2016 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 for over 25 years. 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 quality 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 Research Center, 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. We are also the lead institution coordinating the Potatoes USA National Chip Processing Trial, a collaborative breeding and selection program involving 14 US breeding programs, 10 testing locations, annually evaluating hundreds of new potato clones. 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 DNA fingerprint the varieties and maintain a database with thousands of different potato clones that can be used for variety identification and pedigree analysis. 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. Potatoes USA and collaborating chip processors are supporting national early generation trials through the National Chip Processing Trial (NCPT) which fees lines into the SNaC trials and also fast track lines into commercial NexGen testing. Promising selections from the MSU Breeding Program are entered in the NCPT fast track NexGen program for seed increase and commercial evaluation on grower's farms and chip-processors. We have also been funded through the USDA/SCRI Acrylamide project to link genetic markers with lower acrylamide traits. This research is nearing completion and we have lines with lower tuber asparagine and lower acrylamide forming potential in the processed chips. 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. Last year 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. 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, marketable specific gravity, 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. As these goals are 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. This past 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. We also are creating a companion tissue culture lab at the facility for certified seed activities. In 2016 we began to upgrade the grading line to collect individual tuber weight and count data. We would like to complete this process in 2017 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 2016 field season, progeny from about 500 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 2016 harvest, over 1,000 selections were made from the 60,000 seedlings produced. In addition, about 200 first year selections from elite chip-processing crosses segregating for PVY resistance were made in a commercial field with high scab pressure. All potential chip-processing selections will be tested in January and April 2017 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 100 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 and quickly removes viruses 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 also successfully tested the removal of PLRV.

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 MSR127-2 (scab resistant), 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 and MSZ219-14 (both 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.

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. We are proposing the release of MSX001-4WP as 'Purple Soul.' There is also interest in some additional specialty mini-potatoes for the emerging small size, "mini" 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 promising 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 a table russet, round white, red-skin, and improved Yukon Gold-type yellow-fleshed potatoes. Some of the tablestock lines were tested in on-farm trials in 2016, while others were tested under replicated conditions at the Montcalm Research Center. Promising tablestock lines include MSS576-05SPL, MSV093-1Y, MST252-1Y, MSV179-1, MSW343-2R, MSX324-1P and MSV111-02. 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. We are increasing seed of Missuakee for international markets due to its late blight resistance and Golden nematode resistance. Jacqueline Lee was licensed to Australia.

Disease and Insect Resistance Breeding

Scab: In 2016 we had two locations to evaluate scab resistance: a commercial field with a history of severe common scab infection (kindly provided by 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 MSR127-2, MSU383-A, MST252-1Y, MSV179-1, MSW474-01, MSV383-B, MSZ219-1, MSZ219-14, MSU379-1, MSW509-5, 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 (Table 1). All susceptible checks were scored as susceptible.

Table 1. Scab Disease Nursery Ratings from MSU Montcalm Research Center trials.

	Scab Rating (0-5 High)								
Trial	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**Total**
Variety Trial	5	31	66	72	39	17	3	0	233
Early Generation	28	70	80	82	33	11	4	0	308
Diploid	36	20	30	30	14	0	0	0	124

Note: Lines with a scab rating of 1.5 or less are considered resistant to common scab.

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.

We conducted a three-year selection study at Sackett Potatoes to select scab-resistant chip-processors. Starting with about 5,000 progeny from elite crosses we narrowed the population to about 40 selections that had commercial potential based upon shape, yield, scab resistance, chip-processing quality and high solids. In 2015 we made 18 selections from 40 scab-resistant chip-processing selections. The most most-promising selections have been advanced to replicated trials at MRC and also the NCPT trials. These lines are all in tissue culture but some lines need virus cleanup. MSZ219-1 and MSZ219-14 are the first lines advancing from this cohort.

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 2016 we conducted late blight trials at the Clarksville Research Center. We inoculated with the US23 genotype and the results are summarized in Table 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.

Table 2. Advanced Breeding lines with foliar late blight resistance in inoculated (US23) field trials at the MSU Clarksville Research Center.

LBR Lines	Female	Male
MSAA120-01	M182-1	W126-1
MSAA176-03	U161-1	U016-2
MSAA252-07	NY148	Q089-1
MSQ086-3	Onaway	J461-1
MSQ131-A	F373-8	J461-1
Saginaw Chipper	W1201	NY121
MSS164-6	M188-1	J461-1
MSS576-5SPL	I005-20Y	L211-3
MST145-02	I152-A	L211-3
MST191-2Y	J126-9Y	L766-1
MSW042-01	I152-A	L211-3
MSW154-04	1989-86061	L211-3
MSW324-1	Q070-1	Marcy
MSW353-3	R036-5	Marcy
MSW464-3	M246-B	R102-3
MSW485-02	Q070-1	R156-7
MSX001-9WP	ARS10091WP	L211-3
MSX293-1Y	M288-2Y	Q176-5
MSX495-02	Q131-A	Kalkaska
MSX517-3SPL	Q425-4YSPL	Q176-5
MSX540-4	R061-1	NY139
MSX542-02	R102-3	Megachip
MSY022-02	S176-1	T096-2Y
MSZ219-01	R061-1	R127-2
MSZ219-13	R061-1	R127-2
MSZ219-14	R061-1	R127-2
MSZ436-02Spl	S576-05SPL	Q440-2
MSZ510-04	L211-3	Q440-2
MSZ513-02	L268-D	L211-3
MSZ551-01	M182-1	L268-D
MSZ616-01Y	Nicola	L211-3
MSZ620-01	Muziranzara	L211-3

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. These crosses were planted in 2014 and 715 progeny were selected in the fall. DNA was isolated from those lines in the winter and 45% of the lines were positive for the DNA marker. In 2015 we planted these lines and selected 105 for further study. Each year since 2013 we are making new crosses, making selections and expanding the germplasm base that has PVY resistance (Table 3). We are also using DNA markers to also screen for PVX resistance, PLRV resistance, late blight resistance and Golden nematode resistance.

Table 3. Third year selections with both PVY and scab resistance.

Line	Female	Male	2016 MRC SG	2016 LC SG	2016 SACKETT SG	2015 SPGR	2016 LBR	2016 MRC Scab
BB625-02	W242-1	S297-3	1.080			1.099		
BB230-1	NY148	Q089-1	1.083	1.082		1.093	LBR	2
BB626-03	R061-1	Kalkaska	1.068			1.091	LBR	
BB610-24Y	NY148	T096-2Y	1.070		1.082	1.091		
BB617-08	R061-1	V383-1	1.066		1.083	1.091	LBR	
BB060-01	NY148	S297-3		1.079		1.090		2
BB058-1	NY148	R127-2		1.080		1.089		1.5
BB626-11	R061-1	Kalkaska	1.071		1.081	1.089		
BB610-13	NY148	T096-2Y			1.072	1.085		
BB233-1	NYH15-5	Lamoka	1.067			1.085		1
BB072-02	R061-1	OP	1.063	1.068		1.084		2
BB613-04	R061-1	J126-9Y	1.066		1.074	1.083	LBR	
BB635-15	NYH15-5	S297-3			1.079	1.082		
BB058-3	NY148	R127-2	1.072	1.080		1.082		1.5
BB072-01	R061-1	OP	1.069			1.082		2
BB612-04	R061-1	Atlantic			1.077	1.079		
BB613-07	R061-1	J126-9Y	1.064		1.068	1.079		
BB061-01	NYH15-5	R127-2	1.062	1.073		1.078		2
BB626-06	R061-1	Kalkaska			1.075	1.078		
BB633-08	NYH15-5	R128-4Y			1.072	1.077		
BB630-02	NYH15-5	Kalkaska			1.076	1.076		
BB636-11	NYH15-5	T096-2Y	1.066		1.071	1.076		
BB634-08	NYH15-5	R169-8Y	1.062		1.072	1.076		
BB635-14	NYH15-5	S297-3			1.072	1.076		
BB617-02	R061-1	V383-1			1.067	1.076	LBR	
BB631-04	R061-1	S297-3	1.065		1.070	1.075		
BB610-09Y	NY148	T096-2Y	1.062			1.074		
BB620-10	R061-1	Lamoka			1.063	1.073		
BB719-1	MSL211-3	NY132	1.057	1.062		1.073		2
BB073-04	R061-1	R127-2	1.062	1.068		1.073	LBMR	1.5
BB633-18	NYH15-5	R128-4Y	1.065			1.072		
BB058-4	NY148	R127-2	1.075	1.067		1.072		1.5
BB636-14	NYH15-5	T096-2Y	1.065		1.072	1.072		
BB610-25	NY148	T096-2Y	1.052		1.063	1.071		
BB623-12	R061-1	W140-3	1.063		1.070	1.070		
BB621-03	W027-3	Q086-3	1.061		1.067	1.069		
BB238-01RY	A02267-5PY	Purple Heart	1.054	1.061		1.069		1.5
BB637-17	NYH15-5	Q089-1	1.057			1.068	LBR	
BB636-16	NYH15-5	T096-2Y			1.055	1.068		
BB618-09	R061-1	L292-A	1.067			1.067	LBR	
BB618-02	R061-1	L292-A	1.055		1.060	1.066		
BB637-06	NYH15-5	Q089-1	1.055			1.063		

MSU Lines with Commercial Tracking

McBride (MSJ126-9Y)

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

Strengths: McBride is a chip-processing potato with an attractive round appearance with shallow eyes. McBride has a medium vine and an early to mid-season maturity. This variety has resistance to *Streptomyces scabies* (common scab) stronger than Pike. McBride also has excellent chip-processing long-term storage characteristics and better tolerance to blackspot bruise than Snowden.

Incentives for production: Excellent chip-processing quality with long-term storage characteristics, common scab resistance superior to Pike, and good tuber type.

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 (Spartan Chipper)

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.

Purple Soul (MSX001-4WP)

Parentage: ARS10091 x MSL211-3
Developers: Michigan State University and the MSU AgBioResearch.
Plant Variety Protection: Trademark

Strengths: Purple Heart is a very unique potato variety with a smooth, bright white skin and a surprisingly deep purple flesh. This line has excellent agronomic features for yield, tuber size, and maturity.

MSX540-4

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*), and tolerance to common scab (*Streptomyces scabies*). 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.

MSW485-2

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 Potatoes USA 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.

MSZ219-14

Parentage: Saginaw Chipper x MSR127-2
Developers: Michigan State University and the MSU AgBioResearch.
Plant Variety Protection: To Be Applied For.

Strengths: MSZ219-14 is a chip-processing potato with resistance to potato common scab (*Streptomyces scabies*), late blight (*Phytophthora infestans*), and potato virus Y (PVY). This variety has a high yield with a high specific gravity, and a high percentage of A-size tubers with an attractive, uniform shape. MSZ219-14 has a strong vine and a mid- to late-season maturity, and has demonstrated excellent long-term storage chip-processing quality. MSZ219-14 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 common scab, late blight, and PVY.

II. Germplasm Enhancement

Since 2010 we developed six tetraploid genetic mapping populations and six diploid mapping populations) for late blight resistance, scab resistance, virus resistance, insect resistance and also for tuber quality traits. We have been characterizing these populations for their traits and have conducted the linkage analysis studies using the SNP marker genotyping. The 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.

The diploid genetic material represent material from several 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 and develop inbred lines. 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 Atlantic dihaploids (maternal progeny from Atlantic) to cross to this 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. I am including some pictures to demonstrate the progress we have made in breeding diploid potatoes (Figures 1 and 2).

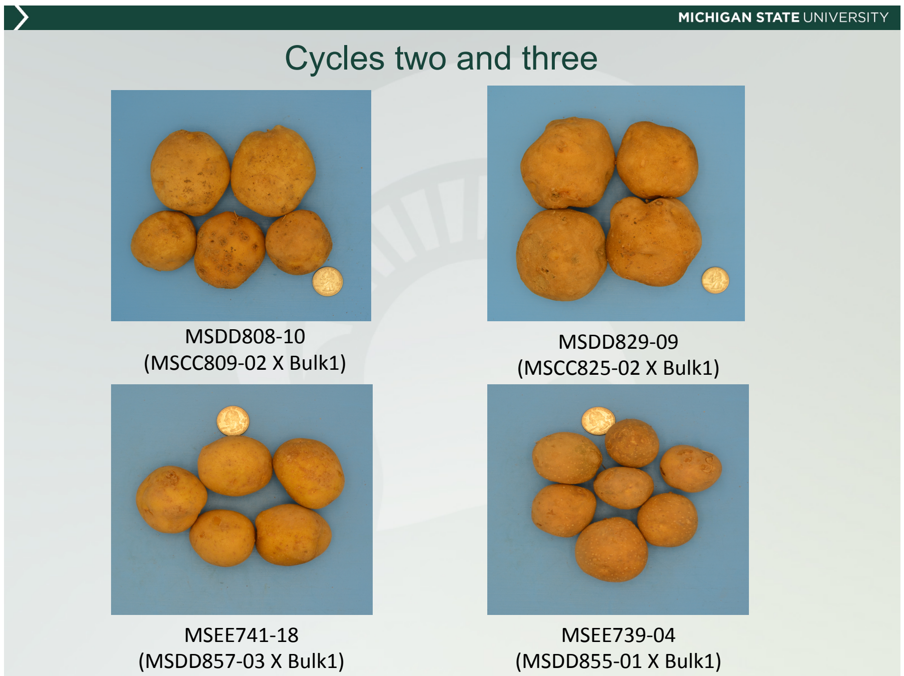

Fig. 1. Diploid selections from Recurrent Selection Cycles 2 and 3.

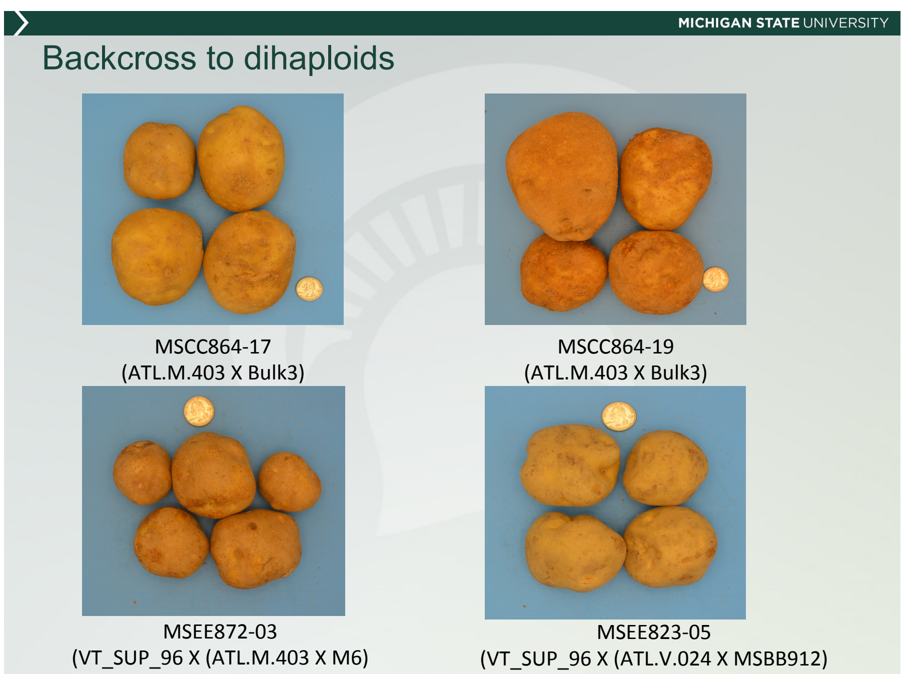

Fig. 2. Diploid selections from Backcross breeding with *S. tuberosum* dihaploids.

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

PVY resistance to three PVY strains (O, N and NTN) of the MSE149-5Y, Classic Russet, Silverton Russet and Russet Norkotah lines were initially evaluated by Jonathan Whitworth in inoculated greenhouse studies. A number of lines with PVY resistance to all strains were identified. Following seed production, we conducted a PVY resistance field tests in 2015 and 2016. In the inoculated field tests at MSU the MSE149-5Y line was resistant to PVY as well as the Classic Russet line (Figure 3). We identified a number of Silverton Russet lines with increased PVY resistance but none with complete resistance to all three PVY strains. The Russet Norkotah lines were not highly resistant.

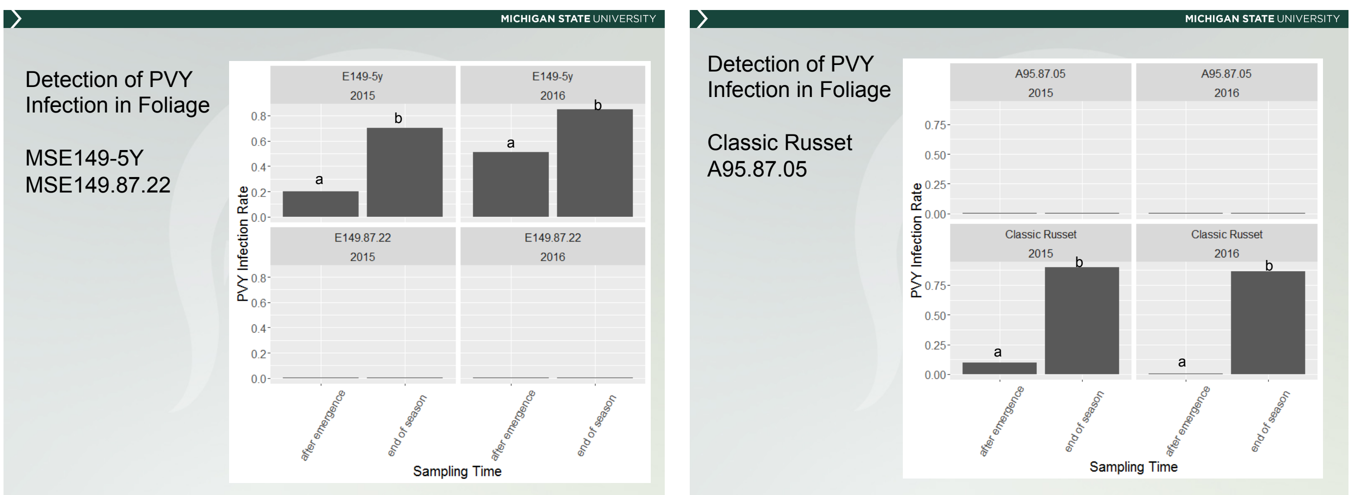

Fig. 3. Detection of PVY infection in foliage in PVY resistance field studies at MSU.

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.

We have also generated lines with the genes for nitrogen use efficiency (NUE) and water use efficiency (WUE). Field trials with reduced fertilizer and non-irrigated conditions were conducted for a subset of these lines in 2014, 2015 and 2016, for NEU and WUE, respectively. The best subset of lines will continue to be tested in 2017. Lastly, we have some lines with the vacuolar acid invertase (*VInv*) silencing. There are three MSE149-5Y lines with good silencing that maintain low reducing sugars in 40 °F

(4 °C) storage. We have made crosses with these lines to study the inheritance of the invertase silencing trait. We will report on these results next year. We have generated a few Kalkaska invertase silencing lines and one line Kal91.03, has resistance to accumulating reducing sugars in 40 °F (4 °C) storage (Figure 4). We tested the agronomic characteristics of Kal91.03 in 2016. The initial results are suggesting that the invertase silencing line has good tuber type, size and similar specific gravity. We will evaluate yield in 2017.

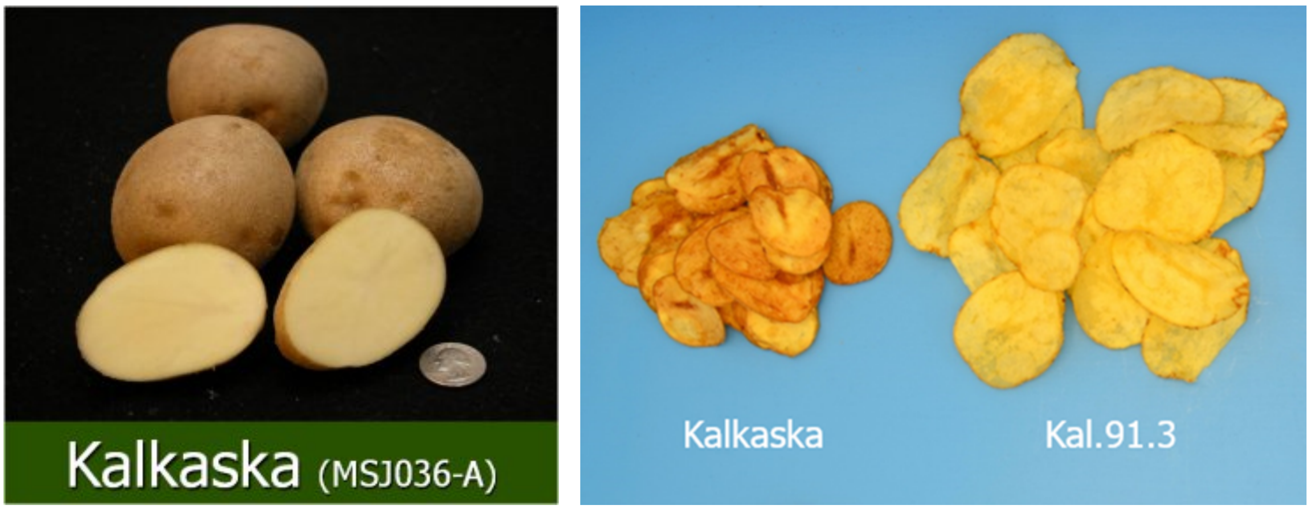

Fig. 4. Kalkaska tubers (left) and chip samples (right) of Kal.91.3 processed directly from 3 months storage at 40 °F (4 °C).