Performance of Commercially Available True Potato Seed Hybrids Grown from Tubers

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Abstract. Nine commercially available true potato seed (TPS) hybrids were compared to four standard clonal cultivars with respect to mean and uniformity of foliar characteristics and tuber traits important to the North American potato industry. The TPS hybrids were planted using second vegetative generation tubers derived originally from botanical seed. Ten plants from each plot were individually evaluated for plant height, vine maturity, early blight symptoms, and verticillium wilt symptoms. Following harvest, yield was determined and the tubers were rated or measured for appearance, shape, specific gravity, and french fry color. The TPS hybrids had mean values for all tuber and foliar traits, except plant height, that were not significantly different from those of one or more of the cultivars; generally, values for the hybrids fell amid those of the cultivars. Two of the hybrids were taller on average than any of the four cultivars. In contrast to the means, trait uniformity of the TPS hybrids was consistently less than for the cultivars. For all foliar traits, except plant height, the TPS hybrids were substantially less uniform than the standard cultivars. For specific gravity and french fry color, two important processing quality traits, the hybrids tended to be less uniform than the cultivars; however, the difference was much less pronounced than for the foliar traits. Four of the hybrids were not significantly less uniform than one or more of the cultivars for french fry color and seven were not less uniform for specific gravity. For many market uses, the TPS hybrids appeared to have the tuber yield and quality characteristics needed to compete with standard clonally propagated cultivars.

Traditionally, potatoes have been propagated vegetatively using tubers. Worldwide, there is a growing interest in developed and developing countries in using botanical or true potato seed (TPS) for large-scale production of potatoes (Renia et al., 1996; Upadhy, 1996). The development of TPS cultivars is considered to be a technological breakthrough that will allow potatoes to be produced and consumed in countries where they were previously unavailable (Ross, 1986). In the last few

years, research has been conducted on TPS in more than 25 countries throughout the world (Umaerus, 1987; Upadhy, 1996). Commercial demand for TPS cultivars has developed

in Asia. In spite of increasing interest, there have been no reports from developed countries of use of TPS for commercial potato production.

The major disadvantages of TPS cultivars have been low tuber yields and a lack uniformity in tuber shape, color, size, and cooking quality (Clulow et al., 1995; Sadik, 1983). The lack of uniformity is of greater concern in established markets of developed countries where product quality is critical and includes specifications for consistency. In 1980, ESCAgenetics (San Carlos, Calif.) began a research program to produce and market TPS hybrids (Kidd, 1994). The major objectives of the research involved breeding to develop parents with high TPS yields and progenies that could compete with clonal varieties in many world markets.

The purpose of the present research was to compare these commercially available TPS hybrids, propagated using second vegetative generation tuber material, with selected clonal cultivars. The comparisons included magnitude and uniformity of traits important for fresh market and processing.

Materials and Methods

ESCAgenetics provided clonal seed from nine F₁ TPS hybrids for evaluation in Spring 1992. The parents of the hybrids were all tetraploid, derived from duplex dihaploids and diploids arising from domestic and wild species of North American, South American, and European origin. The parents resulted from a series of 6-year selection cycles wherein germplasm was selected and intercrossed and then reselected. The breeding objectives for the parental clones included the ability to produce progeny populations with high yield, good external and internal tuber quality, resistance to common field diseases, uniformity and acceptability for important processing quality traits, and high production of true seed following hybridization. During breeding, variability in foliar traits was either ignored or purposely maintained at a high level to increase the potential for wide adaptability.

Table 1. Average plant height, vine maturity, and symptom expression for early blight and verticillium wilt of nine TPS hybrids and four standard cultivars.²

Hybrid/cultivar	Plant ht (cm)	Vine maturity ^y (rating)	Early blight ^x (rating)	Verticillium wilt ^x (rating)
88EX-2	40	3.7	3.3	3.5
88WO-1	41	3.6	3.2	3.6
88WO-13	38	4.0	3.3	3.8
88WR-32	41	3.3	2.9	3.1
88WR-35	44	3.2	2.7	3.0
88WR-49	42	3.8	3.3	3.5
89FWW-101	48*	3.7	3.3	3.4
89FWW-102	49*	3.7	3.1	3.6
89FWW-105	44	3.6	3.2	3.5
Alpha	44	4.1	3.8	4.1
Brador	28	4.1	3.8	4.1
Katahdin	39	3.7	3.1	3.4
Superior	39	1.6	1.8	1.5
LSD _{0.05}	4	0.2	0.4	0.3

²Values for the TPS hybrids, followed by an asterisk, are significantly ($P \leq 0.05$) above or below all of the standard cultivars as determined by LSD.

^yVine maturity was rated on a 1–5 scale, where 1 = very early, 5 = very late.

^xEarly blight and verticillium symptoms were rated on a 1–5 scale, where 1 = severe, 5 = none or slight.

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The hybrids tested had a high commonality of parents, with various combinations of eight parents providing the nine hybrids. The hybrids and their parents were designated as follows: 88EX-2 (NP14 x NP12), 88WO-1 (NP2 x NP11), 88WO-13 (NP2 x NP12), 88WR-32 (NP16 x NP13), 88WR-35 (NP17 x NP22), 88WR-49 (NP14 x NP13), 89FWW-101 (NP13 x NP11), 89FWW-102 (NP13 x NP12), and 89FWW-105 (NP14 x NP2).

The original seed tubers received in 1992 were a random sample of potatoes produced in the second vegetative generation following the planting of botanical seed. Tuber increase of the TPS hybrids was carried out by ESCAgeneitics employees at their production facility in Half Moon Bay, Calif. The increase system used was typical of one of the most probable methods for increasing TPS hybrid seed tubers for commercial potato production in North America. The tubers were produced using certified seed techniques and met California certification standards for the presence of diseases. The tubers consisted of a finite sample of the variability found in these TPS hybrid progeny populations.

Four standard cultivars, 'Alpha', 'Brador', 'Katahdin', and 'Superior' (Agriculture Canada, 1984; New Brunswick Dept. of Agriculture, 1993; Rieman, 1962), were chosen for comparison with the TPS hybrids because they represent the types of cultivars with which TPS hybrids will compete. The standard cultivars were not chosen because they were the most popular cultivars in production in North America, but because they tended to express a wide range of values for many foliar and tuber traits.

Seed tubers of each standard cultivar were obtained from Joseph Pavék [U.S. Dept. of Agriculture(USDA)/Agricultural Research Service, Aberdeen, Idaho] and were produced at Aberdeen from virus-tested stocks. In Spring 1992, seed tubers of TPS hybrids and cultivars were cut by hand to produce seed pieces with a uniform size of ≈ 60 g. The seed pieces were planted on 1 May in a Declo silt loam soil at the Aberdeen Research and Extension Center. The experiment was repeated in 1993. To provide genetic continuity in the TPS hybrid families from year to year, seed potatoes for 1993 were obtained from the 1992 trial by harvesting and bulking one tuber from each plant. One seed piece was cut from each tuber and used to plant one hill in the 1993 trial. This allowed reproduction of the progeny population evaluated in 1992. The seed tubers for the standard cultivars were managed in the same way. The trial in 1993 was planted 3 May and otherwise managed and sampled in the same manner as in 1992.

The experiment was designed as a randomized complete block, replicated four times. Each plot consisted of 24 hills of a TPS hybrid or standard cultivar planted in a single row. Plot dimensions were 0.9 m (between rows) $\times$ 6.1 m. Within a row, seed piece spacing was 25 cm. The plots were sprinkler irrigated and managed as is typical in the region for a main-season potato crop. Subfreezing temperatures killed the vines on 23 Aug. in 1992. In 1993, a

Fig. 1. Uniformity of individually measured plants from nine TPS hybrids and four clonal cultivars for plant height (A), vine maturity (B), early blight symptoms (C), and verticillium wilt symptoms (D). Uniformity was determined by computing the standard deviation for the first 10 plants in each plot. TPS hybrid means accompanied by an asterisk are significantly ($P \leq 0.05$) different from those of all four clonal cultivars, as determined by LSD.

chemical vine desiccant was used to kill the vines on 7 Sept. The plots were harvested on 5 Oct. and 1 Oct. in 1992 and 1993, respectively.

Measurements were made on plants of TPS hybrids and standard cultivars during the growing season and on tubers following harvest. Methods of measurement were designed to characterize mean tendency (magnitude) and uniformity (or variability) of each trait considered. The foliar traits evaluated were plant height, vine maturity, and early blight (*Alternaria solani* Sorauer) and verticillium wilt (*Verticillium dahliae* Kleb.) symptoms. Tuber traits quantified were total and marketable yield, appearance, tuber shape, french fry color, and specific gravity.

The foliar measurements were made individually on the first 10 plants in each plot. Plant height was recorded on 2 July in each year. Vine maturity, early blight symptoms, and verticillium wilt symptoms were assessed on 21 Aug. 1992 and 18 Aug. 1993, respectively. Vine maturity was rated on a 1 to 5 scale, where 1 = plants dead at the time of rating; 5 = plants growing vigorously and still flowering. Early blight and verticillium symptoms were rated on a 1 to 5 scale, where 1 = severe symptoms on all visible foliage; 5 = no symptoms or a few mild symptoms on the lower leaves. For each plot, the mean and standard deviation were calculated. The standard deviation was used as a uniformity score and represented the variability present among the first 10 hills of the plot.

At harvest, tubers were mechanically lifted and laid in place on the soil surface. A 20-tuber subsample was collected from the first 20 plants by randomly harvesting one tuber, weighing between 110 and 400 g, from each plant. The entire plot was then harvested, weighed, and graded, and the total and marketable yields calculated. Marketable yield was defined as all tubers longer than 40 mm with no obvious defects. During grading, appearance and tuber shape scores were recorded. The appearance score was similar to a breeder's preference rating and reflected eye depth, size uniformity, absence of defects, shape uniformity, and skin type. Tubers from each plot

were rated on a 1 to 9 scale, with a higher score indicating a better overall appearance. The tuber shape score was designed to reflect the length : width ratio and was rated on a scale of 1 to 5, where 1 = long and 5 = round.

The tubers in the subsamples were stored at 10 °C for ≈ 3.5 months at which time specific gravity and french fry color were determined. Specific gravity of each individual tuber was measured using the weight-in-air, weight-in-water method. The same tubers were then cut into 0.5-cm-diameter strips with the center strip removed for a french fry test. The strips were fried in vegetable oil at 196 °C for 3.5 min. Immediately after cooking, the strips were rated for color using the USDA French Fry Color Chart. This chart uses a 0 to 4 rating scale, where lower numbers indicate lighter color. For each plot, both the mean and standard deviation were computed for specific gravity and french fry color. As before, the standard deviation was used as a measure of uniformity. Using this calculation method, lower standard deviation values were indicative of more uniformity in the variables measured.

Plot means and standard deviations were combined into a single data set across the 2 years and analysis of variance was completed. Means separation was accomplished using the method of least significant difference (LSD). The performance of the TPS hybrids was evaluated as a direct comparison with the standard clonal cultivars.

Results

The TPS hybrids generally resembled the standard cultivars for most foliar characteristics, but were far less uniform from plant to plant. The uniformity of foliar characteristics was measured mainly to provide a frame of reference for comparing and understanding the amount of variability present in the processing quality characteristics. During flowering, many of the hybrid plots varied from plant to plant for flower color. Three TPS hybrids were exceptions, one had all white flowers and two had white flowers occasionally mixed

with very light pink flowers. Plant architecture also varied widely within each TPS hybrid, while it was consistent within the clonal cultivars.

Average height of plants within each TPS hybrid was similar to that for the standard cultivars, except for two hybrids, 89FWW-101 and 89FWW-102, that were taller than any of the four cultivars (Table 1). Plant height uniformity among the hybrids was also mostly similar to that of the cultivars (Fig. 1A). Only three hybrids, 88EX-2, 88WO-13, and 88WR-32, were less uniform for plant height than the clonal cultivars.

Each of the hybrid families had a mean vine maturity that fell among the means of the cultivars (Table 1). However, the maturity within each hybrid was much less uniform than that within the cultivars (Fig. 1B). Most of the hybrids had individual plants that fell at both extremes of the rating scale. Average scores for early blight and verticillium wilt symptoms of the hybrids fell amid the cultivar means (Table 1). The hybrids were much less uniform than the cultivars for early blight (Fig. 1C) and verticillium wilt (Fig. 1D) symptoms.

Total yields of the TPS hybrids fell mostly between 'Katahdin' and 'Superior', the highest and lowest yielding cultivars, respectively (Table 2). The hybrid 89FWW-101 had the highest yield of any entry in the trial, which was significantly ($P \leq 0.05$) higher than that for 'Brador' or 'Superior'. Marketable yields followed the same trends as total yields (Table 2). Alpha was lower in rank for marketable yield than for total yield because a larger percentage of tubers had external tuber defects, including growth cracks and second growth.

Rank of the hybrids for tuber appearance was between 'Katahdin' and 'Alpha', the highest and lowest-ranked cultivars, respectively (Table 2). Four of the nine hybrids had significantly ($P \leq 0.05$) lower appearance scores than 'Katahdin', while five were rated higher than 'Alpha'. The shape of tubers among the hybrids was mostly round to oval, similar to 'Alpha', 'Katahdin', and 'Superior'. 88WO-13 had longer tubers and was similar in shape

Table 2. Average yield, appearance score, tuber shape, french fry color, and specific gravity of nine TPS hybrids and four standard cultivars.

Hybrid/cultivar	Total yield (t·ha ⁻¹)	Marketable yield (t·ha ⁻¹)	Appearance ^a	Tuber shape ^b	French fry color ^c	Specific gravity ^d
88EX-2	45.5	43.7	7.0	2.8	3.2	1.087
88WO-1	47.4	44.9	6.8	2.3	3.1	1.082
88WO-13	37.4	35.8	6.8	1.8	3.1	1.084
88WR-32	39.4	36.6	6.5	3.5	1.1	1.082
88WR-35	50.6	48.8	7.8	4.5	1.9	1.082
88WR-49	45.7	41.7	7.4	3.9	1.5	1.080
89FWW-101	55.7	53.2	7.1	3.4	1.6	1.089
89FWW-102	47.8	45.7	7.1	3.5	2.1	1.086
89FWW-105	47.2	43.6	6.8	3.3	2.6	1.083
Alpha	50.6	40.8	6.0	2.9	3.0	1.095
Brador	43.2	38.4	6.5	1.9	1.3	1.082
Katahdin	51.1	50.3	8.0	4.0	3.3	1.079
Superior	34.3	33.6	7.4	4.3	3.1	1.075
LSD _{0.05}	5.9	5.9	1.0	0.7	0.4	0.004

^aAppearance was rated on a 1–9 scale, where higher scores indicate better appearance.

^bTuber shape was rated on a 1–5 scale, where 1 = long, 5 = round.

^cFrench fry color was rated using the USDA French Fry Color Chart. Lower numbers indicate lighter color, and values below 3 are considered acceptable.

^dSpecific gravity is an estimation of starch content and was determined using the weight-in-air, weight-in-water method.

to 'Brador'. Hybrids with round tubers had more uniform shape than those with long ones.

The range of average french fry color among the hybrids was similar to that for the clonal cultivars (Table 2). Of the four clonal cultivars, 'Brador' produced the lightest colored french fries and the color was well within the range considered acceptable. Three of the hybrids had average fry color that was not significantly ($P = 0.05$) different from that of 'Brador'. Although three of the hybrids had fry colors above the acceptable limit, none produced fries that were darker than those of 'Katahdin'. Fry color uniformity within each cultivar tended to be better than for the hybrids, but the difference was of a smaller magnitude than for most of the foliar traits (Fig. 2A). 'Superior' had the least uniform fry color of any cultivar. Four of the hybrids, 88WO-1, 88WO-13, 88WR-32, and 89FWW-101, had uniformity that was not significantly ($P \leq 0.05$) worse than for 'Superior'.

Mean tuber specific gravity of the hybrids was between the values for 'Alpha' and 'Superior', the highest and lowest, respectively (Table 2). All of the hybrids had average specific gravity in the range that is considered acceptable for most processing purposes. The

uniformity of specific gravity of all hybrids except 88WR-49 and 88FWW-101, was similar to that found in the majority of the cultivars (Fig. 2B). 'Superior' had the least variable specific gravity of the cultivars.

Discussion

The hybrids evaluated in this study were developed by ESCAgenetics breeders who sought TPS families with uniformity in tuber traits, because they are more important than foliar traits for commercially produced TPS progenies, while ignoring or attempting to maintain variability in foliar traits. This approach led to the evident lack of uniformity in the foliar traits. With the exception of plant height, the TPS hybrids showed considerably less uniformity than the clonally propagated cultivars. Even the apparent uniformity in plant height was probably due to an artifact caused by competition.

The tendency for the TPS hybrids to be variable for maturity and disease resistance was pronounced. They had a wide range of expression for early blight and verticillium wilt symptoms. The nonuniformity of maturity may be detrimental for optimizing crop

production conditions, preparing for harvest, and providing proper storage environment. The hybrids would need to be managed as a late-maturing crop in spite of the presence of early maturing individuals.

The mean values for yield and other tuber traits of the TPS hybrids were generally similar to those for one or more of the standard cultivars. Golmirzaie et al. (1994) reported that F_1 hybrid TPS progenies tended to perform best for yield in comparison to other TPS progeny types, giving them the ability to compete with clonal cultivars. This finding was recently confirmed by Gebremariam et al. (1996). The total and marketable yields obtained from the ESCAgenetics F_1 hybrids were similar to those of the cultivars and were acceptable. Tuber appearance and shape fell within the range expressed by the clonally propagated cultivars.

For two of the most important processing traits, tuber specific gravity and french fry color, most of the TPS hybrids had acceptable means, but tended to be less uniform than the clonal cultivars. French fry color of six of the nine hybrids fell in the acceptable range, while specific gravity of all nine hybrids was acceptable. There was a tendency for the hybrids to be less uniform from tuber to tuber for these processing traits. However, in comparison to the foliar traits, uniformity for french fry color and specific gravity of the hybrids were more similar to those of the clonal cultivars. Some of the hybrids were nearly equivalent to the cultivars for uniformity of these important tuber quality traits, reflecting the selection priorities of the breeders during hybrid development. This outcome provides evidence that parental selection has decreased variability among TPS hybrid populations for these two important internal tuber quality traits.

This study provides some information about the comparative value of crops produced using these TPS hybrids vs. those produced using clonal cultivars. In comparison with the four cultivars included in this study, tuber yields of the hybrids were equivalent. Tuber appearance of most of the hybrids was similar and acceptable. Yield and appearance are the most important characteristics for fresh market potatoes and where round, white potatoes are preferred, these TPS hybrids likely would be competitive with clonal cultivars.

For cultivars with intended use in the processing industry, nonuniformity for important processing quality traits is of more concern than for foliar or other tuber characteristics. Less uniform tubers result in less uniform finished product, a situation that may be unacceptable in many specialized industries. The processing traits of french fry color and specific gravity for many of these hybrids were, on average, similar to those of the cultivars, but the hybrids tended to be slightly less uniform from tuber to tuber. The differences between the uniformity of the hybrids and that of the cultivars was surprisingly small compared to most other traits measured. The degree of difference may not be of practical importance, but this will need to be determined on a larger scale by individual users.

Fig. 2. Uniformity for french fry color (A) and specific gravity (B) of individually evaluated tubers from nine TPS hybrids and four clonal cultivars. Uniformity was determined for each plot by computing the standard deviation for a 20-tuber sample. TPS hybrid means accompanied by an asterisk are significantly ($P \leq 0.05$) different from those of all four clonal cultivars, as determined by LSD.

When all evidence is considered together, this study suggests that TPS cultivars may have the capability of competing successfully with clonal cultivars in some portions of established North American potato markets. Yield, appearance, and internal quality appear to be adequate to make their use feasible. However, they may or may not become established in the United States or Canada, depending on whether they can provide a distinct economic advantage to some portion of the potato industry.

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