strategies into plant breeding programs (Ceccarelli, 2000).

PPB work with onions conducted by Tiemens-Hulscher et al. (2006) supports other study findings that collaborating with organic farmers, particularly in the selection process, can result in cultivars that are better adapted to their needs. This work also found that organic farmers and conventional breeders make similar selections. An interesting aspect of this study was that researchers assumed organic farmers had a broader perspective of plant health than that of conventional breeders. This was apparent in that farmers made selections based on both earliness and downy mildew resistance in the field as well as post-harvest storage traits, whereas the formal breeder made selections based only on storage traits. Selection criteria and results were nearly identical for bulb characteristics such as shape, hardness, and skin firmness. This indicates a common disconnect between the traits that some conventional breeders consider important for agronomic success and the complex needs of organic farmers. Organic farmers rely on certain field traits for successful production whereas conventional farmers can address such issues with synthetic and chemical tools.

In an effort to contribute to the growing knowledge and experience with participatory plant breeding and incorporating farmers into the breeding process, we conducted a study comparing selections made by farmer-breeders and formal breeders using broccoli material developed through the Oregon State University (OSU) Vegetable Breeding Program (VBP). For the purpose of this study farmer-breeders are defined as farmers who have little or no formal training in plant breeding and who are now, or have been in the past, production vegetable farmers. Formal breeders are defined as professionals who have received intensive academic training in plant breeding and genetics. The background of this particular broccoli population (see broccoli chapter for a description of the population development) made for a unique situation in which to assess the differences and similarities among formal and farmer breeder selections. All the material came from the same original source, which was widely variable, allowing us to see and assess the potential segregation due to regional adaptation as well as farmer and formal preferences in the results of their selections.

Broccoli is an ideal crop for PPB because it lends well to mass selection, which is a straightforward and accessible breeding technique for farmers. Given suitably wide variation, gains from selections are rapid since evaluation and selection can be done prior to flowering. As long as a sufficient number of plants (~50) are maintained in each generation to avoid inbreeding depression, mass selection is an effective means for broccoli improvement.

Materials and Methods

This study included one farmer-breeder cultivar ('Solstice'), two farmer-breeder populations ('Common Ground' and 'East Coast'), one formal breeder population ('OSU'), and two F_1 hybrid check cultivars ('Arcadia' and 'Green Goliath'). Population refers to a set of breeding material that is currently under selection and not available as a named cultivar. Transplants of these culitvars and populations were grown and handled in the manner previously described in the breeding work chapter. All field preparation, management, treatments, planting dates, and fertilization regimes were exactly as described for the breeding material.

Year One – 2010

Plots were laid out in a latin square design with four replications. Included in this trial were 'Solstice', Common Ground, East Coast, OSU, 'Green Goliath' and 'Arcadia'. 'Arcadia' was chosen as the check variety because it is widely grown and produced by organic farmers in both the local area and beyond. 'Green Goliath' was initially included in the study because it was considered the best open-pollinated broccoli on the market. Plots consisted of four 25-plant rows on 31 cm (12 in) within and 76 cm (30 in) between row spacing. Data was taken from the middle two rows to reduce impact of edge effects.

At peak physiological maturity when head formation was optimal, the following phenotypic traits were evaluated: days to harvest, canopy height, head height, above ground biomass, head size, head weight, trimming, head color, head firmness, bead size, damage from heat stress, and presence of hollow stems. These assessments were based on the Northern Organic Vegetable Improvement Collaborative (NOVIC) protocols for broccoli evaluation (NOVIC, 2013). Choice of these traits was based on previous collaborative work and input from local organic farmers on what qualities and characteristics are important for an ideal broccoli for organic production.

Plots were harvested when at least five plants had mature, prime heads. Harvest date was noted and days to harvest were calculated from transplant to harvest date. Six individual plants were measured for each trait. Canopy height was measured from ground level to the highest reach of the upper leaves on “typical” plants that were representative of the whole plot. Head height was measured from the soil to the top of the mature head. For above ground biomass the entire plant was cut at soil level and weighed. Head size was measured as head diameter across the widest plane of the crown. For head weight, the head was cut 15 cm (6 in) from the top of the crown and trimmed of all leaves before weighing. Trimming was a subjective rating of 1-5 where 1=excessive trimming needed to 5=minimal trimming needed (Figure 1). Head color was rated on a 1-5 scale where 1= light green and 5=dark blue-green/purple (Figure 2). Head firmness was rated on a 1-5 scale where 1=very loose, 2=soft, 3=intermediate, 4=medium hard, and 5= very firm. Bead size was rated on a 1-5 scale where 1=very fine, 2=fine, 3=medium, 4=medium coarse, and 5=coarse (Figure 3). Beads are the immature flowers that make up the florets of the broccoli head. Tolerance to heat stress was also rated on a 1-5 scale where 1=unmarketable, 2=severe, 3=noticeable, 4=low, and 5=none (Figure 4). Indications of heat stress included leafy heads, uneven bead and floret development (cat’s eye, starring, or rosetting), and head discoloration.

1 3 5

Figure 3.1. Visual scale for rating trimming of broccoli heads from NOVIC protocol (NOVIC, 2013). Heads were cut to 15 cm (6 in) and rated on how much trimming was necessary to arrive at a clean head. Few leaves for trimming was desirable.

Figure 3.2. Behr colored paint chips used to visualize broccoli color ratings (NOVIC, 2013). 1-5 represented from left to right. Color ratings of 4 and 5 were most desirable.

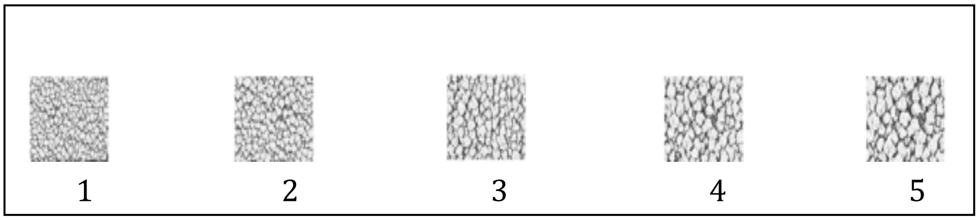

Figure 3.3. Visual scale for rating broccoli bead size (NOVIC, 2013). Smaller bead sizes (1-3) are more desirable as they are often associated with tighter and firmer heads.

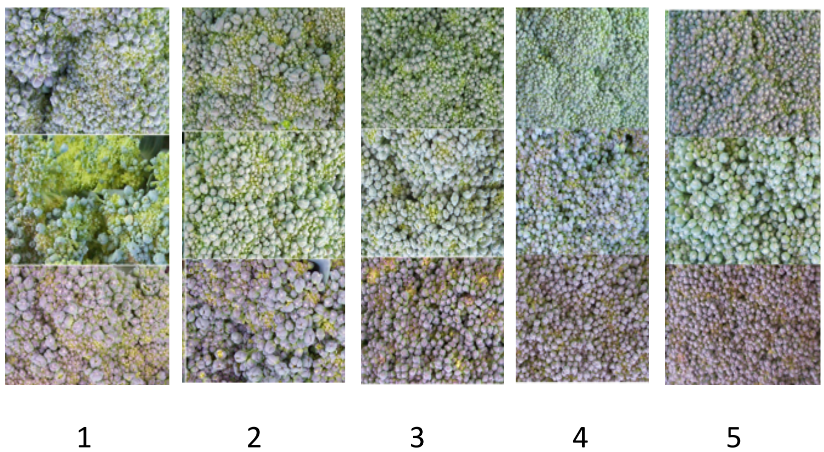

Figure 3.4. Visual scale for rating heat stress tolerance (NOVIC, 2013). 1=unmarketable head, 5=no observable damage

The number of heads with hollow stems out of the six harvested was recorded. After data was collected, exsertion and harvest index was calculated. Exsertion refers to the vertical position of the mature head in relation to the plant canopy. This was calculated by dividing the head height by the canopy height and multiplying 100 to place on a percent basis. Harvest index is a measurement of the useable plant part (in this case the top six inches of head and stem) in relation to the whole plant and is calculated by dividing the head weight by the above ground biomass and multiplying by 100.

Due to differences in maturity and field management constraints, data was not collected from the Arcadia plots in 2010. In order to have comparable check data, results from the NOVIC broccoli variety trial were used. The NOVIC trial was situated in the same field, was planted at the same time and received the same management, treatments, and care as the materials in this study. Data had been collected from the NOVIC trial in the same manner described above. The only differences were that canopy and head height were taken on three randomly chosen plants/plot rather than six and all other characteristics were taken on five individual plants/plot instead of six. Plots had the same between row spacing but the 36 plant single row plots were spaced 46 cm (18 in) within row rather than 31 cm (12 in).

Year Two – 2011

We found that the latin square design used in 2010 did not decrease environmental variation, so the field design was changed to a randomized complete block design for 2011. As in 2010, this trial was made up of 'Solstice', 'Common Ground', 'East Coast', 'OSU', 'Green Goliath' and 'Arcadia'. Plots consisted of three six meter (20 ft) rows on 31 cm (12 in) within and 76 cm (30 in) between row spacing. Data was collected from the middle row only.

In order to capture a full picture of the scope of the peak production and harvest window for all varieties, multiple harvest evaluations were added in 2011. Plots were harvested twice, taking all mature heads each time. Trait evaluations were taken at peak maturity as described for 2010. Instead of basing evaluations on six individual heads/plot, evaluations were averaged over the total number of heads harvested. This was done for head size, head weight, trimming, head color, head firmness, bead size, and damage from heat stress. Hollow stems were counted as a percentage of total heads harvested. Canopy and head height measurements were taken on three plants instead of six (as per the NOVIC trial protocol). Above ground biomass was not taken in 2011.

In order to compensate for the variability due to basing evaluations on differing numbers of plants in the data analysis for 2011, each trait measurement or rating was weighted. For example if a plot had an initial harvest of 15 heads and a second harvest of five heads, every measurement or rating for the initial harvest was multiplied by 0.75 and 0.25 for the second harvest. These two numbers were then either averaged or summed, depending on what was most appropriate to the trait, to come up with a single comparable evaluation or rating.

Year Three – 2012

In 2012 the East Coast population was dropped due to poor performance attributed to lack of adaptation. During 2011 it was discovered that the seed sold as 'Green Goliath' was in fact not an open-pollinated cultivar, but rather an F_1 hybrid known as 'General'. Rather than introduce a new OP check, we kept 'Green Goliath' in the 2012 trial. In January of 2012 we came into contact with the additional farmer bred cultivar 'Myers' Best' that had been selected and developed in Port Townsend, WA. Although we did not use the data in our analyses, we included it in the trial design and evaluated it for all previously identified quality and production traits.

The study field was laid out in a randomized complete block design with three replications. To accommodate other trials in the field, plots were single rows planted with 36 plants on 46 cm (18 in) within and 76 cm (30 in) between row spacing. Data was collected on five randomly chosen individual plants for all traits mentioned above. Counts for percentage of young, prime, and over mature heads were taken once, as close as possible to peak maturity. It was decided that harvest index was a useful calculation so weighing above ground biomass was reinstated.

Data Analysis

Data was analyzed using a weighted least squares linear model. Sample sizes for trait evaluations were variable among years and between the study and NOVIC plots, resulting in an unbalanced data set. To account for this, data was analyzed with weighted values based on sample sizes. Least Squared Means, computed using PROC GLM in SAS (Cary, NC), were used to evaluate all possible pairwise comparisons among cultivars and breeding material for significant differences in each year (no comparisons were made across years). The null hypothesis for this analysis was that trait means were equal for all cultivars.

Normality was graphically assessed with Q-Q plots for all data using R statistical software. Although the data taken on the finite 1-5 scale was not completely normal, the deviations from normality were small. The structure of the data set limited the types of tests we could perform and as such small deviations from normality did not seem significant enough to justify attempting a much more complex nonparametric approach.

A general linear model (including all terms) was fit and checked for interactions:

Response (y) = Cultivar + Year + Cultivar*Year + Replicate(Year) + Error

In order to assess whether the breeding populations, cultivars, and checks were changing over time, yearly changes were compared using linear contrasts in R. Two analyses were run, one on individual cultivars and another on grouped data. The breeding material populations and farmer cultivars were averaged together as one group (referred to as experimentals) and the check cultivars were averaged together as another in order to discern whether the breeding material as a whole was distinct from the checks. For the slope analysis of individual cultivars there were two null hypotheses: 1) The slopes for the experimentals and check cultivars would not be significantly different from zero (there is no change in varietal performance from year to year); and 2) There would be no significant difference in slopes between check cultivars and experimentals (each accession showed the same response from year to year). For the slope analysis of the grouped data, the null hypothesis was that there would be no difference between the experimentals and the check cultivars.

In order to gain insight into production qualities of these cultivars and populations, three yield component calculations were conducted: 1) Total yield was calculated by dividing average head weight by estimated plot area for individual plants (46x76cm and 31x76cm depending on row spacing) to arrive at grams per square meter (it was then multiplied by 100 to scale to metric tons per hectare); 2) Yield per day (aka yield efficiency) was calculated by dividing yield by days to harvest; and 3) Head weight per day was calculated by dividing average head weight by days to harvest. This data was then analyzed using the same statistical model described above. Null hypotheses for these tests were that yield and yield components would not be different among cultivars and populations.

We also calculated estimates of broad sense heritability and standard error of heritability estimates for all traits (both measured and calculated) from the pooled experimental data. These were obtained using the following equation from Hallauer et al. (1988):

$h^2 = \delta^2_g / ((\delta^2(re)) + (\delta^2_{ge}/e) + \delta^2_g)$ and

$SE(h^2) = SE(\delta^2_g) / ((\delta^2(re)) + (\delta^2_{ge}/e) + \delta^2_g)$ where

$SE(\delta^2_g) = 2 / (re)^2 * [(MSCultivars^2/(n+1)) + (MSCultivar*Year^2/((e-1)*(n-1)+2))]$

Results

Intense flea beetle pressure combined with cold early season temperatures that induced pre-mature head development during 2010 created a more stressful environment than other years. Row cover was added to the study in 2011 and 2012 to reduce damage from flea beetles, which resulted in observable, positive changes in plant health and vigor. It was assumed this contributed to less stressful environmental conditions for plant growth in both 2011 and 2012. Yield component calculations indicated significant G x E interactions within and across years. This probably was largely a result of variable environmental conditions and changes in management practices between years.

Pairwise Comparisons

For individual comparisons, all cultivars and populations were compared to the check ‘Arcadia’. To determine differences between the farmer and formal breeder materials, everything was compared to ‘OSU’. We decided not to compare cultivars or populations to ‘Green Goliath’ because we later discovered it was not an open-pollinated variety and thus did not perform as expected.

Differences from ‘Arcadia’ – 2010

All cultivars and populations were significantly earlier for days to harvest, and lighter in biomass than ‘Arcadia’. ‘Green Goliath’ and ‘East Coast’ had significantly shorter head heights and less exsertion than ‘Arcadia’. ‘OSU’, ‘Common Ground’, and ‘Solstice’ all had significantly taller head heights and greater exsertion than ‘Arcadia’. ‘OSU’, ‘Solstice’, and ‘Common Ground’ were also significantly darker green, smaller, and lighter in weight than ‘Arcadia’ for head color, head size, and head weight, respectively. The bead sizes of ‘East Coast’ and ‘Solstice’ were significantly coarser than ‘Arcadia’. ‘Green Goliath’ was significantly firmer than ‘Arcadia’ whereas ‘East Coast’, ‘Common Ground’, and ‘Solstice’ were all less firm than ‘Arcadia’. ‘East Coast’ and ‘Green Goliath’ both had significantly larger harvest indexes than ‘Arcadia’. Heat stress data was only available for the check varieties; ‘Arcadia’ expressed better heat stress tolerance than ‘Green Goliath’. ‘OSU’, ‘Common Ground’, ‘East Coast’, and ‘Solstice’ all had significantly lower yield and smaller head weight per day increase than ‘Arcadia’. Both ‘Common Ground’ and ‘Solstice’ had significantly lower yield efficiency than ‘Arcadia’. However, the yield efficiency of the ‘OSU’ material was not significantly different from ‘Arcadia’ (Table 3.1 and 3.2).

Differences from ‘Arcadia’ – 2011

‘East Coast’, ‘OSU’, ‘Solstice’, and ‘Common Ground’ were all significantly earlier for days to harvest than ‘Arcadia’. As in 2010, ‘Green Goliath’ and ‘East Coast’ had significantly shorter head heights and less exsertion than ‘Arcadia’ and ‘OSU’, ‘Common

Ground', and 'Solstice' all had significantly taller head heights and greater exsertion than 'Arcadia'. 'OSU', 'Solstice', and 'Common Ground' were all significantly darker colored and coarser beaded than 'Arcadia'. 'East Coast' was also significantly coarser beaded than 'Arcadia'. Head weights were significantly heavier for 'Green Goliath' and significantly lighter in weight for 'East Coast' and 'Solstice' than 'Arcadia'. Again as in 2010, 'Green Goliath' was significantly firmer than 'Arcadia' whereas 'East Coast', 'Common Ground', and 'Solstice' were all less firm than 'Arcadia'. 'Green Goliath', 'East Coast' required significantly less trimming than 'Arcadia' and 'Common Ground' required more. 'Arcadia' again expressed better heat stress tolerance than 'Green Goliath'. 'East Coast' and 'Green Goliath' had significantly different total yields than 'Arcadia' (lesser and more respectively). 'Green Goliath' had a significantly higher yield efficiency and growth gain per day compared to 'Arcadia'. 'Solstice' had a significantly lower yield efficiency and smaller head weight per day increase than 'Arcadia'. However, the open pollinated materials 'OSU' and 'Common Ground' expressed no significant differences in yield, yield efficiency, and head weight per day increase as compared to 'Arcadia'.

Differences from 'Arcadia' – 2012

All cultivars and populations were significantly lighter weight in biomass, earlier for days to harvest and had higher percentages of over mature heads at harvest than 'Arcadia'. 'Green Goliath' again had shorter head height and less exsertion than 'Arcadia', whereas 'OSU', 'Common Ground', and 'Solstice' all had significantly taller head heights and greater exsertion compared with 'Arcadia'. As in 2010, 'OSU', 'Solstice', and 'Common Ground' were also significantly darker colored, smaller, and lighter in weight than 'Arcadia' for head color, head size, and head weight, respectively. Again as in 2010 and 2011, 'Green Goliath' was significantly firmer than 'Arcadia' whereas 'East Coast', 'Common Ground', and 'Solstice' were all less firm than 'Arcadia'. 'Green Goliath' had a significantly lower percentage of prime heads, worse heat stress tolerance, a larger harvest index, and greater amount of trimming than ‘Arcadia’. Total yields for ‘OSU’, ‘Common Ground’, and ‘Solstice’ were significantly lower than ‘Arcadia’. Both ‘Common Ground’ and ‘Solstice’ had significantly lower yield efficiency and smaller head weight per day increase than ‘Arcadia’.

Table 3.1a. Summary of trait means by year for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. All cultivars are compared to 'Arcadia' for statistical significance and mean separation.

Cultivar	Days to Harvest[z]		Hollow Stems[y] (%)	Young Heads[x] (%)	Prime Heads[x] (%)	Over Mature Heads[x] (%)	Canopy Height (cm)	Head Height (cm)	
					2010				
Arcadia	70		4	--	--	--	44	32	
Green Goliath	60	***	1	--	--	--	36	24	***
East Coast	54	***	2	--	--	--	33	25	***
OSU	54	***	4	--	--	--	40	38	***
Solstice	54	***	2	--	--	--	36	36	**
Common Ground	54	***	2	--	--	--	38	40	***
					2011				
Arcadia	69		1	--	--	--	55	42	
Green Goliath	70		4	--	--	--	54	35	***
East Coast	59	***	1	--	--	--	51	36	***
OSU	59	***	7	--	--	--	58	49	***
Solstice	59	***	1	--	--	--	54	47	**
Common Ground	59	***	5	--	--	--	56	51	***

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.
[z]Days to harvest were calculated from transplant to harvest; [y]% hollow stems calculated from all harvested mature heads; [x]% young, prime, and over mature heads was calculated from counts of all the plants in a plot.

Table 3.1a Continued

Cultivar	Days to Harvest[z]		Hollow Stems[y] (%)	Young Heads[x] (%)	Prime Heads[x] (%)		Over Mature Heads[x] (%)		Canopy Height (cm)	Head Height (cm)	
	2012										
Arcadia	64		1	29	52		19		54	45	
Green Goliath	57	***	15	5	11	**	85	***	53	38	***
OSU	57	***	18	1	47		52	***	58	52	***
Solstice	57	***	13	0	40		60	***	53	50	**
Common Ground	57	***	17	1	30		69	***	55	54	***
	Averages Across Years										
Arcadia	70		3	--	--		--		--	37	
Green Goliath	62	**	7	--	--		--		48	32	
East Coast	56	***	2	--	--		--		42	30	**
OSU	57	***	10	--	--		--		52	46	
Solstice	57	***	5	--	--		--		48	45	
Common Ground	57	***	8	--	--		--		49	48	*

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.

[z]Days to harvest were calculated from transplant to harvest; [y]% hollow stems calculated from all harvested mature heads; [x]% young, prime, and over mature heads was calculated from counts of all the plants in a plot.

Table 3.1b. Summary of trait means by year for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. All cultivars are compared to 'Arcadia' for statistical significance and mean separation.

Cultivar	Exertion[w] (%)		Trimming[v] (1-5)		Bead Size[u] (1-5)		Firmness[t] (1-5)		Head Color[s] (1-5)		Heat Stress[r] (1-5)	
					2010							
Arcadia	88		3.0		1.2		3.5		2.9		3.2	
Green Goliath	77	**	2.9		2.1		4.0	*	2.6		2.2	***
East Coast	79	*	2.9		4.2	**	2.7	**	2.5	*	--	
OSU	95	*	2.3		3.2		3.1		4.1	***	--	
Solstice	100	**	2.1		3.5	*	2.8	**	4.4	***	--	
Common Ground	104	***	2.0		3.3		2.3	***	4.2	***	--	
					2011							
Arcadia	77		3.1		3.5		3.2		2.5		4.6	
Green Goliath	65	**	3.6	*	2.8		3.7	*	2.2		3.5	***
East Coast	68	*	4.4	***	1.8	***	2.5	**	2.1	*	5.0	
OSU	84	*	2.8		2.6	*	2.9		3.7	***	4.8	
Solstice	88	**	3.1		2.3	*	2.5	**	4.1	***	4.9	
Common Ground	93	***	1.9	***	1.7	***	2.1	***	3.8	***	4.8	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.

[w]Exsertion calculated by dividing head height by canopy height x 100 (a plant with head height equal to canopy height would have an exsertion score of 100); [v]trimming 1=excessive trimming needed and 5=minimal trimming needed; [u]bead size 1=coarse and 5=very fine; [t]firmness 1=very loose and 5=very firm; [s]head color 1=light green and 5=dark blue-green/purple; [r]heat stress 1=unmarketable head and 5=no noticeable damage.

Table 3.1b Continued

Cultivar	Exsertion[w] (%)		Trimming[v] (1-5)		Bead Size[u] (1-5)	Firmness[t] (1-5)		Head Color[s] (1-5)		Heat Stress[r] (1-5)	
	2012										
Arcadia	83		4.5		1.8	4.3		2.6		4.6	
Green Goliath	71	**	3.3	*	1.9	4.8	*	2.3		3.5	***
OSU	90	*	4.3		2.1	3.9		3.8	***	4.5	
Solstice	94	**	4.1		2.6	3.6	**	4.2	***	4.7	
Common Ground	99	***	4.3		1.9	3.1	***	4.0	***	4.8	
	Averages Across Years										
Arcadia	79		3.1		2.5	3.6		2.6		4.2	
Green Goliath	73		3.2		2.4	3.8		2.3		3.3	**
East Coast	73		3.7		3.0	2.7	***	2.4		5.0	*
OSU	90	**	3.0		2.7	3.2		3.9	***	4.7	
Solstice	94	***	3.1		2.9	2.9	*	4.2	***	4.9	*
Common Ground	99	***	2.5	*	2.4	2.5	**	4.0	***	4.8	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.

[w]Exsertion calculated by dividing head height by canopy height x 100 (a plant with head height equal to canopy height would have an exsertion score of 100); [v]trimming 1=excessive trimming needed and 5=minimal trimming needed; [u]bead size 1=coarse and 5=very fine; [t]firmness 1=very loose and 5=very firm; [s]head color 1=light green and 5=dark blue-green/purple; [r]heat stress 1=unmarketable head and 5=no noticeable damage.

Table 3.1c. Summary of trait means by year for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. All cultivars are compared to 'Arcadia' for statistical significance and mean separation.

Cultivar	Head Size (cm)		Head Weight (gm)		Biomass[q] (gm)		Harvest Index[p] (%)	
				2010				
Arcadia	8.9		168.1		915.5		17	
Green Goliath	7.5		129.9		574.2	***	24	**
East Coast	6.2	**	68.1	***	304.9	***	23	*
OSU	7.0	*	63.1	***	343.6	***	18	
Solstice	6.8	*	59.7	***	326.0	***	19	
Common Ground	7.0	*	61.0	***	314.7	***	19	
				2011				
Arcadia	9.9		164.8		--		--	
Green Goliath	12.3	***	276.7	***	--		--	
East Coast	8.7	**	155.0	*	--		--	
OSU	10.1		149.4		--		--	
Solstice	8.8	*	101.6	***	--		--	
Common Ground	11.2	**	146.6		--		--	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.
[q]Biomass was a measurement of all above ground plant matter; [p]harvest index was calculated by dividing head weight by biomass x 100.

Table 3.1c Continued

Cultivar	Head Size (cm)		Head Weight (gm)		Biomass[q] (gm)		Harvest Index[p] (%)	
				2012				
Arcadia	12.9		219.3		1171.6		19	
Green Goliath	11.5		211.5		732.6	***	29	***
OSU	10.7	**	169.5	*	877.4	***	19	
Solstice	10.3	**	128.3	***	787.3	***	16	
Common Ground	10.5	**	141.5	**	781.4	***	18	
				Averages Across Years				
Arcadia	9.4		185.1		1024.3		18	
Green Goliath	10.6		211.6		612.2	**	26	***
East Coast	7.5	**	107.1	***	304.9	***	22	*
OSU	9.1		123.8	**	557.9	**	19	
Solstice	8.5	**	94.0	***	509.2	***	17	
Common Ground	9.6		115.0	**	500.2	***	19	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.
[q]Biomass was a measurement of all above ground plant matter; [p]harvest index was calculated by dividing head weight by biomass x 100.

Table 3.2a. Average yield and yield component calculations by year for broccoli grown under organic conditions at the Lewis Brown Horticultural Farm in Corvallis, OR. 'Arc' column indicates comparison to 'Arcadia' for statistical significance and mean separation. 'OSU' column indicates comparison to 'OSU' for statistical significance and mean separation significance (only OPs compared to OSU).

	Total Yield[z] MT/ha			Yield Efficiency[y] MT/ha/day			Head weight/day[x] gm/day		
	'Arc'		'OSU'	'Arc'		'OSU'	'Arc'		'OSU'
					2010				
Arcadia		2.8			0.04			2.4	
Common Ground	***	1.5		*	0.03		***	1.1	
East Coast	**	1.7			0.03		***	1.3	
Green Goliath		2.2			0.04			2.2	
OSU	***	1.5			0.03		***	1.2	
Solstice	***	1.4		*	0.03		***	1.1	
					2011				
Arcadia		4.3			0.06			2.5	
Common Ground		3.7			0.06			2.6	
East Coast	*	3.6			0.06			2.5	
Green Goliath	***	6.8		***	0.10		***	4.0	
OSU		3.7			0.06			2.6	
Solstice		2.6	**	***	0.04	***	**	1.8	**
					2012				
Arcadia		3.6			0.06			3.4	
Common Ground	***	2.3		**	0.04		***	2.5	
Green Goliath		3.5			0.06			3.7	
OSU	*	2.8			0.05			3.0	
Solstice	***	2.1		**	0.04		***	2.3	**

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels respectively.
[z]Yield was calculated by dividing average head weight by estimated plot area for an individual plant; [y]yield efficiency was calculated by dividing yield by days to harvest; [x]head weight per day was calculated by dividing average head weight by days to harvest.

Table 3.2b. Average yield and yield component calculations by year for broccoli grown under organic conditions at the Lewis Brown Horticultural Farm in Corvallis, OR. 'Arc' column indicates comparison to 'Arcadia' for statistical significance and mean separation. 'OSU' column indicates comparison to 'OSU' for statistical significance and mean separation significance (only OPs compared to OSU).

	Total Yield[z] MT/ha			Yield Efficiency[y] MT/ha/day			Head weight/day[x] gm/day		
	'Arc'		'OSU'	'Arc'		'OSU'	'Arc'		'OSU'
	Averages Across Years								
Arcadia		3.6			0.05			2.8	
Common Ground	***	2.5		*	0.04		***	2.1	
East Coast		--			--			--	
Green Goliath	**	4.1		***	0.07		**	3.3	
OSU	***	2.7			0.05		***	2.2	
Solstice	***	2.0	**	***	0.04	***	***	1.7	***

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels respectively.
[z]Yield was calculated by dividing average head weight by estimated plot area for an individual plant; [y]yield efficiency was calculated by dividing yield by days to harvest; [x]head weight per day was calculated by dividing average head weight by days to harvest.

Differences from 'OSU' – 2010

The 'East Coast' population had a significantly shorter head height, smaller exsertion, lighter head color, and larger harvest index than 'OSU'. The 'Common Ground' population was significantly more exserted than 'OSU' (Table 2).

Differences from 'OSU' – 2011

The 'East Coast' population had significantly shorter head height, reduced exsertion, lighter head color, required more trimming, and had a smaller head size than 'OSU'. The 'Common Ground' population was significantly more exserted, required more trimming, and had heads that were larger and less firm than 'OSU. 'Solstice' had significantly smaller, lighter weight heads than 'OSU'. 'Solstice' displayed a significantly lower yield efficiency and smaller head weight per day increase than 'OSU'.

Differences from 'OSU' – 2012

The only significant difference was that 'Common Ground' population was significantly more exserted and less firm than 'OSU'.

Table 3.3a. Summary of trait means by year for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. All cultivars compared to 'OSU' for statistical significance and mean separation.

Cultivar	Days to Harvest[z]	Hollow Stems[y] (%)	Young Heads[x] (%)	Prime Heads[x] (%)	Over Mature Heads[x] (%)	Canopy Height (cm)	Head Height (cm)		Exsertion[w] (%)		Trimming[v] (1-5)	
					2010							
East Coast	54	2	--	--	--	33	25	***	79	***	2.9	
OSU	54	4	--	--	--	40	38		95		2.3	
Solstice	54	2	--	--	--	36	36		100		2.1	
Common Ground	54	2	--	--	--	38	40		104	*	2.0	
					2011							
East Coast	59	1	--	--	--	51	36	***	68	***	4.4	***
OSU	59	7	--	--	--	58	49		84		2.8	
Solstice	59	1	--	--	--	54	47		88		3.1	
Common Ground	59	5	--	--	--	56	51		93	*	1.9	**

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.

[z]Days to harvest were calculated from transplant to harvest; [y]% hollow stems calculated from all mature, harvested heads; [x]% young, [x]prime, and [x]over mature heads were calculated from counts of all the plants in a plot; [w]exsertion calculated by dividing head height by canopy height; [v]trimming 1=excessive trimming needed and 5=minimal trimming needed.

Table 3.3a Continued

Cultivar	Days to Harvest[z]	Hollow Stems[y] (%)	Young Heads[x] (%)	Prime Heads[x] (%)	Over Mature Heads[x] (%)	Canopy Height (cm)	Head Height (cm)		Exsertion[w] (%)		Trimming[v] (1-5)
						2012					
OSU	57	18	1	47	52	58	52		90		4.3
Solstice	57	13	0	40	60	53	50		94		4.1
Common Ground	57	17	1	30	69	55	54		99	*	4.3
						Averages Across Years					
East Coast	56	2	--	--	--	42	30	***	73	***	3.7
OSU	57	10	--	--	--	52	46		90		3.0
Solstice	57	5	--	--	--	48	45		94		3.1
Common Ground	57	8	--	--	--	49	48		99	*	2.5

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.
[z]Days to harvest were calculated from transplant to harvest; [y]% hollow stems calculated from all mature, harvested heads [x]% young, [x]prime, and [x]over mature heads were calculated from counts of all the plants in a plot; [w]exsertion calculated by dividing head height by canopy height; [v]trimming 1=excessive trimming needed and 5=minimal trimming needed.

Table 3.3b. Summary of trait means by year for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. All cultivars compared to 'OSU' for statistical significance and mean separation.

Cultivar	Bead Size[u] (1-5)	Firmness[t] (1-5)		Head Color[s] (1-5)		Heat Stress[r] (1-5)	Head Size (cm)		Head Weight (gm)		Biomass[q] (gm)	Harvest Index[p] (%)	
							2010						
East Coast	4.2	2.7		2.5	***	--	6.2		68.1		304.9	23	*
OSU	3.2	3.1		4.1		--	7.0		63.1		343.6	18	
Solstice	3.5	2.8		4.4		--	6.8		59.7		326.0	19	
Common Ground	3.3	2.3	***	4.2		--	7.0		61.0		314.7	19	
							2011						
East Coast	1.8	2.5		2.1	***	5.0	8.7	**	155.0		--	--	
OSU	2.6	2.9		3.7		4.8	10.1		149.4		--	--	
Solstice	2.3	2.5		4.1		4.9	8.8	**	101.6	***	--	--	
Common Ground	1.7	2.1	***	3.8		4.8	11.2	*	146.6		--	--	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.
[u]Bead size 1=coarse and 5=very fine; [t]firmness 1=very loose and 5=very firm; [s]head color 1=light green and 5=dark blue-green/purple; [r]heat stress 1=unmarketable head and 5=no noticeable damage; [q]biomass was a measurement of all above ground plant matter; [p]harvest index was calculated by dividing head weight by biomass.

Table 3.3b Continued

Cultivar	Bead Size[u] (1-5)	Firmness[t] (1-5)		Head Color[s] (1-5)		Heat Stress[r] (1-5)	Head Size (cm)	Head Weight (gm)	Biomass[q] (gm)	Harvest Index[p] (%)	
					2012						
OSU	2.1	3.9		3.8		4.5	10.7	169.5	877.4	19	
Solstice	2.6	3.6		4.2		4.7	10.3	128.3	787.3	16	
Common Ground	1.9	3.1	***	4.0		4.8	10.5	141.5	781.4	18	
					Averages Across Years						
East Coast	3.0	2.6		2.3	***	5.0	7.5	107.1	304.9	22	*
OSU	2.6	3.3		3.9		4.7	9.2	123.8	557.9	19	
Solstice	2.8	2.9		4.2		4.8	8.7	94.0	509.2	17	
Common Ground	2.3	2.5	*	4.0		4.8	9.6	115.0	500.2	19	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.
[u]Bead size 1=coarse and 5=very fine; [t]firmness 1=very loose and 5=very firm; [s]head color 1=light green and 5=dark blue-green/purple; [r]heat stress 1=unmarketable head and 5=no noticeable damage; [q]biomass was a measurement of all above ground plant matter; [p]harvest index was calculated by dividing head weight by biomass.

Grouped Pairwise Comparisons

To determine significant differences between the breeding material and check cultivars, pooled experimentals were compared to pooled checks in each year. This gave us the ability to compare overall experimental performances against overall check performances. In order to determine if the pooled experimentals were expressing selection progress over time their slopes between 2010 to 2011 and 2011 to 2012 were compared to the slopes of the pooled checks. Significant differences in slope suggest that the environment was not the sole effect on the trial. Where slopes were significantly different from zero, and experimentals and checks were not significantly different, changes in trait values were attributed to environmental influence. When experimental slope differed significantly from checks, there was assumed to be a GxE influence or a genetic change over time in the populations.

Differences by Year

2010

Experimentals were significantly earlier in days to harvest than checks. Experimentals were significantly more exserted and lighter in biomass than checks. Experimental heads were significantly coarser, looser, darker in color, smaller, and lighter in weight than checks (Table 3).

2011

Experimentals were again significantly earlier in days to harvest than checks. Experimentals were also significantly more exserted than checks. Experimental heads required significantly more trimming and were smaller beaded than checks. They were again significantly looser, darker in color, smaller, and lighter in weight than checks. Experimentals also showed significantly better tolerance to heat stress than checks.

2012

Experimentals were again significantly earlier in days to harvest and exserted than checks. They were also significantly looser, darker in color, smaller, and lighter in weight than checks. Experimentals also had a significantly lower harvest index than checks.

Table 3.4. Summary of trait means for grouped checks and grouped experimentals by year for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. Experimentals compared to checks for statistical significance and mean separation.

Source	Days to Harvest[z]		Hollow Stems[y] (%)	Young Heads[x] (%)	Prime Heads[x] (%)	Over Mature Heads[x] (%)	Canopy Height (cm)	Head Height (cm)		Exsertion[w] (%)		Trimming[v] (1-5)	
							2010						
Checks	65		3	--	--	--	40.2	27.8		85		3.0	
Experimentals	54	***	3	--	--	--	36.9	32.7		95	***	2.3	
							2011						
Checks	70		3	--	--	--	54.7	38.5		69		3.4	
Experimentals	59	***	4	--	--	--	54.8	45.5		84	***	3.1	*
							2012						
Checks	61		8	17	31	52	53.8	41.6		81		3.9	
Experimentals	57	**	16	1	39	60	55.1	52.0		92	***	4.2	
							Averages Across Years						
Checks	65		4	17	31	52	49.6	35.9		78		3.4	
Experimentals	57	***	7	1	39	60	48.9	43.4	*	90	***	3.2	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.

[z]Days to harvest were calculated from transplant to harvest; [y]% hollow stems calculated from all mature, harvested heads; [x]% young, prime, and over mature heads were calculated from counts of all the plants in a plot; [w]exsertion calculated by dividing head height by canopy height x 100; [v]trimming 1=excessive trimming needed and 5=minimal trimming needed.

Table 3.4 Continued

Source	Bead Size[u] (1-5)		Firm[t] (1-5)		Head Color[s] (1-5)		Heat Stress[r] (1-5)		Head Size (cm)		Head Weight (gm)		Biomass[q] (gm)		Harvest Index[p] (%)	
									2010							
Checks	1.7		3.8		2.7		2.7		8.2		149.0		705.5		21	
Experimentals	3.6	**	2.8	***	3.8	***	--		6.8	*	62.4	***	322.3	***	20	
									2011							
Checks	3.2		3.6		2.4		4.1		11.1		225.0		--		--	
Experimentals	2.1	***	2.3	***	3.4	***	4.9	***	9.6	***	138.4	***	--		--	
									2012							
Checks	1.8		4.6		2.3		4.3		12.2		215.4		952.1		24	
Experimentals	2.2		3.5	***	4.1	***	4.7		10.5	**	146.4	***	815.4		18	**
									Averages Across Years							
Checks	2.2		4.0		2.5		3.7		10.5		196.5		828.8		23	
Experimentals	2.6		2.9	***	3.8	***	4.8	***	9.0	***	115.8	***	568.8	***	19	**

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.

[u]Bead size 1=coarse and 5=very fine; [t]firm 1=very loose and 5=very firm; [s]head color 1=light green and 5=dark blue-green/purple; [r]heat stress 1=unmarketable head and 5=no noticeable damage [q]biomass was a measurement of all above ground plant matter; [p]harvest index was calculated by dividing head weight by biomass x 100.

Differences Across Years

2010-2011

Both experimentals and checks had slopes that were significantly different from zero, but not from each other, for the following traits: days to harvest, canopy height, head color, size, and weight. Experimentals and checks had slopes that were significantly different from zero, and significantly different from each other for head height, exsertion, and bead size. For firmness, slopes for neither the experimentals nor the checks were significantly different from zero, but they were significantly different from each other. The experimentals slope for trimming was significantly different from zero, but not significantly different from that of the checks (which was not significantly different from zero) (Table 3.5, Figure 3.5).

2011-2012

Both experimentals and checks had slopes that were significantly different from zero and from each other, for days to harvest and head height. Traits for which slopes for both experimentals and checks were significantly different from zero, but not from each other were: percentage hollow stems, trimming, head size, and head weight. For exsertion and head color the experimentals had slopes significantly different from zero and the checks. Check slopes for bead size and firmness were significantly different from zero and the experimentals. For canopy height slopes for neither the experimentals nor the checks were significantly different from zero, but they were significantly different from each other.

Changes in biomass and harvest index were measured between 2010 and 2012. The experimentals expressed a significantly larger gain in above ground biomass compared to the checks. Both experimentals and checks had slopes significantly greater than zero, but not significantly different from each other, for harvest index.

Table 3.5. Summary of slopes from regression between years for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR. Null hypothesis for checks and experimentals is that the slope over years is not significantly different from zero. Null hypothesis for difference is that the slopes across years for experimentals and checks are not significantly different from one another.

Source	Days to Harvest[z]		Hollow Stems[y]		Canopy Height		Head Height		Exsertion[w]		Trim[v]		Bead Size[u]	
							2010-2011							
Checks	4.5	***	0.0		17.7	***	8.9	***	-0.1	***	0.4		1.4	*
Experimentals	5.5	***	0.0		18.1	***	10.9	***	-0.1	***	0.7	***	-1.5	***
Difference	-1.0		0.0		-0.4		-2.0	***	0.0	***	-0.3		2.9	***
							2011-2012							
Checks	-8.9	***	0.1	**	-0.9		3.0	*	0.1		0.6	*	-1.3	**
Experimentals	-2.0	**	0.1	**	0.2		6.3	***	0.1	***	1.2	***	0.0	
Difference	-6.9	***	0.0		-1.0	*	-3.2	***	-0.1	***	-0.6		-1.4	*

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.
[z]Days to harvest were calculated from transplant to harvest; [y]% hollow stems calculated from all mature, harvested heads; [w]exsertion calculated by dividing head height by canopy height x 100; [v]trim 1=excessive trimming needed and 5=minimal trimming needed; [u]bead size 1=coarse and 5=very fine.

Table 3.5 Continued

Source	Firmness[t]		Head Color[s]		Heat Stress[r]		Head Size		Head Weight		Biomass[q]		Harvest Index[p]	
					2010-2011									
Checks	0.3		-0.3	*	1.4	***	2.9	***	2.9	***	--		--	
Experimentals	-0.2		0.1	*	--		2.9	***	2.9	***	--		--	
Difference	-0.1	**	-0.4		--		-0.1		0.1		--		--	
					2011-2012						2010-2012			
Checks	1.1	***	0.1		0.01		1.2	**	1.2	**	173.9	**	0.03	**
Experimentals	1.1		0.5	**	0.04		0.8	*	0.8	*	493.1	***	0.01	***
Difference	0.0	***	-0.4	***	0.02		0.4		0.4		319.2	***	0.02	

*, **, *** Indicate significance at the 0.05, 0.01, and 0.001 *P* levels, respectively.

[t]Firmness 1=very loose and 5=very firm; [s]head color 1=light green and 5=dark blue-green/purple; [r]heat stress 1=unmarketable head and 5=no noticeable damage; [q]biomass was a measurement of all above ground plant matter; [p]harvest index was calculated by dividing head weight by biomass x 100.

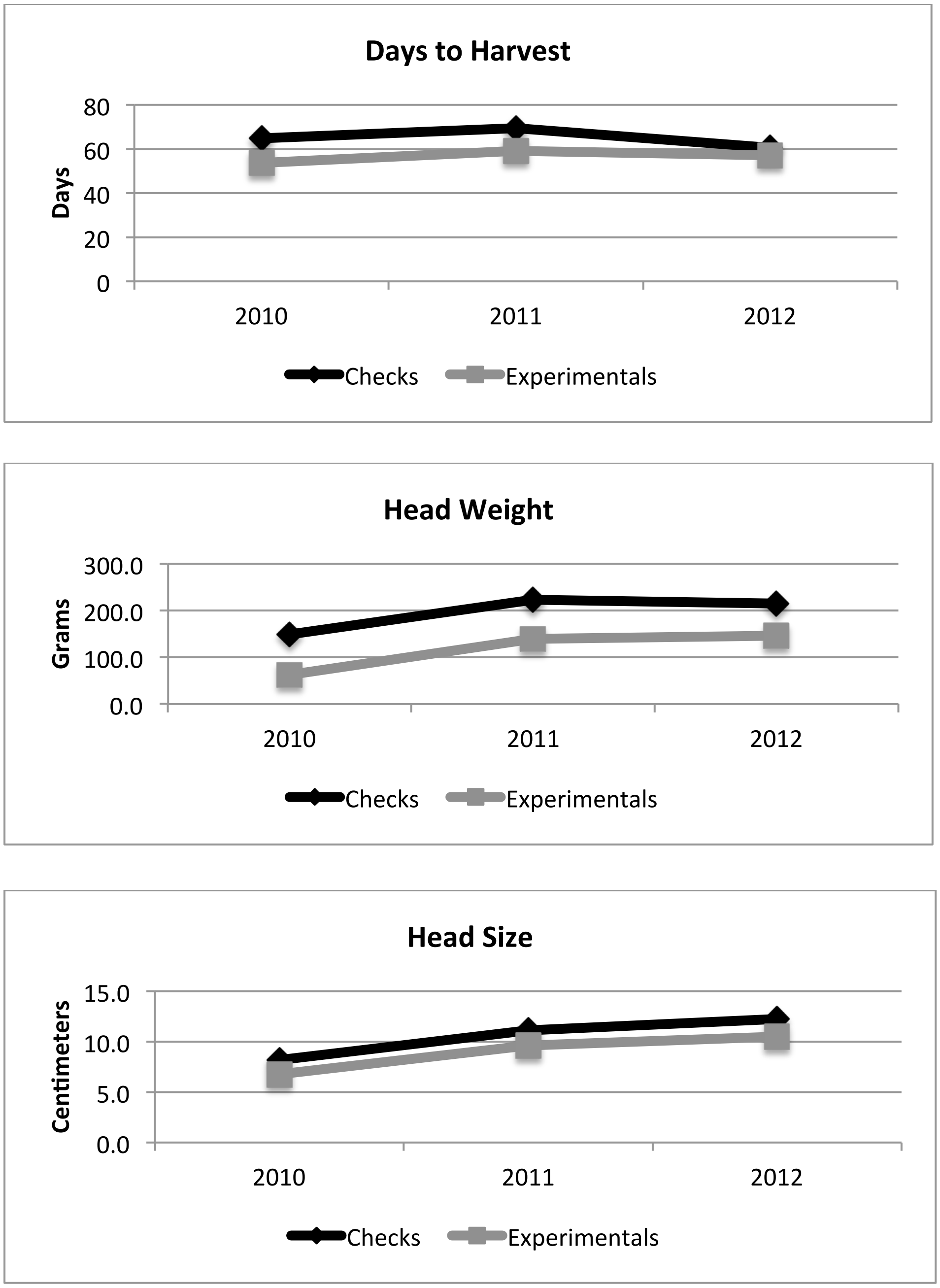

Figure 3.5a. Graphs for traits expressing significant differences across years between pooled experimentals and checks for broccoli grown under organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR

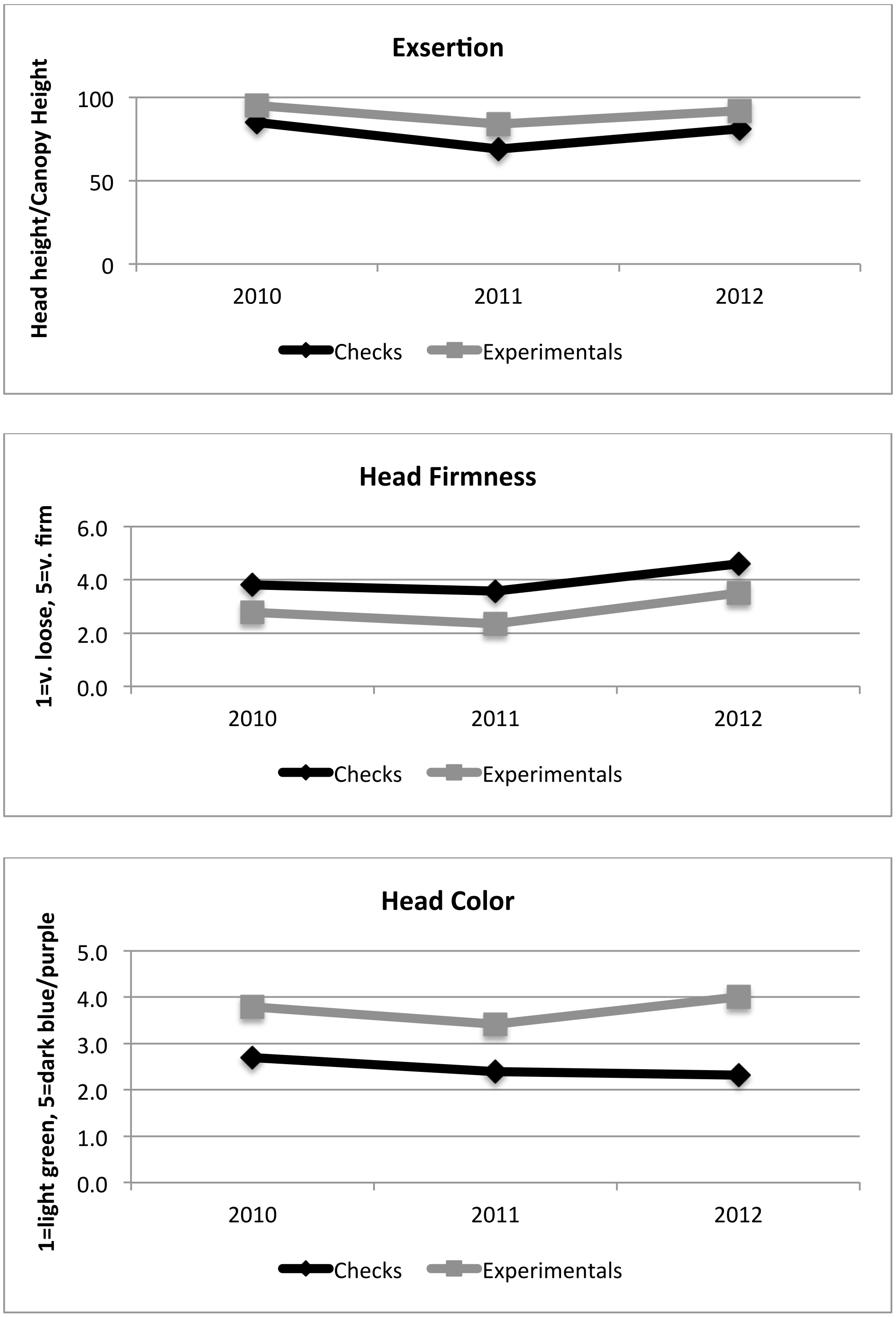

Figure 3.5b. Graphs for traits expressing significant differences across years between pooled experimentals and checks for broccoli grown under organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR

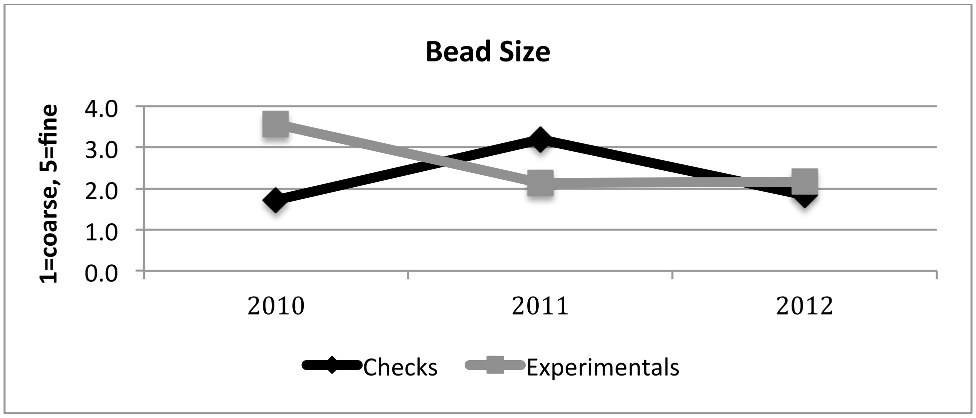

Figure 3.5c. Graphs for traits expressing significant differences across years between pooled experimentals and checks for broccoli grown under organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR

With the exception of replication, all components of the ANOVA models were significant for all yield and yield component calculations. For total yield and yield efficiency it was (graphically) determined that the interactions between cultivars and years were due to differences in magnitude rather than crossover interactions (rankings were consistent across years). Cultivars and populations appeared to perform differently each year for head weight per day. We assumed this was mainly due to large differences in environmental conditions and management practices affecting growth between years rather than genetics.

Heritability

With the exception of bead size, heritability estimates for all traits were high (Table 3.6). Estimates of standard error were extremely large for head weight and biomass. Standard errors were also quite large for head height and harvest index.

Table 3.6 Heritability calculations obtained from pooled experimental data for broccoli grown in organic conditions at the Lewis Brown Horticulture Farm in Corvallis, OR

Trait	h^2	SE (h^2)
% Hollow Stems	0.90	0.00
Canopy Height	0.77	0.10
Head Height	0.95	0.83
Exertion	1.02	0.00
Trimming	0.75	0.07
Bead Size	-0.07	0.03
Head Color	0.99	0.08
Firmness	0.55	0.02
Head Weight	0.75	44.20
Yield	0.75	0.08
Heat Stress Tolerance	0.56	0.01
Biomass	0.78	468.60
Harvest Index	0.87	0.71
Yield Efficiency	0.71	0.00
Head Weight/day	0.71	0.01

Overall Trends

All cultivars and populations expressed significant differences in exsertion and head height from ‘Arcadia’ across all years. ‘Green Goliath’ and ‘East Coast’ tended to group together and express similar differences to ‘Arcadia’. ‘OSU’, ‘Common Ground’, and ‘Solstice’ generally grouped together with similar differences to ‘Arcadia’. The populations and farmer cultivar expressed consistently earlier maturity and lower total yields than ‘Arcadia’. They were also reliably smaller headed, and lighter in weight than ‘Arcadia’. With the exception of the ‘East Coast’ population, they were also consistently more exserted.

The ‘East Coast’ population was distinctly different across the years, for nearly all traits, from ‘Solstice’ and both the ‘OSU’ and ‘Common Ground’ populations. There were very few differences across years, for any of the traits, between 'Solstice' and the 'OSU' and 'Common Ground' populations.

The pooled experimentals expressed significant differences from the checks for nearly all traits in all years. The only traits for which there were consistently no significant differences in each year were percentage of hollow stems, percentages of young, prime, and over mature heads, canopy height, and head height. No clear trends emerged out of the pooled slope comparisons for differences among traits or years.

Discussion

We believe that the addition of floating row cover, almost entirely eliminating stress by flea beetles in the early growth stages, was the main factor in the large increases exhibited across nearly all traits between 2010 and 2011. Although this may have masked any genetic gains made from selection between those two years, it provides a definitive example of the power of cultural practices on the performance of broccoli grown under organic conditions.

It is apparent from the data that depending on the trait, 'OSU', 'Common Ground', and 'Solstice' are both similar to each other, and distinctly different from the check variety 'Arcadia'. 'OSU', 'Common Ground', and 'Solstice' were most notably different from 'Arcadia' for days to harvest (generally about two weeks earlier), head height and exsertion (taller and more exserted), head color (darker), head size (smaller), head weight (lighter), and total yield (less). As was mentioned in the previous chapter, increasing exsertion is correlated with decreased head weight (and likely head size as well) (Baggett et al., 1995), which could account for the consistently noted difference between 'Arcadia' and these populations. It is also universally accepted that earlier maturing materials and cultivars are lower yielding than later maturing material (because the later maturity allows more time for the plant to accumulate resources for building a heavy, dense head). The yield and yield component comparisons indicate that the open pollinated materials are significantly lower yielding than the F_1 hybrid checks; these open pollinated materials do not have the high degree of heterosis that gives F_1 hybrids a higher yield capacity.

The 'East Coast' population was dropped in the midst of the study because it did not exhibit acceptable performance in the maritime climate of the Pacific Northwest (PNW). Although this was disappointing, it does demonstrate the wide variability and vast genetic potential present in the original population material. The performance and physical attributes of the 'East Coast' population were distinctly different from the other populations and cultivars selected from the original OSU VBP material, whereas 'OSU', 'Common Ground', and 'Solstice' were markedly similar for most traits. This could point to specific adaptation to the environments of the PNW, or be evidence for a convergence of selection criteria due to closer contact and less distance between OSU and the farmer-breeders who developed 'Common Ground' (in Olympia, WA) and 'Solstice' (in Williams, OR). The 'East Coast' material was selected primarily on Long Island and on the Freeville farm in Ithaca, NY in coordination with Cornell University. The 'East Coast' material displayed noticeably large trait quality differences from the 'OSU', 'Common Ground', and 'Solstice' material even though they were all derived from the same original material. We do not know whether these differences represent Regional preferences or adaptation to different environmental conditions. Although 'East Coast' is not suitable for PNW production, we have had some recent confirmation of the utility of this cultivar on the eastern seaboard where it is performing well for North Carolina State researchers (Bernstein, pers. comm. 2013).

There were very few notable differences between 'OSU' and the farmer-breeder populations and cultivar. The most numerous significant differences were found in 2011, most of which were between 'OSU' and 'East Coast'. 'Common Ground' exhibited significant differences from 'OSU' for exsertion (greater), trimming (required more), firmness (less), and head size (larger). 'Solstice' expressed significant differences from 'OSU' for head size (smaller) and head weight (lighter). It should be noted that harvest timing directly impacts firmness and trimming; harvesting too early results in need for more significant trimming and harvesting too late lends to looser heads. It is also possible that early or mis-timed harvests negatively influenced head weight and size. This should be kept in mind, as it was it was not always possible to conduct evaluations at exact peak maturity.

As a group, the experimentals ('OSU', 'Common Ground', 'Solstice', and 'East Coast') were significantly different from the pooled checks ('Arcadia' and 'Green Goliath') for nearly all traits in all years. The rate at which these changes were taking place over time was inconsistent, significantly different between some years and not between others. Rates of change were also not consistent for any given trait, with the exception of head height. The consistently negative difference between experimentals and checks was highly significant for head weight. We assume that by reducing environmental variability with larger sample sizes, additional check varieties, and increased replication across environments and time these rates of change would express more discernible and consistent trends.

The consistently earlier maturity and darker head color of 'OSU', 'Common Ground', and 'Solstice' could provide a market advantage for organic growers. The darker head colors of these cultivars make them distinct and different from other broccoli. In a (farmers) market setting this material will be eye catching and interesting to the public, drawing people in and creating new business. The shorter time to maturity could allow growers to extend the window of broccoli availability by bringing this unique and interesting broccoli to market in early spring or extending production into the warmer months of summer (when damage from heat stress can become a serious problem for other cultivars). Another potential market advantage for the 'OSU' material comes from a previous as yet unpublished study that revealed the 'OSU' material has enhanced nutrition potential. Study results showed significantly higher carotenoid levels in the 'OSU' material as compared to 23 commercial hybrid and open pollinated cultivars (Myers, per. comm. 2013). Because enhanced carotenoids are associated with the darker green color in other vegetables, ‘Common Ground’ and ‘Solstice’ would be expected to have higher carotenoid levels as well. Our work with this study has shown the potential of ‘OSU’, ‘Common Ground’, and ‘Solstice’ to become viable and vibrant open pollinated alternatives to the current OP cultivars on the market today.

In the winter of 2012 we came into contact with an additional farmer breeder who had been making selection from and working with the OSU VBP broccoli material in Port Townsend, WA for nearly 10 years. The cultivar ‘Myers’ Best’ is currently available as a result of this farmers’ work. We included ‘Myers’ Best’ in our trials for observation in the 2012 season. ‘Myers’ Best’ performed remarkably similar to the ‘OSU’, ‘Common Ground’, and ‘Solstice’ across all of the quality and production traits. The convergence of these three independently selected populations led us to propose two hypotheses: that a PNW ideotype for organic broccoli had been discovered from the original OSU VBP broccoli material; and alternatively, that the original population lacked genetic variability for the traits evaluated in this study. The distinctly different performance of the ‘East Coast’ selected material demonstrated the potential for widely different populations to be developed from the original source material and implies that genetic variation was not lacking. Thus the resulting similarity of the four populations developed along the West Coast from the Olympic Peninsula to Southern Oregon suggests a regional selection pressure unlike that present in New York. Selection was probably composed of a combination of environmental (climate, soil type, pest pressure) as well as a social pressures (interactions among formal- and farmer-breeders), but it is unclear what portion was due to each of these factors.

This study has provided results demonstrating improvements in quality traits for the OSU VBP and farmer-bred broccoli material in reference to check cultivars. However, we cannot say whether or not these quality improvements will directly transfer to productivity trait increases. We have also added to the existing pool knowledge that exists on the differences and similarities between formal and farmer-breeder selection results. We found that for many important quality traits the selection results of formal and farmer-breeder cultivars are not distinctly different. Although the scope of this study is limited by small sample size, our results agree with previous study findings that formal and farmer-breeder selections are often not distinctly different; thus providing evidence for continuing to support the involvement and education of farmers in plant breeding, especially in reference to organic production systems.

Chapter Four: Impacts of Collaboration in Participatory Plant Breeding

Introduction

There are many benefits to participatory and collaborative research. The unique know-how, knowledge, and perspectives of farmers, formal breeders, seeds people, and end users are all validated and given consideration in participatory plant breeding (PPB). The process of participatory research and breeding is socially valuable to all participants and all end-users of PBB material (farmers, growers, vegetable eaters). Involving farmers and end users early on in the breeding process not only keeps the work relevant and effective, it also fosters creativity, community, innovation, and companionship (Desclaux et al., 2012).

Farmer empowerment is considered an important part of PPB (Almekinders and Elings, 2001; Ceccarelli and Grando, 2007). It is easy to lose sight of the importance of empowering farmers with plant breeding skills and knowledge in the midst of the highly sophisticated and industrialized system of agriculture in the United States. However, the increased ability, knowledge, and new skill development that come from engaging in on-farm and participatory plant breeding all contribute to increased empowerment and adeptness, which are beneficial for farmers and researchers alike.

It is easy to show that adoption of newly released varieties is increased with PPB, and that the yields of selections by farmers equal or out-perform those selected by breeders; but it is more challenging to pin down how farmers feel empowered by PPB. According to work by Ceccarelli and Grando (2007) PPB has moral, ethical, and psychological benefits that "are the consequence of a progressive empowerment of the farmers' communities; these benefits affect sectors of their life beyond the agricultural aspects." When Ceccarelli and Grando (2007) asked farmers what benefits they obtained from PPB, typical responses included: their quality of life has improved, they feel happier because they have gone from passive receivers of information to active protagonists, and their opinion is valued.

Farmer participation is not a new idea. Farmers have been selecting and molding the phenotypes, and thus the genotypes, of crops for thousands of years without schooling and education in plant breeding (Ceccarelli and Grando, 1997). Farmers are extremely competent selectors of varieties and seeds (Almekinders and Elings, 2001; Ceccarelli et al., 2000; Dawson et al., 2008). In fact, farmers are the original plant breeders and seed savers. The formal research sector has just as much potential to learn from farmers, as farmers have to learn from professional research.

In order to contribute to the growing wealth of knowledge on collaborative research and how PPB can contribute to the ongoing success of organic breeding work, we conducted interviews with farmers involved with the broccoli breeding efforts of the Northern Organic Vegetable Improvement Collaborative (NOVIC). By capturing the stories and experiences of the formal breeders and farmer breeders involved with Oregon State University (OSU) vegetable breeding program (VBP) broccoli project (funded through NOVIC) we hope to provide insight into some of the benefits and challenges of PPB work.

Materials and Methods

Approval to conduct interviews with human subjects was obtained through the Institutional Review Board (IRB) at Oregon State University. This process included generating study descriptions, sample interview questions, consent documents and completing ethics training. IRB approval was granted before interview subjects were contacted and invited to participate in the study. Refer to Appendix 2 for copies of all IRB documents.

Involvement with the OSU vegetable breeding program (VBP) organic broccoli project was a prerequisite for involvement in study interviews. This limited the interviews to two farmer-breeders, Julie Puhich and Jonathan Spero, and one formally trained public plant breeder, Dr. Jim Myers. Due to the narrow focus and restrictions for participation the results of this study cannot be extrapolated beyond these three individuals.

We knew the interview subjects previous to this study through work with other collaborative breeding and variety trialing projects. Initial contact to invite subjects to formally participate in this study was done via email. Once consent to interview was obtained, in-person interviews were scheduled with each participant.

Semi-structured interviews were conducted in person during September and October of 2012. Interview questions posed to each participant can be found in Appendix 2. Interviews were conducted on the farms of Julie Puhich in Olympia, WA, Jonathan Spero in Williams, OR, and in the office of Dr. Myers at Oregon State University. Interviews lasted approximately one and a half hours. With the consent of interviewees, all interviews were audio recorded using a hand held Olympus recorder. After transcription all recordings were destroyed. Transcripts were stored on a password-protected computer. Once transcription was complete, interviews were coded for common themes.

Results and Discussion

Formal and Farmer-breeder Profiles

Dr. Jim Myers, the formal plant breeder in this study, has been the Baggett-Frazier endowed chair of Vegetable Crop Breeding at Oregon State University since 1996. He received both a Master's and a PhD from the University of Wisconsin in plant breeding and genetics with a minor in botany (1983 and 1986 respectively). At OSU, Dr. Myers' primary work foci have been breeding improved blue lake type green beans and broccoli (inbred and F_1 hybrids) for the processing industry. Dr. Myers' breeding work at OSU is somewhat unique in that he works on a number of different vegetable crops (many breeders focus on a single crop species); his breeding work also includes tomatoes, peas, dry beans, and mild-type habaneros. He conducts breeding work in both conventional and organic production systems.

To begin this collaborative broccoli project Dr. Myers initiated a convergent-divergent selection scheme that lasted for seven years (2001-2007). Each year, anywhere from one to six organic growers participated in producing seed of their own on-farm broccoli selections from material generated through the OSU VBP. Each grower returned a portion back to Dr. Myers at OSU where it was blended together with his selections as well as those of all other participating farmers. Dr. Myers' expectation was that if there were a certain set of qualities and characteristics that were essential for organic adaptation, this convergent-divergent, multiple-environment selection method would target them.

Jonathan Spero, one of the farmer breeders in this study, is a long-time plant breeder and seed producer. Jonathan and his partner Jesse have been farming approximately seven and a half acres of certified organic farmland know as Lupine Knoll in Williams, Oregon since 1999. Currently, the farm is not self-supporting and

Jonathan's breeding work is supplemented by Jesse's off-farm work. Although he has been involved with the broccoli project for 10 years, breeding corn is Jonathan's main focus. He also produces seed and breeding work with tomatoes, lettuce, and pumpkins. He markets his cultivars through several small-scale seed companies in Southern Oregon including: Siskiyou Seeds, Horizon Herbs, Bountiful Gardens, FedCo, and the Family Farmers Seed Cooperative. Jonathan has recently released the cultivar 'Solstice' for sale from his selections of the OSU VBP broccoli material.

Julie Puhich, another farmer breeder, is currently working with the OSU broccoli material at her farm in Olympia, WA. She owns Common Ground Farm, a 15-acre organic farm, about two to three of which is in mixed vegetables. Common Ground is certified organic for seed crops. She began farming and growing vegetables in the Olympia region in 1980 and started her own Community Supported Agriculture (CSA) program in 1990. Julie produces between 30 and 40 different crops throughout the season for her CSA customers. Her CSA is just large enough to sustain her livelihood and although the enrollment numbers fluctuate year-to-year, she generally supplies around 50 shares. A valuable evolution in Julie's vision of food has occurred as a result of her working through a CSA model in that she has come to think of food as a common, shared entity rather than simply a commodity.

Dr. Myers, Julie, and Jonathan all became engaged in plant breeding out of a shared passion and interest in plants and biology. Although each had a different and unique experience that set them on the path of plant breeding work, initially they were all inspired by how powerful and amazing the effects of selection and breeding can be in shaping the future of our food.

Interview Themes

Empowerment emerged as a strong theme in this work. Through increased skills, knowledge, shared experiences, and community building Dr. Myers, Julie, and Jonathan have all found enormous benefit from their involvement in this project.

Perhaps the most profound example of empowerment and the impact of plant breeding and PPB work are illustrated by a fundamental change in Julie's relationship with plants and seeds; she has come to see seed as a personal and relational resource, rather than viewing it simply as a commodity to be purchased. She can now differentiate between seed quality issues, cultural practice issues, and crop genetics when a crop fails to perform to her standards. When faced with a crop failure she can now see the cultivar adaptation potential born from any survivors. Although she may not always capitalize on these breeding opportunities, there has been a critical shift in her thinking that has empowered her to realize the abundant potential for cultivar improvement and her capability to play a role in it.

For Jonathan the increased access to formally trained plant breeding professionals that collaborative research provides has been intellectually empowering. He is relatively geographically isolated down in Southern Oregon and this project has brought him into contact with people who are like-minded and knowledgeable about plant breeding and seed production. Jonathan reaches out to Dr. Myers and other professionals when his breeding work does not progress as he expected, or when unexpected results occur. This has increased his breeding efficiency, enhanced his plant breeding capabilities, skills and knowledge, and reduced (some of) the guesswork he comes up against in his work.

For Dr. Myers the empowerment gained from this project for Dr. Myers has been of a more subtle nature. His interactions with Julie, Jonathan, and many other growers involved with the NOVIC project have caused him to pay closer attention to his crop development and helped him to develop an alternative perspective to bring to his breeding work. The majority of his breeding work is focused on developing cultivars for the processing industry, rather than for small scale, low input, and organic farming systems. This collaborative broccoli work has also provided him with new ideas and experiences which now serve as fodder for how to conduct effective, targeted research and breeding projects beyond the normal scope of traditional plant breeding. He finds this particularly valuable in organic breeding, where the research sector doesn't really have a good idea of what to breed for and what traits are truly needed for reliable and robust production.

Community development, networking, and the synergy created through collaborative research also emerged as common themes among these interviews. Jonathan in particular found that everyone in the organic plant breeding community as a whole have been "wonderfully open and willing to share and wanting to help further understanding." In times where increasing consolidation in the seed industry and strongly held intellectual property protections hinder collaboration, information sharing is becoming less and less common. Dr. Myers feels there is a fruitful synergy that occurs when he is with farmers that enhances the work and builds community. Working with the NOVIC project has brought Dr. Myers, Julie, and Jonathan not only in closer contact with each other, but has also built networks between them and many other growers, professionals, students, and seeds people through events such as on-farm breeding workshops, field days, annual meetings, and conferences; all of which have served to strengthen and enhance the collaborative nature of this work and the community which it serves.

Another benefit and theme from this work is the success of bioregional seed development. Both Julie and Jonathan have been successful in making selections to develop broccoli materials that are optimally adapted to their specific growing environments and challenges. Dr. Myers has succeeded in developing a broccoli population that is performing well across the mid-Willamette Valley in Oregon (as evidenced by NOVIC on-farm trials) and seems to have strong potential for adaptation and reliable production in organic systems throughout the Pacific Northwest (PNW). The successful development and use of the cultivar 'Myers Best' by Steve Habezetser in Port Townsend, WA (discussed in chapter 3) further demonstrates the adaptability and successful contribution of this material for superior performance of an open pollinated broccoli for organic systems. Both Julie and Steve intend to keep their cultivars and materials local and hope to supply their neighbors and fellow regional growers with a superior broccoli. Jonathan has already begun to distribute 'Solstice' through both regional and national seed companies, indicating the potential for use beyond the PNW. The material developed through the OSU VBP will soon be released for both regional and national sales as well under the cultivar name 'Benton'.

Challenges and Lessons

Integrating plant breeding into her farmscape and schedule has been challenging for Julie. The broccoli project demands significant time and attention, and often evaluations conflict with peak harvest times for other crops. Recently she has begun harvesting broccoli from non-selected breeding plants and distributing them through her CSA. It was a real watershed moment for Julie when she realized she could harvest her breeding material for her CSA; this allowed her to pay attention to the broccoli during critical times rather than trying to maintain it separately and take time out from other farming activities to assess and evaluate it. Now she evaluates and harvests the broccoli simultaneously. Also her CSA customers are her target audience, so it makes a whole lot of sense to integrate her breeding work in this manner because it creates a situation where every moment she is working with the broccoli is in the context of its end use. It's novel, creative, and flexible approaches such as this that makes on-farm plant breeding possible for many small-scale growers.

For Dr. Myers the biggest challenge of this project has been avoiding the potential for contamination and keeping seed sources separate. The introduction of Gailan (Chinese broccoli) material from outcrossed selections made early on in New York (sometime between 2005 and 2007) increased the variability and reduced the quality of the population when that seed was blended back into the original material. It's been a struggle for him to recover from that and come back to material of acceptable quality. This experience also made him aware of the potential for contamination and spreading of seed borne diseases. If diseased seed were incorporated, it could be spread around to everyone participating in the collaboration. The best way to prevent outcrossing and disease contamination would be to grow out the selections from each collaborating grower in isolation each year and assess them before blending and sending them out to others. Although effective, and safe, this could prove to be too time consuming for crops such as broccoli.

Communication and transportation have also been big challenges with participatory work for Dr. Myers. Getting out to farmer's fields when the crop is in a peak evaluation stage can be extremely challenging when distance is a factor, and when it conflicts with peak times for other crop work. Oversight may be required to ensure outcrossing is being actively prevented and farmers are observing all necessary constraints. This can be straining on budgets and other commitments.

Conclusions

The collaborative nature of this broccoli breeding work has been positive and valuable for all involved. Julie stated that both OSU and OSA have valued her knowledge and been able to help her recognize her skills as both a farmer and a plant breeder. Jonathan values the potential for collective improvement benefit through PPB. He especially appreciates the opportunity to gain knowledge and insight by having multiple farmers growing the same crop simultaneously in their own environments. Dr. Myers regards collaborative research as a partnership where he is learning from farmers' observation skills and experience, while concurrently sharing his experience and expertise in genetics.

Dr. Myers, Julie, and Jonathan all believe that breeding for organic systems is important and necessary. They all agree there is a lack of stability in the availability of seed for the organic community and that farmer-breeders have a significant role to play in the re-vitalization of the organic seed system. Participatory plant breeding projects such as this one have, and will continue to, build important partnerships, empower farmers and researchers alike, and contribute a rich diversity of locally and regionally adapted cultivars to a vibrant future of sustainable agriculture.

This collaborative broccoli project has been successful for all involved. Jonathan has developed the cultivar 'Solstice' which is now being sold through an increasing number of seed catalogues, demonstrating that farmer-breeders can develop cultivars with specific adaptation to organic systems. The OSU VBP is increasingly close to releasing a variety tentatively named 'Benton' out of this work, and Julie continues to integrate and develop her breeding skills and confidence while working with the broccoli material on her farm. It is likely that Julie will not formally release a cultivar, but instead will continue to refine the material to suit her needs and eventually share her material with other growers in her community. The agricultural community at large stands to benefit from the increased cultivar options created from such projects. It is our hope that the continued success of this project inspires others to integrate participatory methods and models into their plant breeding work.

Chapter Five: Discussion and Conclusions

The quantitative studies included in this thesis produced mixed results. The data from each expressed a large amount of environmental variation that made it challenging to make clear conclusions. Increased replication both over space and time should help remedy this situation and provide better data from which to draw strong conclusions. These studies were also limited by the lack of commercially available open pollinated broccoli cultivars for comparison. It would have bolstered the potential impact of the OSU VBP and farmer-breeder cultivars to know how they perform in relation to currently available OP cultivars. It would have also been ideal to conduct comparison trials in the fall production season for broccoli to obtain a more comprehensive picture of the performance potential of the OSU VBP and the farmer-breeder materials.

The data set generated from the population comparison study presents interesting possibilities for further analysis. One possibility would be to conduct multiple correlation tests on the traits evaluated in order to build a model for an ideal broccoli. This kind of analysis could also be used to find associations among quality traits and get an idea of how they are affected by breeding and selection.

In order to truly know if the OSU VBP and farmer-breeder broccoli cultivars are better adapted to organic production systems than their conventionally bred counterparts a multi-year, side-by-side trial is necessary. Such a set of trials was beyond the scope of the resources available for this project. However these sorts of trials would add valuable data to the evolving conversation surrounding organic plant breeding and the issue of direct selection in target environments.

The information generated from the interviews conducted with Dr. Myers, Julie Puhich, and Jonathan Spero also provides fertile ground for continued research. Very little has been done to investigate and document both the immediate and ongoing benefits and impacts of participatory research in the United States. There is unlimited opportunity to dig deeper into the social experiences of those participating in collaborative research. Increasing our understanding of the social benefits of collaborative agricultural research could add enormous benefit to the current efforts to bolster organic plant breeding in particular and all of organic agriculture in general.

Although the extremely limited and narrow sample population prohibits us from making any inferences outside of this particular study, our work has demonstrated the potential and positive outcomes achievable with the use of participatory plant breeding for organic production systems. The collaborative nature of this project and the knowledge gained from the network of participating farmers has been a critical element of the OSU VBP's ability to begin breeding for organic systems. Broccoli turned out to be an excellent crop choice as its lifecycle lends itself well to mass selection techniques, which are easy and accessible for farmer-breeders to use. Farmer engagement helped the VBP to understand what traits are important for organic broccoli production; farmers were engaged to define quality, handling, and harvest traits of primary importance. This involvement benefited farmers by giving them access to resources and skill development that allowed them to implement and follow through on plant breeding projects on their farms. Farmers have also had ownership in the project, which has served to keep the research relevant to their needs as well as increasing the potential for adoption and use of any varieties released from the project. This project has shown that farmer-breeders can develop varieties that are specifically bred for and adapted to organic production systems (e.g. 'Solstice' Broccoli). The organic community at large stands to benefit from the increased varietal options created from such projects. Although this project has already been quite successful in a number of ways, there is still much to learn about the traits necessary for robust organic production and how we can best breed for them. Through the support of the NOVIC project, the OSU VBP will continue to gain understanding and insight into breeding for organic systems through collaborative work with farmers.

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Appendix 1 – Analysis of Variance (ANOVA) Output Tables for all Traits

%Young

source	df	MS	P-value
model	4	1.00	0.5
variety	2	1.00	0.44
rep	2	1.00	0.44
error	4	1.00	
CV=	300	R^2=	0.5

% Prime

source	df	MS	P-value
model	4	78.9	0.38
variety	2	0.4	0.99
rep	2	157.4	0.18
error	4	57.4	
CV=	17.14	R^2=	0.58

% Over Mature

source	df	MS	P-value
model	4	52.8	0.38
variety	2	6.8	0.84
rep	2	98.8	0.19
error	4	37.8	
CV=	11.29	R^2=	0.58

% Hollow Stems

source	df	MS	P-value
model	4	0.1	0.03
variety	2	0	1.00
rep	2	0.3	0.01
error	4	0.0	
CV=	57.74	R^2=	0.90

Canopy Height

source	df	MS	P-value
model	4	26.4	0.57
variety	2	1.4	0.96
rep	2	51.4	0.25
error	40	35.8	
CV=	10.24	R^2=	0.07

Head Height

source	df	MS	P-value
model	4	54.5	0.14
variety	2	73.6	0.09
rep	2	35.4	0.31
error	40	29.3	
CV=	10.53	R^2=	0.16

Exsertion

source	df	MS	P-value
model	4	110.7	0.15
variety	2	163.8	0.08
rep	2	57.5	0.40
error	40	61.9	
CV=	8.89	R^2=	0.15

Biomass

source	df	MS	P-value
model	4	47791	0.05
variety	2	33153	0.18
rep	2	62428	0.05
error	40	18662	
CV=	16.73	R^2=	0.20

Head Weight

source	df	MS	P-value
model	4	1709	0.29
variety	2	1869	0.26
rep	2	1549	0.32
error	40	1333	
CV=	21.84	R^2=	0.11

Harvest Index

source	df	MS	P-value
model	4	6.0	0.69
variety	2	2.0	0.82
rep	2	10.0	0.40
error	40	10.6	
CV=	15.82	R^2=	0.05

Trimming

source	df	MS	P-value
model	4	0.2	0.87
variety	2	0.2	0.80
rep	2	0.3	0.67
error	40	0.7	
CV=	18.90	R^2=	0.03

Head Size

source	df	MS	P-value
model	4	6.8	0.14
variety	2	9.8	0.08
rep	2	3.7	0.38
error	40	3.7	
CV=	17.78	R^2=	0.15

Bead Size

source	df	MS	P-value
model	4	2.3	0.001
variety	2	4.1	0.002
rep	2	0.5	0.40
error	40	0.5	
CV=	33.09	R^2=	0.30

Head Color

source	df	MS	P-value
model	4	0.6	0.47
variety	2	0.2	0.78
rep	2	1.1	0.22
error	40	0.7	
CV=	20.65	R^2=	0.08

Firmness

source	df	MS	P-value
model	4	1.2	0.06
variety	2	0.7	0.23
rep	2	1.6	0.04
error	40	0.5	
CV=	17.15	R^2=	0.20

Heat Stress

source	df	MS	P-value
model	4	0.6	0.18
variety	2	0.1	0.82
rep	2	1.1	0.06
error	40	0.3	
CV=	12.56	R^2=	0.14

Total Yield

source	df	MS	P-value
model	24	4.7	<.0001
year	2	28.4	<.0001
variety	5	5.9	<.0001
rep(year)	8	0.1	0.75
year*variety	9	1.7	<.0001
error	36	0.2	
CV=	15.40	R^2=	0.94

Yield Efficiency

source	df	MS	P-value
model	24	0.001	<.0001
year	2	0.005	<.0001
variety	5	0.001	<.0001
rep(year)	8	0.000	0.80
year*variety	9	0.000	0.0003
error	35	0.000	
CV=	15.16	R^2=	0.91

Head Weight Gain/Day

source	df	MS	P-value
model	24	1.9	<.0001
year	2	9.9	<.0001
variety	5	3.2	<.0001
rep(year)	8	0.1	0.65
year*variety	9	0.4	0.002
error	35	0.1	
CV=	14.10	R^2=	0.93

Appendix 2 – Institutional Review Board Documents

Approved Protocol

Initial Consent Email

Consent Form

Interview Questions

Email to Obtain Permission to use Names

RESEARCH PROTOCOL
26 June 2011

1. Protocol Title Farmer-Researcher Collaboration in an Organic Broccoli Breeding Project

PERSONNEL

2. Principal Investigator Dr. James R. Myers
3. Student Researcher(s) Laurie McKenzie
4. Investigator Qualifications: The PI has a Ph.D. in Plant Breeding and Genetics with about 34 years of experience in the discipline, and 14 years in vegetable breeding. He has been involved in participatory plant breeding in East Africa as a co-PI in the Bean/Cowpea Collaborative Research Support Project (1990-2007) and with the Northern Organic Vegetable Improvement Collaborative (2008-present). The PI regularly participates in taste test panels of vegetable breeding lines and released varieties developed by the vegetable breeding and genetics program (taste test panels are conducted by Food Science and Technology personnel with IRB approval obtained and maintained by FST). The PI has also supervised a graduate student (Peter Mes, Ph.D., Breeding Tomatoes for Improved Antioxidant Activity, OSU, June, 2005) who documented the effect of varying carotenoid profiles of tomato genotypes on concentration of carotenoids in blood plasma of human subjects.
5. Student Training and Oversight: The student researcher has developed the protocol for this study with the approval and oversight of the PI. The student has designed the interview questions with editing by the PI. The student has been trained as to how to handle interview data and how to maintain confidentiality of all participants. Prior to this initial application, the student has successfully completed the required certificate of education ethics training. The PI will oversee all aspects of the interview administration, data handling, data management, and storage of data on password protected computers. The recruitment email will be sent to participants through the PI. The student will download and analyze data and report final results in the form of reports and/or manuscripts for publication.

FUNDING

6. Sources of Support for this project (unfunded, pending, or awarded)

This study is funded through the Northern Organic Vegetable Improvement Collaborative (NOVIC). Although the grant does not specifically indicate coverage for this particular study, it is covered under the umbrella of graduate work. The grant does not specify the particular work of graduate students but instead indicates the importance for the "training of graduate students in plant breeding". Since this study is designed to increase the understanding of the collaborative plant breeding process we felt this research was appropriate. While NOVIC is a multi-institutional project. The research proposed here does not involve other institutions.

- Indicate internal and/or external funding source: USDA-NIFA-OREI
- Grant/contract number: 2009-51300-05585
- Name of PI on Grant: James R. Myers
- Grant title: Northern Organic Vegetable Improvement Collaborative (NOVIC)

DESCRIPTION OF RESEARCH

7. Description of Research: The purpose of this research is to document the process, opinions, and experiences of organic farmers and researchers who are involved in a collaborative plant breeding project with organic broccoli. The intent is to use this information for the publication and presentation of Laurie McKenzie's Master of Science thesis for the Horticulture Department at Oregon State University. The information will be synthesized into case studies and used in collaboration with replicated field data to analyze the differences and similarities among breeding practices used by farmers and researchers.

8. Background Justification: Organic vegetable production has seen consistent growth in the agricultural sector over the last several years. With the National Organic Practices (NOP) requiring the use of organically produced seed, farmers are feeling pressured to find new varieties to replace some old standards that do not meet the NOP requirements. With the increasing consolidation of seed companies organic growers have seen many old standard vegetable varieties disappear from the market. In recent years organic plant breeding has been receiving an increasing amount of attention from breeders and farmers alike. Farmers are constantly seeking vegetable varieties with superior performance and adaptability as well as a consistent and reliable supply source. Participatory and collaborative methods have long been used in developing countries to find and create crop varieties that are best suited for challenging production environments; only recently have these (collaborative) methods been used in the United States. Current research suggests that participatory plant breeding methods are an effective (and efficient) means to developing new crop varieties, especially for low-input environments such as organically managed ones. As public resources for plant breeding decline it becomes (more) essential to integrate the knowledge and wisdom of farmers into the breeding and varietal development process. The interviews in this study will help to elucidate the role farmers can play in the future of collaborative plant breeding and varietal development and what indirect benefits both farmers and researchers stand to gain from working together.

9. Subject Population: This study involves four people: three farmers and one OSU professor; all four people are currently known to both the PI and the student researcher. The broccoli population from which each of the three farmers have been making selections from was developed by the PI. The three farmers became involved sometime between 2001 and 2007 when a number of farmers participated in making selections from this OSU broccoli population through the Farmer Cooperative Genome Project and the Organic Seed Partnership. Two of the farmers have continued to retain contact with Dr. Myers at OSU and are currently involved with the NOVIC project. The third farmer approached Dr. Myers and Ms. McKenzie at a recent conference and offered seed of his selections and agreed to allow use of it for our research.
10. Consent Process: An informed consent document has been provided to the IRB with the application (see attachment). Once participants have affirmatively responded to our invitation email interviews will be scheduled and conducted. This consent document will be presented to participants at the time of interviewing.
11. Methods and Procedures: This study will involve recruitment of the four participants as soon as IRB approval is obtained. Participants will be sent an email regarding the study and given one week to respond (see attachment). Once responses have been received interviews will be scheduled to take place as soon as possible. Interviews will be conducted in person by the student researcher at a location convenient to the participants. Interviews will last one to two hours. Upon consent of participants interviews will be audio recorded. Also upon consent photographs of participants will be taken. No more than two follow-up interviews will be conducted via email and/or phone contact should the researchers need clarification or further information about any of the questions discussed. All interviewing will be completed by the end of September 2012.

    Information recorded from the interviews will be transcribed, coded, and formed into case studies. These case studies will be paired with replicated, statistically analyzed field data to draw conclusions and make recommendations regarding the use of collaborative plant breeding methods.
12. Compensation: No compensation will be given to the participants of this study.
13. Cost: There are no costs incurred by the participants to take part in this study.
14. Anonymity or Confidentiality: Interview information will be retained on a password-secured computer that resides in a locked office in the laboratory of the PI (4051C) located in the OSU Department of Horticulture Ag and Life Sciences Building, Corvallis, OR. Recordings of the interviews will be destroyed as soon as transcription is completed. Identifying information such as names, photographs, and farm locations will be recorded with participant consent.

Transcripts, along with photographs, will be stored on this secure computer in digital format for three years after the termination of the study (until the fall of 2015). During the study the student researcher will work with the data on a password-secured personal laptop computer.

15. Risks: There are no foreseeable risks to participants in this study.
16. Benefits: There are no direct benefits to participants in this study. The information generated from this study will increase the general pool of knowledge for collaborative plant breeding and hopefully the experiences of those involved will inspire future collaborative work.
17. Assessment of Risk:Benefit ratio: There is greater benefit to this study than there is risk. The information gathered from these interviews will provide the organic plant breeding community with an enhanced understanding of the process, experience, and benefits of collaborative research.

Dear Farmer-

We are contacting you in order to formally invite you to participate in a study on the role of farmers and researchers in collaborative plant breeding for the purpose of research for Laurie McKenzie's Master of Science thesis at Oregon State University. The title of her study is "Farmer-Researcher Collaboration in an Organic Broccoli Breeding Project". You are being contacted because you have a history of working with an organic broccoli population that was developed at Oregon State University by Dr. James R. Myers. Dr. Myers is the Principal Investigator for this study and you may contact him at any time with any questions or concerns you may have by email at myersja@hort.oregonstate.edu or by phone at (541) 737-3083.

Laurie would like to conduct an in-person interview with you focused on your opinions and experiences both with collaborative plant breeding and plant breeding in general. These interviews will be conducted at your convenience sometime before the end of September 2012. Interviews will be done in a semi-structured style with some pre-determined questions along with ample time for diversions and discussion. The pre-determined questions will be made available to you at your request. The interview will take between one and two hours. At any time, you may choose not to participate in the interview.

We will make every effort to maintain confidentiality in our work with you. Laurie will have a consent document for you to sign upon arrival for your interview indicating that your participation is voluntary and outlining some important details of the study. This study is not designed to benefit you directly and there are no foreseeable risks to your participation.

If you are willing to participate in this study please reply to both Dr. Myers and Laurie McKenzie (mckenzil@onid.orst.edu) stating so. You may "reply all" to this email. Please reply by _______ (one week from when email is sent). Thank you for your time and consideration.

Regards,

Dr. Jim Myers and Laurie McKenzie

CONSENT FORM

Project Title: Farmer-Researcher Collaboration in an Organic Broccoli Breeding Project
Principal Investigator: Dr. James R. Myers
Student Researcher: Laurie McKenzie
Sponsor: Northern Organic Vegetable Improvement Collaborative
Version Date: 10 June 2012

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1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to document the process, opinions, and experiences of organic farmers and researchers who are involved in a collaborative plant breeding project with organic broccoli. The information obtained from this interview will be used in the synthesis and publication of Laurie McKenzie's Master's of Science thesis at Oregon State University (OSU).

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you have been making (breeding) selections from a broccoli population developed at Oregon State University by Dr. Myers.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

The study involves interviews. You will be asked a series of questions about your experiences with and opinions on plant breeding in general, your specific work with broccoli, and the collaborative breeding process. All your responses are voluntary. You may skip any questions you prefer not to answer.

The interview will be conducted in a semi-structured style with a number of pre-determined questions as well as ample time for discussion and elaboration. A copy of the pre-determined questions will be made available to you if you wish.

The interview will take one to two hours. The initial interview will be conducted in person. The study team member will meet you at a mutually agreed upon location to conduct the interview. No more than two follow up interviews will be conducted via email and phone contact.

With your consent an audio recording of the interview will be taken. Once the recording has been transcribed it will be destroyed. The recording is an optional part of this study you may still participate if you choose not to be recorded. With your consent you may be photographed for the presentation of this research. Being photographed is also an optional part of this study and you may still participate if you choose not to be photographed.

_____I agree to be audio recorded.

Initials
______I do not agree to be audio recorded.
Initials

______I agree to be photographed.
Initials

______I do not agree to be photographed.
Initials

Because it is not possible for us to know what studies may be a part of our future work, we ask that you give permission now for us to use your personal information without being contacted about each future study. Future use of your information will be limited to studies about collaborative and/or participatory plant breeding. If you agree now to future use of your personal information, but decide in the future that you would like to have your personal information removed from research database, please contact Dr. Myers at Oregon State University at myersja@hort.oregonstate.edu or by phone at (541) 737-3083.

______You may store my information for use in future studies.
Initials
______ You may not store my information for use in future studies.
Initials

We may contact you in the future for another similar study. You may ask us to stop contacting you at any time.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?
There are no foreseeable risks and/or discomforts associated with being in this study.

There is potential for follow-up communication via email after the interview is completed. The security and confidentiality of information sent by email cannot be guaranteed. Information sent by email can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

6. WHAT ARE THE BENEFITS OF THIS STUDY?
This study is not designed to benefit you directly.

7. WILL I BE PAID FOR BEING IN THIS STUDY?
You will not be paid for being in this research study.

8. WHO IS PAYING FOR THIS STUDY?
The NOVIC (Northern Organic Vegetable Improvement Collaborative) project is paying for this research to be done.

9. WHO WILL SEE THE INFORMATION I GIVE?

Findings from this study will be made available to all NOVIC project participants (information may be used for such things as continuation documents, conference presentations, project publications, field days, and workshop materials). Because there are only four participants in this study, it is likely that you will be easily identifiable.

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you. In order to ensure confidentiality, we will use only your initials on any and all data forms and store transcripts on a password-protected computer file.

9. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?
Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without penalty, it will not affect your participation in NOVIC. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

10. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact: Dr. Myers at OSU – (541) 737-3083, myersja@hort.oregonstate.edu.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed): ______________________________

______________________ ______________________

(Signature of Participant) (Date)

______________________ ______________________

(Signature of Person Obtaining Consent) (Date)

Interview Questions

1. What interests you about plant breeding?
2. What are your experiences with plant breeding?
3. What drew you to participate in this broccoli project?
4. What is your definition of plant breeding?
5. What do you see as the "professional's" role in plant breeding (this could be a University employee, extension specialist, or someone employed as a plant breeder for a seed vegetable company)?
6. What do you see as the farmer's role in plant breeding?
7. Who do you believe should be doing plant breeding and why?
8. Why is it important to you to be involved with plant breeding?
9. What is your ideal of collaborative plant breeding between researchers and farmers?
10. What have been your experiences with collaborative plant breeding?
11. What do you see as the goal(s) of collaborative plant breeding?
12. What values are important to you in reference to plant breeding in general and collaborative plant breeding in particular?
13. Do you think collaborative plant breeding is effective? Efficient? Worthwhile? How come?
14. In what ways, if any, has becoming involved with plant breeding impacted your farming?
15. Could you walk me though a general overview of the process you use to accomplish your plant breeding projects?
16. Do you think your process is similar and/or different than what professional plant breeders/farmers do?
17. In what ways do you think they are similar or different?
18. I am taking field measurements on things like head size, head weight, plant height, and head color for the broccoli you have been selecting. What, if anything, would it mean to you if your selections were not significantly different from those made by researchers or other farmers?
19. What would it mean to you if they were determined to be different?
20. How confident are you in your plant breeding skills?
21. On a continuum from novice to expert where would you place yourself in terms of your plant breeding knowledge and experience?
22. Where do you see gaps in your knowledge?
23. Are you actively making an effort to close those gaps? How do you go about this?
24. What are your selection criteria?
25. How have your selection criteria changed over time? What has influenced those changes?
26. What do you like about plant breeding?
27. What do you dislike about plant breeding?

28. What, or who, influences your plant breeding the most?
29. Do you spend time during your “off” hours planning for and/or researching plant breeding? If so, what do you do?
30. On a scale of one to ten, one being not interested at all and ten being extremely interested, how would you rate your interest in plant breeding in general and collaborative breeding in particular?
31. What criteria do you think are most important for good plant breeding?
32. What do you think makes for good plant breeding?

Dear Farmer-

I am writing to request permission to use your name in the publication of my Masters thesis and associated research documents and presentations. Thank you for participating in this research, it has been an honor to work with you.

You have previously given consent to participate in this study. The only change to what you have previously consented to is the explicit permission to use your real name, instead of a pseudonym, in my published thesis, associated research documents and presentations. I believe this will not cause you any harm or pose any risks to your wellbeing.

If you are willing to allow me to use your name in this way please respond to this email to that effect. Your response will be considered sufficient permission. Thank you for your time and efforts in this matter. If you have any questions or concerns please contact myself or Jim Myers.

Regards,
Laurie McKenzie, Graduate Student
(541) 908-2155
mckenzil@onid.orst.edu

Jim Myers, Project Principal Investigator
(541) 737-3083
myersja@hort.oregonstate.edu