Professional Paper

Master of Agriculture

USING PARTICIPATORY PLANT BREEDING STRATEGIES TO OBTAIN GARDENER FEEDBACK IN A POTATO BREEDING PROGRAM

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Agriculture

Colorado State University

Fort Collins, Colorado

Spring 2018

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ABSTRACT

USING PARTICIPATORY BREEDING STRATEGIES TO OBTAIN GARDENER FEEDBACK IN A POTATO BREEDING PROGRAM

Plant breeding programs rely on feedback from individuals that produce, use, and consume the products of their program, selections and cultivars. In a potato breeding program this includes potato growers, shippers, processors, and consumers. The Colorado State University Potato Breeding and Selection Program developed a home gardener trial program in which Master Gardener volunteers grew, evaluated, and completed surveys on six specialty potato selections developed by the Potato Breeding Program. These gardeners lived in seven counties in Colorado and grew one or two different potato selections. The Potato Breeding program used aspects of participatory plant breeding in this initiative, including creating a survey, asking gardener opinions, and by using qualitative scales to measure gardener preference. Participatory breeding relies on grower feedback during the cultivar development process to help plant breeders create locally adapted crops based on farmer needs and priorities. It allows plant breeders and farmers to understand how a new crop cultivar preforms in a variety of locations, and to evaluate disease resistance, yield potential, and other agronomic traits for a particular market. The researchers conducted a two-year study with six potato selections, and analyzed completed survey data. They identified consistencies in feedback across cultivars and locations, indicating similar challenges to production, and compared ranking and preference to identify cultivars the gardeners selected over others.

ACKNOWLEDGEMENTS

First, I would like to thank Dr. David Holm for encouraging me to pursue a graduate degree while I worked for him. His material support of my research, generosity with my work time, and professional advice have been crucial in my professional development in the last three years. I am also grateful to Caroline Gray, the Potato Breeding and Selection Program Research Associate, for her time, support, and encouragement. Many student workers helped me to sort, bag, and label potato samples. Drs. Barbara Wallner and Nancy Irlbeck have been instrumental in supporting me as I chose classes and developed my professional paper. Dr. Becca Jablonski graciously agreed to act as an outside committee member. Finally, the following Cooperative Extension personnel have helped make my project possible. They include: Robin Young (Archuleta and Custer County), Roberta Tolan (Archuleta), Carol O'Meara (Boulder), Irene Shonle (Gilpin), Eric McPhail (Gunnison), Dan Schroder (Summit), and Mark Platten (Teller). Their willingness to find participants, distribute potatoes, and collect surveys was both generous and kind.

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CHAPTER 1 – INTRODUCTION

The Colorado State University Potato Breeding and Selection Program relies on feedback from potato farmers, industry groups, shippers, potato processors, other researcher personnel and consumers so it can continue to develop superior potato cultivars. Fostering collaborative relationships and obtaining feedback in a systematic manner can be challenging, as both plant breeders and collaborators balance many responsibilities and priorities, especially during potato planting and harvest.

The Potato Breeding Program has developed evaluation forms for potato growers and shippers to complete when they work with a potato developed by Colorado State University. Feedback from these groups is solicited during farm visits, field days, and during the annual selection evaluation meeting. Input from these stakeholders helps the plant breeder to continue to develop potato cultivars that are suited to the needs of the Colorado potato industry. Until recently, the Potato Breeding Program did not ask home gardeners for feedback on Colorado potato selections. Primarily, this is because commercial potato growers are the targeted audience for new potato cultivars. These farmers can grow large plantings of promising new potato selections, and observe their performance in commercial storage. Conversely, home gardeners typically grow only a few potatoes and consume them shortly after harvest. However, home gardeners are suited to provide feedback on some specialty potato selections, making them a good population for study in an initial feedback program started by the Potato Breeding Program. The researchers used strategies established by previous participatory plant breeding programs to solicit, evaluate, and understand home gardener feedback on new potato selections developed in Colorado (Holm, 2018a).

Background

Farmers play a crucial role in the cultivar development process, but are often consulted during the late stages of a breeding process or are only invited to grow material shortly before commercial release (Ceccarelli, 2014). Home gardeners are not traditionally grouped with farmers as they typically grow only a small amount of plants and do not sell food crops as their main source of income. However, home gardeners may be a valuable source of feedback on promising new crop selections in conjunction with farmers. There are multiple instances of plant breeders developing a new crop selection with ostensible benefits, only to have it rejected by the people who grow it, consumed it, and were supposed to benefit from it. In 1952, a USDA Extension agent attempted to replace the low-yielding traditional corn grown by a farming community in central New Mexico with a high-yielding, vigorous hybrid. The local population rejected it due to its color, taste, and texture. Clearly, farmers and consumers do not adopt a cultivar based solely on yield or disease resistance, but also on characteristics that are harder to reliably measure, such as flavor, ease of growing, and their knowledge of market demands (Apodaca, 1952).

As the average farm size in Colorado continues to increase, there will be fewer and older farmers growing crops on larger farms in the future (Total farms and ranches in Colorado, 2017). Plant breeders may therefore have to consider input from other sources, such as home gardeners. This strategy can help plant breeders obtain feedback on niche cultivars, such as specialty potatoes, that are not typically grown on large acreages. This feedback will be based on small scale production, the most likely environment for specialty type potatoes. This feedback can be a form of leveraging production of these cultivars because of their assessment of quality of specialty selections.

Participatory plant breeding (PPB) has three main goals. First, it seeks to increase the productivity and profitability of the crop through the creation and adoption of improved, acceptable, and locally adapted cultivars. Second, it benefits the crop users, including the farmer, processor, marketer, and others in the supply chain from farm to consumer. The users can be a narrow, specific group of people with participatory plant breeding focusing on one crop commonly grown in one region, or a broader group of many farmers spread over a larger area. Finally, participatory plant breeding benefits farmers by building their skills in evaluating and choosing selections, and in producing their own crop seed (Brouwer, Murphy, & Jones, 2016).

Statement of the Research Problem

There is evidence that PPB has been successfully applied in developing counties under specific circumstances. Participatory plant breeding is less suited to crop improvement efforts in the United States where crops are grown on a large scale with access to agricultural technology (Van de Fliert & Braun, 2002). However, home gardeners in the United States may have more in common with farmers in developing counties in that most grow a small amount of a crop, consume it themselves or sell only a portion of the crop locally, use limited inputs, and cultivate land they live near instead of choosing where their live based on access to fertile land, inputs, and markets. Therefore, consumer feedback should be collected at some point in the breeding program, especially on selections with distinct traits. Due to the similarities of the two groups, participatory plant breeding strategies may be useful in obtaining gardener feedback.

Research Questions

1. Using a participatory plant breeding model, what feedback can Master Gardeners provide to a plant breeding program on advanced potato selections?

2. What feedback is most relevant and useful to the Colorado State University Potato Breeding and Selection Program?

3. Does gardener feedback mirror plant breeder decisions on either continuing to evaluate a selection or removing it from evaluation?

4. Is the information provided by Master Gardeners relevant to horticulture agents working for Colorado State University Cooperative Extension? That is, does gardener feedback demonstrate an understanding of horticultural principles of vegetable production, or indicate areas where gardeners may benefit from additional training?

Definition of Terms

Advanced Selection- A potato selection that had been evaluated by a breeding program for at least five years in the Colorado State University Potato Breeding and Selection Program.

Gardener Evaluation Program- Developed by the Colorado State University (CSU) Potato Breeding and Selection Program, this initiative solicits Colorado Master Gardener feedback on potato selections currently under evaluation.

Master Gardener- A volunteer trained in horticulture and gardening by CSU Cooperative Extension staff. They promote the mission of Colorado State University Cooperative Extension by sharing gardening information via classes, workshops, articles, garden help phone lines, and staffing booths at community events (Small, 2017).

Participatory Plant Breeding- A process that occurs when farmers are involved in a plant breeding program with opportunities to make decisions at different stages during the breeding process (Ceccarelli & Grando, 2009).

Selection- A new type of potato resulting from a cross pollination that is under evaluation prior to potential commercial release. An advanced selection is a type of selection.

Specialty Potato- A type of potato that has flesh or skin coloration distinct from russet and chip potatoes. This can include red, purple, or yellow flesh, bicolor or pinto type skin, and fingerling shape (Holm, 2018).

Cultivar- A cultivated variety, which has originated and persisted under cultivation, and is true-to-type and genetically uniform (DeJong, Sieczka, & DeJong, 2011).

A note on potato cultivar names: The CO at the beginning of each clone number indicates that the cross pollination resulting in potato seed was done by the Colorado Potato Breeding and Selection Program. The first two numbers, such as 05 indicate the year that the cross pollination was done. The following three numbers indicate the family number. The number after the dash is the selection number made from the family, so -11 describes the eleventh selection made. Finally, the letters at the end of a selection name describe first the skin color and second the flesh color. P/RPW describes a selection with purple skin and red, white, and purple flesh (Holm, 2018).

Significance of the Study

One of the challenges in potato cultivar development is producing cultivars that both consumers and the processing industry like. Consumers may enjoy the taste of a potato selection, but it may be challenging to store and be prone to sprouting. This selection would then not be commercially successful. Conversely, farmers may value a selection for its multiple disease resistances and consistent size profile, but consumers may dislike its texture or appearance.

The Colorado State University Potato Breeding and Selection Program primarily breeds russet and white potato cultivars, but about 10% of the program is dedicated to producing specialty potatoes. These potatoes can have yellow, red, or purple flesh, and are typically grown by home gardeners who purchase potato tubers from a seed catalog. Some commercial growers produce specialty potatoes as a source of disease free seed for garden catalog companies or

provide them to specialty retail grocery stores. Additionally, few Colorado residents are aware of the CSU Potato Breeding and Selection Program. Master Gardeners specifically would benefit from sharing in the mission of the Potato Breeding and Selection Program. This group could help by providing feedback to the program, which exists in part to support anyone in Colorado growing potatoes (Holm, 2018.).

Researcher's Perspective

The researchers designed a survey based on participatory breeding strategies. This project was intended to be a pilot program in soliciting gardener feedback, and the results of this initial study can be used to refine the outreach aspect of the Potato Breeding and Selection Program at Colorado State University. There are many ways of obtaining grower feedback, including interviews, forced choice exercises, games based on hypothetical scenarios, and surveys (Steinke & van Etten, 2017). A survey-based strategy was chosen because of low initial costs and the amount of time available during the growing season.

Existing relationships with CSU Extension personnel to support and promote this initiative were utilized. The Potato Breeding and Selection Program is based in a rural area with no Master Gardener program, but the plant breeder has developed professional relationships with Cooperative Extension County Directors in Colorado. Collaborating with the County Directors removed travel obligations as the Extension personnel live in or near the county they serve. Participating County Directors were then able to recruit local Master Gardeners in a targeted manner, as this population was of interest in the study. Master Gardeners were chosen as survey respondents, as they have all received training in gardening and were more likely to be successful in cultivating a potato crop from planting to harvest.

The scale of this two-year program was small, again due to researcher time limitations. This program was in addition to the normal workload, so five counties in Colorado were chosen as a manageable program size. This smaller scale resulted in less data, but the evaluation program was designed so that the scope can be increased later if appropriate.

Several products associated with this research project were developed. First, based on gardener feedback, the home potato gardening Extension bulletin was revised. The current Extension article on home potato production was published in 1999, and some information is now out of date. An evaluation form that can be used by other potato breeding programs or Extension specialists who work with potatoes was developed. Finally, the results of this study will be shared with participating county directors, who can use the gardener feedback to understand topics where Master Gardeners may benefit from additional training.

CHAPTER 2 – REVIEW OF THE LITERATURE

Literature Research Strategy

Using the Colorado State University Library system, the researcher began a literature review search using the key phrases "participatory plant breeding," collaborative plant breeding," and "farmer participation." Peer reviewed journals published after 2000 were viewed first, with journal articles written before 2000 used for historical perspective or information on how participatory plant breeding has been used in the past.

Journal provenance was also an important issue. Participatory plant breeding has been conducted and studied primarily in developing counties, so journal articles that included one or more authors from a more developed county, based on author affiliation, were especially interesting. The research questions focus on a breeding program in the United States, so researcher perspectives from similar situations were important.

The literature review was focused on participatory plant breeding as a whole, and includes some aspects of participatory plant breeding that were not incorporated in the program at Colorado State University due to cost or time constraints. Recent literature typically describes projects of a larger scope than the research carried out in Colorado. Participatory breeding initiatives with published results were typically multi-year, collaborative efforts involving several researchers and multiple locations. Currently, participatory breeding is carried out only with small-scale farmers, not home gardeners. This review identified and described aspects of participatory breeding and feedback strategies that could be applied to research in the United States.

Defining Participatory Plant Breeding

There are several definitions of participatory plant breeding. One of the more succinct is "a type of breeding which is done in collaboration with farmers and is based on selection for specific adaptation" (Ceccarelli, Guimaraes, & Weltzein, 2009, p.133). While some definitions differ in details, a few aspects remain the same. It is a process in which a professional plant breeder, typically working for a university or internal crop improvement center, collaborates with farmers to develop new cultivars (Dawson, Murphy, & Jones, 2008). The breeder seeks to "fit crops to the environment, not environments to crops" (Mendum & Glenna, 2010, p. 82).

"Clearly, there are many different types of interactions a plant breeder can have with the public, but only some are considered participatory plant breeding." Morris and Bellon contrast a global approach to a participatory approach and describe the advantages and disadvantages of each (2004, p. 23). The global approach eliminates redundancies by creating a central plant material repository, allows for exchange of germplasm between participating breeding programs, and easily facilitates multi-location testing of similar or identical research plots at different testing sites. However, it is challenging for global plant breeding to breed for a wide variety of diverse environments. Global schemes may also have weak links to the end uses for which the cultivars are developed, and do not typically include testing on farms where the new cultivar will be grown (Whitcombe et al., 2005).

Therefore, a local, or participatory aspect to the plant breeding process has several advantages over a global approach. First, participatory plant breeding is suitable for developing cultivars that perform well in specific environments, geographical areas, or under certain management conditions. It increases the chance that farmers will adopt and grow the new

selection as they have a relationship with a local plant breeder who has previously sought their feedback on potential new cultivars (Ceccarelli et al., 2009).

Despite these benefits, there can be some shortcomings to adopting participatory plant breeding strategies. This includes a higher cost to breeding programs, as participatory plant breeders work in a smaller geographic area and spend time working extensively with farmers, both of which require the investment of time and money. Participatory plant breeding also requires an investment from famers of time, land, and inputs to trial new selections (Morris & Bellon, 2004).

Plant breeders using participatory initiatives seek farmer participation in several areas of the breeding process. This includes information sharing on the economic, physical, and technological resources to which the farmers have access. It also includes an understanding of the tradeoffs farmers are willing to accept (Asrat, Yesuf, Carlsson, & Wale, 2010). With the understanding that there is no perfect crop plant, growers share with the plant breeder what the most important crop characteristics are, which are the least important, and which would be beneficial but not necessary. For example, growers may be limited by a short growing season. A promising new selection that does not mature in a typical season will be unacceptable, regardless of other traits (Li, Lammerts van Bueren, Jiggins, & Leeuwis, 2012).

Some farmers may contribute seed of current preferred selections to researchers, especially if they are less common or have not previously been used as a germplasm resource. Farmer participation can also include asking farmers to grow trials of new selections on their farms. The farmer, researcher, or both working together can conduct these on farm trials (Barcellini, Prost, & Cerf, 2015). This allows the researcher to observe the selections under realistic conditions outside of more precise research environments. Ultimately, this participation

leads to greater success in the adoption of improved crop cultivars, as the farmer has been consulted and included during the cultivar development and trialing process. (Jalleta, 2004).

Farmers in marginal or variable areas prefer yield stability to high, but sometimes variable yields. For example, famers working with the wheat breeding program at Washington State University indicated that they would rather grow cultivars that consistently yielded 40 bushels per acre instead of cultivars that could yield up to 60 bushels but sometimes only 20 bushels under challenging environmental conditions (Dawson et al., 2008b).

Participatory plant breeding is best suited to a specific set of circumstances. First, it is most commonly used in areas that are not used for large-scale crop production. These large operations typically have a lower tolerance for crop variability or multiple cultivars grown in the same area, necessitating different planting and harvest dates and machinery (Chiffoleau & Desclaux, 2006). Second, it is more common in minor crops that have not been the focus of large-scale, formal plant breeding efforts. Participatory plant breeding is also effective when crop users are diverse, locally unique, or use the crop in a distinct way from other users. This strategy is more effective in marginal areas with variable or extreme environments such that a selection strategy must account for selection resilience (Vom Brocke et al., 2010).

Most research on participatory plant breeding has been carried out in self-pollinating crops, such as rice and barley. Self-pollinating crops do not require labor-intensive pollen collection and manual pollination, saving farmer and researcher time. Additionally, the edible part of the plant is also the seed, so farmers do not have to change their harvest technique or harvest a non-food portion of the crop to save seed (Li, Lammerts van Bueren, Huang, Qin, & Song, 2013). Finally, participatory plant breeding is most successful in areas with complex agronomic processes, such as intercropping, silvaculture, or terracing, and in low-input

environments with limited access to modern agricultural technology (Myers, McKenzie, & Voorips, 2011).

There are many circumstances where participatory plant breeding is less appropriate. This includes areas where crop end users have similar expectations for a product, or value uniformity and consistency in the crop product. When farmers have access to many agricultural inputs and technologies, such as fertilizers, pesticides, irrigation systems, and tractors for tillage, planting, and harvesting, participatory initiatives may not fit within the defined framework. If a farmer has access to and is satisfied with the results from soil amendments, it is less necessary to identify a crop selection that needs low nutritional inputs. Finally, when a crop is grown over a large, uniform area with similar weather and climate patterns, a locally adapted approach is unnecessary (Almekinders, Mertens, van Loon, & van Bueren, 2014).

While not all participatory plant breeding program are identical, most involve the following six characteristics:

1. Farmers and breeders discuss their objectives for the participatory plant breeding program. This includes an understanding of the agronomic traits desired by farmers and a realistic understanding of what the plant breeder can accomplish based on the project timeline. Famers and breeders can also determine what genetic material will be used in the program, such as landraces, modern cultivars, or existing material the breeder has developed.
2. The farmers evaluate material in their fields at an early stage of the breeding program. In early stages of this program, farmers could evaluate only a few plants of a potential new selection. Decision making can be based on ranking strategies, or choosing a selection if it is better than the other choice.

3. Farmers are consulted in major decisions of the breeding project. This is especially relevant in choosing which material to keep and discard. Farmers can also suggest changes to the selection and evaluation strategy.

4. Selection is decentralized and focused on specific adaptation. Each location is considered independently, and a selection is not discarded at one location due to its performance at another. That is, a farmer will not be forced to stop evaluation of a selection only because it performs poorly at other sites in a region.

5. The breeder provides agronomic guidelines based on his or her knowledge of the selection, its pedigree, or likely response to weather conditions in the evaluation locations. However, farmers are encouraged to treat the selections according to their normal agronomic practices to determine if a selection will be successful. This can include using organic management, intercropping, and different crop rotations. Further, this information may be useful in developing cultivar specific management practices.

6. While program objectives are determined at the beginning of the program, they are continually monitored by the breeder and participating farmers. Farmers and breeders may suggest changes or improvements to the program based on selection performance (Weltzein & Christinck, 2009).

Some of the variability in participatory plant breeding programs is based on famer goals. When breeders focus on developing a cultivar for resistance to a specific disease, on-station evaluation may be more relevant when a breeder can do controlled inoculation studies, which should not be carried out on a farm. Additionally, if there are known markers for resistance to this disease, researchers may screen for that marker before giving seed to a farmer for evaluation (Ceccarelli, 2014).

Participatory Variety Selection

Some researchers believe that farmers do not need to participate in all aspects of the breeding process. Farmers cannot always be expected to profitably grow crops and work as a surrogate plant breeder. It may be most helpful to the breeding process to have farmers involved at the beginning and end stages of a breeding program (Walker, 2006). This means farmers would help with setting goals and selection criteria for a program, and would evaluate a few well-chosen new selections that the plant breeder believes are superior (Courtois et al., 2001).

This is called participatory variety selection and is often used interchangeably with participatory plant breeding. However, there are some key differences. It is part of participatory plant breeding and involves seeking farmer feedback on a few promising selections developed by plant breeders. Especially in traditional plant breeding programs that do not use genetic marker technology, many early generation selections must be screened or evaluated to identify a few superior lines. Plant breeders typically do this work by growing a few plants of each selection, and rejecting selections that display low yield, high disease susceptibility, or unsuitable season length requirements. Therefore, farmers are invited to the evaluation process once researchers have narrowed the selection pool to a few potential selections and a large enough seed source has been produced. Participatory variety selection is the most commonly used aspect of participatory plant breeding (Li et al., 2013).

Participatory Plant Breeding and Organic Agriculture

PPB may be especially relevant to organic farmers. Cultivars that are bred and evaluated under conventional methods can be grow organically, but may not be suited for organic cultivation (Wayman et al., 2016). For example, a particular vegetable cultivar may have acceptable resistance to common pests using conventional pesticides, but the organic alternatives

may fail to control the pests, making the new cultivar inappropriate for organic management (Reid, Yang, Salmon, Navabi, & Spaner, 2010). Crops grown organically tend to have lower yields then their conventional counterparts, in some cases due to higher pest and disease incidence, as well as limited options for controlling them (Murphy, Campbell, Lyon, & Jones, 2007). A recent literature review of 155 studies found that organic yields were 19.2 percent lower than conventional yields (Ponisio, M'Gonigle, Mace, Palomino, de Valpine, & Kremen, 2015). One important reason for this gap is the production of crops bred for conventional conditions using organic management. This means that cultivars were developed that have acceptable yields, resistance to pests and diseases, and other agronomic traits under typical applications of fertilizers, insecticides, and fungicides. Breeders therefore select for response to management practices, not necessarily for innate resistance to a pest without chemical control (Torricelli, Negri, & Ciancaleoni, 2014).

Low-input and organic farms typically face a wider range of environmental conditions that must be adapted to, rather than corrected with pesticides, insecticides, or synthetic fertilizers, as is the case on conventional farms (Ghaouti, Vogt-Kaute, & Link, 2008). By emphasizing the development of locally adapted cultivars, participatory plant breeding is especially relevant for organic producers who have fewer "tools" to treat problems during the growing season. Cultivars developed specifically for a given environment will likely be more resistant to common pests and diseases, and be well adapted to local soil types and environmental conditions (Shelton & Tracy, 2016). Organic farmers also value cultivars that can compete with weeds, are adaptable to intercropping, and exhibit higher yields in response to organic soil amendments (Sooby, Landeck, & Lipson, 2007).

In fact, these conditions make organic farmers more similar to farmers in less developed countries farming on marginal land with few resources. Both organic farmers and farmers in developing countries grow crops using low input systems (Kamran, Kubota, Yang, Randhawa, & Spaner, 2014). While American organic famers choose to limit the fertilizers and pesticides they can use, farmers in developing countries have limited access to these resources due to supply or cost. Some organic farmers have chosen to limit off-farm inputs by growing cover crops or raising organic livestock for manure (Singh, Teran, Lema, & Hayes, 2011). Both farm environments are more heterogeneous than conventional farms in terms of environmental stresses (Dawson et al., 2008b). However, low off-farm input does not necessarily mean low soil fertility and poor yields, as many farmers in both the United States and developing countries maintain high soil fertility using green manure, crop rotation, and animal manure. While participatory plant breeding may not be relevant to large scale, commercial agriculture, it can be a beneficial approach to cultivar development on organic farms (Desclaux, 2005).

Qualitative Feedback

In past participatory plant breeding projects, farmers have provided qualitative feedback to plant breeders on the selections that are trialed. One project on organic tomatoes in Italy asked farmers to provide feedback using a zero to four scale, with a score of zero indicating very bad and four indicating very good. Using this scale, farmers described plant development, vigor, health, fruiting, rot, splits in fruit, trueness to type size and shape, incidence of green shoulder, earliness, and resistance to over ripening. Researchers noted that exact physiological data may have been more directly useful to plant breeders, such as the marketable weight of fruit from each plant, average number of rotten tomatoes per plant, and plant weight instead of vigor.

However, the farmers in this study chose new selections based on these qualitative traits and did not collect this quantitative data (Campanelli et al., 2015)

In a participatory plant breeding program in Germany, famers grew 49 cultivars of fava beans using their standard agronomic practices at five different farms. They used a nine-point scale to describe lodging, incidence of Botrytis, and plant maturity. Additionally, they visually estimated yield at maturity and scored it based on the same scale. They also noted their "personal appreciation" for the selection, taking into account performance over the season, disease resistance, and yield. Researchers found that the farmers personal appreciation was highly correlated to visual estimation of yield and actual yield as measured after harvest. Additionally, two farm sites displayed significant positive correlation between locations, suggesting that selections chosen by one farm would likely be acceptable at the other (Ghaouti et al., 2008).

Evaluating Qualitative Feedback

One method of determining the validity of famer feedback is to compare it to breeder feedback on the same selection. In India, local farmers evaluated sets of 15 selections of rice at 12 locations. Researchers compared the qualitative scores assigned by the farmers at each location against both the breeder score at that location and scores given by famers growing the same selection at a different location. They found high concordance between breeder and farmer scores, but did not determine statistical significance due to the small sample size of plant breeders. They also found that farmer scores between locations were not as concordant, demonstrating that differing environmental conditions, irrigation practices, weather, or market preferences caused the farmers to prefer different cultivars at their different locations (Courtois et al., 2001).

All approaches for collecting farmer feedback have trade-offs between many requirements, such as scalability, replicability, ease of collecting data, and granularity, which is the ability to group and analyze data by groups of famers beyond the aggregate sample. Appraisal, used in participatory plant breeding to indicate a discussion between farmers and the breeder on the merits of the plants throughout the season can yield highly granular data, but requires significant time and facilitation skills. Conversely, quantitative methods yield replicable data if farmers have been taught a standardized method of data collection for yield, disease incidence, and plant maturity (Smajgl & Ward, 2015). Ranking plants in order of preference is rapid, locally adapted, and does not require specialized training. However, they can provide a limited view of farmer priorities if the farmers do not discuss the rationale behind their rankings (Annicchiarico, 2007).

Finally, stated choice, or asking farmers to choose one selection over another can easily include many respondents, but is time-intensive and requires a series of quick decisions for growers who have ideas and preferences for cultivars, but may not have compared all cultivars to the others before the stated-choice activity (Joshi et al., 2012). All of these feedback strategies involve some degree of time and financial investment. Especially when the plant breeder is required to be present during farmer reporting at multiples sites, the amount of time required to hear and understand farmer feedback is a major portion of a participatory breeding project (Humphries et al., 2015).

A group of researchers that studied participatory bean breeding in nine locations in Honduras developed a card game that famers could play with scientists or other project representatives. Farmers were offered a choice between two cards that depicted agronomic traits. In one example, famers were asked to choose between a selection with lower yield and higher

pest resistance, or a slightly higher yield with less pest resistance. This was drawn in Figure 1 with beans representing yield and pictures showing the amount of pest damage.

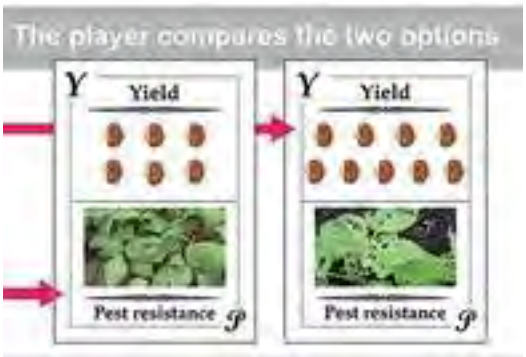


Figure 1. A forced choice card created by Steinke and van Etten (2017).

This game could be played with an individual or with a group, asking people to raise their hand or move to one side to indicate preference for a card. The researchers recorded each person's answer, and later compared it to previously collected demographic data, such as gender, age, farm location, farm size, and main crop grown. The scientists analyzed the data at each location and compared the data between each of the nine locations to create a set of breeder priorities at each location. They also noted which locations had similar priorities, suggesting that these locations may accept many of the same selections. The researchers found that famers at all locations were willing to accept lower yields and poorer market quality in exchange for pest resistance, good taste, and a specific plant size and architecture (Steinke & van Etten, 2017).

Participatory breeding programs can sometimes yield incomplete data sets. There may be a different number of replicates in each treatment at each location or between locations, differences in agronomic practices such as fertility, irrigation, and disease management, and observations recorded at different times in the growing season. Additionally, it can be challenging to compare scores based on qualitative scales, such as scoring a selection on grain set from one to five with one indicating very poor set and five describing excellent grain set.

Unless farmers have been instructed in how and when to score the plants, a rating of three from one farmer may differ from another farmer awarding a score of three (Steinke, van Etten, & Zelan, 2017). In large studies that have multiple replications at several farms in more than one heterogeneous region, some statistical tools can help researchers understand and interpret their data. This includes using a mixed-models approach of stability analysis and a variance-covariance matrix. Both tools can account for the interaction of the treatment by the environment, and measure treatment stability across multiple environments (Raman, Ladha, Kumar, Sharma, & Piepho, 2011).

The Role of Cooperative Extension Services in Participatory Plant Breeding

One challenge of participatory plant breeding is that it requires the plant breeder to take on the role of a Cooperative Extension agent in addition to their normal duties. In many cases, a plant breeder is only tangentially involved in Extension, and does not both create new cultivars and develop relationships with farmers, encourage them to trial new plants, and incorporate the feedback into their breeding program (Morris & Bellon, 2010). Some participatory plant breeding initiatives incorporate Cooperative Extension personnel as liaisons between plant breeders and farmers. Extension agents can work closely with both parties and use their expertise in agriculture or horticulture to assist in the cultivar development and selection process (McKinley et al., 2017). Additionally, Extension personnel may have existing relationships with farmers prior to a participatory breeding initiative, and can provide credibility to a plant breeder, convincing otherwise hesitant farmers of the benefits of participation (van de Fliert & Braun, 2002).

Depending on project funding, some participatory breeding projects may have the resources to hire and train scientists to facilitate farmer feedback sessions and accurately report

information to the plant breeder. Agriculture students, Non-Governmental Organization (NGO) employees, or others working in agriculture can be trained to receive and understand farmer feedback in some circumstances, reducing both the cost to and time investment from the plant breeder (Bowser et al., 2014). This strategy works best when feedback methods are not overly technical, using tools such as Likert-type scales, yes or no questions, and asking farmers to select from a list of pre-written statements such as “this selection was mature at harvest time,” or “this selection grew under my typical watering strategy” (Ponti, Hillman, & Stankovic, 2015).

If a breeder is present only during planting and at harvest, farmers may alter experimental protocols or stop evaluating the selections. This is more likely if farmers are unclear about the benefits that participatory breeding provide, what their role and responsibilities are, and why they were asked to collect and record data at certain points in the growing season. In one example, a farmer assumed that the plant breeder would be collecting data throughout the growing season, and did not record disease pressure and incidence, date of flowering, and crop height. This lack of data prevented the breeder from providing a recommendation for the selection. The researchers provide a contrasting example with regular visits from a Cooperative Extension agent familiar with plant breeding research. Frequent, scheduled check-ins can also provide informal feedback opportunities as growers discuss the qualities they have noticed in selections under evaluation (Hauser, Lindtner, Preshler, & Probst, 2016).

Relative Efficiency of Participatory Plant Breeding

The relative efficiency of any plant breeding initiative, including a participatory breeding project, can be assessed using three factors: first, the ratio between the number of cultivars adopted to the number of crosses performed, second; the response to selection; and third, the cost to benefit ratio (Witcombe, Gyawali, Subedi, Virk, & Joshi, 2013). One challenge in comparing

the efficiency of participatory plant breeding to typical plant breeding is that adoption occurs during selection and before formal cultivar release in participatory plant breeding, but the reverse is true in conventional plant breeding (Maredia & Raitzer, 2010). The number of released cultivars overestimates breeding efficiency, as a released cultivar that is never adopted by farmers does not benefit for them. Percent adoption can range from ten to 90 percent based on literature from the past 30 years (Ceccarelli, Grando, & Capettini, 2011; Kelley, Rao, Weltzein, & Purohit, 1996). Yield is only one of many criteria farmers use when choosing to adopt a selection, so higher yields do not guarantee farmer adoption (Aw-Hassan, Mazid, & Salahieh, 2008).

Participatory plant breeding initiatives may have access to greenhouses or off-site nurseries in warmer climates, which allow breeders more opportunities to evaluate selections or to increase seed of promising selections more quickly (Annicchiarico, 2007). Decentralized selection in the target environments early in the evaluation process of a breeding program can increase response to selection. This is because research stations and other highly controlled sites cannot capture the range of agronomic practices that famers use (Murphy, Lammer, Lyon, Carter, & Jones, 2004). In typical, university led plant breeding programs, final stages of evaluation are carried out at a few grower fields. While plant breeding research stations may be more precise in measuring weather, inputs, and yield, the selections chosen in this environment may not be directly relevant to on-farm environments of potential adopters. This is further complicated by fact that new cultivars take many years to develop. Between the time a farmer chooses breeding priorities and later develops a new cultivar, farmer priorities may change. These changed priorities may decrease the rate of adoption of new selections (Cullis, Smith, & Coombes, 2006).

Limited seed availability of the early-generation selections can cause the plant breeder to limit initial selection evaluation to research stations. However, early stage evaluation typically focuses on evaluating a selection as a poorer or better performer than a standard cultivar. This relies on a ranking strategy to determine if a selection should continue in evaluation, as yield data is inaccurate when only a few plants are grown. This can be done successfully on farms, allowing farmers to make better than/ poorer than decisions, limiting evaluation to the most promising selections early on in the selection scheme (Wolfe et al., 2008).

Participatory plant breeding can be more expensive than comparable breeding programs due to the time investment, multi-site testing, and organizing many farmers. However, these costs can be combatted by the strategies to increase efficiency described above. Three studies in the last 20 years have found no cost difference between PPB and conventional breeding programs (Mangione, Senni, Puccioni, Grando, & Ceccarelli, 2006; Smale et al., 2003; & Ceccarelli, Galie, Mustafa, & Grando, 2012). These studies evaluated participatory breeding initiatives in Mexico and Syria. The researchers found that the rate of adoption was higher in participatory programs, and that yield gains were comparable. Additionally, the researchers in Mexico identified multiple social benefits, which are hard to measure and quantify. This included more farmer interaction during and after the program, an increased willingness to share seed and genetic resources between farmers, and increased community engagement of women famers in the project (Smale et al., 2003).

Finally, participatory plant breeding can have larger environmental benefits. Like social benefits, the benefit to the environment is difficult to measure and has not been extensively studied. When implemented in several regions, plant breeding can increase the diversity of crops grown, called agrobiodiversity (Cardinale, Duffy, Gonzalez, Hooper, Perrings, & Venail, 2012).

This can make an area with multiple crop cultivars more resilient in the face of pests and diseases (Crowder, Northfield, Strand, & Snyder, 2010). Additionally, the continued evaluation and improvement of crop cultivars allows farmers to be more resilient in the face of severe and extreme weather, and therefore climate change (Hooper, Adair, Cardinale, Byrnes, Hungate, & Matulich, 2012). In fact, participatory plant breeding was recommended in a recent report to the United Nations on the Right to Food (DeSchutter, 2014).

Previous Participatory Plant Breeding Projects in the United States

Farmer Interest in PPB at Washington State University

Some research has been carried out in the United States using participatory breeding projects. In Washington State, researchers identified wheat farmer demographics that made them more likely to be interested in a participatory plant breeding project. First, younger farmers and those with fewer years of experience farming were more interested. This is likely because they were more willing to invest time in a long-term project that would take many years to produce benefits. They were also more willing to experiment with different methods of production and crop cultivars, while older farmers used production practices and crop types they knew worked well on their farms. Additionally, famers with more education were more interested in participatory plant breeding. Researchers speculated that a college education, specifically at a land-grant institution, would make farmers familiar with Washington State University, which was leading the participatory breeding program. The majority of famers surveyed were graduates of Washington State University, and were more likely to know of the researchers involved in the project.

Interestingly, larger farm size was correlated with a greater interest in participatory plant breeding. This appears to be contradictory to the belief that participatory plant breeding is most

relevant to small farmers, but there are several explanations. First, those with large farms are likely to have marginal fields or areas that consistently support poor yields or disease. Second, the researchers reported that larger farmers tend to have more resources, including labor and capital, to devote to a participatory breeding project. Third, large farms may have their own research and development program, and are able to conduct on-site research. Larger farms that have this infrastructure in place and employees who already conduct research on the farm may be more easily able to incorporate participatory plant breeding. Finally, some larger farmers may have become successful partially by innovating and trying new practices. They may then be more likely to have favorable perceptions of other types of experimentation.

Farmers who saved their own seed, grew three or more public wheat cultivars, and were interested in transitioning land to certified organic practices were also likely to be interested in participatory breeding. Those who have had past positive experiences with Washington State University Cooperative Extension and research faculty had more favorable attitudes towards participatory breeding activities. This demographic data indicates that while not all American farmers are interested in participatory plant breeding, there are groups of interested famers who believe they can benefit from including in the plant breeding process (Dawson & Goldberger, 2008).

The Seed Project

Mendum and Gelnna (2010) organized a six-year participatory plant breeding initiative in the United States between 2001 and 2007. They worked with 250 organic farmers in the northeast United States with farms between 20 and 1500 acres. Most farmers primarily grew vegetables, but some also raised livestock and grew forage crops. Called the Seed Project, this initiative resulted in five vegetable cultivars suited for organic production in the northeast,

including two pepper cultivars resistant to cucumber mosaic virus, three improved melon cultivars, and one broccoli cultivar. Farmers grew selections outdoors during the growing season, and university plant breeders grew them during the winter in greenhouses, accelerating the breeding process.

One of the obstacles in this project was that university plant breeders typically had strong connections to conventional farmers who grew a target crop on a large scale and had space to conduct multiple on-farm trials each year. Organic growers felt that they were less connected with academic plant breeders. Additionally, farmers described consumer preference as a challenge when purchasing seed created bred for conventional agricultural and growing it under organic conditions. Especially at farmers markets or Community Supported Agriculture programs (CSAs), consumer preference can differ widely by region. One farmer mentioned that his CSA customers disliked a cucumber cultivar because it was not the "correct" shade of green. Another farmer mentioned that because he sold all of his produce locally, long-storing cultivars necessary for commercial production were not useful for his operation. Finally, farmers described the need to have unique cultivars that the grocery store and other farmers do not have. The ability to differentiate themselves was important to small farmers who relied on personal connections with repeat customers (Mendum & Gelnna, 2010).

Open Pollinated Sweet Corn

Researchers in Minnesota studied participatory plant breeding in sweet corn between 2008 and 2013. In the first four years of the study, the farmer and corn breeder made selections based on important traits identified by the farmer. Between 2012 and 2013, the selections were grown at two other, similar farms, and were evaluated for suitability using a randomized complete block design. All selections evaluated were produced by crossing publicly available

hybrid cultivars. The progeny of these crosses was cross pollinated by hand to produce the final selection population. The breeder and farmer evaluated each selection when the plants were at the "eating stage," or ready for consumer purchase. They used a one to five scale to rate common rust resistance, cob tip fill, ear shape, kernel flavor, and kernel tenderness. If any selection displayed symptoms of corn smut (*Ustilago maydis*), it was discarded, despite other characteristics (Shelton & Tracy, 2015).

While all traits evaluated by the breeder and farmer were important, flavor and tenderness were weighted heavily, with no selection scoring a three or below advanced for further evaluation in the next year. The researchers found that in four cycles of selection, the farmers chose selections that had a statistically significantly higher number of kernel rows, stand counts, and fewer days to silking compared to selections available at the beginning of selection. Before the first selection cycle, the farmers rated the average flavor of selections as 2.8. At the end of four selection cycles, the average flavor rating of remaining selections was higher at 3.6. Additionally, farmers at all three locations chose selections with long, tight husks, which can deter corn earworm and decrease crop losses (Shelton & Tracy, 2015).

The researchers concluded that the farmer-breeder collaboration resulted in agronomic trait gains over the four selection and two evaluation cycles. Selection of traits important to organic corn growers, such as rust resistance, husk protection, and soil germination were not evaluated in this study, but were identified as topics for future research (Shelton & Tracy, 2015).

Intellectual Property in Participatory Plant Breeding

Plant breeders employed by land-grant universities are expected to produce cultivars that are available to everyone. However, private breeding programs must profit from and retain ownership of the cultivars they create. Laws such as the Bayh-Doyle Act of 1980 allows public

plant breeders to describe their work as intellectual property, and in some cases obtain Plant Variety Protection. The intellectual property of a plant breeding program is subject to a Materials Transfer Agreement (MTA) when a famer evaluates a new selection created by that program. In some cases, MTAs prohibit crossing the selection, while in other cases it is at the digression of the breeder. Additionally, there can be fees associated with evaluating a university-produced selection. While some research programs are able to provide seed for free, others must charge farmers for seed, shipping costs, or special packaging. When a farmer sells a selection to consumers, he may also pay a fee to the breeding program, typically a small percentage of profits from that selection (Kloppenburg, 2004).

In the Seed Project, MTAs were described as multi-page, complicated legal documents that were not written for famer ease of use. A challenge encountered by the project was that universities and private seed companies have their own procedures for allowing farmer evaluation, with different levels of oversight, fee structures, and restrictions on breeding a new cultivar. While the Seed Project reported that farmers understood why they had to pay the university and seed companies for the new cultivats, the authors noted that payment may be an obstacle for some farmers (Morris & Bellon, 2004).

Scale of Participatory Plant Breeding

Due to its time intensive nature, participatory plant breeding does not occur at the same scales as conventional breeding programs. The participation of multiple farmers requires significant researcher time, and many farmers have limited space and resources to devote to evaluating new crop selections. In a study of fava bean recombinant inbred lines, researchers planted 49 distinct genotypes in plots that were each 500 square feet on five farms in Germany.

Each farmer managed the trial according to typical agronomic practices for the farm (Ghaouti et al., 2008).

Ceccarelli (2014) suggested a scale where the number of initial selections to trial is determined by working in reverse. He suggested that one to three selections can realistically be selected after four years of evaluation at a given location, from an elite population of five potential selections. In the previous or third year, about 20 percent of material is selected for further evaluation. In the second year, about 15 percent are selected, while about ten percent are selected during the first evaluation year. Using a final goal of three selections, farmers would then alter the number of selections chosen after the first year based on initial trial size. Therefore, in a scenario with enough time, land, and grower attention, a farmer could evaluate up to 1,667 selections in the fist year, with breeder instruction to choose only the top 167 selections (Ceccarelli, 2014).

One factor that limits the scale of participatory plant breeding is the need to involve many farmers to evaluate selections. This is complicated by multi-region trials where each region is treated independently, and multiple farmers are needed in each region. As selection becomes more precise in subsequent years and breeders and farmers can incorporate past yield and disease data into decision-making strategies, trial locations should increase (Douthwaithe & Hoffecker, 2017). One strategy to maximize the efficiency of on-farm trials is to have one grower in each location conduct evaluations during the first two years of the selection scenario described above. In the third year, a second farm site is added, and in the fourth and final year, thee to five farmers at each location should grow and evaluate the selection (Reguieg et al., 2013). This increased feedback at later stages is especially important as farmers choose between more advanced and increasingly locally adapted selections. This strategy can combat a limitation of participatory

plant breeding, which is the coordination of and data collection from multiple farmers. In this scheme, the number of selections under evaluation decreases as the number of farmers increase. More farmers will then provide feedback on later years of evaluation as they trial advanced material (Ceccarelli, 2014).

Funding Participatory Plant Breeding Research in the United States

In the past 20 years, grant requests for proposals (RFPs) have favored funding short-term, cutting-edge research of national importance over longer research projects focusing on state-level issues (Sparger, Norton, Heisey, & Alwang, 2013). Because the result of a participatory plant breeding project is the creation, identification, and production of locally adapted cultivars, it does not readily scale to the national level. Additionally, it is often carried out over multiple years as farmers grow selections under different weather conditions, and evaluate different storage and marketing strategies. Individual farmers are most likely to see direct benefits of cultivars developed by participatory plant breeding, with indirect benefits to consumers in the forms of increased choice, taste, and perceived quality (Eksvard & Rydberg, 2010). Again, because the result is locally adapted, few farmers outside of the target region would benefit. These characteristics can limit the types of funding sources available for participatory plant breeding (Huffman, Norton, Traxler, Frisvold, & Foltz, 2006).

CHAPTER 3 – METHODOLOGY, RESULTS, DISCUSSION, AND CONCLUSIONS

Methodology

In the spring of 2016, the Colorado Potato Breeding and Selection Program Home Gardener Evaluation Program, also called the Gardener Evaluation Program, began. Because this research involved human subjects, a protocol was submitted to the Colorado State University Institutional Review Board using eProtocol. The Review Board determined that this research was exempt and could proceed (see Appendix A). In March 2016, seven Colorado State University Cooperative Extension county directors were contacted and asked for their cooperation. They were in the following counties: Archuleta, Boulder, Custer, Gilpin, Gunnison, Summit, and Teller. Especially in rural counties far from the Front Range, county directors often have horticulture responsibilities when there is no dedicated horticulture agent. These county directors agreed to participate and identify Master Gardeners and other community members interested in trialing one or two potato selections during the summer. The county directors were given an advertising flier and a letter explaining their time commitment and responsibilities (see Appendices B & C).

Six specialty potatoes were chosen for evaluation. Specialty potatoes refer to potato selections that are not russet or chip potatoes. They often have distinct characteristics, such as a fingerling shape, colored skin, or colored flesh. These selections were CO00405-1RF, CO04067-8R/Y, CO05028-4P/PY, CO05028-11P/RWP, CO05037-2R/Y, and CO05037-3W/Y. The letters after the dash indicate the potato appearance, with F describing a fingerling type, R/Y describing a potato with red skin and yellow flesh, and P/PY describing a potato with purple skin and purple and yellow flesh. P/RWP describes a potato that has purple skin and a variable amount of red, purple, and white flesh. These selections were chosen for several reasons. First, processing

russets are the main priority of the Colorado Potato Breeding and Selection program, but home gardeners do not have access to commercial storage facility or french fry plants where important evaluation determines if a selection is suitable for commercial production. Likewise, home gardeners do not have commercial chipping facilities to determine the success of a chip or round white processing selection. While some gardeners may prefer to evaluate russet or round white potatoes, anecdotal evidence from discussions with gardeners suggested that home gardener preferred to grow specialty potatoes. Second, specialty potatoes tend to have unique traits that make them attractive to consumers. Since the home gardeners are also consumers, they can evaluate potato selections based on what they expect to purchase at a grocery store or farmers market. Finally, due to their unique traits, specialty potatoes may be acceptable even with lower yields or a variable size profile that is unacceptable for russet and round white cultivars. This "trade off" can be recognized by home gardeners, who do not rely on potatoes as their source of income, and who may be willing to accept a potato with some perceived negative traits if it has excellent flavor or a distinctive appearance. While these potatoes may not be grown on a commercial scale, they may be suitable for sale at a farmers market, specialty grocery store, or garden center (Holm, 2018).

The potatoes were chosen because they were designated as "advanced selections," or potato selections that had been evaluated by the Potato Breeding and Selection Program for at least five years and were available for potato famers to evaluate. This ensured there was an adequate seed source available and that gardeners could grow more than one plant. Advanced selections have consistently displayed positive agronomic traits, such as acceptable yield, disease resistance, attractive appearance, and size profile, making them good candidates for commercialization (Holm, Gray, & Zavislan, 2016). Providing advanced selections to gardeners

was a targeted approach that allows them to have input on the most promising selections, instead of asking for feedback on selections that are unlikely to be successful on a commercial scale. Because the participants were home gardeners, they were unlikely to have space available to grow ten different potato plantings in their backyards. Instead, they grew one or two selections which used less space than screening earlier generation material.

Master Gardeners are volunteers trained in horticulture and gardening practices by Colorado State University Extension staff. They promote the mission of Colorado State University Cooperative Extension by sharing gardening information via classes, workshops, articles, garden help phone lines, and staffing booths at community events. They were chosen as participants in this research because they had previous gardening experience, were already community volunteers, and were interested in furthering the mission of Colorado State University (Small, 2017). Other community members who were not Master Gardeners were also able to participate, both to increase the number of participants and to include interested people who may not be able to participate in the Master Gardener program.

After each of the seven county directors confirmed the number of participants for the growing season, the Potato Breeding and Selection Program bagged, labeled, and shipped the potato seed to each county, and included evaluation forms and letters to gardeners (see Appendices D & E). County Directors were also sent a brief PowerPoint presentation to share with participants that had images and definitions of some of the technical terms used in the survey (see Appendix F). Seed was shipped to each county for gardener pick up in April of 2016. Most county directors chose to keep the box of potato tubers in their office, alert participants that potatoes were available for pickup, and allowed participants to get their potatoes during business hours.

During the summer, participants grew about five potato plants of either one or two different selections in their gardeners. They were instructed to treat the potato plants as a normal part of their garden, and to water and fertilize them as they would any other potatoes. Participants returned their completed evaluation forms to the Potato Breeding and Selection Program at the end of the growing season after they harvested their potatoes. This typically happened in October, but some evaluations were returned as late as January the following year.

The evaluation form was a two-page documents that asked gardeners about their garden, level of expertise, planting and harvest dates, irrigation practices, the incidence of severe weather, pests and diseases, and potato tuber defects. It also included a sensory evaluation where gardeners rated taste, texture, and aroma of the potatoes, as well as a question on preparation method(s) used. The final questions were about the gardener's recommendations for the selection. This includes asking if the gardener would grow the selection again, if Colorado State University should continue evaluating the selection, and what the gardener liked and did not like about the potatoes they grew.

A preliminary data analysis of the surveys returned in 2016 was conducted, noting the number of responses from each county, what selection they grew, and the gardeners' overall impressions. Thirty-eight completed surveys were returned in 2016. An additional eight surveys were returned but were excluded from analysis. Two surveys were returned with only the first page completed, one did not list a selection number or description, four had half or fewer of the questions answered, and one survey was returned in the mail but had been left out in the rain and was illegible.

The program continued for a second year in 2017, which increased the number of surveys returned and allowed for continued evaluation of the same selections. Some participants grew

potatoes for two years in a row, but the 2017 survey did not ask if the respondent grew potatoes in 2016.

Methodology in 2017 was like that in 2016. The same seven County Extension Directors agreed to participate in a second year of evaluations, and provided the number of participants to the Potato Breeding and Selection Program. The potato samples were again bagged, labeled, and shipped to each county. Fifty-eight sample bags were sent to participating counties in 2016, and 62 samples in 2017. The number of bags sent to each county was either based on County Director estimation of likely participants or the number of participants they recruited before sending a final seed request. Table 1 is a breakdown of the number of potato sample bags sent to each county in 2016 and 2017.

Table 1

Potato Samples Sent to Each County in 2016 and 2017

Year	Archuleta	Boulder	Custer	Gilpin	Gunnison	Summit	Teller	Total
2016	8	12	8	9	10	5	6	58
2017	6	15	7	9	12	5	8	62
Total	14	25	15	18	22	10	14	120

In the Fall of 2017, 37 surveys were returned, of which 31 were analyzed. The six excluded surveys included two that did not include the second page, two that did not list a selection number, and two that were incomplete. Along with the results from 2016, these surveys were compiled and prepared for analysis, for a total of 69 surveys.

Findings

Table 2 lists each selection, a description of its appearance, and the number of times it was grown in 2016 and 2017. Table 3 displays the selection number and the number of times it

was grown in each county in between 2016 and 2017. All six selections were not grown in every county during both years. In some cases, no one in a particular county grew a selection, as in Summit County, where only four selections were grown, or in Archuleta, Custer, Gilpin, and Teller County, where surveys were returned for five selections. All six selections were grown in Boulder and Gunnison Counties. CO00405-1RF was grown by the most gardeners, while CO05037-2R/Y was grown by the fewest.

Table 2

Frequency of Potato Selections Grown in 2016 and 2017

Selection	Description	Number Grown in 2016	Number Grown in 2017	Total Number Grown
CO00405-1RF	Fingerling with red skin and white flesh	10	7	17
CO04067-8R/Y	Red skin and yellow flesh	3	5	8
CO05028-4P/PY	Purple skin, varying amounts of purple and yellow flesh	6	5	11
CO05028-11P/RWP	Purple skin, varying amounts of red, white, and purple flesh	8	3	11
CO05037-2R/Y	Red skin and yellow flesh, small tuber profile	2	4	6
CO05037-3W/Y	White skin and yellow flesh, small tuber profile	9	7	16

Table 3

Frequency of Potato Selections Grown in Seven Counties

Selection	Archuleta	Boulder	Custer	County Gilpin	Gunnison	Summit	Teller
CO00405-1RF	3	6	1	1	4	0	2
CO04067-8R/Y	1	2	1	2	1	1	0
CO05028-4P/PY	1	3	1	2	3	0	1
CO05028-11P/RWP	0	3	4	0	3	0	1
CO05037-2R/Y	0	2	0	1	1	1	1
CO05037-3W/Y	4	2	1	1	4	3	1
Total Number of Surveys per County	9	18	8	7	16	5	6

About half of the gardeners (33) reported that they were experts, with 34 rating their gardening skill as intermediate, and only two reporting that they were beginning gardeners. The potato planting date varied by county, but not by year. Boulder County residents planted their potatoes as early as April 20th in 2016 and April 23rd in 2017, while the earliest planting date in Teller County was May 24th in 2016 and May 20th in 2017. Residents of Gilpin, Gunnison, and Summit Counties indicated later planting dates consistent with Teller County, while Custer County gardeners planted their potatoes between early and mid-May both years.

Most respondents (47) planted potato seed directly in the ground. Potatoes were grown in raised beds 16 times during the two seasons in five counties, excluding Gilpin and Gunnison. All six selections were grown in raised beds at least once. Six survey respondents grew their potatoes in either pots or fabric bags sold by garden centers specifically for growing root crops. Gardeners had the option of indicating soil type as either primarily sand, silt, clay, or loam. Few gardeners responded to this question, but five indicated sandy soil, two selected silt, and ten chose clay

Planting depth of the garden trials is summarized in Figure 2. The majority of gardeners (39) planted their potatoes at a depth of three to five inches. This is an appropriate depth for single drop, or small potatoes that weight about two and a half ounces. Sample bags contained tubers this size so that gardeners would not have to cut the seed pieces. Twenty-seven gardeners planted their potatoes deeper, between four to more than seven inches. Three gardeners did not indicate planting depth in their surveys. Fifty-six gardeners planted the tubers as whole seed pieces, while nine gardeners cut the tubers into at least two pieces, and four gardeners did not indicate if they cut the potatoes or left them whole.

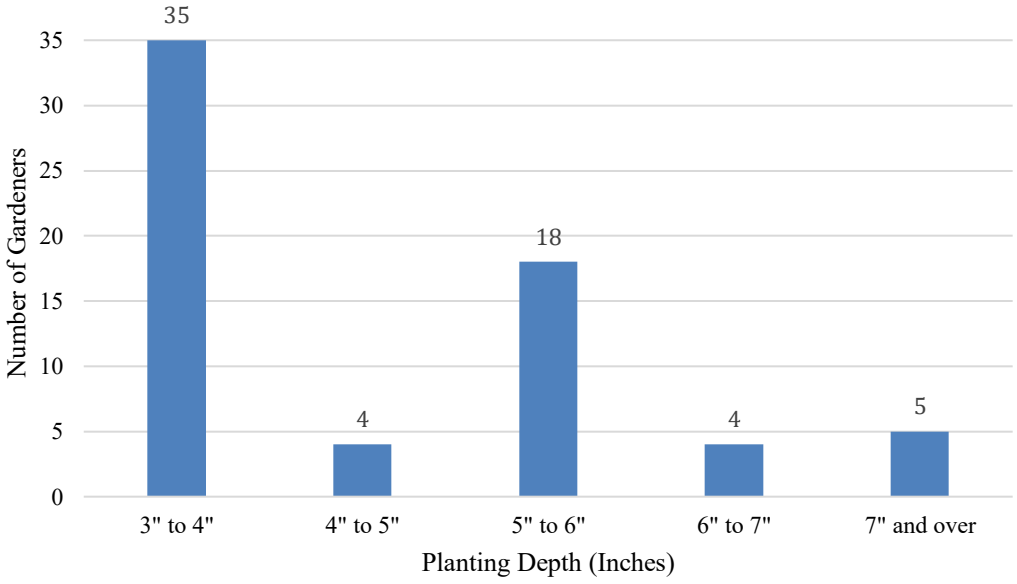


Figure 2. Frequency of planting depths.

Thirty-three surveys indicated a within-row spacing of fewer than six inches, and another thirty-three spaced the potatoes between six inches and twelve inches. One respondent used a spacing of eighteen inches, and three did not answer the question on in-row spacing.

The gardeners reported variable fertility practices during the growing season, reported in Table 3. Nine did not apply any fertilizer while they grew potatoes, while the other sixty applied a soil amendment or fertilizer at least once. Compost was the most commonly used type of

fertilizer, and five gardeners included a note that their compost was from manure. Eight gardeners applied synthetic fertilizer, with three specifically naming Miracle Grow as their method of fertilizing. Finally, of the gardeners that applied a natural, but non-compost fertilizer, three applied bone meal, two used a fish emulsion, and one applied biochar.

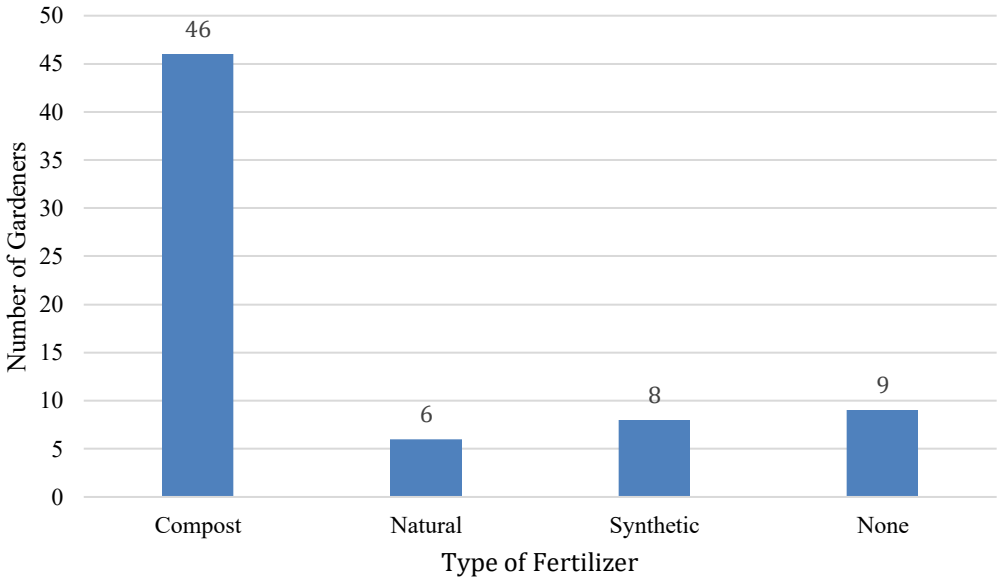


Figure 3. Type of fertilizer used.

In Figure 4, the frequency of fertilizer application also varied. Most gardeners (42) fertilized once during the growing season, with eleven responding that they applied fertilizer at the time of planting. Of those who applied fertilizer monthly, eleven used compost, four used a natural fertilizer, and two used a synthetic fertilizer. The only respondent who applied fertilizer weekly used a synthetic liquid fertilizer.

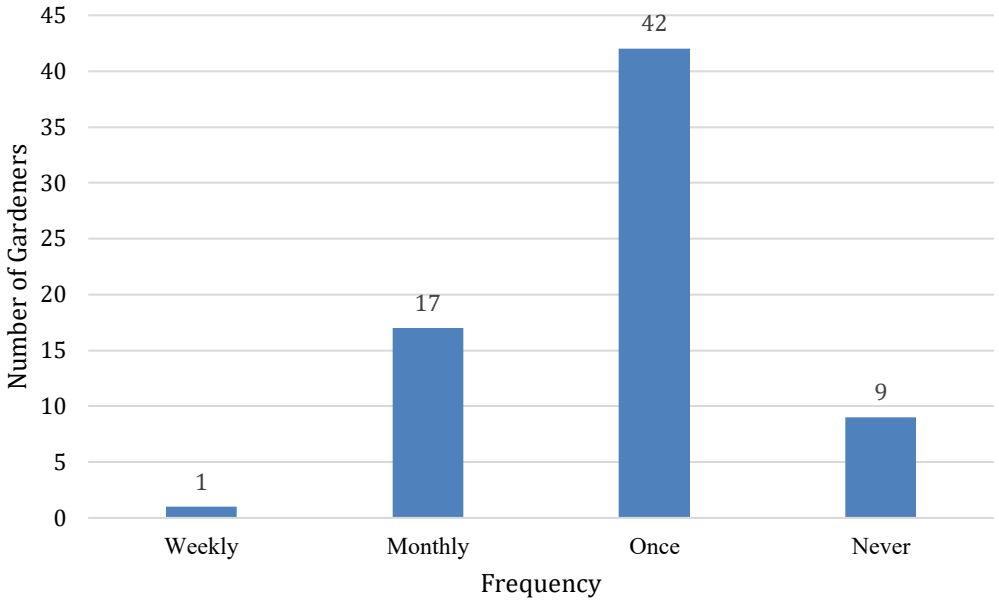


Figure 4. Frequency of fertilization.

In Figure 5, almost half of the respondents (31 surveys) used a hose to water their potatoes, while 24 used a drip irrigation system and 12 used a sprinkler, as either a built-in sprinkler system or mobile garden sprinkler. Two gardeners did not answer the question on watering practices. Gardeners were also asked about the frequency of watering and were provided responses of either every day, every two days, or every three days. The data show that most gardeners who watered every three days used a drip irrigation system, while most gardeners that watered their potatoes every two days used a hose. Most gardeners that watered daily used a sprinkler.

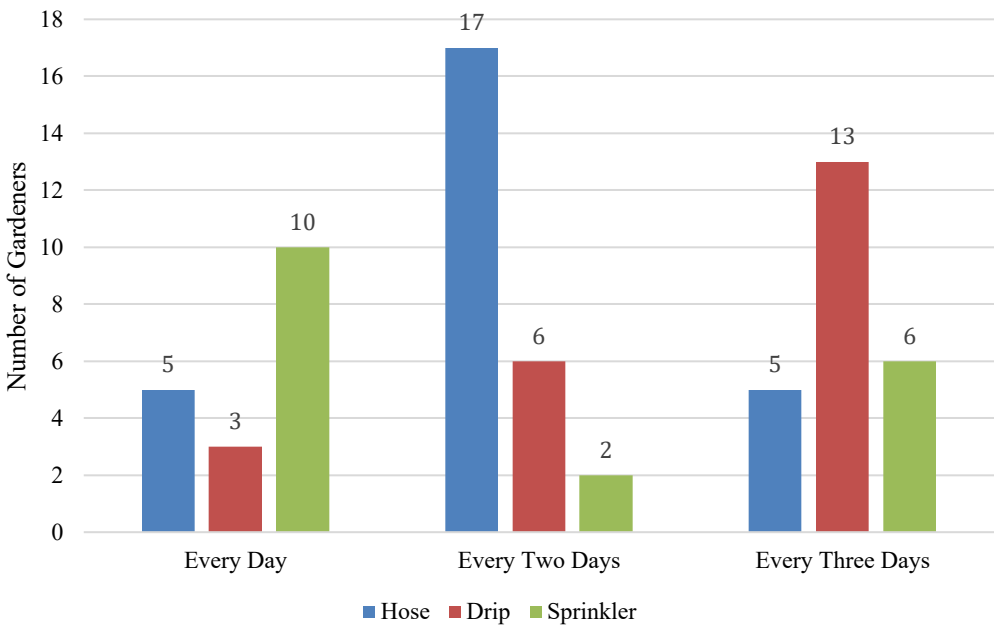


Figure 5. Watering practices and frequency.

Gardeners were asked if their gardens experienced any severe weather between planting and harvest, including hail, frost after planting, heavy rain, or drought, and responses were recorded in Figure 6. Many gardeners did not select any option, either indicating that they had no severe weather or because they chose not to reply. Of the 39 gardeners that responded to the question, nineteen selected two types of severe weather, for a total of 58 responses. Heavy rain was the most commonly reported weather event, with equal numbers of hail and frosts after planting reported. Seven surveys reported that gardeners experienced drought.

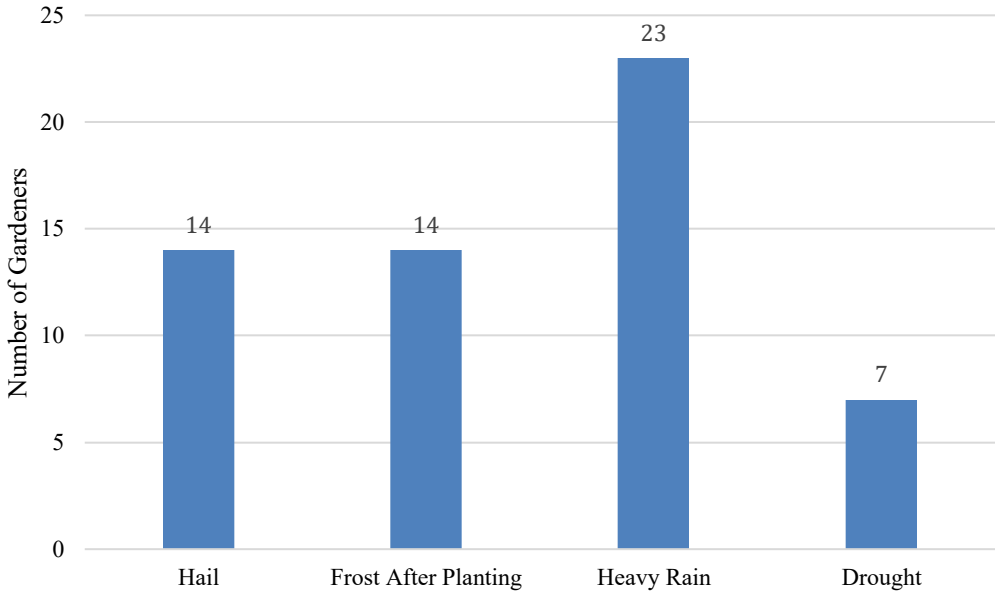


Figure 6. Severe weather incidence.

Participants also had the option of indicating if they experienced any bacterial, fungal, viral, or insect pathogens during the growing season, with the option to write the name of the pathogen, if known. Fifteen surveys described a pest or disease problem, including the presence of some insects and descriptions of a potential disease. The insects observed on potato plants included aphids, flea beetles, grasshoppers, potato tomato hornworm, potato tomato psyllid, slugs, and small flies. Disease descriptions included brown spots on the leaves, shriveled leaves, and lower leaf yellowing.

The PowerPoint presentation the gardeners were given had pictures of potato defects to help gardeners describe tubers that were misshapen, green, or had growth crack, hollow heart, second growth, or insect damage (see Appendix F). Gardeners were not asked if they had viewed the PowerPoint. There were 46 responses with no defects reported, and 23 with at least one type of defect. There were five surveys reporting growth crack, eight greening, eleven misshapen, one second growth, ten insect damage, and none with hollow heart. Gardeners were asked to use a one to five scale in this question and several others following. In this case, a score of one

corresponded to a small amount of damage, while a response of five indicated severe damage. Insect or rodent damage was rated as the most severe, with an average rating of 2.2, while second growth was rated as least severe, as the only response was a rating of one. Because of the small number of both surveys and number of gardeners that reported defects, the defects were not analyzed by each potato selection.

The second part of the survey asked about potato preparation, sensory evaluation, and gardener impressions and recommendations. Respondents were first asked how they prepared their potatoes, with the option to select more than one method of preparation. Table 4 describes these results. In Table 5, the participants rated 129 different potato preparations on a scale of one to five. A score of one indicated that the potato was not suitable for this preparation method and a score of five indicated that the potato selection was very suitable for this preparation method. For example, if a potato was boiled but broke apart in the water, it would be scored as a one. Conversely, if a potato was fried and retained an acceptable shape, color, and appearance after frying, it would be scored as a five. Gardeners were asked to base their ratings on the performance of the store-bought selection they use for a cooking method, and compare the potato selection they were evaluating to the commercial cultivar. The most common preparation method was boiling, with 41 ratings, while the least common method was microwaving, with only four reports of microwave preparation.

Table 4

Preparation Method for Six Potato Selections

	Method of Preparation				
Selection	Baked	Fried	Mashed	Boiled	Microwaved
CO00405-1RF	11	8	5	10	0
CO04067-8R/Y	2	3	4	6	0
CO05028-4P/PY	5	7	2	6	0
CO05028-11P/RWP	5	4	4	4	1
CO05037-2R/Y	1	4	1	4	1
CO05037-3W/Y	10	4	4	11	2
Total	34	30	20	41	4

Table 5

Ratings for Different Preparation Methods of Six Potato Selections

	Method of Preparation Rating					
Selection	Baked	Fried	Mashed	Boiled	Microwaved	Average Rating
CO00405-1RF	4.4	4.5	4.0	4.0	N/A	4.2
CO04067-8R/Y	2.0	3.3	4.0	3.8	N/A	3.5
CO05028-4P/PY	3.6	4.4	3.0	4.5	N/A	4.1
CO05028-11P/RWP	4.8	5.0	4.8	5.0	4.0	4.8
CO05037-2R/Y	4.0	4.25	1.0	4.0	4.0	3.8
CO05037-3W/Y	4.2	3.25	4.5	3.8	4.5	4.0

Underlined numbers indicate that less than three participants evaluated this selection. Ratings were based on a one (unsuitable for this preparation method) to five (very well suited for this preparation method) scale. N/A indicates no selection was evaluated using this method.

CO05028-11P/RWP received the highest overall rating on all preparation methods with a score of 4.8 out of five, indicating that participants found it suitable for all preparation methods. CO04067-8R/Y had the lowest average rating of 3.5, due to its low rating as a baked potato. However, only two participants baked and rated this selection. Of the selections that had more than two participant ratings, CO05028-4P/PY had the lowest baked rating of 3.6, with three participants writing in that the purple color was significantly lighter after baking. CO05028-11P/RWP had the highest rating as a baked potato, with five participants giving it an average score of 4.8. CO04067-8R/Y had the lowest rating as a fried potato, while CO05028-11P/RWP had the highest rating based on the feedback of four participants. Mashed potato ratings were relatively consistent across selections with more than two ratings, with scores between 4.0 and 4.5. CO05037-3W/Y and CO04067-8R/Y had the lowest rating as boiled potatoes at 3.8, while CO05028-11P/RWP had the highest score of 5.0 based on four ratings. Only four respondents evaluated CO05028-11P/RWP, CO05037-2R/Y, and CO05037-3W/Y as microwaved potatoes.

All 69 completed surveys included a sensory evaluation. The number of sensory evaluations per selection correspond with the total number of each selection grown in Table 2. In Table 7, CO05028-11P/RWP was rated the highest on a one to five scale for taste, where one indicated a very poor taste and five indicated a very good taste, with a score of 4.5. CO05037-2R/Y had the lowest taste rating at 3.3. CO00405-1RF had the highest texture rating, with a score of 4.4, while CO05037-2R/Y had the lowest rating of 3.3. Finally, CO05028-11P/RWP and

CO05028-4P/PY both had the highest aroma rating of 4.2, while CO04067-8R/Y had the lowest aroma rating of 3.6.

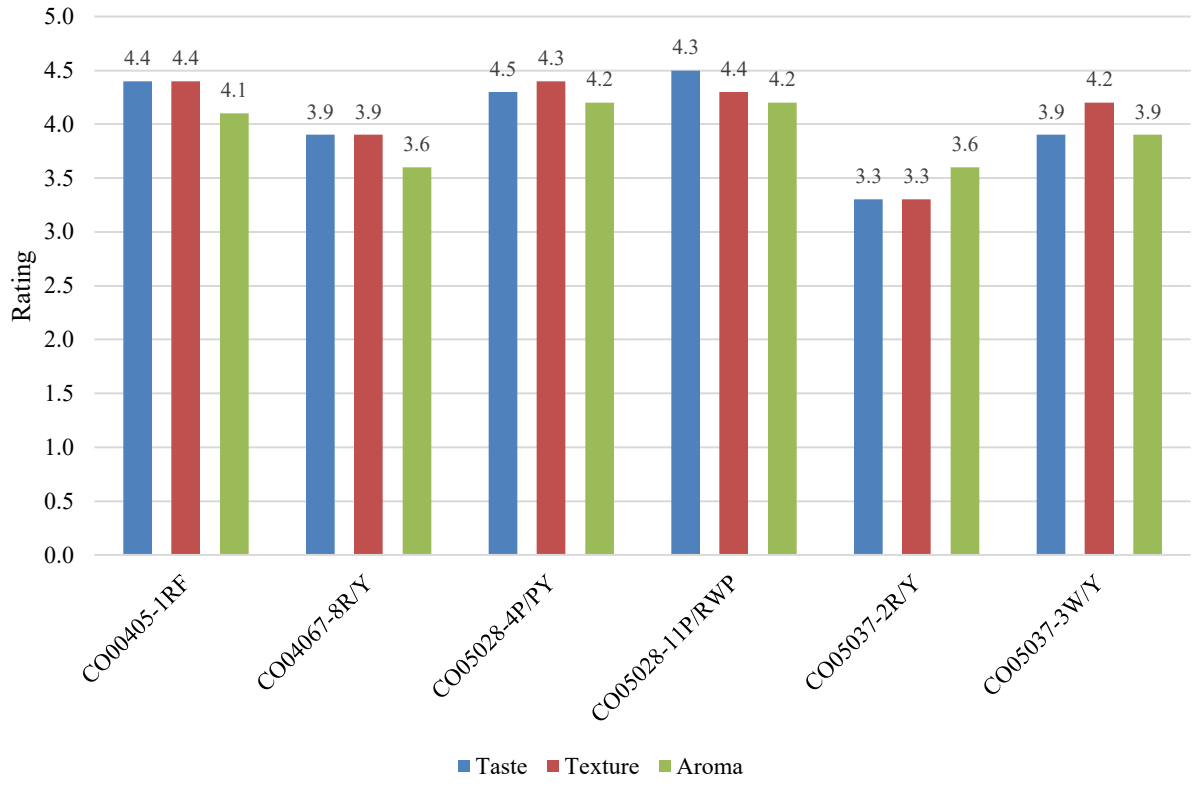


Figure 7. Sensory evaluation rating for six potato selections.

Next, gardeners were asked if they would grow and consume this selection again, given its performance as a garden plant and a food. Results were summarized in Table 8. All gardeners responded to this question for a total of 69 responses. All eleven gardeners would grow CO05028-11P/RWP in their gardens again based on its past performance, while only 38%, or three gardeners would grow CO04067-8R/Y a second time. After CO05028-11P/RWP, the next most preferred selections to grow again were CO00405-1FR with 76% willing to grow it again, followed by 73% for CO05028-4P/Y, 63% for CO05037-3W/Y, and 50% for CO05037-2R/Y.

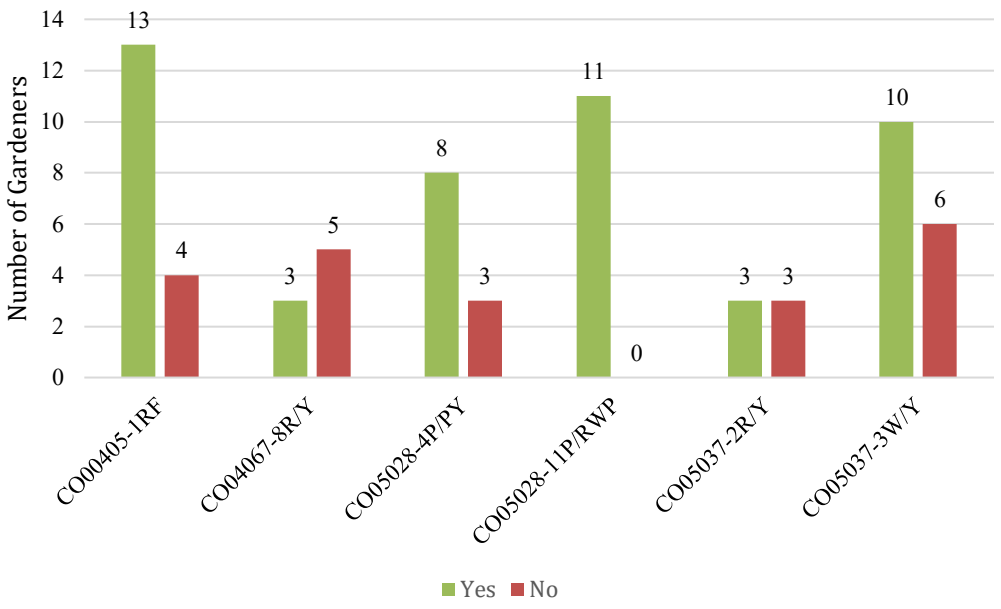


Figure 8. Participant decision on growing potato selections again.

Gardeners were then asked their opinion on how CSU should treat the potato selection in the future. They could recommend that CSU discard the selection and no longer evaluate it for commercial release, continue evaluation and collect more data on the selection, or name and release the selection, making it available for purchase. These results were summarized in Table 9. Eleven, or 65% of gardeners who evaluated it recommended naming and releasing CO00405-1RF, while only one gardener recommended naming and releasing CO05037-2R/Y. All eleven gardeners recommended either continuing to evaluate or naming CO05028-11P/RWP. Most participants who grew CO05037-3W/Y, 63%, recommended further evaluation. CO05028-4P/PY also received positive recommendations, with five gardeners each recommending continued evaluation or release, while only one recommended discarding the selection. Gardeners who grew CO04067-8R/Y were divided almost evenly on recommendations, with two choosing to name and release; while three each chose either continued evaluation or discarding.

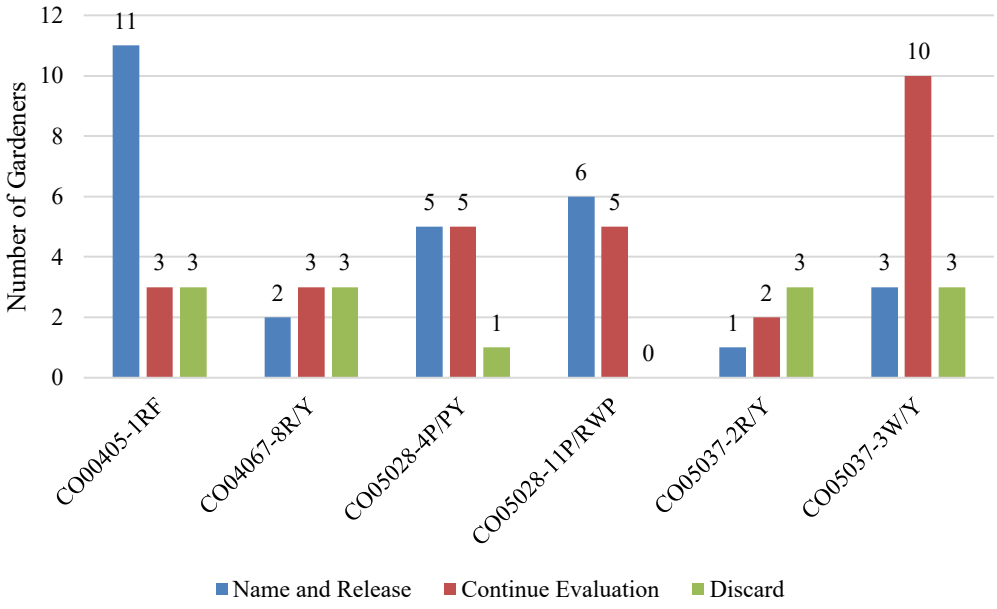


Figure 9. Gardener recommendations on six potato selections.

The gardeners were provided one line to write what they liked and disliked about the potato selection they grew. Sixty-five of the surveys had at least one comment, and 47 of the surveys had both "like" and "dislike" comments. Twelve of the positive comments were related to color, and gardeners used words such as nice, great, beautiful, and fun to describe the tuber skin and flesh colors. Seven of these comments were about the flesh color of CO05028-11P/RWP, which has different colored flesh that creates a tie-dye effect. Twenty-two comments were related to taste, as the participants used phrases such as "creamy texture and excellent flavor," "excellent taste," "nice presentation and buttery taste." There were three positive comments about tuber size, including "good mix of small and medium size potatoes," and "potatoes were a uniform size." One gardener mentioned, "I harvested 15 pounds from seven plants, which I am happy about."

Comments in response to the "dislike" question were more specific. Nine respondents mentioned they had a low yield from each plant, and used phrases such as, "it looks like they

stopped growing in June," "a lot of work for a few potatoes," and "I got three pounds of potatoes from a six foot row." Nineteen comments stated that the potatoes were "too small," "very small," or "the largest ones were golf ball sized." These nineteen comments were spread proportionally between the six selections grown. Ten of the "too small" comments were from 2016, while nine were from 2017.

A few of the gardeners described the problems they observed, stating that "the roots seemed mushy when I harvested," "there were small brown bugs on three potato tubers," and "the leaves were brown and crispy but the potatoes were ok." A few gardeners provided recommendations to the potato breeding program. Some of these include, "I would like to grow a potato variety adapted to high altitude weather," "I wish I had potatoes that could get bigger in a short growing season," "I want to learn more about organic pest management techniques," and "I want to have more guidance on fertilizing because my plants looked so small."

Sixty-eight gardeners responded to the question asking if they would be interested in evaluating potatoes the following year, 38 in 2016 and 30 in 2017. This question was included in 2016 to indicate if a county would have enough participants in 2017 should the study continue for a second year. It was kept in the survey in 2017 to measure participant satisfaction with the program and their willingness to continue to volunteer their time. In Figure 10, 79% of gardeners in 2016 and 83% in 2017 were interested in evaluating potatoes again, for an average of 81% of participants who would continue growing and evaluating potatoes.

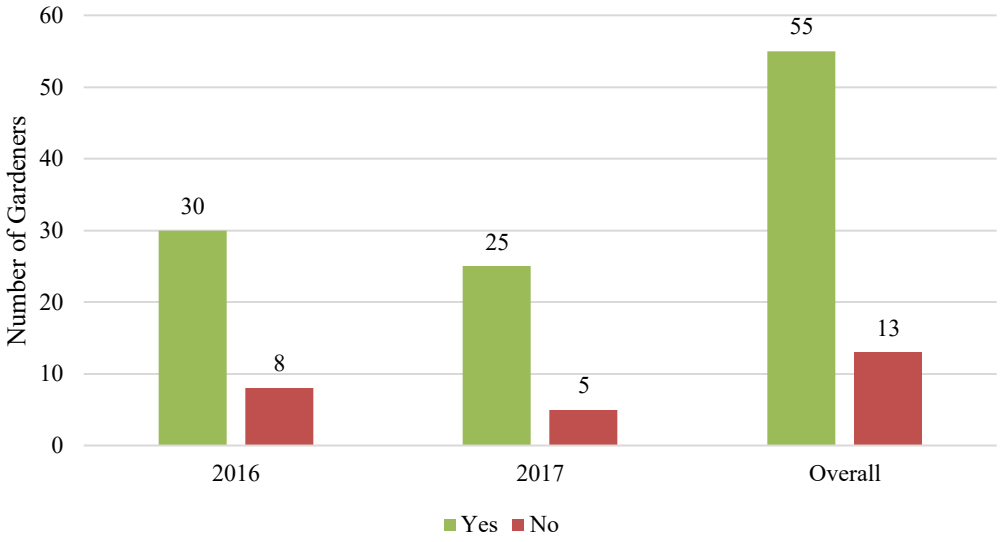


Figure 10. Gardner decision on continued participation.

Finally, the researchers were interested in what types of potatoes the participants were interested in evaluating, and therefore growing in their gardens. Gardeners could choose more than one selection from a list with the following options: round white, purple flesh, red flesh, russet, and fingerling potatoes. In Figure 11, 49 gardeners answered this question with a total of 148 responses. Each responding gardener selected an average of three responses.

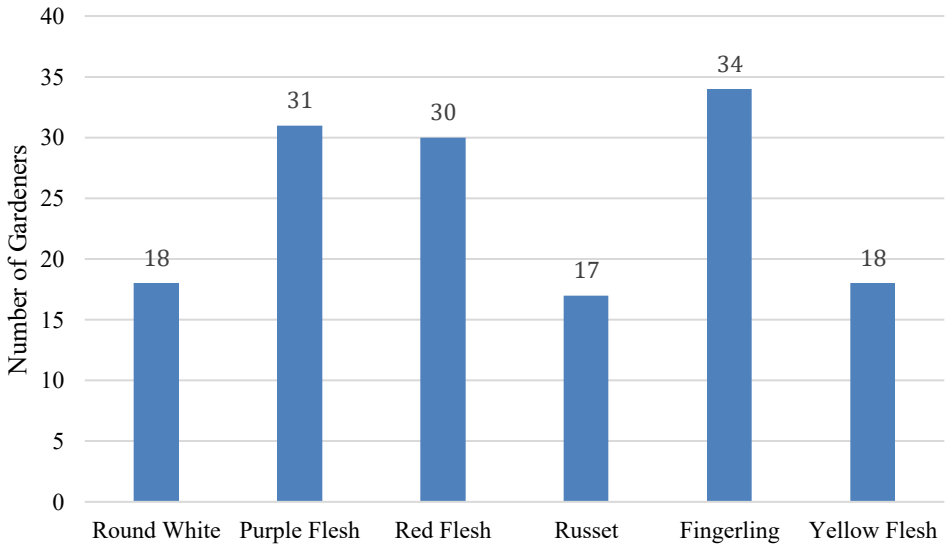


Figure 11. Gardner potato preference for evaluation.

The highest percentage of responses was for fingerling potatoes, with 23% of selections indicating fingerling potatoes. Purple flesh and red flesh specialty type potatoes were also popular, with 31 and 30 selections each, respectively. Only about 12% each of the responses indicated an interest in trying round white potatoes, russet potatoes, or yellow flesh potatoes.

Discussion

While the researchers sent an equal number of samples of each selection to each county, some volunteers either changed their mind about participating prior to sample pick up, or received their potatoes but did not return a survey. Additionally, different numbers of people agreed to trial potatoes in 2016 and 2017. These factors contributed to the different numbers of selections grown at each county during each of the two years. Because of the smaller sample size of only 69 surveys, different counties could not be treated as groups or microclimates for separate analysis. Only five surveys were returned from Summit County, where participants evaluated three selections, in contrast with 18 from Boulder County where all six selections were grown.

The survey response rate was high, with 69 complete responses from 120 surveys sent to participating counties, a rate of 58%. This response rate may have been high due to the participation of County Directors that interacted with each gardener as they distributed potato tuber samples in the spring and collected completed surveys in the fall. Master Gardeners had an existing relationship with the County Director through their volunteer work and were already invested in helping to further the mission of Colorado State University. An additional factor may be that Master Gardeners in each county know each other, and discussed the Potato Evaluation Program during the summer, reminding participants to collect data and later return the survey.

Gardeners were provided with small potatoes that weighed about two and a half ounces. Potato tubers of this size do not need to be cut prior to planting. A possible explanation for small potato size could be that gardeners were cutting their potatoes into smaller pieces before planting. Because developing potato plants use the seed piece as a source of nutrients before they emerge from the soil and photosynethsize, adequate seed size is important in early potato development (Bohl, Nolte, Kleinkopf & Thornton 2000). Potato plants grown from smaller seed pieces can be slower to emerge from the soil, produce fewer shoots, and ultimately have smaller tubers (Bohl, Stark & McIntosh 2011). Especially when combined with a deeper than recommended planting depth of more than five inches, gardeners may have had slow-to-emerge plants which then had fewer days of tuber bulking before harvest.

While 46 respondents applied compost to their potatoes, composting can be challenging in cool, dry climates that describe most of the counties in which the potatoes were grown. In these conditions, it can take a long time for compost to completely break down. If gardeners applied unfinished compost, or compost that still has matter that must be broken down, they could have experienced “burn” or damage to young plants from the continuing decomposition process. This restricted nitrogen availability could have also contributed to small tuber size, and potato plants require nitrogen for growth, and indirectly for tuber bulking (Nelson, 2013).

Between the summer of 2017 and the present, the Potato Breeding Program had made decisions about the fate of some of these potatoes. CO00405-1RF, CO04067-8R/Y, CO05037-2R/Y, and CO05037-3W/Y are still available for commercial grower evaluation. However, CO05028-11P/RWP and CO05028-4P/PY are available for exclusive release. This means the Potato Breeding Program has determined that these two selections are unlikely to be commercially released by Colorado State University. Individuals or commercial entities could

arrange to have exclusive rights to control the production and marketing of these potato selections. In this example, gardener feedback did not mirror Colorado seed grower decisions about the fate of these selections. While the Potato Breeding and Selection Program is confident that these selections have the potential to become named cultivars, no Colorado seed grower was willing to "champion" or further assess commercial potential. Both of these selections received high scores in the sensory evaluation, and the majority of respondents indicated that Colorado State University should continue to evaluate or name and release these two selections. Gardeners were interested in having these selections available for purchase.

However, these selections are specialty potatoes with variability in flesh color that may be unacceptable to commercial producers. During evaluation by the Colorado Potato Breeding and Selection program in 2015, when the selections were last evaluated, both CO05028-11P/RWP and CO05028-4P/PY were given average fry color and texture scores, indicating that have potential as processing potatoes. By listing these selections as "available for exclusive release" instead of discarding them, the Potato Breeding and Selection program acknowledged that these potatoes have many positive traits making them worthy of cultivation (Holm, Gray, & Zavislan, 2016). Another potential, but unlikely market is garden catalog businesses, which offer unique plants and vegetables to home gardeners, but may be hesitant to deal in the intellectual property of variety development. While the other selections are still available for grower evaluation and have not been discarded, it is too soon to tell if they will be named and released by Colorado State University or by an exclusive release arrangement with another company. The evaluation process leading up to the decision to name and release a selection can take up to fourteen years (Holm, 2018).

The most helpful feedback for the Colorado Potato Breeding and Selection program was the information in preparation, sensory evaluation, and recommendations, including willingness to grow again and selection likes and dislikes. On a commercial scale, potato in-row and between-row spacing is carefully controlled based on the desired size profile of the tubers, and pesticides and fertilizers are applied based on pest pressure and soil quality and type. Therefore, information on each gardener's cultural practices over the summer were not relevant to cultivars that are only grown on a commercial scale.

In contrast, growers who collaborate with CSU and evaluate potato selections do not conduct sensory evaluations of the potatoes they grow in a formalized manner. There were some differences between the average sensory evaluation scores for each selection, indicated that gardeners preferred to eat some selections to others. Many participants wrote comments about what they liked and disliked, which is helpful feedback for selections that will likely be grown by home gardeners in the future.

Relevance to Other Disciplines

While 60 out of 69 respondents used some type of fertilizer, they may not have an appropriate nutrient management strategy. Forty-two gardeners only fertilized once, typically at or shortly after planting, which may be insufficient in marginal or nutrient depleted soil. It is possible that some gardeners did not need to fertilize if they had built up soil fertility in their gardens over several years using compost, green manures, or other soil management strategies. However, the small scale of these gardens makes this scenario unlikely. The largest complaint participants had about the potato selections was that the tubers were too small. No gardeners mentioned a low number of tubers, so it is likely that the potato plants set a normal amount of potatoes which then failed to reach a large enough size. Figure 12 shows the harvest from a

garden in Gilpin County in 2017. There are many potatoes, but the largest ones are about 1.5 inches in diameter.

Figure 12. The harvested tubers of CO04067-8R/Y.

While a short growing season may have limited tuber bulking in mountain counties, most potatoes in Boulder County were planted in late April and harvested in mid-September, for an average of 131 days between planting and harvest for all 18 gardeners. This should have been long enough for most tubers to reach a marketable size. This indicates that Master Gardeners may not have an understanding of the soil fertility needs of potatoes. Especially if the Master Gardener curriculum is focused on annual ornamental plants or perennial trees and shrubs, nutrient management in food crops may be mentioned only briefly. The researchers updated the home potato gardening Extension bulletin to address some of these problems (see Appendix G). Additionally, there are other Extension bulletins that address gardening in cool, short season environments. This includes Colorado Mountain Gardening Basics and Vegetable Gardening in the Mountains (Shonle & Potts, 2014; Shonle 2014). Master Gardeners may benefit from reading these bulletins or other resources on short season gardening.

Gardener feedback indicated that this was an enjoyable project for Master Gardeners, and this model could be useful for developing activities for this group. Regardless of the involvement of a plant breeder, Master Gardeners may enjoy trialing a few types of a common garden plant and reporting their findings to others. This could help Master Gardeners develop recommendations for vegetables they have successfully grown in a challenging environment, such as a high altitude or area with a short growing season. As volunteers trained in gardening, community members look to Master Gardeners for advice. Being able to recommend a specific variety, brand, or growing method can help Master Gardeners further their mission. Many participants wrote to me in notes attached with their evaluations that they got together with other participants and shared the potato dishes they made, that their children helped to dig up the potatoes, or that they became more involved in their community garden because of this project. Several participants sent me pictures of their potato gardens, harvested tubers, or of their families enjoying gardening together (See Appendix H).

Recommendations for Further Research

There were two competing factors in this survey design. First, the survey needed to be thorough and collect as much information as possible from the gardeners to better understand how the potatoes were grown and used. However, the survey also needed to be appropriate for the volunteer audience. This necessitated an appropriately brief survey of two full pages, and questions that did not require scientific equipment or data collection skills that Master Gardeners were unlikely to possess. While it would have been useful information, gardeners were not required to get a soil test and report the pH, electrical conductivity, and nutrient profile. Similarly, they did not report the exact number of inches of irrigation applied, include a fertilizer sample, or use a taxonomic key to identify pests and diseases on their potato plants. Because some

gardeners harvested their crop as new potatoes and later in the fall, participants were not asked to weigh the tubers from each plant during harvest. These limitations resulted in an overview of the growing season and selection performance, but not a complete picture.

In the future, more robust evaluation may be done by groups of people. The most complete surveys that contained comments and notes in the margins were often returned by a group of people who grew a selection together. This happened in Boulder, Gilpin, and Teller Counties, where Master Gardeners grew the potatoes in a community garden that was managed by Cooperative Extension and the Master Gardeners. This shared responsibility made it more likely that someone monitored the plants for pests and diseases on a regular basis, watered the plants on a set schedule, and harvested the plants at an appropriate time. A group of people may be better able to collect more data during the growing season if the responsibilities were shared among them.

For example, a possible survey improvement would be to collect cumulative Growing Degree Days between planting and harvest using the Colorado Climate Center developed by Colorado State University (Colorado Climate Center, 2017). Groups could also take a picture of the plant once a week, so that the researchers could identify pest and disease problems. When gardeners were asked about insects and diseases, they had a low response rate, possibly indicating a lack of knowledge or confidence in identifying potato diseases or garden pests.

A future survey may receive more complete information by splitting some of the questions in the current survey design. For example, gardeners were asked to select within- and between-row spacing of the plants in the same question. This may have been confusing to some respondents, as several surveys indicated either within or between row spacing, but not both. Check boxes can give the appearance of a multiple choice question where only one answer is

allowed, and gardeners completing the survey quickly may not have read the “please check all that apply” note.

Another change to the survey should be in the area of severe weather. The question currently does not distinguish between one event and a recurring pattern, or ask if the potato plants were damaged because of this event. Therefore, a gardener could have reported hail because it hailed once before the plants emerged, or because it hailed every day for a week, killing two of the plants. This distinction could be important in drawing conclusions about gardener feedback.

The higher response rate on the second page of the survey indicates that gardeners may be more interested in sharing their overall perceptions on a potato selection as opposed to answering close-ended questions on the weather, irrigation, fertilization, and plant spacing. Using the group model, it is possible to designate one person as the data recorder for a specific topic, such as monitoring for severe weather or overseeing irrigation practices. These questions which had a lower response rate could then be shared between many people, and allow participants to spend most of their time rating the potato sensory characteristics, sharing likes and dislikes about the selection, and providing recommendations to the Potato Breeding and Selection Program.

REFERENCES

Almekinders, C.J., Mertens, L., van Loon, J.P., & van Bueren, E.T. (2014) Potato breeding in the Netherlands: A successful participatory model with collaboration between farmers and commercial breeders. *Food Security, 6*(4), 515-5124. Doi:10.1007/s12571-014-0369-x

Annicchiarico, P. (2007). Wide versus specific-adaptation strategy for lucerne breeding in Northern Italy. *Theoretical Applied Genetics, 114,* 647-657. doi:10.1007/s00122-006-0465-1

Apodaca A. (1952). Corn and custom: The introduction of hybrid corn to Spanish American farmers in New Mexico. In E.H. Spicer (Ed.), *Human Problems in Technological Change, a Casebook* (pp. 35-39). New York, NY: Russell Sage Foundation.

Asrat, S., Yesuf, M., Carlsson, F., & Wale, E. (2010). Farmers' preferences for crop variety traits: Lessons for on-farm conservation and technology adoption. *Ecological Economics*, *69*(12), 2394-2401. https://doi.org/10.1016/j.ecolecon.2010.07.006

Aw-Hassan, A., Mazid, A., & Salaheih, H. (2008). The role of informal farmer-to-farmer seed distribution in diffusion of new barley varieties in Syria. *Journal of Experimental Agriculture, 44*, 413-431. doi:10.1017/S001447970800642

Barcellini, F., Prost, L., & Cerf, M. (2015). Designers' and users' roles in participatory design: What is actually designed by participants? *Applied Ergonomics, 50,* 31-40. https://doi.org /10.1016/j.apergo.2015.02.005

Bowser, A., Hansen, D., Preece, J., He, Y., Boston, C., & Hammock, J. (2014, June). *Gamifying citizen science: A study of two user groups.* Paper presented at Proceedings of the companion publication of the 17th ACM conference on Computer supported cooperative work & social computing, Atlanta, Georgia.

Bohl, W.H., Nolte, P., Kleinkopf, G.E., & Thornton, M.K. (2000). Potato seed management: Seed size and age. Retreived from cals.uidaho.edu/edcomm/pdf/CIS/CIS1031.pdf

Bohl, W.H., Stark, J.C., & McIntosh, C.S. (2011). Potato seed piece size, spacing and seeding rate effects on yield, quality, and economic return. *American Journal of Potato Research, 88*(6), 470-478. https://doi.org/10.1007/s12230-011-9213-4

Brouwer, B.O., Murphy, K.M., & Jones, S.S. (2016). Plant breeding for local food systems: A contextual review of end-use selection for small grains and dry beans in Western Washington. *Renewable Agriculture and Food Systems, 31*(2), 172-184. https://doi.org/ 10.1017/S1742170515000198

Campanelli, G., Accairri, N., Campion, B., Delveccio, S., Leteo, F., Fusari, P., & Ceccarelli, S. (2015). Participatory tomato breeding for organic conditions in Italy. *Euphytica, 204*(1), 179-197. https://doi-org.ezproxy2.library.colostate.edu/10.1007/s10681-015-1362-y

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., & Venail, P. (2012). Biodiversity loss and its impact on humanity. *Nature, 489,* 59-67. doi:0.1038/ nature11148

Ceccarelli, S. (2009). Evolution, plant breeding and biodiversity. *Journal of Agriculture and Environment for International Development, 103,* 131-145. doi:10.1017/S002185961000 0651

Ceccarelli, S. (2014). Efficiency of plant breeding. *Crop Science, 55*(1), 87-97. doi:0.2135/crop sci2014.02.0158

Ceccarelli, S., Galie, A., Mustafa, Y., & Grando, S. (2012). Syria: Participatory barley breeding-farmers input becomes everyone's gain. In: M. Ruiz & R. Vernooy (Eds.), *The custodians of biodiversity: Sharing access and benefits to genetic resources* (pp. 53-66). Abingdon, England: Earthscan.

Ceccarelli, S, & Grando, S. (2009). Participatory plant breeding. In M. Carena (Ed.), *Handbook of plant breeding* (395-414). New York, NY: Springer

Ceccarelli, S., Grando, S., & Capettini, F. (2011). Barley breeding history, progress, objectives, and technology, Near East, North and East Africa and Latin America. In: S.E. (Ed.), *Barley: Production, improvement and uses.* (pp. 210-220). Ames, Iowa: Wiley-Blackwell.

Ceccarelli, S., Guimarães, E. P., & Weltzien, E. (2009). *Plant breeding and farmer participation*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Chiffoleau, Y., & Desclaux, D. (2006). Participatory plant breeding: the best way to breed for sustainable agriculture?. *International journal of agricultural sustainability*, *4*(2), 119-130. https://doi.org/10.1016/S0038-0296(02)01308-0

Colorado Climate Center. (2017). Retrieved from http://climate.colostate.edu/gdd.html

Courtois, B., Bartholome, D., Chaudhary, G., McLaren, C.H., Misra, N.P., Mandal, S., Pandey, T., Paris, C., Piggin, K., Prasad, A.T., Roy, R.K., Sahu, V.N., Sahu, S., Sarkarung, S.K., Sharma, A., Singh, H.N., Singh, O.N., Singh, N.K., Singh, R.K., Singh, S., Singh, P.K., Sinha, B.V.S., Takhur, R. (2001). Comparing farmers and breeders rankings in varietal selection for low-input environments: A case study of rainfed rice in eastern India. *Euphytica 122*, 537–550. https://doi.org/10.1023/A:1017994906544

Crowder, D.W., Northfield, T.D., Strand, M.R., & Snyder, W.E. (2010). Organic agriculture promotes evenness and natural pest control. *Nature, 466*, 109-113. doi:10.1038/nature 09183

Cullis, B.R., Smith, A.B., & Coombes, N.E. (2006). On the design of early generation variety trials with correlated data. *Journal of Agricultural Biological and Environmental*

Statistics, 11(4), 381-393. doi:10.1198/108571106X154443

Dawson, J.C., & Goldberger, J.R. (2008a) Assessing farmer interest in participatory plant breeding: Who wants to work with scientists? *Renewable Agriculture and Food Systems, 23*(3), 177-187. doi:10.1017/S1742170507002141

Dawson, J.C., Murphy, K.M., & Jones, S. (2008b). Decentralized selection and participatory approaches in plant breeding for low-input systems. *Euphytica, 160,* 143-154. https://doi.org/10.1007/s10681-007-9533-0

DeJong, H., Sieczka, L.B., & DeJong, W. (2011). *The complete book of potatoes: What every grower and gardener needs to know.* Portland, OR: Timberland Press.

DeSchutter, O. D. (2014). Final report: The transformative potential of the right to food. *Report of the special rapporteur on the right to food.*

Desclaux, D. (2005, May). Participatory plant breeding methods for organic cereals. In *Proceedings of the COST SUSVAR/ECO-PB workshop on organic plant breeding strategies and the use of molecular markers* (pp. 17-23).

Douthwaite, B., & Hoffecker, E. (2017). Towards a complexity-aware theory of change for participatory research programs working with agricultural innovation systems. *Agricultural Systems,* 155, 88-102. https://doi.org/10.1016/j.agsy.2017.04.002

Eksvard, K., & Rydberg, T. (2010). Integrating participatory learning and action research and systems ecology: A potential for sustainable agriculture transitions. *Systems of Practical Action Research, 23,* 467-486. https://doi.org/10.1007/s11213-010-9172-6

Ghaouti, L., Vogt-Kaute, W., & Link, W. (2008). Development of locally-adapted faba bean cultivars though a participatory breeding approach. *Euphytica, 162*(2), 257-268. doi: 10.1007/s10681-007-9603-3

Hauser, M., Lindtner, M., Prehsler, S., & Probst. (2016). Farmer participatory research: Why extension workers should understand and facilitate farmers' role transitions. *Journal of Rural Studies,* 47, 52-61. https://doi.org/10.1016/j.jrurstud.2016.07.007

Holm, D.G. (2018.) *Generalized potato breeding and selection scheme used at the SLV research center.* Retrieved from http://potatoes.colostate.edu/programs/potato-breeding/resource-center/

Holm. D.G. (2018a). *Resource center.* Retrieved from potatoes.colostate.edu/programs/potato-breeding /resource-center/

Holm, D.G., Gray, C.P. & Zavislan, K.A. (2016). *2015 Research progress report: Potato breeding and selection.* Retrieved from http://potatoes.colostate.edu/programs/potato-breeding/resource-center/

Hooper, D.U., Adair, E.C., Cardinale, B.J., Byrnes, J.E.K., Hungate, B.A., & Matulich, K.L. (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature, 486,* 105-108. doi:10.1038/nature11118

Huffman, W. E., Norton, G., Traxler, G., Frisvold, G., & Foltz, J. (2006). Winners and losers: Formula versus competitive funding of agricultural research. *Choices*, *21*(4), 269-274. Retrieved from http://www.jstor.org/stable/choices.21.4.0269

Humphries, S., Rosas, J. C., Gómez, M., Jiménez, J., Sierra, F., Gallardo, O., & Barahona, M. (2015). Synergies at the interface of farmer–scientist partnerships: agricultural innovation through participatory research and plant breeding in Honduras. *Agriculture & Food Security*, *4*(1), 27. https://doi.org/10.1186/s40066-015-0046-0

Jalleta, T. (2004). Participatory evaluation of the performance of some improved bread wheat (*Triticum aestivum)* varieties in the Jijiga Plains of Eastern Ethiopia. *Journal of Experimental Agriculture, 40*, 89-97. doi:10.1017/S0014479703001479

Joshi, K. D., Devkota, K. P., Harris, D., Khanal, N. P., Paudyal, B., Sapkota, A., & Witcombe, J. R. (2012). Participatory research approaches rapidly improve household food security in Nepal and identify policy changes required for institutionalization. *Field Crops Research*, *131*, 40-48. https://doi.org/10.1016/j.fcr.2012.03.001

Kamran, A., Kubota, H., Yang, R. C., Randhawa, H. S., & Spaner, D. (2014). Relative performance of Canadian spring wheat cultivars under organic and conventional field conditions. *Euphytica*, *196*(1), 13-24. https://doi.org/10.1007/s10681-013-1010-3

Kelley, T.G., Rao, P.P., Weltsein, E. & Purohit. (1996). Adoption of improved cultivars of pearl millet in an arid environment: Straw yield and quality considerations in western Rajasthan. *Journal of Experimental Agriculture, 32*, 161-171. https://doi.org/10.017/ S0014479700026077

Kloppenburg, J.R. (2004). *First the seed: The political economy of plant biotechnology.* Madison, Wisconsin: University of Wisconsin Press.

Li, J., Lammerts van Bueren, E. T., Huang, K., Qin, L., & Song, Y. (2013). The potential of participatory hybrid breeding. *International Journal of Agricultural Sustainability*, *11*(3), 234-251. https://doi.org/10.1080/14735903.2012.728050

Li, J., Lammerts van Bueren, E.T., Jiggins, J., & Leeuwis. (2012). Farmers' adoption of maize (*Zea mays* L.) hybrids and the persistence of landraces in Southwest China: Implications for policy and breeding. *Genetic Resources for Crop Evoluton, 59*, 1147-1160. doi:10. 1007/s10722-011-9750-1

Mangione, D., Senni, S., Puccioni, M., Grando, S., & Ceccarelli, S. (2006). The cost of participatory barley breeding. *Euphytica, 150,* 289-306. doi:10.1007/s10681-006-0226

Maredia, M.K., & Raitzer, D.A. (2010). Estimating overall returns to international agricultural research in Afric through benefit-cost analysis: A “best-evidence” approach. *Journal of Agricultral Economivs, 41,* 81-100. doi:10.1111/j.1574-0862.2009.00427.

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., & Ryan, S. F. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, *208*, 15-28. https://doi.org/10.1016/j.biocon.2016.05.015

Mendum R., & Glenna, L. (2010). Socioeconomic obstacles to establishing a participatory plant breeding program for organic growers in the United States. *Sustainability, 2*(1), 73-91. doi:10.3390/su2010073

Morris, M.L., & Bellon, M.R. (2004). Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. *Euphytica, 136,* 21-35. doi: 10.1023/B:EUPH.0000019509.37769.b1

Murphy, K. M., Campbell, K. G., Lyon, S. R., & Jones, S. S. (2007). Evidence of varietal adaptation to organic farming systems. *Field Crops Research*, *102*(3), 172-177. https: //doi.org/10.1016/j.fcr.2007.03.011

Murphy, K., Lammer, D., Lyon, S., Carter, B., Jobes, S.S. (2004). Breeding for organic and low input farming systems: An evolutionay-participatory breeding method for inbred cereal grains. *Renewable Agriculture and Food Systems, 20*(1), 48-55. doi:10.1079/RAF200486

Myers, J. R., McKenzie, L., & Voorrips, R. E. (2011). 16 Brassicas: Breeding Cole Crops for Organic Agriculture. *Organic Crop Breeding*, *251*, 7-13. https://doi.org/10.1051/agro/ 2009032

Nelson, W. (2013). *Home composting*. Retrieved from ccetompkins.org/resources/compost-home-composting-brochure

Ponisio, L.C., McGonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P., & Kremen, C. (2015). Diversification practices reduce organic to conventional yield gap. *Proceedings of the Royal Society, Biological Sciences, 282,* 17-23. http://dx.doi.org/10.1098/rspb.2014.1396

Ponti, M., Hillman, T., & Stankovic, I. (2015, October). Science and Gamification: The Odd Couple? In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play* (pp. 679-684). ACM.

Raman, A., Ladha, J.K., Kumar, V., Sharma, S., & Piepho, H.P. (2011). Stability analysis of farmer participatory trails for conservation agriculture using mixed models. *Field Crops Research, 121,* 450-459. https://doi.org/10.1016/j.fcr.2011.02.001

Reid, T.A., Yang, R., Salmon, D.F., Navabi, A., & Spaner, D. (2010). Realized gains from

selection for spring wheat grain yield are different in conventional and organically managed systems. *Euphytica, 177*(2), 253–266. https://doi.org/10.1007/s10681-010-0257-1

Reguieg, M., Labdi, M., Benbelkacem, A., Hamou, M., Maatougui, M.E., Grando, S., & Ceccarelli, S. (2013). First experience on participatory barley breeding in Algeria. *Journal of Crop Improvement, 27*, 1-18. doi:10.1080/15427528.2013.794756

Shelton, A.C., & Tracy, W.F. (2015). Recurrent selection and participatory plant breeding for improvement of trwo organic open-pollinated sweet corn (*Zea mays* L.) populations. *Sustainability, 7*(5), 5139-5152. doi:10.3390/su7055139

Shelton, A.C., & Tracy, W.F. (2016). Participatory plant breeding and organic agriculture: A synergistic model for organic variety development in the United States. *Elementa, 4,* 1-13. doi:10.12952/journal.elementa.000143

Shonle, I. (2014). Vegetable gardening in the mountains. *Colorado State University Extension Publication* 7.248. Colorado State University. extension.colostate.edu/topic-areas/yard-garden/vegetable-gardening-in-the-mountains-7-248/

Shonle, I. & Potts, L. (2014). Colorado mountain gardening basics. *Colorado State University Extension Publication* 7.244. Colorado State University. extension.colostate.edu/topic-areas/yard-garden/colorado-mountain-gardening-basics-7-224/

Singh, S. P., Terán, H., Lema, M., & Hayes, R. (2011). Selection for Dry Bean Yield On-Station Versus On-Farm Conventional and Organic Production Systems. *Crop science*, *51*(2), 621-630. doi:10.2135/cropsci2010.02.0063

Smajgl, A., & Ward, J. (2015). Evaluating participatory research: Framework, methods and implementation results. *Journal of Environmental Management, 157,* 311-319. https://doi .org/10.1016/j.jenvman.2015.04.014

Small, M. (2017, Aug 24). *About the Colorado master gardener program.* Retrieved from: www. cmg.colostate.edu/about.shtml

Smale, M., Bellon, M.R., Aguirre, J.A., Roasa, I.M., Mendoza, J., Solano, A.M., Martinex, R., Ramirez, A., & Berthaud, J. (2003). The economic costs and benefits of a participatory project to conserve maize landraces of farms in Oaxca, Mexico. *Agricultural Economics, 29,* 265-275. doi: 10.1111/j.1574-0862.2003.tb00163

Sooby, J., Landeck, J., & Lipson, M. (2007, May). 2007 National organic Research agenda: Outcomes from the scientific congress on organic agricultural research. Davis, CA.

Steinke, J., & van Etten, J. (2017). Gamification of farmer-participatory priority setting in plant breeding: Design and validation of "AgroDuos." *Journal of Crop Improvement, 31*(3), 536-378. doi:0.1080/15427528.2017.1303801

Steinke, J., van Etten, J., & Zelan, P.M. (2017). The accuracy of farmer-generated data in an agricultural citizen science methodology. *Agronomy for Sustainable Development, 37,* 32-44. doi:10.1007/s13593-017-0441-y

Sparger, J. A., Norton, G. W., Heisey, P. W., & Alwang, J. (2013). Is the share of agricultural maintenance research rising in the United States?. *Food policy*, *38*, 126-135. https://doi.org/10.1016/j.foodpol.2012.11.004

Total farms and ranches in Colorado unchanged in 2017. (2017). Retrieved from kiowacounty press.net/content/total-farms-and-ranches-colorado-unchanged-2017

Torricelli, R., Negri, V., & Ciancaleoni, R. (2014). Performance and stability of homogenous and heterogeneous broccoli (*Brassica olaracea* L. var. Plenck) varieties in organic and low-input conditions. *Euphytica, 199,* 385-395. https://doi.org/10.1007/s10681-014-1139-8

Van de Fliert, E., & Braun, A.R. (2002). Conceptualizing integrative, farmer participatory research for sustainable agriculture: From opportunities to impact. *Agriculture and Human Values, 19*, 25-38. https://doi.org/10.1023/A:1015081030682

Vom Brocke, K., Trouche, G., Weltzien, E., Barro-Kondombo, C. P., Gozé, E., & Chantereau, J. (2010). Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria. *Field Crops Research*, *119*(1), 183-194. https://doi.org/10.1016/j.fcr.2010.07.005

Wletzein, E., & Christinck, A. (2009). Methodologies for priority setting. In S. Ceccarelli, E.P. Guimaraes & E. Weltzein (Eds.), *Plant breeding and farmer participation* (pp.75-105). Rome, Italy: FAO.

Walker T. S. (2006). Participatory varietal selection, participatory plant breeding, and varietal change, in *World Development Report 2008*. Washington, DC: World Bank.

Wayman, S., Kucek, L.K., Mirsky, S.B., Ackroyd, V., Cordeau, S., & Ryan, M.R. (2016). Organic and conventional farmers differ in their perspectices on cover crop use and breeding. *Renewable Agriculture and Food Systems, 32*(4), 376-385. doi:10.1017/S1742170516000338

Whitcombe, J.R., Gyawali, S., Subedi, M., Virk, D.S., & Joshi, K.D. (2013). Plant breeding can be made more efficient by having fewer, better crosses. *Plant Biology, 13*(22), 12-24. doi: 10.1186/1471-2229-13-22

Witcombe, J.R., Joshi, K.D., Gyawali, S., Musa, A.M., Johansen, C., Virk, D.S., & Sthapit, B.R. (2005). Participatory plant breeding is better described as highly clinet-oriented plant breeding: Four indicators of client-orientation in plant breeding. *Experimental Agriculture, 41*(3), 299-319. https://doi.org/10.1017/S0014479705002656

Wolfe, M.S., Baresel, J.P., Desclaux, D., Goldringer, I., Hoad, S., Kovacs, G., Loschenberger, F., Miedaner, T., Ostergard, H., & Lammerts van Bueren, E.T., (2008). Development in breeding cereals for organic agriculture. *Euphitca, 163,* 323-34. doi:10.1007/s10681-008-9690-9

APPENDICES

Appendix A: Institutional Review Board Exemption

Research Integrity & Compliance Review Office
Office of Vice President for Research
Fort Collins, CO 80523-2011
(970) 491-1553
FAX (970) 491-2293

Date: March 1, 2016

To: **David Holm, Ph.D., Horticulture and Landscape Architecture**
Katrina Zavislan, Horticulture and Landscape Architecture

From: IRB Coordinator, Research Integrity & Compliance Review Office
(RICRO_IRB@mail.colostate.edu)

Re: Colorado State University Potato Evaluation Program for Home Gardeners

Funding: Internal

IRB ID: 030 -18H **Review Date:** March 1, 2016
This project is valid from three years from the review date.

The Institutional Review Board (IRB) Coordinator has reviewed this project and has declared the study exempt from the requirements of the human subject protections regulations with conditions as described above and as described in 45 CFR 46.101(b):

Category 2 - Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Category 6 - Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

The IRB determination of exemption means that:

This project is valid for three years from the initial review. After the three years, the file will be closed and no further research should be conducted. If the research needs to continue, please let the IRB Coordinator know before the end of the three years. You do not need to submit an application for annual continuing review.

- You must carry out the research as proposed in the Exempt application, including obtaining and documenting (signed) informed consent if stated in your application or if required by the IRB.
- Any modification of this research should be submitted to the IRB through an email to the IRB

Coordinator, prior to implementing any changes, to determine if the project still meets the Federal criteria for exemption.

- Please notify the IRB Coordinator (RICRO_IRB@mail.colostate.edu) if any problems or complaints of the research occur.

Please note that you must submit all research involving human participants for review by the IRB. **Only the IRB or designee may make the determination of exemption**, even if you conduct a similar study in the future.

Appendix B: Letter to County Directors

Colorado State University®
Knowledge to Go Places
Agricultural Experiment Station
San Luis Valley Research Center
0249 East Road 9 North
Center, Colorado 81125
(719) 754-3594

Dear County Director,

Thank you for participating in the San Luis Valley Research Center Potato Evaluation Program. The Research Center will provide you with potato seed for volunteer gardeners to grow and evaluate. We would like a minimum of five volunteers from your county to grow two new selections each. This year we are focusing on evaluating specialty potatoes, which typically have red, yellow, or purple flesh. Gardeners will complete an evaluation form about the selections they grew, and will return it to the Research Center. This data will help the program continue to develop superior potatoes for Colorado. Below is a tentative timeline for the summer:

April 4th: Deadline to reply with the number of master gardeners or other community members that would like to evaluate potatoes this summer. Feel free to include yourself in the total.

April 11th to 15th: Seed pick up or delivery. You are welcome to pick up seed from the Research Center. If you are unable to do so, we will ship the seed to your county office.

Summer: Volunteers grow potatoes and complete evaluation forms.

September 30th: Deadline to turn in evaluation forms. Email responses are preferable, but I can provide self-addressed envelopes if necessary.

During this time, I will:
- Provide you with an accurate number of potatoes based on your request
- Be available to answer questions about growing potatoes, pest or disease problems, or other issues
- Send out email reminders to volunteers if they are comfortable providing their contact information
- Share the results of the completed surveys as part of my M.Ag professional paper

I would like participating counties to:
- Distribute potatoes, a letter to volunteers, and an evaluation form to each gardener
- Remind gardeners to complete and return evaluations
- Remind gardeners that they cannot save for seed, sell, or distribute raw tubers

Please get in touch if you have any questions or comments. Additionally, please contact the Research Center if your volunteer gardeners or others would like to arrange a tour of the farm; we'd love to have you come visit!

Trina Zavislan
Research Associate
Potato Breeding and Selection
San Luis Valley Research Center- Colorado State University
719-480-1716
Potatoes.colostate.edu/potato-breeding
Facebook.com/SLVRC.potatoes

Appendix C: Recruitment Flier

Help Colorado State University Make Better Potatoes

The CSU San Luis Valley Research Center develops new potato selections for farmers and home gardeners in Colorado. We depend on your feedback to help us develop superior cultivars.

The Research Center will provide you with free potatoes developed in Colorado.

Volunteer gardeners will grow potatoes currently under evaluation and submit an evaluation form with feedback.

Interested? Contact your local Cooperative Extension office or csutuber@gmail.com.

Appendix D: Potato Evaluation Form

Potato Evaluation Form

Thank you for growing potatoes developed by the CSU Potato Breeding Program! This form will help ensure that we develop potato varieties relevant to home gardeners in Colorado.

Gardener Information

What potato cultivar did you grow? _____

In what county and zip code were they grown? _____

How were the potatoes grown? Please check all that apply.

- ☐ In a raised bed
- ☐ In a greenhouse
- ☐ In the ground
- ☐ In potting mix
- ☐ In garden soil
- ☐ In rocky soil
- ☐ In sandy soil
- ☐ In clay soil
- ☐ In loam soil
- ☐ Other_____

Please rate your gardening expertise.

☐ First time gardener ☐ Intermediate ☐ Expert

Season Overview

Planting date: _____

First harvest date: _____

How did you plant the potatoes?

- ☐ About 1 to 2" deep
- ☐ About 5 to 6" deep
- ☐ As whole potatoes
- ☐ About 3 to 4" deep
- ☐ Other_____
- ☐ As cut up seed pieces

Within and between row spacing: please check all that apply

- ☐ Plants about 6" apart
- ☐ Plants about 12" apart
- ☐ More than 12"
- ☐ About 1' between rows
- ☐ About 1.5' between rows
- ☐ About 2' between

Fertilizing practices: please check all that apply

- ☐ Weekly
- ☐ Monthly
- ☐ Never
- ☐ Once
- ☐ Synthetic (Ex. Osmocote)
- ☐ Compost
- ☐ Natural (Ex. Bone meal)
- ☐ Other _____

Irrigation practices: please check all that apply

- ☐ Daily
- ☐ Every other day
- ☐ Every three days
- ☐ Using a sprinkler system
- ☐ Using a hose/watering can
- ☐ Drip system

Severe weather during the growing season: please check all that apply

- ☐ Hail
- ☐ Heavy rain
- ☐ Drought
- ☐ Frost after planting
- ☐ Other _____

Pests and diseases: please check all that apply. Please list the name of the pest or disease if you know it. More information on pests and diseases: msue.anr.msu.edu/uploads/files/growingpotatoes.pdf

- ☐ Bacteria _____
- ☐ Virus _____
- ☐ Fungi _____
- ☐ Insects _____

0249 East Road 9 North, Center CO 81125. Phone: 719-480-1716. Email: csutuber@gmail.com

Potato Quality

Did your potatoes have any defects? If so, please rate from 1 (very mild) to 5 (very severe).

☐ Growth Cracks	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	☐ Hollow Heart	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
☐ Greening	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	☐ Second Growth	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
☐ Misshapen	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	☐ Insect/Rodent damage	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Potato Preparation

How were the potatoes prepared? Please rate from 1 (poor) to 5 (excellent) how suitable the potatoes were for each method you used.

☐ Baked	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	☐ Boiled	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
☐ Fried	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	☐ Microwaved	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
☐ Mashed	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	☐ Other _____	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Sensory Evaluation

Please rate the potato taste, texture, and aroma.

Very poor taste	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	Very good taste
Very poor texture	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	Very good texture
Very poor aroma	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐	Very good aroma

Recommendations

I would grow this variety again:

☐ Yes | ☐ No

CSU should:

☐ Discard this variety ☐ Continue Evaluation ☐ Name and release

What I liked about this variety:

_____

What I did not like about this variety:

_____

I would like to evaluate potatoes next year: ☐ Yes | ☐ No

I am interested in evaluating these types of potatoes:

Round white potatoes	☐ Yes | ☐ No	Russet potatoes	☐ Yes | ☐ No
Purple flesh specialty potatoes	☐ Yes | ☐ No	Fingerling potatoes	☐ Yes | ☐ No
Red flesh specialty potatoes	☐ Yes | ☐ No	Other _____	

Go to http://potatoes.colostate.edu/programs/potato-breeding/cultivars/ for more information on potatoes currently available for evaluation.

Please email this completed form to csutuber@gmail.com, fax it to 719-754-2619, or mail it to 0249 East Road 9 North, Center CO 81125 Attn. Trina Zavislan.

Please note: These potatoes are under evaluation and have not been released to the general public. Therefore, you may not save for seed, sell or distribute raw tubers, but we encourage you to share cooked potatoes with your friends and neighbors!

0249 East Road 9 North, Center CO 81125. Phone: 719-480-1716. Email: csutuber@gmail.com

Appendix E: Letter to Participants

Agricultural Experiment Station
San Luis Valley Research Center
0249 East Road 9 North
Center, Colorado 81125
(719) 754-3594

Dear Gardener,

Thank you for growing and evaluating potatoes developed by the CSU San Luis Valley Research Center! Your feedback helps us develop better potato cultivars for Colorado home gardeners. Please complete and return an evaluation form by October 15th, 2017.

If you need another copy of the evaluation form, please contact either your extension agent or myself (csutuber@gmail.com). The form can be returned by any of the methods below.

Email: Katrina.zavislan@colostate.edu
Fax: 719-754-2619
Mail: SLV Research Center Attn. Trina Zavislan 249 E. Rd 9 N., Center CO 81125

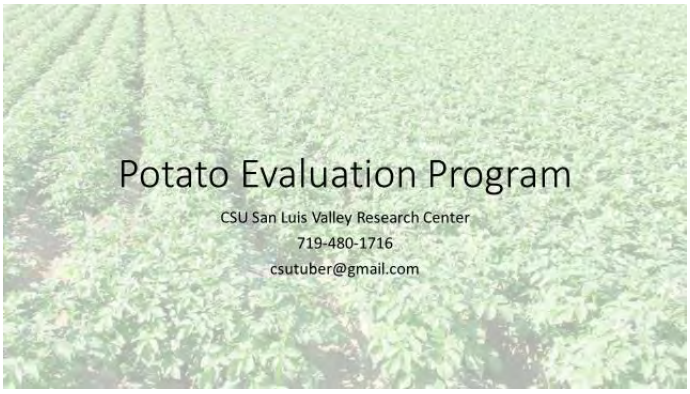
Please note: These potatoes are under evaluation and have not been released to the general public. Therefore, you may not save for seed, sell or distribute raw tubers, but we encourage you to share cooked potatoes with your friends and neighbors!

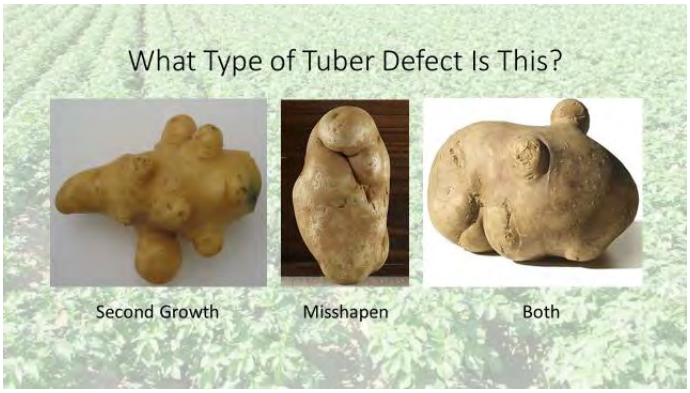
The purpose of this study is to better understand how home gardeners grow and use potatoes. You are free to skip any questions on the evaluation form, and can stop participating at any time. There are no anticipated risks to participation in this program. The information you provide will be handled confidentially. Your name or other identifying information will not be used in any report. This program asks you to garden, which you should only do if you feel physically able. You may wish to eat these potatoes after considering potential allergies and dietary preferences. The potatoes provided are the same species as those found in grocery stores, and are given to you without additives.

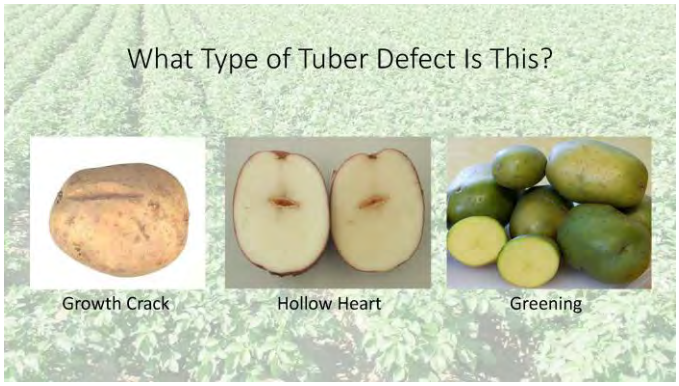
If you have any questions or comments about the program, feel free to email or call me at 719-480-1716, and katrina.zavislan@colostate.edu. To contact the principal investigator, please email david.holm@colostate.edu or call 719-480-2511.To learn more about the San Luis Valley Research Center and Colorado potatoes, please visit our website: potatoes.colostate.edu, or follow us on Facebook at facebook.com/SLVRC.potatoes.

Happy planting,
Trina Zavislan
Research Associate
Potato Breeding and Selection
San Luis Valley Research Center

Appendix F: PowerPoint Presentation Sent to County Directors and Participants







What Type of Tuber Defect Is This?

Insect Damage

Rodent Damage

Potato Preparation

- Did the potato perform the way you expected?
- Is it as good or better than the potatoes you buy from the grocery store for this purpose?

Sensory Evaluation

- Taste: Is the potato too sweet, bitter, or does it just taste weird?
- Texture: Is the potato too grainy, mushy, or watery the way you prepared it?
- Aroma: Does the potato have a good smell?

Appendix G: Revised Home Potato Gardening Extension Bulletin

POTATOES IN THE HOME GARDEN

By K.A. Zavislan, D.G. Holm, and R. Young (2017)

Potatoes are an interesting crop that can be successfully grown in Colorado home gardens. The potato, or *Solanum tuberosum*, is in the plant family Solanaceae. It is related to peppers, tomatoes, and eggplants but is adapted to higher elevations and therefore harsher growing conditions. Native to the Andes region of South America, they were brought to Europe and later North America. Potatoes are a good source of vitamin C, potassium, vitamin B6, and fiber, and are naturally fat free.

Potatoes vary in shape, size, skin color, and flesh color. Some common types are russets, reds, whites and specialty (including fingerling) potatoes. Gardeners should choose a variety based on the length of the growing season, disease pressure, garden size, and desired use. A few popular potato cultivars developed by Colorado State University include:

Name	Type	Use	Maturity	Notes
Canela Russet	Russet	Baking	Medium	Long term storage potential
Colorado Rose	Red Skin	Boiling	Medium	Good red skin color retention
Mercury Russet	Russet	Baking, frying	Very early	Suitable for short growing seasons
Purple Majesty	Specialty	Roasting, sautéing	Early	Purple pigments are antioxidants
Red Luna	Specialty	Boiling	Medium	High yield
Yukon Gold*	Specialty	Boiling, roasting	Medium	Attractive yellow flesh

* Yukon Gold is not a CSU cultivar, but is very popular with home gardeners.

GETTING SEED

Potatoes in the grocery store are typically treated with a sprout inhibitor and will not grow if planted in a garden. It is best to buy certified seed each spring that is inspected and within acceptable limits for diseases. Garden centers, reputable garden catalogs, or your local CSU Extension Agent are all sources of certified seed.

PREPARING SEED

Prior to cutting, the potatoes should be kept between 50^0 and 65^0 Fahrenheit away from direct sunlight for up to two weeks before planting to encourage germination and growth. In areas with short growing seasons, gardeners may use green sprouting to encourage early growth. To do this, arrange the potatoes in a single layer in an area exposed to light, such as a kitchen counter. When sprouts appear on part of the potato, turn it over to encourage even growth. The tubers should be planted before the sprouts reach one inch long.

Tubers, or part of potato tubers, are called seed pieces when they are planted in the soil. Each seed piece should have at least two eyes, as the stems will emerge from the eyes and grow into mature plants. If possible, plant small potatoes that are about 1 to 2 inches in diameter. These seed pieces do not need to be cut. The small tubers will not have a wound from cutting, and will therefore have no risk of disease transfer from a knife or of the cut

site drying out. Potatoes smaller than 1 inch in diameter should not be used as seed as they have limited stored nutrients available resulting in slower growth. Larger potatoes can be cut into 2 to 3 ounce pieces in preparation for planting. Best practices include:

- Cut blocky pieces, not long thin ones
- Make smooth, not jagged cuts. This reduces the risk of seed piece rot
- Dip the cutting knife in a 10% bleach solution between potatoes. This prevents disease transmission from an infected potato to a healthy one.

Cut potato seed pieces can be planted immediately if the soil temperature is 55^0F or above. Alternately, the seed pieces can be kept in a dark humid room for 4 to 7 days before planting. This will encourage callus, or scar tissue to form, protecting the cut site from diseases in the soil.

SOIL PREPARATION AND FERTILIZING

Gardeners should identify a spot in their garden with well-drained soil and no low spots where standing water can pool to plant their garden. Potatoes grow best in a sandy loam soil, but gardeners can manage a wide variety of soil types. Sandy soils can dry out quickly and may need more frequent watering. Soil that is high in clay can produce misshapen potatoes and should be tilled to break up large clumps prior to planting. Adding finished compost can provide organic matter and nutrients to the soil. However, both fresh manure and grass clippings can have weed seeds or too much salt. Additionally, manure may have been exposed to herbicides that can damage vegetable plants.

To apply the correct amount of fertilizer and manage the soil appropriately, gardeners should test their soil every year to determine pH, organic matter, and nitrogen levels. This can be done at the CSU Soil, Water, and Plant Testing Lab by bringing in a gallon size bag ¾ full of dry soil for sampling. Understanding the soil characteristics allows the gardener to select the appropriate type and amount of fertilizer. If a soil test is not available, a soluble vegetable fertilizer applied at the rate recommended on the package is typically sufficient.

It is important to rotate crop families about every three years to maintain healthy soil. If potatoes are planted in the same place for several years, pathogens can thrive in the soil and easily infect the next potato crop. Planting a new crop in a different family deprives the potato pathogen of the host it requires. Most pests and diseases can damage plants of the same botanical family, but cannot harm unrelated crops. The legume family, including beans and peas, is a good choice for crop rotation due to its ability to build nitrogen in the soil, while potatoes can deplete the nitrogen.

PLANTING

Potatoes can be planted up to two weeks before the last killing frost. The soil temperature should be at least 55^0F during the day and 45^0F at night as cool, wet soil can delay sprout emergence or cause seed pieces to rot. Seed pieces should be planted about four inches deep, about 12 inches apart, in rows that are about 36 inches apart. Plant with the sprouts or eyes facing up. Spacing can be adjusted based on the type of potato that is planted. Those with smaller size profiles, such as fingerling potatoes, can be planted closer together. However, potatoes planted too far apart can become misshapen or develop hollow heart.

Gardeners should add an additional two inches of soil around the top of the plant when they are start to emerge from the soil. This is called hilling and ensures that the developing tubers are covered by soil and not exposed to sunlight. Mulching is recommended to avoid damaging roots, which may extend a foot from the base of the plant, and to retain soil moisture. Wood chips and straw are acceptable sources of mulch to soil if they effectively block light. Checking frequently for exposed tubers and adding more soil and mulch will help keep potatoes from being exposed to sunlight and turning green. Green potatoes should be discarded and not eaten.

WATERING

Potatoes require consistent soil moisture. Variability such as infrequent or too heavy watering can cause growth cracks, irregular shape, and hollow heart. Gardeners should determine the appropriate frequency and duration of watering based on the weather, soil type, and the water needs of other plants in their garden. Potatoes typically need about two inches of water per week. A rain gauge placed at ground level near the potato plants will indicate how many inches of water the plants receive. The period of highest water need is in late June to early August when the potato foliage is fully developed. This is usually when the plant flowers and the leaves are dark green. As the plants begin to turn yellow and mature in late summer, gardeners can water less to encourage tuber development and prevent potatoes from rotting.

PESTS

It is important for gardeners to learn to identify and control pests and diseases on their potato plants. This will improve yields, reduce waste, and protect the commercial potato industry in Colorado. Because most home gardeners plant potatoes on a small scale, it is not cost effective to purchase and apply pesticides. Instead, planting crop rotations with nitrogen fixers (legumes) and frequent visual inspection are key to maintaining plant health. If potatoes are grown every year, they should be grown in different areas of the garden, for example in different raised bed than in the previous year. Some pests and diseases only infect one type of vegetable, and planting it in the same area year after year creates a favorable environment for infection.

Weeds

Weeds should be identified and controlled frequently, as they can act as hosts of potato diseases and compete for water and nutrients. Weed control is especially important while the potato plants are less than a foot tall and fast growing weeds can outcompete the young potatoes. Most weeds thrive on disturbance to the soil and can even grow from fragmented pieces of root, so it is best to pull them out by as much of the root as possible instead of cultivating them into the soil with a hoe or rake. This also prevents tuber and potato root damage.

Diseases

The best strategy to prevent potato diseases is to avoid conditions that favor disease development. This means maintaining soil moisture, checking regularly for unhealthy plants, and growing disease resistant cultivars. Most seed borne diseases are preventable by using certified seed. Gardeners should check their potato plants regularly, and remove

any that appear stunted, yellow, have shriveled leaves, or look suspicious. To avoid the potential spread of disease, these plants should be put in the garbage, not a compost pile. This most common potato disease gardeners encounter is powdery scab. Potatoes with this disease are still edible, but gardeners may choose to plant a cultivar more resistant to scab if it is a problem in their garden. Rotating crops also helps to interrupt disease cycles and prevents the depletion of nutrients.

Insects

Frequent scouting for pests allows gardeners to identify and respond to insect problems before they become severe. Look on the underside of leaves, around the base of the plant, and other hard to see areas for insect eggs, larvae, and adults. Using a hand lens may be helpful to see small insects. Removing juvenile insects reduces the population and prevents a major pest problem from developing. Pests can be removed by hand or using a high-pressure garden hose.

HARVEST

Indicators of mature potato plants include vine yellowing and death, and skin set, when the potato skin does not peel off when rubbed. Immature or new potatoes are harvested during the summer before the plant is completely mature and should be eaten right away. These potatoes have a thin skin, bruise easily, and are not suitable for storage. Potatoes should be harvested before the first severe frost. If the potato plants are still green close to this time, the vines can be cut to about six inches tall one to two weeks before the desired harvest date. Decreasing watering during this time will also help the tubers mature and develop the skin. A fork or large shovel should be used to lift the plants out of the ground to avoid cutting the potatoes. Gardeners can expect about two pounds of potatoes per plant, but this is dependent on the cultivar, weather, and competition from pests, weeds, and diseases.

STORAGE

After the potatoes are harvested, they should be stored in a dark place with high humidity at 50 to 60F for about two weeks to cure, or set the skin. This can be done in a cooler part of the house, such as a utility room with a portable humidifier. The potatoes are now ready for long term storage in the dark at about 40F, which keeps the potatoes from sprouting or shriveling up. The tubers should not be kept in sealed containers, but should be stored in burlap bags or slotted bins that allow for airflow. If they will be eaten within a week, potatoes can be stored at room temperature.

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Appendix H: Gardener Images

Clockwise from top left: A gardener uses a brick to mark a row of CO05037-3W/Y potatoes in Gunnison County. A family member of a Boulder County Master Gardener stands with the potato harvest. The harvested tubers of CO00405-1RF in Gilpin County. The daughter of a Teller County participant holds tubers off CO05037-3W/Y.