2017 MSU POTATO BREEDING AND GENETICS RESEARCH REPORT
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INTRODUCTION

At Michigan State University, we have been dedicated to developing improved potato varieties for the chip-processing and tablestock markets since 1988. The program is one of four integrated breeding programs in the North Central region supported through the USDA/NIFA Potato Special Grant. At MSU, we conduct a comprehensive multi-disciplinary program for potato breeding and variety development that integrates traditional and biotechnological approaches to breed for disease and insect resistance that is positioned to respond to scientific and technology opportunities that emerge. We are also developing more efficient methods to breed improved potato varieties.

In Michigan, variety development requires that we primarily develop high yielding round white potatoes with excellent chip-processing from the field and/or storage. In addition, there is a need for table varieties (russet, red, yellow, and round white). We conduct variety trials of advanced selections and field experiments at MSU research locations (Montcalm Research Center, Lake City Experiment Station, Clarksville Research Center, and MSU Agronomy Farm), we ship seed to other states and Canadian provinces for variety trials, and we cooperate with Chris Long on grower trials throughout Michigan. Through conventional crosses in the greenhouse, we develop new genetic combinations in the breeding program, and also screen and identify exotic germplasm that will enhance the varietal breeding efforts. With each cycle of crossing and selection we are seeing directed improvement towards improved varieties (e.g. combining chip-processing, scab resistance, PVY resistance, late blight resistance and higher specific gravity). I am happy to see the increase in scab, late blight and PVY resistance in the breeding material and selections. Through the USDA/AFRI SolCAP project we developed a new set of DNA genetic markers (8,303) called SNPs that are located in the 39,000 genes of potato. We now have expanded the number of SNPs to 22,000 and are further expanding the number of SNPS to 35,000 on the next version of the array. This SolCAP translational genomics project has finally giving us the opportunity to link genetic markers to important traits (reducing sugars, starch, scab resistance, etc.) in the cultivated potato lines and then breed them into elite germplasm. The SNPs also allow us to accurately fingerprint the varieties (DNA ID database). In addition, our program has been utilizing genetic engineering as a tool to introduce new genes to improve varieties and advanced germplasm for traits such as

insect resistance, late blight and PVY resistance, lower reducing sugar, nitrogen use efficiency and drought. Furthermore, Potatoes USA (USPB) is supporting national early generation trials called the National Chip Processing Trial (NCPT) which will feed lines into the SNaC (SFA) trials and also fast track lines into commercial testing. We are taking advantage of the NCPT fast track to have seed increased for promising chip-processing lines. We also have funding to develop genome editing technologies that may not be classified as genetic engineering through a USDA/BRAG grant. This technology can be used to introduce lower sugars, bruising and asparagine. We also hope to use the technology to edit late blight resistance genes. We also have a USDA/AFRI diploid breeding grant to develop some foundational diploid breeding germplasm. In 2015 we were awarded the USAID grant to generate late blight resistance potatoes for Bangladesh and Indonesia. This project brings us into cutting edge GM work with Simplot and the International Potato Center. Lastly we have NSF-funded grants to better understand the potato genome and study wound-healing in potato. We feel that these in-house capacities (both conventional and biotechnological) put us in a unique position to respond to and focus on the most promising directions for variety development and effectively integrate advanced technologies with the breeding of improved chip-processing and tablestock potatoes.

The breeding goals at MSU are based upon current and future needs of the Michigan potato industry. Traits of importance include yield potential, disease resistance (scab, late blight, early die, and PVY), insect (Colorado potato beetle) resistance, chipping (out-of-the-field, storage, and extended cold storage) and cooking quality, bruise resistance, storability, along with shape, internal quality, and appearance. If these goals can be met, we will be able to reduce production input costs as well as the reliance on chemical inputs such as insecticides, fungicides and sprout inhibitors, and improve overall agronomic performance with new potato varieties.

Over the years, key infrastructure changes have been established for the breeding program to make sound assessments of the breeding selections moving through the program. In 2016 year we constructed a greenhouse to expand our breeding and certified minituber seed production. This greenhouse is at the MSU Crops facility on south campus. In 2016 we began to upgrade the grading line and we would like to complete this process in 2018 then expand storage capacity in the near future.

I. Varietal Development

Breeding

The MSU potato breeding and genetics program is actively producing new germplasm and advanced seedlings that are improved for cold chipping, and resistance to scab, late blight, and Colorado potato beetle. For the 2017 field season, progeny from about 400 crosses were planted and evaluated. Of those, the majority were crosses to select for round whites (chip-processing and tablestock), with the remainder to select for yellow flesh, long/russet types, red skin, and novelty market classes. During the 2017 harvest, over 1,000 selections were made from the 40,000 seedlings produced. In addition, about 500 first year selections from elite chip-processing crosses segregating for PVY resistance were made. All potential chip-processing selections will be tested in January and April 2018 directly out of 45°F (7.2°C) and 50°F (10°C) storages. Atlantic, Pike (50°F chipper) and Snowden

(45°F chipper) are chip-processed as check cultivars. Selections have been identified at each stage of the selection cycle that have desirable agronomic characteristics and chip-processing potential. At the 12-hill and 30-hill evaluation state, about 200 and 80 selections were made, respectively; based upon chip quality, specific gravity, scab resistance, late blight resistance and DNA markers for PVY and Golden nematode resistance. Selection in the early generation stages has been enhanced by the incorporation of the scab and late blight evaluations of the early generation material. We are pushing our early generation selections from the 30-hill stage into tissue culture to minimize PVY issues in our breeding and seed stock. We are now using a cryotherapy method that was developed in our lab to remove viruses. We feel that this technique predictably as well as quickly remove virus from tissue culture stocks. Our results show that we are able to remove both PVY and PVS from lines, but PVS can be difficult to remove in certain lines. We tested the removal of PLRV and succeeded. Over 2000 lines are maintained in tissue culture for the breeding and genetics program.

Chip-Processing

Over 80% of the single hill selections have a chip-processing parent in their pedigree. Our most promising advanced chip-processing lines are MSX540-4 (scab, late blight and PVY resistant) MSV313-2 (scab resistant), MSW485-2 (late blight resistant), MSV358-3 (scab resistant), MSW075-2 (scab resistant), MSZ222-19 (scab resistant), MSZ242-09 (scab resistant) and MSZ219-1, MSZ219-13 and MSZ219-14 (all three sibs are scab, late blight and PVY resistant). We have some newer lines to consider, but we are removing virus from those lines. We are using the NCPT trials to more effectively identify promising new selections. Manistee was licensed to Canada and Chile. MSR127-2, Saginaw Chipper and MSX540-4 are being tested in Australia.

Tablestock

Efforts have been made to identify lines with good appearance, low internal defects, good cooking quality, high marketable yield and resistance to scab, late blight and PVY. Our current tablestock development goals now are to continue to improve the frequency of scab resistant lines, incorporate resistance to late blight along with marketable maturity and excellent tuber quality, and select more russet and yellow-fleshed lines. We have also been selecting some pigmented skin and tuber flesh lines that fit some specialty markets. There is also interest in some additional specialty mini-potatoes for the “Tasteful selections” market. We have interest from some western specialty potato growers to test and commercial these lines. From our breeding efforts we have identified mostly round white lines, but we also have a number of yellow-fleshed and red-skinned lines, as well as some purple skin selections that carry many of the characteristics mentioned above. We are also selecting for round white, red-skin, and improved Yukon Gold-type yellow-fleshed potatoes. Some of the tablestock lines were tested in on-farm trials in 2017, while others were tested under replicated conditions at the Montcalm Research Center. Promising tablestock lines include MSV093-1, MST252-1Y, MSV179-1, MSW343-2R, MSX569-1R and MSX324-1P. We have a number of tablestock selections with late blight resistance (MSS576-5SPL and MST145-02). MSZ109-8PP and MSZ109-10PP are purple-fleshed chippers with deep purple flesh, round shape and attractive skin. Jacqueline Lee was licensed to Australia and is

being grown in Central America for its late blight resistance. Spartan Splash, Blackberry and our virus resistance Red Marker potato are being marketed in the specialty markets.

Disease and Insect Resistance Breeding

Scab: In 2017 we had two locations to evaluate scab resistance: a commercial field with a history of severe scab infection (Sackett Potatoes) and a highly infected site at the Montcalm Research Center in the commercial production area. The commercial site and the Montcalm Research Center both gave us high infection levels. The susceptible checks of Snowden and Atlantic were highly infected with pitted scab. Promising resistant selections were MSV313-2, MST252-1Y, MSV179-1, MSX324-1P, MSW474-01, MSZ219-1, MSZ219-13, MSZ219-14, MSZ222-19 as well as the Z-series selections from the commercial scab site. The high level of scab infection at the on-farm site with a history of scab infection and MRC has significantly helped with our discrimination of resistance and susceptibility of our lines. The MRC scab site was used for assessing scab susceptibility in our advanced breeding lines and early generation material and is summarized below (Figure 1). All susceptible checks were scored as susceptible.

Fig. 1. Scab Disease Nursery Ratings from MRC trials

Trial	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	Total
Variety Trial	0	24	75	69	58	30	3	3	0	262
Early Generation	3	46	52	69	64	29	11	4	1	279
Diploid	2	9	27	27	30	11	5	1	0	112

Based upon this data, scab resistance is increasing in the breeding program. These data were also incorporated into the early generation selection evaluation process at Lake City. We are seeing that this expanded effort is leading to more scab resistant lines advancing through the breeding program. The ability to select under commercial settings at Sackett Potatoes is accelerating our ability to select for scab resistant varieties. MSZ219-1, MSZ219-13, MSZ219-14, MSZ022-07, MSZ222-19 and MSZ242-09 are some of the first scab resistant chippers to advance through this effort.

Late Blight: Our specific objective is to breed improved cultivars for the industry that have foliar and tuber resistance to late blight using a combination of conventional breeding, marker-assisted strategies and transgenic approaches. Through conventional breeding approaches, the MSU potato breeding and genetics program has developed a series of late blight resistant advanced breeding lines and cultivars that have diverse sources of resistance to late blight. In 2017 we conducted late blight trials at the Clarksville Research Center. We inoculated with the US23 genotype and the results are summarized in Figure 2. Over fourteen sources of resistance can be traced in the pedigrees of these resistant lines. This data infers that we have a broad genetic base to combine resistance genes and also should be able to respond to changes in the pathogen.

Fig. 2. Advanced Breeding lines with foliar late blight resistance to US23

LINE	N	RAUDPC[1] MEAN	*Pedigrees go w/ RAUDPC Sort* Female	Male
A02507-2LB (Payette)	3	0.2	EGAO9702-2	GemStar Russet
MSW121-5R	3	1.2	MSM182-1	NDTX4271-5R
MSY474-8	3	1.5	MSM182-1	Haig Ind 98
MSW464-3	3	1.6	MSM246-B	MSR102-3
MSW324-01	3	2.1	MSQ070-1	Marcy (NY112)
MSZ464-3	3	2.1	MSQ070-1	Alca Tarma
MSW092-1	3	2.2	MSL106-AY	Montserrat
MSZ562-4	3	2.8	Muruta	MSL211-3
MSZ219-13	3	2.9	Saginaw Chipper (MSR061-1)	MSR127-2
Ciklaman	3	3.2	I 71 17 6	Magyar rozsa
MSU088-01	3	3.3	MSK061-4	Missaukee (MSJ461-1)
MSU016-2	3	3.5	Boulder (MSF373-8)	MSN105-1
MST148-3	3	3.7	MSI152-A	Yukon Gold
MSX497-02	3	5.1	MSQ131-A	MSL268-D
MST145-02	3	5.6	MSI152-A	MSL211-3
MSV403-3	3	6.7	MSQ070-1	MSN099-B
MSZ219-46	3	6.7	Saginaw Chipper (MSR061-1)	MSR127-2
Musica	3	6.7	CMK1993-042-055	Lady Christl
MSZ424-1R	3	6.7	NY121	MSR217-1R
MSZ219-44	3	7.1	Saginaw Chipper (MSR061-1)	MSR127-2
MSX497-06	2	7.6	MSQ131-A	MSL268-D
MSW128-2	3	8.9	MSM171-A	MSQ176-5
MSZ219-01	3	9.7	Saginaw Chipper (MSR061-1)	MSR127-2
W13014-5rus	3	9.8		
MSZ219-14	3	9.8	Saginaw Chipper (MSR061-1)	MSR127-2
MSW496-1RUS	3	10.1	Classic Russet (A95109-1Rus)	W1879-1RUS
MSZ263-4	3	10.3	MSU088-1	McBride (MSJ126-9Y)
MSV235-2PY	1	10.5	Malinche	Colonial Purple (MSN215-2P)

PVY: We are using PCR-based DNA markers to select potatoes resistant to PVY. The gene is located on Chromosome 11. In our first round we made crosses in 2013 to generate over 7,000 progeny segregating for PVY resistance. Each year since 2013 we are making new crosses, making selections and expanding the germplasm base that has PVY resistance (Fig. 3). We are also using DNA markers to also screen for PVX resistance, PLRV resistance, late blight resistance and Golden nematode resistance.

Fig. 3 PVY resistant selections in the breeding program

Year	Family	PVYR
YR0	MSFF	111 Families
YR1	MSEE	466 Selections to DNA screen
YR2	MSDD	36 Selections
YR3	MSCC	11 Selections
YR4	MSBB	23 Selections

MSU Lines with Commercial Tracking

Manistee (MSL292-A)

Parentage: Snowden x MSH098-2
Developers: Michigan State University and the Michigan Agricultural Experiment Station
Plant Variety Protection: Applied for.

Strengths: Manistee is a chip-processing potato with an attractive round appearance with shallow eyes. Manistee has a full-sized vine and an early to mid-season maturity. Manistee has above average yield potential and specific gravity similar to Snowden. This variety has excellent chip-processing long-term storage characteristics and a similar to better tolerance to blackspot bruise than Snowden.

Incentives for production: Excellent chip-processing quality with long-term storage characteristics, above average yield, specific gravity similar to Snowden, and good tuber type.

Saginaw Chipper (MSR061-1)

Parentage: Pike x NY121
Developers: Michigan State University and the Michigan Agricultural Experiment Station
Plant Variety Protection: Trademark

Strengths: MSR061-1 is a chip-processing potato with resistance to common scab (*Streptomyces scabies*) and moderate foliar late blight (*Phytophthora infestans*) resistance. This variety has medium yield similar to Pike and a 1.079 (average) specific gravity and an attractive, uniform, round appearance. MSR061-1 has a medium vine and an early to mid-season maturity.

Incentives for production: Chip-processing quality with common scab resistance similar to Pike, moderate foliar late blight resistance (US8 genotype), and uniform, round tuber type.

MSV093-1Y

Parentage: McBride x MSP408-14Y
Developers: Michigan State University and the MSU AgBioResearch.
Plant Variety Protection: To Be Applied For

Strengths: MSV093-1Y is a high yield potential yellow-flesh breeding line with an attractive, round tuber shape. This line has demonstrated excellent high yield potential in replicated trials at the MSU Montcalm Research Center and on grower field trials throughout Michigan. This yellow flesh line has excellent internal quality (few defects) and a low incidence of blackspot bruise. MSV093-1Y also has moderate scab tolerance. MSV093-1Y has a strong vine and a mid-early season maturity.

Incentives for production: High yield potential with an attractive tuber shape with good yellow flesh with excellent internal quality.

MSR127-2

Parentage: MSJ167-1 x MSG227-2
Developers: Michigan State University and the MSU AgBioResearch.
Plant Variety Protection: To Be Applied For.

Strengths: MSR127-2 is a chip-processing potato with resistance to common scab (*Streptomyces scabies*). This variety yields greater than Atlantic and Snowden, has a 1.086 (average) specific gravity, and an attractive, uniform, round appearance. MSR127-2 has a strong vine and a full-season maturity, and has demonstrated excellent long-term storage chip-processing quality.

Incentives for production: Long-term chip-processing quality with common scab resistance similar to Pike, and uniform, round tuber type.

MSX540-4 (Mackinaw)

Parentage: Saginaw Chipper x Lamoka
Developers: Michigan State University and the MSU AgBioResearch.
Plant Variety Protection: To Be Applied For.

Strengths: MSX540-4 is a chip-processing potato with resistance to potato virus Y (PVY), late blight (*Phytophthora infestans*), tolerance to common scab (*Streptomyces scabies*), and demonstrated tolerance to *Verticillium* wilt. This variety has average yield with a high specific gravity, and a high percentage of A-size tubers with an attractive, uniform shape. MSX540-4 has a strong vine and a mid- to late-season maturity, and has demonstrated excellent long-term storage chip-processing quality. MSX540-4 has performed well in multiple locations in the PotatoesUSA National Chip Processing Trials (NCPT).

Incentives for production: Long-term chip-processing quality with resistance to PVY and late blight, and tolerance to common scab.

Morphological Characteristics:
Plant: Medium height vine, semi-erect with a balance between stems and foliage visible, and flowers.
Tubers: Round tubers with lightly netted, tan colored skin. Tubers have a creamy-white flesh with a low incidence of internal defects.

Agronomic Characteristics:
Vine Maturity: Mid- to late-season maturity.
Tubers: Smooth shaped tubers with lightly netted, tan colored skin and a creamy-white flesh.
Yield: Average yield under irrigated conditions, with uniform A-size tubers.
Specific Gravity: Averages similar to above Snowden in Michigan.
Culinary Quality: Chip-processes from short to long-term storage.
Diseases: Resistant to PVY and late blight (*Phytophthora infestans*), tolerant to common scab (*Streptomyces scabies*).

MSW485-2 (Huron Chipper)

Parentage: MSQ070-1 x MSR156-7
Developers: Michigan State University and the MSU AgBioResearch.
Plant Variety Protection: To Be Applied For.

Strengths: MSW485 is a chip-processing potato with resistance to and late blight (*Phytophthora infestans*), and stronger tolerance to common scab (*Streptomyces scabies*) than Atlantic. This variety has high yield and good specific gravity, with attractive, uniformly round tubers. MSW485-2 has a strong vine and a mid-season maturity, and has demonstrated excellent long-term storage chip-processing quality. MSW485-2 has performed well in multiple locations in the PotatoesUSA National Chip Processing Trials (NCPT) and national SFA (SNaC) trials.

Incentives for production: Excellent chip-processing quality out of the field and long-term chip quality with resistance to late blight and a good size profile.

Morphological Characteristics:
Plant: Medium height vine, semi-erect with a balance between stems and foliage visible, and flowers.
Tubers: Uniform, smooth, round tubers with lightly netted, tan colored skin. Tubers have a white flesh with a low incidence of internal defects.

Agronomic Characteristics:
Vine Maturity: Mid-season maturity.
Tubers: Smooth, round tubers with lightly netted, tan colored skin and a white flesh.
Yield: Above average yield under irrigated conditions, with uniform tubers.
Specific Gravity: Averages similar to above Atlantic and Snowden.
Culinary Quality: Chip-processes from short to long-term storage.
Diseases: Resistant to late blight (*Phytophthora infestans*) and tolerant to common scab (*Streptomyces scabies*).

MSX569-1R (Ilse Royale)

Parentage: MSS002-2R x MSS544-1R
Developers: Michigan State University and the MSU AgBioResearch.
Plant Variety Protection: To Be Applied For.

Strengths: MSX569-1R is a fresh market variety with an attractive red skin, bright white flesh, excellent round tuber shape, and tolerance to common scab (*Streptomyces scabies*). This variety has average yield with a high percentage of A-size tubers with an attractive, uniform shape. The bright red skin is highly desirable in the fresh market, and also maintains good red color in storage. This line has demonstrated good marketable yield potential in replicated trials at the MSU Montcalm Research Center, on grower field trials throughout Michigan, as well as in North Central Regional Trials, and trials in Florida and North Carolina. MSX569-1R has excellent internal quality (few defects) and a low incidence of blackspot bruise.

Incentives for production: Fresh market variety with a bright red skin, attractive tuber size and shape, excellent internal quality, and tolerance to common scab.

***Morphological Characteristics**:*
Plant: Medium height vine, semi-erect with a balance between stems and foliage visible, and flowers.
Tubers: Round tubers with a smooth, bright red colored skin. Tubers have an attractive white flesh with a low incidence of internal defects.

***Agronomic Characteristics**:*
Maturity: Mid-season maturity.
Tubers: Round tubers with a red skin and an attractive white flesh.
Yield: Average yield under irrigated conditions, similar or better than Red Norland.
Specific Gravity: Good fresh market specific gravity (1.055 in Michigan).
Culinary Quality: Excellent culinary quality.
Diseases: Tolerance to common scab (*Streptomyces scabies*).

II. Germplasm Enhancement

The trait mapping populations have been a major research focus for us over the previous four years as we try to correlate the field data with the genetic markers. We now have DNA SNP markers linked to late blight resistance, scab resistance, chip color, tuber asparagine and specific gravity. We will now start using this linkage information to assist us in breeding. Our first SNP marker is linked to a gene for late blight resistance on Chr. 9 and the second is located on Chr. 10 with new ones recently identified on Chr. 4 and Chr. 5. The ability to use the DNA markers to stack a set of late blight resistance genes will lead to durable late blight resistance.

The diploid genetic material represent material from South American potato species and other countries around the world that are potential sources of resistance to Colorado potato beetle, late blight, potato early die, and ability to cold-chip process. We are now placing more emphasis on the diploid breeding effort because of the advantages the breeding system brings when we introduce the ability to self-pollinate a line. Features of diploid breeding include 1) a simpler genetic system than current breeding methods, 2) tremendous genetic diversity for economic traits, 3) minimal crossing barriers to cultivated potato, 4) the ability to reduce genetic load (or poor combinations) through selfing and 5) the ability to create true breeding lines like wheat, soybeans and dry beans. We are also using some inbred lines of *S. chacoense* that have fertility and vigor (also a source of *Verticillium* wilt resistance to initiate our efforts to develop inbred lines with our own diploid germplasm. We have over 40 populations that we are cycling to make selections and we also selected diploid progeny from Atlantic, Superior, Manistee, MSZ219-14, Kalkaska, MSR127-2, MSS576-5SPL and others to cross to the self compatible material so we can develop inbred chip-processing diploid lines. This new diploid potato breeding project is expanding to develop promising lines to use as parents in the future as well as to think about F1 hybrid varieties like the breeders release with corn.

We have used lines with *Verticillium* wilt resistance, PVY resistance, and cold chip-processing. We are monitoring the introgression of this germplasm through marker assisted selection. Through previous GREEEN funding, we were able to continue a breeding effort to introgress leptine-based insect resistance using new material selected from USDA/ARS material developed in Wisconsin. With our new diploid breeding initiative we have developed a mapping population to link the beetle resistance with SNP markers. We will continue conducting field screening for resistance to Colorado potato beetle at the Montcalm Research Center. These lines are being used crosses to further transmit insect resistance.

III. Integration of Genetic Engineering with Potato Breeding

Regarding late blight resistance, we have many lines with the RB gene for late blight resistance transformed into MSU lines. The addition of the RB gene allows us to test the effect of multiple resistance genes on the strength of resistance. Our data supports the need to pyramid the late blight resistance R-genes to achieve the best levels of resistance. The RB gene is in Jacqueline Lee and MSL268-D. We now have generated some lines with 3-R-genes stacked with one transformation

We have also generated lines with the genes for water use efficiency (WUE). Field trials with reduced fertilizer and non-irrigated conditions were conducted for a subset of these lines from 2014 to 2017. The XERICO gene is showing the most promise. Lastly, we have generated and selected a Kalkaska invertase silencing line (Kal91.03) that has resistance to accumulating reducing sugars in 40F storage. We tested the agronomic characteristics of Kal91.03 in 2016 and 2017. The initial results are suggesting that the invertase silencing line has good tuber type, size and similar specific gravity. This suggests that we can correct sugar issues in a chip processing lines with this genetic engineering strategy. We will continue to evaluate in 2018.

Chipped directly after 3 months at 40F