PENNSYLVANIA VEGETABLE MARKETING AND RESEARCH PROGRAM
PENNSYLVANIA VEGETABLE GROWERS ASSOCIATION
2017 RESEARCH REPORT

Breeding tomatoes for disease resistance and other desirable characteristics for production in PA

Majid R. Foolad
Professor of Plant Genetics
Department of Plant Science, The Pennsylvania State University, University Park, PA 16802

Goals of the Penn State tomato genetics and breeding program:

Develop breeding lines and F_1 hybrid cultivars of tomato with disease resistance and other desirable horticultural characteristics suitable for production in PA.

Research Activities Pursued in 2017 Included the Followings:

Objective 1: Development of fresh-market (FM) tomato breeding lines with LB resistance, conferred by *Ph-3* and/or *Ph-5* resistance genes.

Objective 2: Development of processing tomato breeding lines with LB resistance, conferred by *Ph-3* and/or *Ph-5* resistance genes.

Objective 3: Development and evaluation of fresh-market (FM) experimental F_1 hybrids with LB resistance. These hybrids will also have other desirable traits, including EB resistance, high yield, and superior fruit quality.

Objective 4: Development and genetic analysis of a recombinant inbred line (RIL) population of tomato segregating for LB resistance. This population will be used for identification and verification of new LB resistance genes and transferring to PSU tomato breeding lines.

Objective 5: Genetic characterization of additional (recently identified) sources of LB resistance in tomato.

Objective 6: Development and field evaluation of fresh-market (FM) experimental F_1 hybrids with high yield, EB resistance, and other desirable characteristics including fruit quality.

Objective 7: Development and field evaluation of processing experimental F_1 hybrids with high yield, EB resistance, and other desirable characteristics including fruit quality.

Objective 8: Development of fresh-market (FM) experimental F_1 hybrids in collaboration with a seed company (co-hybrids) and evaluation under multiple field locations.

Objective 9. Field evaluation of Penn State advanced fresh-market (FM) and processing breeding lines.

2017 Research Progress:

(Please note that the research described here is a summary of work conducted during 2017 in the tomato genetics and breeding program at Penn State with funds received from different sources, including the $12,000 from the PVMRP/PVGA. While funds from PVMRP/PVGA have been very helpful, not all of the research described below was the result of such funds.)

Summary

In 2017, we grew several hundreds of fresh-market (FM) and processing tomato entries (including PSU inbred lines and F_1 hybrids, families, commercial material, etc.) under field conditions and evaluated them for numerous desirable characteristics, including yield, disease resistance, fruit quality, etc. From among the PSU inbred lines and families, numerous lines were selected for advancement, and further evaluation and characterization. We grew over one hundred experimental hybrids, some of which in multiple locations and replications, and evaluated them for potential commercialization. Throughout the year, we also conducted many experiments in the greenhouse, including growth and evaluation of numerous PSU inbred lines and families for late blight (LB) resistance, hybridizations among inbred lines to develop experimental hybrids, and generation advancement. Further, laboratory experiments were conducted throughout the year for DNA genotyping, and characterization of various tomato germplasm. One of the major accomplishments of the *Penn State Tomato Breeding Program* in 2017 was the commercial release of a fresh-market tomato cultivar, named ***Valentine***, which was developed in collaboration with Johnny's Selected Seeds http://www.johnnyseeds.com/vegetables/tomatoes/valentine-organic-f1-tomato-seed-3371G.html?cgid=tomatoes#start=1. This variety won an All-American-Selections (AAS) award (http://all-americaselections.org/winners/).

Abbreviations: *EB: early blight; FM: fresh-market; GH (greenhouse); LB: late blight; RILs: recombinant inbred lines.*

Objective 1: *Development of fresh-market (FM) tomato breeding lines with LB resistance, conferred by Ph-3 and/or Ph-5 resistance genes*

Ph-3 was previously identified as a LB-resistance gene by other researchers, and has been incorporated into several commercial FM tomato breeding lines and hybrid cultivars. *Ph-5* was recently identified as a new LB-resistance gene at Penn State (Reference: *Merk HL, H Ashrafi and MR Foolad. 2012. Selective genotyping to identify late blight resistance genes in an accession of the tomato wild species Solanum pimpinellifolium. Euphytica: 187:63-75*). We have been conducting research to transfer *Ph-3* and *Ph-5* resistance genes to our FM tomato-breeding lines. During winter (February) 2017, we grew and evaluated for LB resistance all of our 17 FM families/lines with *Ph-3* (9) or *Ph-5* (8) resistance gene under GH conditions. From each family, two most resistant plants were selected, which were grown to maturity and advanced to the next generation. The progeny of these resistant families was subsequently grown in the GH and seedlings were transplanted into the field in late-June 2017. During the field season, the 17 FM tomato families/lines with *Ph-3* (9 families) or *Ph-5* resistance gene (8 families) were evaluated for various horticultural characteristics. From among the 9 families with *Ph-3* resistance, 2 families were eliminated and 7 plants (one from each of the other 7 families) were selected. Similarly, from among the 8 families with *Ph-5* resistance, one family was eliminated and 7 plants (one from each of the other 7 families) were selected. The total of 14 plants with LB resistance (7 with *Ph-3* and 7 with *Ph-5* resistance genes) were grown to maturity under field conditions and advanced to the next generation. All of these families (lines) are considered to be LB resistant. In 2018, these plants will be grown under field conditions for evaluation of other desirable horticultural characteristics. By the end of field season in 2018, we expect that we will have advanced FM breeding lines with LB resistance and other desirable horticultural characteristics; these lines should be ready for making experimental hybrids. In fact, during winter/spring 2018, we will be developing a total of 40 new FM experimental F_1 hybrids with LB resistance derived from different crosses. Some of these hybrids will have only *Ph-5* resistance gene, some *Ph-5+Ph-3, and some Ph-5+Ph-3+Ph-2.* In 2018, these experimental hybrids will be evaluated under greenhouse conditions for LB resistance and under field conditions for other desirable horticultural characteristics (described in 2018 proposal).

Objective 2: *Development of processing tomato breeding lines with LB resistance, conferred by Ph-3 and/or Ph-5 resistance genes*

Ph-3 was previously identified as a LB resistance gene by other researchers and has been incorporated into several commercial fresh-market (FM) tomato breeding lines and hybrid cultivars. *Ph-5* was recently identified as a new LB-resistance gene at Penn State. We have been conducting research to transfer *Ph-3* and *Ph-5* resistance genes to our processing tomato-breeding lines. During winter 2017, we grew and evaluated our 19 processing families/lines with *Ph-3* (9) or *Ph-5* (10) resistance gene for LB resistance under greenhouse (GH) conditions. From each family, two most resistant plants were identified, grown to maturity, and advanced to the next generation. The progeny of these resistant families was subsequently grown in the GH and 6-week old seedlings were transplanted into the field in late-June 2017. During the field season, the 19 processing tomato families were evaluated and screened for various horticultural characteristics. From among the 9 families with *Ph-3* resistance, 7 plants (one from each of 7 families) were selected for advancement. Similarly, from among the 10 families with *Ph-5* resistance, 4 plants (one from each of 4 families) were selected for advancement. The total of 11 plants with LB resistance (7 with *Ph-3*, and 4 with *Ph-5*) were grown to maturity under field conditions and advanced to the next generation. All of these families (lines) are considered LB resistant. In 2018, these plants will be grown under field conditions for evaluation of other desirable horticultural characteristics. By the end of field season in 2018, we expect that we will have advanced processing breeding lines with LB resistance (*Ph-3* or *Ph-5*) and other desirable horticultural characteristics; these lines should be ready for making experimental hybrids. In fact, during winter/spring 2018 we are making crosses between one PSU LB resistant processing breeding line (with *Ph-5* resistance) and 6 PSU elite processing breeding lines with other characteristics to develop 6 processing experimental F_1 hybrids with LB resistance. In 2018, these experimental hybrids will be evaluated under greenhouse conditions for LB resistance and under field conditions for other desirable horticultural characteristics (described in 2018 proposal).

Objective 3: *Development and evaluation of fresh-market (FM) experimental F_1 hybrids with LB resistance. These hybrids will also have other desirable traits, including EB resistance, high yield, and superior fruit quality*

In 2017, we developed 34 FM Experimental Hybrids with LB resistance, of which 17 had *Ph-3* resistance gene and 17 had *Ph-5* resistance gene. The 34 FM Experimental Hybrids were evaluated for LB resistance in the greenhouse, and also were grown on raised beds with plastic in the field and evaluated for other desirable characteristics. In general, hybrids with *Ph-3* resistance gene only did not show strong LB resistance, whereas those with *Ph-5* resistance gene exhibited more resistance. It seems that it may not be useful to have only *Ph-3* resistance gene. However, under field conditions, some hybrids seemed pretty good in terms of other horticultural characteristics, and those hybrids will be re-trialed in 2018. Based on the results of 2017, in 2018 we will be making a total of 40 FM experimental hybrids with *Ph-5* only, *Ph-5+Ph-3, or Ph-5+Ph-3+Ph-2* resistance genes.

Objective 4: *Development and genetic analysis of a recombinant inbred line (RIL) population of tomato segregating for LB resistance. This population will be used for identification and verification of new LB resistance genes and transferring to PSU tomato breeding lines*

As reported before, previously we had identified a *Solanum pimpinellifolium* accession (PI 270443) with a very high level of resistance to LB. Subsequently, we investigated the genetic control of LB resistance in this accession, including the inheritance of resistance (*Merk HL and MR Foolad, 2012. Parent-offspring correlation estimate of heritability for late blight resistance conferred by an accession of the tomato wild species Solanum pimpinellifolium. Plant Breeding: 131: 203-210*) and identification and mapping of resistance genes (*Merk HL, H Ashrafi and MR Foolad. 2012. Selective genotyping to identify late blight resistance genes in an accession of the tomato wild species Solanum pimpinellifolium. Euphytica: 187:63-75*). We also used this accession for breeding tomatoes with LB resistance, as described above (*Ph-5* resistance gene). The resistance in this accession has been determined to overcome situations when the *Ph-2 + Ph-3* combination may fail (personal observation, as well as results obtained by a collaborator at NC State). Thus, we selected this accession for further genetic analysis, including identification and characterization of LB resistance genes present in this accession and their use for breeding tomatoes with LB resistance. As explained in previous reports, we have developed a recombinant inbred line (RIL) population from crosses between this accession and a LB-susceptible elite tomato breeding lines. During 2017, this population was advanced to F_{10} generation. Further, the F_8, F_9 and F_{10} generations were screened and evaluated for LB resistance under greenhouse conditions. This population will be used for detailed genetic characterization of LB resistance exist in PI 270443. Since 2017, we have been working on developing genetic markers for this population to develop a genetic map and conduct genetic analysis to identify the gene(s) controlling LB resistance in PI 270443. Genetic marker development was outsourced to an external organization. Unfortunately, there were issues with marker development, and we had to switch to a different organization for marker development. Recently, we submitted new DNAs of the RIL population to the new place, and currently are waiting to obtain marker results. Once markers are generated, we will develop a genetic map that will be used for mapping LB resistance genes in this population. The genetic mapping will be based on LB resistance data in F_8, F_9 and F_{10} generations. The purpose of this project is to confirm the LB resistance genes in this population and work towards their fine mapping and characterization. Once the resistance genes are mapped and fine-mapped, they will be used for breeding purposes and development of LB-resistant breeding lines and hybrid cultivars. This is an ongoing long-term project.

Objective 5: *Genetic characterization of additional (recently identified) sources of LB resistance in tomato*

In addition to the identification and characterization of LB-resistant *S. pimpinellifolium* accession PI 270443 (described above), we have been investigating the genetic basis of LB resistance in four other new accessions of *S. pimpinellifolium*, namely PI 270441, PI 270442, PI 163245 and PI 224710, which we had identified in our investigations at Penn State (as reported previously). In 2017, we continued our experimental research on one of these accessions, PI 224710. We developed new segregating populations from crosses between this accession and an elite tomato breeding line susceptible to LB. We screened the population for LB resistance in different generations, and identified individuals/families suitable for further molecular genetic analysis to identify and map LB resistance genes. Similar to that for the PI 270443 RIL population (described above), we decided to outsource marker development to a commercial company. Agreement has been made with the company, and we will be sending them tissues of the mapping population for genotyping (specifically genotyping-by-sequencing; GBS) and marker development. Once markers are developed, we will use them to develop a genetic map of the population and conduct genetic mapping to identify genes controlling LB resistance in PI 224710. Once the resistance genes identified, they will be used in breeding new tomatoes with LB resistance.

In 2017, in addition to the experimental research on PI 224710, we worked on the other three accessions (PI 270441, PI 270442, PI 163245), mainly analyzing our research results, preparing research manuscripts, and submitting manuscripts for publication in refereed journals. For example, for accession PI 270441 we submitted a manuscript to journal *Plant Breeding*, which was accepted for publication and recently published (*Sullenberger, MT, M Jia, S Gao and MR Foolad. 2018. Genetics analysis of late blight resistance in Solanum pimpinellifolium accession PI 270441: heritability and response to selection. Plant Breeding 137:89–96. https://doi.org/10.1111/pbr.12561*). Below is the abstract of the published paper:

Genetic analysis of late blight resistance in Solanum pimpinellifolium accession PI 270441: heritability and response to selection

MATTHEW T. SULLENBERGER, MENGYUAN JIA, SIHUI GAO, and MAJID R. FOOLAD

Abstract. Late blight (LB), caused by *Phytophthora infestans*, is a destructive disease of tomato (*Solanum lycopersicum*) worldwide. Currently, there are few commercial cultivars of tomato with resistance to LB, and the disease is mainly controlled by heavy use of fungicides. Due to the emergence of fungicide-resistant pathogen isolates, there is a concerted effort to identify new genetic sources of resistance and breed new resistant cultivars. A recent screening identified several new tomato accessions with strong resistance to LB. Here we report on the genetic basis of LB resistance in *S. pimpinellifolium* accession PI 270441, as determined by generation means analysis and analysis of response to selection, using populations derived from crosses with LB-susceptible breeding line Fla. 8059. Heritability of LB resistance ranged from 0.76 to 0.78, and the minimum number of genes was estimated 1 – few. These results suggest that transfer of LB resistance from PI 270441 to the cultivated tomato should be feasible

via a traditional backcross breeding approach. Genetic mapping studies are underway to identify molecular markers associated with resistance in this accession.

Similarly, for accession PI 270442 we submitted a manuscript to journal *Advanced Studies in Biology*, which was accepted for publication and recently published (*Sullenberger MT and MR Foolad. 2018. Genetic characterization of late blight resistance in Solanum pimpinellifolium accession PI 270442. Adv Studies Biol 10: 13 – 32. https://doi.org/10.12988/asb.2018.71231*). Below is the abstract of the published paper:

Genetic Characterization of Late Blight Resistance in Solanum pimpinellifolium Accession PI 270442

MATTHEW T. SULLENBERGER and MAJID R. FOOLAD

Abstract. One of the most destructive foliar diseases of the cultivated tomato (*Solanum lycopersicum*) is late blight (LB), caused by the oomycete *Phytophthora infestans*. Due to the limited number of commercial tomato cultivars with resistance to this disease, control is mainly through cultural practices and heavy use of fungicides. The appearance of fungicide-resistant *P. infestans* genotypes, however, necessitates identification of new genetic sources of host resistance to the disease and subsequent breeding of new resistant cultivars. Several new sources of resistance to tomato LB were identified in a recent screening of the tomato related wild species *S. pimpinellifolium*. In the present study, we examined the genetic basis of LB resistance in accession PI 270442, through parent-offspring correlation analysis, generation means analysis, and analysis of response to selection, using populations derived from crosses with a LB-susceptible tomato breeding line. Across experiments, estimates of heritability (h^2) for LB resistance ranged from 0.56 – 0.86, suggesting the heritable nature of this resistance and possibility of effectively transferring LB resistance from PI 270442 to the cultivated tomato genetic background through phenotypic selection and traditional backcross breeding. Genetic mapping studies are currently underway to identify the associated molecular markers for LB resistance in PI 270442.

Also, for accession PI 163245 we recently submitted a manuscript to a refereed journal and is currently under review for publication consideration. Below is the abstract of the submitted manuscript:

Identification and mapping of late blight resistance QTLs in tomato accession PI 163245

ERIK W. OHLSON, HAMID ASHRAFI AND MAJID R. FOOLAD

Abstract. Late blight (LB), caused by the oomycete *Phytophthora infestans*, is one of the most devastating diseases of tomato (*Solanum lycopersicum*) and potato (*S. tuberosum*) worldwide. The importance of LB on tomato has increased due to the occurrence of aggressive and fungicide-resistant clonal lineages of *P. infestans*. Consequently, identification and characterization of new sources of genetic resistance to LB has become a priority in tomato breeding. Previously, we reported accession PI 163245 as a promising

source of highly-heritable LB resistance for tomato breeding. The purpose of this study was to identify and map QTLs associated with LB resistance in this accession, using a trait-based marker analysis (a.k.a selective genotyping). An F_2 mapping population (n = 560) derived from a cross between a LB-susceptible tomato breeding line (Fla. 8059) and PI 163245 was screened for LB resistance, and the most resistant (n = 39) and susceptible (n = 35) individuals were selected for genotyping. Sequencing and comparison of the reduced representation libraries (RRLs) derived from genomic DNA of the two parents resulted in the identification of 33,385 putative SNP markers, of which 233 genome-wide markers were used to genotype the 74 selected F_2 individuals. The marker analysis resulted in the identification of four LB-resistance QTLs conferred by PI 163245, located on chromosomes 2, 3, 10 and 11. Research is underway to develop near-isogenic lines (NILs) for fine-mapping the QTLs and develop tomato breeding lines with LB resistance introduced from PI 163245

Results from all these studies will be used for breeding tomatoes with LB resistance.

Objective 6: *Development and field evaluation of fresh-market (FM) experimental F_1 hybrids with high yield, EB resistance, and other desirable characteristics including fruit quality*

The ultimate goal of a tomato-breeding program is to develop F_1 hybrids from crosses between advanced inbred lines, and evaluate them for commercial production. During the past several years, we have developed many advanced breeding lines of FM tomatoes (cherry, grape, plum, large size) with numerous desirable characteristics. Many of these lines are ready to be used as parents to develop experimental hybrids. During the winter and spring 2017, we developed a total of 102 new FM experimental hybrids, all of which were large-size (slicer/beef) tomatoes. Of these experimental hybrids, 34 had desirable traits including LB resistance (described above) and the rest (68) had many desirable traits, not including LB resistance. In 2017, the 68 hybrids were grown under different field conditions, as described below:

Objective 6-1: Evaluation of hybrids on bare ground in Rock Springs, PA. All 68 experimental hybrids were grown on bare grounds in Rock Springs, PA, and evaluated for desirable horticultural characteristics. In general, unfortunately the field conditions were not good; there were issues with soil compaction, flooding, and herbicide effects. So, most hybrids did not perform to their full genetic potential, and useful data could not be obtained. However, all of these hybrids will be regenerated and grown under field conditions in 2018, using raised beds with plastic.

Objective 6-2: Evaluation of hybrids on raised bed with plastics in Rock Springs, PA. A total of 23 of the 68 experimental hybrids were selected (based on previous years' data) and grown on raised bed with plastic in two replications. This experiment was very successful, and extensive data were collected from all 23 hybrids. Evaluations were conducted in different stages: general data were collected on the overall performance of the 23 hybrids, and yield data were collected based on multiple harvests.

Objective 6-3: Evaluation of hybrids on raised bed with plastics in Rock Springs (Mike Orzolek's Field). A total of 11 of the 64 experimental hybrids were grown in Mike Orzolek's field and evaluated for various horticultural characteristics. These plants were grown on raised beds with plastic. Mike uses special fertility treatments, and it was interesting to see the response of the hybrids under his growing conditions. Generally, most hybrids did very well, good data were collected. All of these hybrids will be re-evaluated in 2018.

Objective 6-4: Evaluation of hybrids on raised bed with plastics in Landisville, PA. A total of 10 of the 64 experimental hybrids were grown and evaluated in Tim Elkner's field at Penn State Southeast Agricultural Research and Extension Center in Landisville, PA. These plants were grown on raised bed with plastic and were staked. We travelled to Landisville on August 24, 2017 and evaluated plants. These plants were planted later than other material by Tim, and there was issues with bacterial diseases. However, plants were evaluated for bacterial disease resistance, fruit size, uniformity and overall performance. All of these hybrids will be re-evaluated in 2018.

Objective 6-5: Evaluation of hybrids in Lackawanna County, PA. Seed of 10 of the 64 experimental hybrids were provided to Extension Educator John Esslinger to grow in a farmer field in Lackawanna County. In collaboration with a grower, John grew and evaluated the hybrids for Fruit Weight/10 plants, # Fruit, and total FW in two different dates. He used two commercial varieties, Mt. Merit and Mt. Fresh, as control. John provided data to the *Penn State Tomato Breeding Program*. Generally, Penn State Hybrids did very well. All of these hybrids will be re-evaluated in 2018.

Objective 6-6: Growth of PSU hybrids by PVGA President David Miller. A total of 10 of the 64 experimental hybrids were provided to David Miller (2017 PVGA President), to grow and evaluate in his field. However, due to unexpected causes, such as flooding, Dave lost this tomato trial and was not able to evaluate or provide data. All of these hybrids will be re-evaluated in 2018.

At the end of season in 2017, based on the 2017 field data, as well as data from previous years, a total of 18 experimental hybrids were chosen for large-scale production of hybrid seeds to conduct field trials in multi-locations in 2018. A contract was signed with a seed production company in Costa Rica for seed production. Parental lines of these hybrids were shared with the company in Costa Rica. We expect to receive 2000 or more seed of each of the 18 hybrids sometime in early April 2018. Seeds will be distributed to to different seed companies and growers for commercial evaluation in 2018.

Objective 7: *Development and field evaluation of processing experimental F_1 hybrids with high yield, EB resistance, and other desirable characteristics including fruit quality*

During the past several years, we have developed many advanced breeding lines of processing tomatoes with numerous desirable horticultural characteristics, including disease resistance (in particular resistance to EB), improved fruit quality (color, firmness, size, shape, etc.), high yield, and adaptation to PA/northeast conditions. Many of these lines are ready for use as parents to develop experimental F_1 hybrids. In 2017, for the first time, we developed a total of 30 experimental F_1 hybrids from crosses among PSU processing lines (5 as males and 6 as females). These hybrids were grown under field conditions in summer 2017 and evaluated for various desirable characteristics required for commercial production under PA conditions. Due to unexpected issues in the field, including soil compaction, experimental hybrids did not exhibit their full genetic potential. However, the hybrids were evaluated, and several of them were deemed desirable. In 2018, we will be repeating these hybrids and evaluating them under field conditions, along with an additional 6 experimental processing hybrids with LB resistance (developed from crosses with PSU processing breeding lines with LB resistance).

Objective 8: *Development of fresh-market (FM) experimental F_1 hybrids in collaboration with a seed company (co-hybrids) and evaluation under multiple field locations*

In collaboration with Sakata America seed company, in 2017 we developed a total of 35 new FM experimental F_1 hybrids from crosses between 7 PSU elite inbred lines and 5 from the company. During field season in 2017, the 35 hybrids were planted in a field at Rock Springs, PA. During the field these hybrids were evaluated. Unfortunately, the field conditions were not good and reliable data could not be obtained. However, generally, these hybrids were not performing well and not very desirable.

Objective 9. *Field evaluation of Penn State advanced fresh-market (FM) and processing breeding lines*

Fresh-market Tomatoes: Over the years, we have developed many fresh-market (FM) tomato inbred lines (including large round, plum, cherry and grape tomatoes) with desirable horticultural characteristics, including high yield, disease resistance (in particular resistance to EB), fruit quality (including size, shape, color, firmness, taste/flavor, tolerance to physiological disorders, etc.) and adaptation to PA condition. Every year during our field season we grow these inbred lines for further evaluation and selection. The purpose of this research is to develop elite breeding lines of FM tomato with multiple desirable horticultural characteristics, which could be used for development of commercial processing F_1 hybrids. Briefly, in 2017, we grew and evaluated 36 large-size FM lines, and all were advanced to the next generation. Almost all lines are of high quality and can potentially be used to develop experimental F_1 hybrids. In 2018, a major focus will be development of experimental hybrids of large-size FM tomatoes using our inbred lines (as described above).

Processing Tomatoes: Over the past several years we have developed many advanced lines of processing tomatoes with numerous desirable horticultural characteristics, including disease resistance (in particular resistance to EB), improved fruit quality (color, firmness, size, shape, tolerance to physiological disorders, etc.), high yield, and adaptation to PA conditions. In 2017, the processing tomato breeding lines (34 lines) were grown under field conditions and evaluated for various traits, including EB resistance, fruit color and other quality traits, earliness in maturity, plant type, final yield, and overall disease resistance (bacterial and fungal). The purpose of this research has been to develop processing tomato-breeding lines with multiple desirable horticultural characteristics. Due to unexpected issues in the field, including soil compaction, our processing inbred lines did not exhibit their full genetic potential. However, evaluation of these lines indicated presence of many desirable lines in our germplasm, which should be useful for development and evaluation of experimental hybrids. In 2017, all 34 advanced breeding lines were advanced to the next generation, and will be evaluated under field conditions in 2018. Further, in 2018, we are developing a total of 36 experimental hybrids of processing tomatoes, developed from crosses between different PSU processing tomato breeding lines, and will be evaluated under field conditions.

Other Research Conducted in 2017:

Evaluation of tomato germplasm in collaboration other seed companies

In 2017, we grew hundreds of other tomato lines/hybrids in collaboration with three seed companies. The goals of these collaborations include development of co-hybrids between PUS and seed companies for evaluation and potential commercialization. These collaborations are ongoing and will be extended in 2018.

Evaluation of commercial inbred lines and hybrid cultivars and comparison with Penn State material

For comparison with PSU tomato germplasm, in 2017 we grew and evaluated a total of 13 processing and 59 FM inbred lines and hybrid cultivars.

Publications:

Ohlson EW, H Ashrafi and **MR Foolad**. 2018. Identification and mapping of late blight resistance QTLs in tomato accession PI 163245. Submitted for Publication.

Gonda I, H Ashrafi, DA Lyon, SR Strickler, AM Hulse-Kemp, Q Ma, H Sun, K Stoffel, S Futrell, TW Thannhauser, Z Fei, AE Van Deynze, LA Mueller, JJ Giovannoni and **MR Foolad**. 2018. Development of a GBS-based high-density genetic map of a tomato RIL population, useful for high-resolution QTL mapping. Submitted for Publication.

Sullenberger MT and **MR Foolad**. 2018. Genetic characterization of late blight resistance in *Solanum pimpinellifolium* accession PI 270442. *Adv Studies Biol* 10: 13 – 32. https://doi.org/10.12988/asb.2018.71231

Sullenberger, MT, M Jia, S Gao and **MR Foolad**. 2018. Genetics analysis of late blight resistance in *Solanum pimpinellifolium* accession PI 270441: heritability and response to selection. *Plant Breeding* 137:89–96. https://doi.org/10.1111/pbr.12561

Foolad MR. 2017. Tomato breeding at Penn State. In: *Proc. Mid-Atlantic Fruit and Vegetable Convention*, January 31 - February 2, Hershey, PA, pp 192-195.