P L A N T B R E E D I N G A N D S E E D S C I E N C E
Volume 49 2004

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THE DEVELOPMENT OF COLD CHIPPING POTATO PARENTAL LINES FOR BREEDING CULTIVARS SUITABLE FOR PROCESSING

ABSTRACT

The objective of this research was to determine if variation for cold chipping exists in two breeding populations 4×-4× and 4×-2× potato hybrids. Twenty four potato genotypes of a population of 4×-4× hybrids (originated from crosses between parents with good chipping quality) were tested under field conditions at Młochów Research Center of the Plant Breeding and Acclimatization Institute over three years. Traits evaluated included: total tuber yield, marketable yield, starch content, chip colour after cold storage at 4°C, content of reducing sugars, tuber appearance. Out of 24 tested clones three have been selected with outstanding low accumulation of reducing sugars after cold storage (4°C), stable light chip colour and increased starch content. They were also described in trials as having moderate yielding ability, good tuber appearance and satisfied level of resistance to PVY, PLRV and *Phytophthora infestans*. Of four tested diploid parents in 4×-2× crosses, the DG 93-332 and the HT/HZ84-PH-151 were more suitable for creation of tetraploid generations combining low content of glucose with increased starch content, good yielding ability and satisfied tuber appearance.

Key words: breeding, cold chipping, potato, reducing sugars, starch content

INTRODUCTION

Most of potato cultivars presently used for the production of potato chips and French fries accumulate significant amounts of reducing sugars when stored at temperatures below 7°C (Burton, 1978; Lisińska and Leszczyński, 1989; Zgórska and Frydecka-Mazurczyk, 2000). This cold-induced sweetening process reduces product quality since dark bitter potato chips and French fries result after frying process (Coffin *et al.*, 1987; Sowokinos, 2001). This undesirable flavor and colour of potato chips and French fries is due to products of the Maillard reaction (Schallenberger *et al.*, 1959). Tubers of such cultivars prior to processing must be subjected to reconditioning. Recontitioning at the temperature

Communicated by Henryk J. Czembor

15-18°C for 2-3 weeks of potatoes stored below 7°C decreases the concentration of reducing sugars to acceptable level (Talburt and Smith, 1967; Lisińska and Leszczyński, 1989). For potato growers, however, reconditioning requires time and increases their expenses.

At present, an important breeding objective in the development of potato chipping cultivars is resistance to cold-induced sweetening. Such type of cultivars would provide several benefits for raw material quality like: less shrinkage, retention of dry matter, decreased disease loss, limited use of sprout inhibitors and extended marketability (Ewing, 1974; Pereira *et al.*, 1994; Thill and Peloquine, 1995).

Some clones were identified among wild and primitive cultivated potato species which showed little accumulation of reducing sugars after cold storage (Thill and Peloquin, 1994; Jakuczun *et al.*, 1995; Hamernik and Hanneman, 1998). Introgression of this trait from wild or primitive cultivars into *S. tuberosum* required several generations of crossing, backrossing and selection (Thill and Peloquine, 1995). The regular search of clones capable to produce light coloured chips after storage at 4.5°C was begun in 1965 in Minnesota breeding programme (Lauer and Shaw, 1970). The development of processing cultivars and improved parental lines with low level of reducing sugars at cold storage (4-6şC) is being an important objective of breeding programmes both in North America (Pavek, 1987; Thill and Peloquine, 1995) and in Europe (Mackay *et al.*, 1997; Putz, 1999). However, parental value of good cold-chippers ND860-2, ND2221-6 and another ones containing *S. phureja* ancestry are limited because of their short dormancy (Ehlenfeldt *et al.*, 1990). The time taken for the development of cold-chipping cultivars may be shortened if the desired heritable variation can be found within *S. tuberosum* genepool comprising agronomically adapted material.

Our study was undertaken:

(1) to provide information about variation for chip colour after cold storage (4°C) within a pool of tetraploid selections and tetraploid-diploid hybrids;

(2) to identify potato tetraploid clones capable to produce light coloured chips after cold storage at 4°C; (3) to evaluate selected tetraploid clones for tuber yield, quality traits, and some important resistance traits.

MATERIAL AND METHODS

Plant material

Two groups of breeding material were used for the study. The first one was represented by 24 clones and four standard cultivars grown in field trials over three years (1999-2001) at Młochów Research Center of the Plant Breeding and Acclimatization Institute (IHAR). The clones had been identified during routine screening in 1998 as having potential to

produce light golden chips after cold storage (4°C) and reconditioning. Selected standard cultivars differed in their suitability for processing. Cv. Saturna is commonly processed into chips both in West Europe and in Poland. Mila and Triada are Polish cultivars both for table and processing use, while Maryna is non-chipping cultivar (Zgórska and Frydecka-Mazurczyk, 1997).

The second group of breeding material consisted of 96 seedlings originated from four interploid crosses (4×-2×) between good chipping tetraploid and diploid parents and 48 seedlings from two 4×-4× crosses was evaluated in field experiment in 2000 and 2001. Each of 4×-2× crosses (Brodick × DG 98-916; Signal × DG 88-89; Signal × DG 93-332; M-62643 × HT/HZ84-PH-151) and 4×-4× crosses (M-62643 × Signal; M-62654 × Signal) was represented by 24 seedlings pre-selected for tuber appearance from the initial 60 individuals.

Each trial was planted as a randomized complete block design (Table 1). Soil at IHAR Młochów's Experimental Field is loamy sand and was fertilized with 100 kg × ha^{-1} of N, 75 kg × ha^{-1} of P_2O_5, 165 kg × ha^{-1} of K_2O, 75 kg × ha^{-1} of S, and 19 kg × ha^{-1} of MgO. Preventive disease and insect control were used in all trials. The trials were harvested at full maturity stage.

Table 1

The overview of field trials conducted at Młochów Research Center, IHAR

Group of the breeding material	Year of the experiment	Number of replicates	Number of tested genotypes	Size of the plot	Evaluated traits:		
					Agronomic	Chip colour	Sugar content
I (clones)	1999	2	28 (24 clones + 4 cvs)	8 plants		+	
I (clones)	2000	2	28 (24 clones + 4 cvs)	30"	+	+	
I (clones)	2001	2	28 (24 clones + 4 cvs)	30"	+	+	+
			24 × 6 families:				
II (seedlings)	2000	1	4 families 4×-2×	1 plant			+
			2 families 4×-4×				
II (seedlings)	2000	3	24 clones	2 plants	+		+

assessed using Potato Test Stripes produced by PRECISION LABS

Traits recorded

The overview of recorded traits is shown in the Table 1. Agronomic traits were evaluated in three trials: I/2000, I/2001, and II/2001. Yield of each plot was graded according to tuber size. Weight of all tubers with diameter > 40 mm, expressed as a percent of total yield was rated as marketable yield. Depth of eyes were scored on 1-9 scale, where 9 means very shallow eyes. The incidence of tubers with defects was recorded in percentage according to method applied by Domański (2001).

Date about resistance of selections to pathogens were obtained in routine testing of parental lines according to methods given by Pietrak

(2001) in case of evaluation for resistance to viruses PVY, PLRV and PVM; Stefan and Malinowska (2000) in case of evaluation for resistance to wart disease and eelworm; Zarzycka (2001) in case of evaluations for resistance to late blight and mixed rots caused by *Erwinia carotovora* ssp. *atroseptica* + *Fusarium* sp.

At harvest one sample of 10 medium sized (55-60 mm diameter) tubers, free from disease and damage symptoms was collected from each plot to evaluate chip colour. Chips were produced directly after three months storage at 4°C. Three 1.6 mm thick slices were cut transversally from mid-section of each tuber. Slices were fried in hydrogenated vegetable oil at 180°C in a thermostatically controlled chip fryer until bubbling ceased. Chip colour was visually assessed on a 1 to 9 scale using the colour cards of IBVL (9 = extremely pale).

The 25-tuber samples of nine selections that produced acceptable to industry chips after cold storage were analysed for reducing sugar and sucrose contents using method given by Talburt and Smith (1967).

Each of 144 seedlings from the trial II/2000 and standard cultivar Saturna were assessed for glucose content using Sugar Test Tapes produced by PRESISION LABS, INC. (West Chester, USA). In 2000, after 4 months storage at 4°C, the 4-tuber samples were taken for assessment of glucose content. In 2001 the assessment was repeated in the case of 22 seedlings with significantly lower level of glucose than cv. Saturna. The glucose content evaluation included two separate four-tuber samples from each seedling after their storage for 4 months at 4°C.

Statistical analysis

Combined analysis of variance for chip colour was carried out, next the analysis of individual genotypes, within which genotype × years interactions were estimated (Table 2). To identify clones with higher chip colour scores than standard cultivar Saturna across years, a pair-wise analysis of variance between individual tested clones and above mentioned standard was additionally carried out. All these analyses were carried out using SERGEN v.3 software (Caliński *et al.*, 1998). Additionally, twelve ANOVA's, five for glucose content of Ist year seedlings, and one for each of assessed agronomic trait of the IInd year seedlings were performed.

RESULTS AND DISCUSSION

The analysis of variance for chip colour after cold storage (4°C) for selected 24 clones from *4*×-4× crosses and four cultivars indicated that the variability of the means for genotypes, years, and genotypes × years interaction were all highly significant (Table 3). It is worth to point out that the input of genotypic component in the observed phenotypic variation found was high (62.4%). This result has shown that variation for chip colour after cold storage (4°C) exists between tetraploid *S. tuberosum* selections.

Table 2

Average chip colour of selected tetraploid clones from 4×-4×progenies after three months storage at 4°C and their interaction with years. Three year data, Młochów 1999-2001

Clone	Mean ± S.D. Chip colour score on 1-9 scale	F-statistic for interaction with years	Estimates of main effect: clone - cv. Saturna	F-statistic for main effect: clone - cv. Saturna
M-62705	6.4 ± 0.2	1.72 ns	1.05	52.92*
M-62724	6.2 ± 0.2	0.49 ns	0.83	192.31**
M-62741	6.1 ± 0.3	1.71 ns	0.57	15.21 ns€
M-62774	6.4 ± 0.2	1.41 ns	1.05	69.63*
Ranges for the reminder clones:				
20 clones:	2.3 - 6.0	0.69 - 50.39	0.17 - (-3.10)	0.06 - 126.73
Standard cvs:				
cv. Maryna	2.5 ± 0.9	12.49**	- 2.85	31.54*
cv. Mila	4.6 ± 0.4	0.96 ns	- 0.82	23.31*
cv. Triada	4.7 ± 0.4	0.11 ns	- 0.68	1.11 ns
cv. Saturna	5.4 ± 0.2	0.07 ns		
Critical values at the level:				
$\alpha = 0.05$		3.11		18.51
$\alpha = 0.01$		4.88		98.50

* , ** - significant at $\alpha = 0.05$ and $\alpha = 0.01$ respectively; ns – not significant

Table 3

Mean squares and variance components from combined ANOVA for chip colour after three month storage at 4°C directly and after reconditioning for two weeks of 24 tetraploid clones and four standard cultivars. Three year data, Młochów 1999-2001.

Source of variation	Degrees of freedom	Mean squares and variance components from combined ANOVA for chip colour after three month storage at 4°C			
		Directly		After reconditioning for two weeks	
		Mean square	Variance components	Mean square	Variance components
Years	2	1.09**	0.018 - (1.8)	1.06**	0.018 - (2.2)
Genotypes	27	4.42**	0.627 - (62.4)	3.92**	0.597 - (74.2)
Genotypes × Years	54	0.66**	0.300 - (29.9)	0.34**	0.150 - (18.6)
Error	81	0.06	0.060 - (6.0)	0.04	0.040 - (5.0)

** - Significant at a = 0.01; proportional values are given in brackets

It was high enough to indicate that genetic improvement for the above mentioned trait could be made through selection. Studies at the Scottish Crop Research Institute also provided evidence for the presence of variation for low-temperature sugar stability among *S. tuberosum* clones. (Brown *et al.*, 1990; Mackay *et al.*, 1990). After storing the 24 clones and four cultivars for three months at 4°C, none of the cultivars (Table 2) chipped acceptably to industry directly from cold storage (with chip colour scored > 6). Four clones M-62705, M-62724, M-62741, M-62774

produced chips with acceptable colour scored from 6.1 to 6.4. Each of these clones indicated also low interaction with years and their mean scores for chip colour exceeded this one of standard cultivar Saturna, the most important chipping cultivar in Poland and Europe. Above mentioned selections were also stable for starch content (Domański *et al.*, 2002).

Table 4.

Agronomic characteristics and disease resistance of selections with pale chip colour after cold storage. Agronomic data from 2000 and 2001

Trait	M-62705	M-62724	M-62741	M-62774	cv. Saturna
Maturity / No of trials	em / 2	em / 2	m / 2	m / 2	m / 2
Total tuber yield: t/ha	41.5	38.5	46.7	40.5	37.3
Percent of standard	94	87	99	89	82
Marketable yield: (Percent of total yield)	89	80	97	94	77
Starch content - (%)	19.2	17.4	19.1	19.1	17.0
Tuber shape	r-ov	ov	r-ov	ov	r-ov
Tuber size - (scale 1-9)	6.2	5.5	7.2	6.8	5.0
Depth of eyes - (scale 1-9)	7.3	7.0	7.0	7.0	6.4
Incidence of secondary growth - (%)	0.3	2.5	4.2	6.1	13.8
Incidence of growth cracking - (%)	0.6	0.0	0.6	0.0	0.0
Incidence of hollow heart - (%)	5.0	0.0	30.0	0.0	0.0
Incidence of internal rust spot - (%)	3.5	5.0	29.7	0.8	26.7
Content of reducing sugars after storage at 4°C [% fresh weight]	0.06	0.09	0.15	0.07	0.39
Content of sucrose after storage at 4°C [% fresh weight]	0.24	0.17	0.24	0.14	0.36
Resistance for:					
Wart disease	R	R	R	S	R
Potato cyst nematodes (Ro1)	S	S	S	S	R
Late blight; foliage / tuber - (scale 1-9)	6/5	3/3	5/6	4/4	4/5
Erwinia spp. + Fusarium sp. - (scale 1-9)	5	4	3	5	nt
PVY - (scale 1-9)	(8-9)	(8-9)	(5-6)	(8-9)	4
PLRV - (scale 1-9)	(5-6)	(5-6)	(4)	(7)	6.5
PVM - (scale 1-9)	(5-6)	(7-8)	(7)	(4)	4

Explanation: - for early maincrop (em) trials as standard check were used cvs: Kolia, Mila for maincrop (m) trials as standard check were used cvs: Ania, Danusia; r-ov = round-oval;ov = oval, initial evaluation – given in brackets () , R – resistant, S – susceptible, scale 1-9 (9 = best) nt – not tested

The identification of good chipping clones used as parental lines for further breeding resulted with three selections. The selections M-62705, M-62724, M-62774 originating from parental line breeding program showed little accumulation of reducing sugars and significantly decreased content of sucrose after cold storage in comparison to cv. Saturna, increased starch content and good tuber appearance (Table 4). They

were also described in trials as having moderate yielding ability and satisfied level of resistance to pathogens except that for potato cyst nematodes. The selections M-62705, M-62724, M-62774 besides of good chipping characteristics demonstrated also high resistance to PVY and moderate resistance to PLRV, and PVM. The selections M-62705, M-62724 posses additionally resistance to wart disease and medium resistance to mixed rots. The clone M-62741 is useless as a parent because of the presence of severe internal defects in its tubers.

Table 5

Analysis of variance of four 4×-2× families and two 4×-4× families for content of glucose after 4 months cold storage at 4°C. Młochów 2000

Source of variation	Degrees of freedom	Mean square
4×-2× and 4×-4× families	5	0.333**
4×-2× families	3	0.392**
4×-4× families	1	0.074 ns
4×-2× families vs. 4×-4× families	1	0.420**
Error	5	0.013

Table 6

Analyses of variance of seedlings within 4x-2x families for content of glucose after 4 months cold storage at 4°C. Młochów 2000

Source of variation	Degrees of freedom	Mean squares in families:			
		Brodick × DG 88-916	Signal × DG 88-89	Signal × DG 93-332	M-62643 × HT/HZ84-PH-151
Seedlings	23	2.200**	1.139**	0.937**	2.132**
Error	23	0.077	0.118	0.125	0.272

Analysis of variance (Table 5) indicated highly significant differences between 4×-4× and 4×-2× families for the level of glucose after 4 months of cold storage. The majority of the variation observed was due to differences among 4×-2× families. Appreciable variation (Table 6) was present among seedlings within 4×-2× families as well. Both types of variation existed among 4×-2× progenies, providing the opportunity for selection of improved clones for use in further cycles of crossing.

Average agronomic performance of seedlings selected for low content of glucose, indirect measure of acceptable chip colour, was presented in Table 7. The higher frequency of perspective clones was observed in progenies derived from tetraploid-diploid crosses than tetraploid crosses. During selection following criteria were applied: low accumulation of glucose (< 0.25% of fresh weight); yield, mean tuber weight, and depth of eyes (≥ mean of cv. Mila – $LSD_{0.05}$); freedom from tuber defects (secondary growth, growth cracking, short dormancy). Out of tested diploid parents, the DG 93-332 and the HT/HZ84-PH-151 were more suitable for creation of progenies combining low content of glucose

with increased starch content, yielding ability and satisfactory tuber appearance. However, clones derived from HT/HZ84-PH-151 (containing *S. phureja* ancestry) often produced tubers with short dormancy.

Table 7

Agronomic characteristics of seedlings selected for low content of glucose and originated from interploid (4×-2×) crosses. Młochów 2001

Seedling	Half-sib family	Tuber yield [kg per 2 plants]	Mean tuber weight [g]	Starch content [%]	Approximate glucose content [1-5 score]	Depth of eyes [1-9 score]	Comments
R-5	DG 98-916 (2×)	2.02	81.0	13.4	2.3 ab	5.8	
R-15	DG 98-916 (2×)	1.98	93.4	12.8	2.2 b	6.8	
R-16	DG 98-916 (2×)	2.01	121.6	10.9	1.6 b	5.9	
R-45	DG 88-89 (2×)	2.85	83.8	14.6	2.4 ab	6.9	
R-56	DG 93-332 (2×)	2.33	83.9	17.1	1.8 b	6.4	
R-57	DG 93-332 (2×)	2.78	92.6	16.9	2.0 b	6.8	
R-58	DG 93-332 (2×)	2.44	95.8	19.4	2.0 b	6.7	
R-60	DG 93-332 (2×)	3.37	77.1	18.3	2.6 ab	6.1	
R-70	DG 93-332 (2×)	2.56	77.4	17.6	2.6 ab	6.4	
R-72	DG 93-332 (2×)	2.81	76.5	16.1	2.4 ab	6.4	
R-73	HT/HZ84-PH-151 (2×)	2.13	53.9	16.9	2.2 b	6.8	sh. dorm.
R-74	HT/HZ84-PH-151 (2×)	2.95	62.8	16.4	1.5 b	7.0	sh. dorm.
R-78	HT/HZ84-PH-151 (2×)	2.67	94.4	17.8	2.6 ab	7.5	
R-79	HT/HZ84-PH-151 (2×)	3.24	98.0	14.6	2.2 b	6.7	sh. dorm.
R-82	HT/HZ84-PH-151 (2×)	2.04	78.2	15.8	1.9 b	6.8	
R-85	HT/HZ84-PH-151 (2×)	2.79	61.8	15.6	2.5 ab	6.8	sh. dorm.
R-88	HT/HZ84-PH-151 (2×)	3.37	68.4	16.2	2.3 ab	7.1	
R-91	HT/HZ84-PH-151 (2×)	3.06	63.8	15.3	1.6 b	7.2	
R-94	HT/HZ84-PH-151 (2×)	2.50	52.1	18.1	1.7 b	7.1	
R-110	M-62643 (4×)	2.95	73.1	14.8	1.8 b	6.4	
Mila		2.03	91.2	17.3		6.6	
Saturna					3.4 a		
	LSD	0.51	23.7	1.2	0.6	0.5	

1 – 0%, 2 - 0.10%, 3 – 0.25%, 4 – 0.50%, 5 – 2.00% glucose in fresh weight, mean of 2000 and 2001; Comparable means followed by the same letter are not significantly different ($\alpha = 0.05$) according to Tukey's Honestly Significant Difference Test; sh. dorm. – short dormancy

The present pool of parents for the development of cold chipping clones, obtained from interploid crosses can be enriched by our selections. However, they need evaluation of agronomic performance and chipping quality in frying tests.

In 2002 our best cold chipping selections the M-62724 and the M-62774 were delivered as parental forms to Polish breeding companies PMHZ Strzekęcin and HZ Zamarte. At this moment the information on their combining ability is not available.

Broad-sense heritability of chip colour after cold storage estimated by Pereira *et al.* (1995) in two families of cold chipping clone ND860-2 was moderate and ranged from 0.39 to 0.66. The clone ND860-2 was found in the origin of cultivar NorValley outstanding in cold-sweetening resistance bred by Novy *et al.* in 1998.

In our opinion parental lines the M-62724 and the M-72774 give a chance to develop new cultivars suitable for processing from cold storage. More, as the parental lines M-62724 (cross: Agria × DG.88-89) and M-62774 (cross: Agria × PW-363) posses in their origin parents with positive general combining effects (Domański *et al.*, 2000).

CONCLUSIONS

A considerable genetic variation in potato chip colour after cold storage exists within the pool of tetraploid parental lines developed at Research Center Młochów of the Plant Breeding and Acclimatization Institute. Best selections have been offered to Polish breeders.

Three selections were identified directly from cold storage (M-62705, M-62724, M-62774) combining low concentration of reducing sugars after cold storage, increased starch content, satisfactory resistances to viruses and good tuber appearance. They were also capable of produce acceptable by industry light coloured chips with reletive high stability of this trait over years.

The use of *2n* polen-producing diploid parents the DG 93-332 and the HT/HZ84-PH-151 may be useful for the development of new cold chipping parental lines. The perspective clones combining low content of glucose with increased starch content, good yielding ability and satisfied tuber appearance were selected from 4×-2× progenies with higher frequency than from 4×-4× progenies.

ACKNOWLEDGEMENTS

This research was supported in part by Polish breeding companies: HZ Zamarte and PMHZ Strzekęcin.

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