Sweetpotato ‘Beauregard’ Mericlones Vary in Yield, Vine Characteristics, and Storage Root Size and Shape Attributes

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Abstract. Yield tests and evaluation of selected storage root and vine characters were conducted among 12 ‘Beauregard’ sweetpotato [*Ipomoea batatas* (L.) Lam.] mericlones. Maximum yield differences were 43%, 48%, 79%, and 40% for U.S. #1, canners, jumbos, and total marketable yield, respectively. Additive main effect and multiplicative interaction (AMMI) biplot analysis was useful in graphically presenting the yield differences and stability patterns of mericlones. Differences were also detected in vine length, internode diameter, and internode length. Digital image analysis of U.S. #1 storage roots also revealed differences in storage root minor axis length, roundness, and elongation attributes. The results provide valuable information for enhancing current methods of evaluation and selection of mericlones for inclusion in sweetpotato foundation seed programs.

The implementation of a virus-tested (VT) sweetpotato foundation seed program ensures the availability and sustained productivity of superior cultivars. In contrast to the conventional method of generating foundation seed, i.e., hill selection of breeder seedstock followed by vegetative propagation from storage root-derived shoots, meristem-tip culture followed by nodal propagation from a virus-tested (VT) mericlone selection comprise the starting material for VT foundation seed. Alconero et al. (1975) first documented the feasibility of using tissue culture techniques as therapy for viruses infecting sweetpotato. Subsequently, apparent yield differences were detected between virus-infected and putatively “virus-free” sweetpotatoes (Hahn, 1979; Huett, 1982). Moreover, other desirable attributes of in vitro-derived plants have been observed. For instance, nodal culture reduced

DNA marker polymorphisms (Villordon and LaBonte, 1996) and produced good stands of phenotypically similar plants (Templeton-Somers and Collins, 1986). Low incidence of marker polymorphisms is desirable because this indicates fewer detectable mutations and other genomic anomalies among clones. Recently, Kano and Nagata (1999) reported that virus-tested cuttings initiated more vigorous roots compared to virus-infected treatments. Furthermore, Wallace et al. (1999) showed that yields increased from 7% to 130% in virus-tested clones relative to virus-infected counterparts. In addition, they also reported up to 118% yield variability within the virus-

tested mericlones. This information suggests that mericlones potentially exhibit large variations in yield. Thus, tests over several planting dates, years, and locations may be necessary to ensure that sufficient data are available prior to selecting a mericlone for seedstock use. The objective of this study was to evaluate the performance of mericlones in several environments as well as assess the uniformity of selected vine and storage root traits.

Materials and Methods

Twelve VT mericlone selections (Table 1) were planted on three planting dates (early, mid, and late season) in Chase (Gilbert series: fine-silty, mixed, thermic Typic Glossaqualfs) during 2000. The following year, early-season tests were established in Wisner (Gilbert series), Iota (Iota series: fine, smectitic, hyperthermic Vertic Hapludalfs), and Cecilia (Loreauville series: fine-silty, mixed, superactive, hyperthermic Mollic Endoaqualfs) while early-, mid-, and late-season trials were planted in Chase. Each VT mericlone originated from a single root selection and was subjected to meristem-tip culture and virus indexing (three successive grafts to *Ipomoea setosa*) followed by in vitro nodal propagation of an individual mericlone that was found to be apparently free of viruses. Generation 0 (G0) greenhouse-grown transplants (VT mericlones directly increased from in vitro cultures) were used in all tests in Chase. Generation 1 (G1) seed derived from the G0 plants were stored over winter for bedding the following year. Transplants (cuttings) derived from the field-grown G1 seed were used in Wisner, Cecilia, and Iota. Combinations of planting dates, years, and locations were considered as individual environments. Randomized complete-block designs with four replications were used. Planting dates were defined as early (mid- to late May), mid (late May to mid-June), and late (mid-June onward). In the 2000 tests, 20 transplants per plot were placed 0.3 m apart within rows that were 1 m wide in Chase. Adjacent plots were separated with a buffer row. An unplanted 1.5-m alley separated blocks. In 2001, similar procedures

Table 1. Means for yield of U.S. #1, canners, jumbos, and total marketable yield (TMY) of 12 sweetpotato ‘Beauregard’ virus-tested mericlones across nine environments in Louisiana.

Mericlone	No. of environments	Yield ^a (t·ha ⁻¹)			
		U.S. #1	Canners	Jumbos	TMY
94-14	7	29.26 ± 2.15	10.25 ± 1.01	5.58 ± 1.08	39.51 ± 2.32
97-7-4	8	26.57 ± 2.17	10.93 ± 0.90	6.41 ± 1.09	37.50 ± 2.04
97-6-1	9	25.14 ± 1.51	10.48 ± 0.89	6.87 ± 0.77	35.62 ± 1.73
97-9-7	9	24.61 ± 2.00	10.00 ± 0.58	6.41 ± 0.90	34.62 ± 1.97
H3-5	9	24.95 ± 2.17	10.27 ± 1.01	5.84 ± 1.17	35.22 ± 2.05
B-63	9	24.65 ± 1.24	10.53 ± 0.75	8.19 ± 1.33	35.18 ± 1.11
L2-3	7	22.87 ± 2.54	8.59 ± 0.92	9.09 ± 1.99	31.47 ± 2.36
H2-1	8	22.24 ± 1.93	8.49 ± 0.75	5.58 ± 0.93	30.73 ± 1.99
B-73	6	21.29 ± 2.01	8.04 ± 0.80	5.31 ± 0.85	29.33 ± 1.98
97-10-5A3	8	21.15 ± 1.73	9.43 ± 0.98	5.07 ± 0.82	30.59 ± 1.63
97-5-1	8	20.70 ± 1.76	7.35 ± 0.74	8.28 ± 1.15	28.05 ± 1.44
97-10-11A6	6	20.42 ± 2.34	8.04 ± 0.99	6.81 ± 1.50	28.46 ± 2.60
LSD _{0.05}		3.07	1.84	2.29	2.75
P value		0.0021	0.0008	0.0264	<0.0001

^aU.S. #1 (5.1 to 8.9 cm diameter and 7.6 to 22.9 cm long), canner (2.5 to 5.1 cm in diameter and 5.1 to 17.8 cm in length), and jumbo (larger than both groups but marketable). Means ± SE.

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were used, except that 25 transplants per plot were put out. Plots located in growers' fields in Cecilia, Iota, and Wisner were not separated by buffer rows. Cultural practices recommended by the Louisiana Cooperative Extension Service (LCES) were followed for all planting dates in Chase. Individual growers were responsible for cultural practices in Cecilia, Iota, and Wisner. Days to harvest ranged from 115 to 140. Although 115 d was the preferred number of growing days, inclement weather routinely caused delays in harvest. Roots were graded and weighed into U.S. #1 (5.1 to 8.9 cm diameter and 7.6 to 22.9 cm in length), canner (2.5 to 5.1 cm in diameter and 5.1 to 17.8 cm in length), and jumbo (larger than both groups but marketable).

Vine length, internode length (7th internode from the first fully opened leaf), and vine diameter (7th node from the first fully opened leaf) were measured from 10 sample plants per replicate from the Chase midseason test in 2000. In addition, a total of 1057 U.S. #1 storage roots were randomly sampled from the 2000 early-season and 2001 midseason tests in Chase for digital image analysis (DIA) using Image Tool (Univ. of Texas Health Science Center at San Antonio, available from <ftp://maxrad6.uthscsa.edu>). The number of U.S. #1 storage root samples per mericlone ranged from 34 to 49 in 2000 and 14 to 65 in 2001. Seven storage root attributes or variables were measured and subjected to DIA analysis, including area, perimeter, roundness, elongation, compactness, major axis length, and minor axis length. The details of the image analysis procedure are described in Villordon and Wallace (2002).

Yield, vine, and storage root measurements were subjected to analysis of variance (ANOVA) using the GLM procedure of SAS (SAS Inst., Cary, N.C.). The AMMI analysis was carried out following the procedure described by Gauch (1992) using SAS programming statements outlined by Hernandez and Crossa (2000). ANOVA on storage root yield was performed on an unbalanced data set due to the fact that numbers of replications and VT mericlones were not the same in all environments. A balanced data set of nine VT mericlones, seven environments, and three replicates was used in the AMMI analysis. This data set consisted of results from the Chase (2000 early-, mid-, and late-season and 2001 mid- and late-season), Wisner (2001 early-season), and Iota (2001 early-season) tests.

Results and Discussion

Storage root yields. Differences were detected among mericlones in all yield grades. The differences between the highest and lowest yielding mericlone were 43%, 48%, 79%, and 40% for U.S. #1, canners, jumbos, and total marketable yield (TMY), respectively (Table 1). The subsequent AMMI analysis using a balanced data set detected significant VT mericlone $\times$ environment interactions for the canner and TMY grades (Table 2). The biplot of the interaction principal component

Fig. 1. Additive Main Effects and Multiplicative Interaction (AMMI)-1 biplots for the 'Beauregard' virus-tested (VT) mericlone (A) U.S. #1, (B) canner, and (C) total marketable yield (TMY) balanced data set, showing both main and interaction effects for both mericlones and environments. Triangles denote VT mericlones; rectangles denote environments (IPCA = interaction principal component analysis axis). 00EARCH, 00MIDCH, and 00LATCH = early-, mid-, and late-season 2000 tests in Chase, respectively. 01MIDCH and 01LATCH = mid-, and late-season 2001 tests in Chase, respectively. 01EARWI and 01EARIO = early 2001 tests in Wisner and Iota, respectively. Means are from a balanced data set consisting of seven environments and nine VT mericlones. The vertical line represents the grand mean.

analysis axis-1 (IPCA-1) against the mean estimate of the U.S. #1, canner, and TMY yield, respectively, are shown in Fig. 1A–C. The biplots were extremely informative in graphically displaying the yield and stability patterns of the VT mericlones. For instance, in the economically important U.S. #1 grade, the biplot illustrates that 94-14 and 97-7-4 were both good performers and demonstrated stable yields (IPCA scores near zero) across the sample of environments used in the study (Fig. 1A). Several VT mericlones that clustered around the mean U.S. #1 yield, B-63, H3-5, 97-9-7, and H2-1, showed less stable yield patterns across environments (Fig. 1A). A similar yield and stability trend involving the same VT mericlones is shown for TMY (Fig. 1C). The use of AMMI analysis to potentially enhance the analysis and interpretation

of multi-genotype and multi-environment trials has been demonstrated in other crops. For example, Ebdon et al. (1998) used the AMMI model in evaluating evapotranspiration rates in Kentucky bluegrass cultivars (*Poa pratensis* L., KBG) and concluded that this approach helps in detecting and providing a more complete interpretation of genotype $\times$ environment interaction (GEI) compared with ordinary ANOVA. Other potential applications include identification of mega-environments for achieving optimum yields (Gauch and Zobel, 1997), evaluation of GEI for resistance to spider mites in strawberries (*Fragaria* L. sp.) (Medina et al. 1999), and field assessment of *Musa* to virus infection in multilocation trials (Ortiz, 1996).

Vine and storage root characteristics. Differences in vine length (26%), internode

Table 2. Mean squares from the AMMI analysis for yield of U.S. #1, canners, jumbos, and total marketable yield (TMY) of nine sweetpotato 'Beauregard' VT mericlones grown in seven environments in Louisiana.

Source of variation ^y	df	MS ^z			
		U.S. #1	Canners	Jumbos	TMY
Total	188				
Model	64	227.17***	44.13***	79.51***	265.42***
Block	2	20.43	10.98	33.90	7.21
Mericlone (M)	8	77.57*	22.48	16.67	156.88***
Environment (E)	6	2056.65***	311.01***	698.45***	2152.62***
M × E	48	32.03	15.75*	14.52	58.37***
IPCA1	13	57.40	30.18***	21.00	79.81***
IPCA2	11	28.62	19.54	20.92	80.85***
Residual	24	19.86	6.21	8.08	36.43
Error	124	28.62	8.60	16.90	24.34

^zMean square. The significance of the AMMI models is based on postdiction.

^yIPCA1 = Interaction Principal Component Axis-1; IPCA2 = Interaction Principal Component Axis-2

NS, *, **, *** Nonsignificant or significant at $P = 0.05$, 0.01 , or 0.001 , respectively.

Table 3. Selected sweetpotato vine characteristics of 'Beauregard' VT mericlones, midseason planting, Chase, La., 2000.^z

VT mericlone	Vine characteristic (cm)		
	Length	Internode length	Internode diam
B-63	132.30 ± 8.16	7.14 ± 0.32	0.38 ± 0.01
H2-1	129.63 ± 4.65	6.79 ± 0.39	0.39 ± 0.01
B-73	125.72 ± 7.39	6.73 ± 0.37	0.35 ± 0.01
97-10-11A6	124.87 ± 6.70	6.30 ± 0.28	0.37 ± 0.01
97-10-5A3	124.46 ± 6.62	6.43 ± 0.25	0.39 ± 0.01
L2-3	113.35 ± 8.22	5.89 ± 0.39	0.41 ± 0.01
H3-5	109.32 ± 5.33	6.45 ± 0.29	0.40 ± 0.01
97-5-1	108.37 ± 5.33	5.50 ± 0.21	0.42 ± 0.01
94-14	105.00 ± 4.28	5.58 ± 0.35	0.43 ± 0.01
97-9-7	104.47 ± 7.82	5.58 ± 0.44	0.41 ± 0.01
97-6-1	101.78 ± 6.87	5.23 ± 0.23	0.39 ± 0.01
97-7-4	96.74 ± 4.15	5.05 ± 0.18	0.43 ± 0.01
LSD _{0.05}	18.30	0.91	0.02
P value	0.0002	<0.0001	<0.0001

^zInternode length and diameter were measured at the 7th internode from the first fully opened leaf. Vine length was measured from the base to the uppermost leaf tip of the longest vine. Measurements were taken 45 d after transplanting. Mean of 10 sample plants/replicate, four replications. Means ± SE.

length (29%), and diameter (18%) were detected among the 12 VT mericlones (Table 3). Digital image analysis of a number of storage root properties also revealed differences in minimum axis length (root width), roundness, and compactness (Table 4). The variability observed among these measurements suggests that, in addition to using yield data in selecting the best performing VT mericlones, representative vine and storage root characteristics should be considered. For instance, if VT mericlones with generally shorter vines in addition to high yield are preferred, 94-14 and 97-7-4 are likely candidates. However, VT mericlones with shorter vines may be more difficult to increase quickly in greenhouses and lengthen the time for ideal transplant length in grower plant beds. Additional investigations are required to assess the significance of the DIA attributes in VT mericlone evaluations. However, it does appear that relative to B-63, the current VT mericlone used by the Louisiana foundation seed program, 94-14 had a smaller storage root width, but comparable roundness and compactness attributes.

The variation detected not only in yield among 'Beauregard' VT mericlones but also in vine and storage root and shape attributes across several environments underscores the need for foundation seed programs to routinely evaluate several mericlones. The current study suggests that maintaining mericlones as well as evaluating these over several planting dates, years, and locations provide benchmark information about yield levels and the potential performance of a mericlone for use as seedstock. The biplots generated via AMMI analysis enhanced the interpretation of multi-environment data and facilitated the efficient analysis of main as well as interaction effects. The AMMI model identified mericlones that were potentially stable across planting dates, years, and locations, as well as the yield potential of specific environments.

Table 4. Digital image attributes of U.S. #1 storage roots^z of 'Beauregard' sweetpotato virus-tested mericlones as measured by Image Tool.^y

Mericlone	Attribute ^x						
	AREA	PERI	MAXIS	MINA	ELON	ROUND	COMP
97-10-11A6	89.13 ± 3.07	47.41 ± 1.13	18.67 ± 0.43	7.13 ± 0.18	2.69 ± 0.01	0.50 ± 0.01	0.57 ± 0.01
97-6-1	87.54 ± 2.67	50.56 ± 2.98	17.92 ± 1.16	7.33 ± 0.13	2.73 ± 0.31	0.50 ± 0.01	0.64 ± 0.01
97-5-1	87.10 ± 2.24	47.87 ± 1.89	16.64 ± 0.77	7.66 ± 0.12	2.27 ± 0.14	0.51 ± 0.01	0.65 ± 0.01
97-7-4	87.02 ± 2.48	49.80 ± 2.71	17.64 ± 1.05	7.34 ± 0.11	2.47 ± 0.14	0.50 ± 0.01	0.63 ± 0.01
B73	86.51 ± 2.11	46.27 ± 1.77	17.12 ± 0.82	7.22 ± 0.11	2.54 ± 0.23	0.53 ± 0.01	0.63 ± 0.01
H2-1	86.45 ± 2.49	49.57 ± 1.90	17.90 ± 0.80	6.98 ± 0.12	2.75 ± 0.25	0.46 ± 0.01	0.60 ± 0.01
B63	85.60 ± 2.02	47.17 ± 1.53	17.00 ± 0.75	7.21 ± 0.20	2.52 ± 0.20	0.51 ± 0.01	0.63 ± 0.01
H3-5	85.20 ± 3.24	51.85 ± 3.25	19.13 ± 1.38	6.67 ± 0.13	3.13 ± 0.32	0.46 ± 0.01	0.59 ± 0.01
L2-3	84.12 ± 4.18	46.42 ± 4.45	18.52 ± 2.06	6.78 ± 0.18	2.89 ± 0.39	0.57 ± 0.02	0.60 ± 0.02
97-9-7	83.29 ± 2.98	46.01 ± 0.82	16.66 ± 0.30	6.89 ± 0.10	2.46 ± 0.05	0.50 ± 0.01	0.62 ± 0.01
97-10-5A3	83.13 ± 2.41	48.40 ± 2.69	17.65 ± 1.06	6.96 ± 0.11	2.81 ± 0.36	0.50 ± 0.01	0.62 ± 0.01
94-14	75.43 ± 2.11	42.59 ± 0.94	15.40 ± 0.28	6.87 ± 0.14	2.28 ± 0.06	0.53 ± 0.01	0.63 ± 0.01
LSD _{0.05}	7.67	7.21	2.98	0.39	0.03	0.03	0.02
P value	0.257	0.554	0.618	<0.0001	<0.0001	<0.0001	<0.0001

^zStorage roots were randomly sampled from a 2000 early-season test and a 2001 midseason test planted in Chase, Louisiana.

^yUTHSCSA Image Tool program (developed at the Univ. of Texas Health Science Center at San Antonio, and available from the Internet by anonymous FTP from <ftp://maxrad6.uthscsa.edu>).

^xAREA = area of object. PERI = perimeter, length of outside boundary. MAXI = maximum axis length, length of the longest line that can be drawn through the object. MINA = minimum axis length, object perpendicular to MAXI. ELON = elongation, MINA : MAXI ratio. As ratio decreases from 1, object becomes more elongated. ROUND = roundness, $(4 \times PI \times \text{area}) / \text{perimeter}$, 1 - object is more round. COMP = compactness, $\sqrt{(4 \times \text{area} / PI) / \text{MAXI}}$. 1 = roughly circular object. $PI = 3.1416$. Definitions for most attributes are defined in the UTHSCSA documentation. All units in cm. Samples ranged from 38 to 115. Means ± SE.

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