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Evaluation of Sweetpotato Cultivars and Breeding Lines for Yield and Wireworm Damage

Experimental field site. The study was carried out at Washington State University Northwestern Washington Research and Extension Center (WSU NWREC) Mount Vernon, WA (48°43'24" N, 122°39'09" W, elevation 6 m). The experimental field site was located in the Pacific Northwest, with a cool, humid summer climate, with 16 ºC average daily temperature, 11 ºC average minimum and 22 ºC average maximum temperature, and 79% average relative humidity (AgWeatherNet, 2021). The soil type is Skagit silt loam (superactive, nonacid, mesic Fluvaquentic Endoaquepts) (USDA NRCS, 2019).

Experimental design and plot establishment. The experiment had a randomized complete block design with 8 treatments, 4 replications and 15 plants per plot. Treatments included 1 NPGS accession, PI 666141, and 3 breeding lines, 04-284, 04-136 and 04-791, from USDA ARS (P.A. Wadl, Research Geneticist). Treatments also included 1 breeding line, NC09-122, and 3 cultivars, Monaco, Beauregard, and Covington, from North Carolina State University (J. Schultheis, Horticultural Science; G.C. Yencho and K. Pecota, Sweetpotato Breeding Program, Raleigh, NC). All planting material was from roots harvested from our 2021 field experiment and stored on site. 'Covington', which is susceptible to wireworm, was the control treatment.

On 22 Mar. 2022, we selected storage roots from our 2021 harvest for propagation. Roots were medium-sized, about 4 cm diameter, with good shape and color, and free from any damage. For pre-sprouting, the selected roots were placed in bulb crates in a chamber on a wire bench in a greenhouse set at 24–29 ºC (Fig. 1). The chamber was a PVC frame covered with clear plastic and contained a humidifier (WarmMist Humidifier, Model V750, Procter & Gamble, Cincinatti, OH). Roots were pre-sprouted in 2 weeks, and on 5 Apr. 2022, they were placed in flats for slip production. Flats were filled with potting mix (Sunshine #3 N&O; Sun Gro Horticulture, Agawam, MA) and the roots were placed horizontally on the surface such that roots did not touch in the flats (Fig. 2). The flats were partially covered with a clear dome to maintain humidity and air circulation. The flats were placed in a greenhouse set at 24–29 ºC and watered as required to keep the potting mix damp (watering occurred about every day). On 23 May, 2022, flats were moved to an open-ended high tunnel for hardening off for 1 week. In the morning of 29 May 2022, slips were cut and stored in black crates in a cool, shaded location (Fig. 3). Slips were then transplanted to the field on 29 May 2022 (Fig. 3).

To prepare the field for planting, fertilizer (16N–7P–13K; Wilbur-Ellis, San Francisco, CA) was applied to the center of the row at the rate of 112 $kg \cdot ha^{-1}$ of nitrogen with a 1.8 m drop-spreader (Gandy, Owatonna, MN) just before the bed was formed. Raised beds were 15-20 cm high and 0.8 m wide, spaced 1.8 m center to center. Drip irrigation tape (T-Tape, Model 508-08-340, 0.20 mm, 20-cm emitter spacing, 4.23 $L.min^{-1}$ per 100 m flowrate; Rivulis, San Diego, CA) was laid during bed shaping simultaneously with polyethylene (PE) mulch (1 mil, 1.2 m wide;

Filmtech, Allentown, PA). Slips were planted in a single row at 20 cm spacing. In each bed, plots were separated by 1.5 m (Fig. 4).

Weather data. Air temperature, RH, solar radiation, and rainfall data during the cropping season were collected from the WSU AgWeatherNet station located approximately 140 m from the experimental field plots. Soil temperature and moisture data were recorded (ZL6; Meter Environment, Pullman, WA) at 15-minute intervals with sensors (TEROS 11; Meter Environment, Pullman, WA) installed 10 cm deep in the center of the plot in the center of replicate 2.

Plant stand and growth. Plant stand was measured as the total number of live plants per plot 4 weeks before harvest, at 25 Aug. 2022. The length of the longest vine was measured from the base to the tip of the vine for the center five plants in each plot 2 weeks after transplanting and then twice per month till 25 Aug. 2022. Percent canopy cover was measured using the cellphone application Canopeo, developed by the Soil Physics Research Group at Oklahoma State University (Patrignani and Ochsner, 2015). Canopy cover was measured for the center five plants in each plot 4 weeks after transplanting and then twice per month till 25 Aug. 2022.

Yield and wireworm damage. Vines were cut on 26 Sept. 2022 to prevent interference with harvesting. Sweetpotatoes from center five plants were hand-harvested on 29 Sept. 2022 for yield and wireworm damage assessment (Fig. 5). The number and weight of harvested sweetpotatoes were recorded for each plot, and total and marketable yield were calculated for each treatment. Average number of sweetpotatoes per plant was also calculated for each treatment. Sweetpotatoes were sorted into categories using U.S. standards for grades of sweetpotatoes (USDA, Agricultural Marketing Service, 2005): Jumbo (>23 cm length and >9 cm diameter), U.S. No. 1 (7.5–23 cm length and 4–9 cm diameter), U.S. No. 2 (≥3.8 cm diameter) and non-marketable (storage roots smaller than U.S. No. 2, of any size with off-shapes and/or damages from disease, insects, bruises, or other means) (Fig. 6). Root damage by wireworm was rated using a severity index based on the number of feeding scars (no scars = 0, 1-5 scars = 1, 6-10 scars = 2, >10 scars = 4) (Schalk et al., 1993), and percentage of wireworm damaged roots was calculated. The remaining section of each plot was harvested on 6 Oct. 2022 using a potato digger and roots were cured and stored (Fig. 7).

Results

Environmental and soil conditions. The average air temperature for the growing season (31 May through 26 Sept.) was 17 ℃ with average minimum temperature 11 ℃ and average maximum temperature 23 ℃. Average daily RH was 77%. Total precipitation and solar radiation during the growing season were 92.7 mm and 2305 $MJ \cdot m^{-2}$, respectively. Average soil temperature and average volumetric water content at 10-cm depth under PE mulch were 22 ℃ and 0.24 $cm^3 \cdot cm^3$, respectively. Air temperature, relative humidity, solar radiation, and soil moisture content in the 2022 growing season were on par with the average for the area (Table 1).

Plant stand and growth. Plant stand was 100% for all treatments (data not presented). The length of the longest vine differed due to treatment, increased over the growing season, and there was an interaction between treatment and week after transplanting. ‘PI 666141’ maintained the longest vine length throughout the growing season and vine length was 121 cm at 10 WAT (Table 2). ‘Monaco’ and ‘04-284’ had the shortest vine length at 10 WAT (41.2 cm on average). Percent canopy cover differed due to treatment and increased over the growing season, and there was an

interaction between treatment and week after transplanting. At 10 WAT, 'NC09-122' and 'PI 666141' had significantly higher canopy cover (97% on average) while '04-136' had the lowest (62%) (Table 3).

Yield and wireworm damage. 'Beauregard', 'Covington', 'PI 666141', '04-284', '04-791' produced the highest total and marketable storage root yield (30 $t \cdot ha^{-1}$ and 23.6 $t \cdot ha^{-1}$ on average, respectively) (Table 4). Although 'NC09-122' had one of the highest total storage root yields (23.6 $t \cdot ha^{-1}$), it produced the lowest marketable yield (8.2 $t \cdot ha^{-1}$) due to smaller size roots. 'Beauregard', 'Monaco', '04-136', '04-284', and '04-791' produced the lowest percentage of non-marketable roots (17% on average; range 13%-22%). Non-marketable roots were mostly due to smaller root size than U.S. no. 2 grade. 'Beauregard', 'Covington', '04-284', and '04-791' produced 4 marketable roots per plant on average (range 4-5 marketable roots per plant). None of the cultivars and breeding lines produced Jumbo grade yield except PI 666141 (1.2 $t \cdot ha^{-1}$). U.S. No. 1 grade yield was the highest for 'Beauregard', '04-284', and '04-791' (20.4 $t \cdot ha^{-1}$ on average; range 18-23 $t \cdot ha^{-1}$) while U.S. No. 2 grade yield was the highest for 'Covington' (11 $t \cdot ha^{-1}$).

Wireworm damage severity did not differ due to treatment; on average 76% of marketable roots had no scars, 20% had 1-5 scars, and 1% had 6-10 scars. Of 'Beauregard' marketable roots, 11% had >10 scars (Table 5).

Conclusions

Sweetpotato is a potential alternative crop for northwest Washington. 'Beauregard', 'Covington', 'PI 666141', '04-284', and '04-791' produced greater than the national average total yield (24.7 $t \cdot ha^{-1}$), but only 'Beauregard' produced greater than the national average marketable yield. Non-marketable sweetpotatoes were mostly because of smaller than U.S. no. 2 grade roots which might be due to narrower in-row spacing used in this study. These smaller roots could be used as whole baked sweet potatoes if sold to restaurants or at farmers markets. Future research studies should investigate in-row spacing to identify the most suitable spacing for each cultivar and breeding line in this region to obtain high-valued U.S. no. 1 grade roots. Wireworm infestation is unpredictable and there are limited control options for organic farmers. Thus, it is necessary to continue evaluating wireworm resistant lines so that use of resistant varieties is an option for farmers.

Table 1. Environmental and soil conditions during the sweetpotato growing season (31 May to 26 Sept.) at Mount Vernon, WA, in 2022 and the 20-year average.

Environmental parameters[z]	2022	Average
Average daily air temperature (°C)	17	16
Average daily max air temperature (°C)	23	22
Average daily min air temperature (°C)	11	11
Air thermal accumulation	708	749
Total solar radiation ($MJ \cdot m^{-2}$)	2305	2232
Relative humidity (%)	77	79
Total rainfall (mm)	93	140
Soil temperature (°C)[y,x]	22	19
Soil thermal accumulation[y]	1033	1188
Soil volumetric water content ($cm^3 \cdot cm^3$)[y,x]	0.24	0.21

[z]Data from Washington State University Ag WeatherNet Station located 140 m from the field site.
[y]Average value was calculated from 2017 and 2018 at 10 cm depth under the polyethylene (PE) mulch during the growing season. PE mulch was 25.4 μm (Filmtech, Allentown, PA).
[x]Measured every 15 min at 10 cm depth under the PE mulch with data loggers (Hobo Onset, Bourne, MA), and averaged for the growing season.

Table 2. Vine length of eight sweetpotato varieties and breeding lines grown at 20 cm in-row spacing and measured every 2 weeks from 15 June to 15 Aug. at Mount Vernon, WA, in 2022.

Treatment[z]	Vine length (cm)				
	2 WAT[y]	4 WAT	6 WAT	8 WAT	10 WAT
Beauregard	9.0 d[x]	11.2 bc	20.5 bc	55.8 b	78.8 cd
Covington	9.3d	11.4 bc	21.3 bc	53.9 bc	65.2 d
Monaco	18.6 ab	16.8 b	20.1 bc	30.6 d	40.1 e
NC09-122	5.9 d	9.0 c	28.4 b	64.5 b	82.7 bcd
PI 666141	23.1 a	23.2 a	63.5 a	118.5 a	120.9 a
04-136	11.0 cd	11.8 bc	16.8 c	55.3 b	87.0 bc
04-284	9.0 d	10.1 c	18.9 bc	35.2 cd	42.2 e
04-791	15.7 bc	12.0 bc	22.0 bc	73.8 b	102.3 ab
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[z]Sweetpotatoes were grown with black polyethylene mulch (1 mil, 1.2 m wide; Filmtech, Allentown, PA).
[y]WAT denotes weeks after transplanting.
[x]Means followed by the same letter in the same column are not significantly different at $P < 0.05$; means were discriminated using Tukey's honestly significant difference.

Table 3. Canopy cover of eight sweetpotato varieties and breeding lines grown at 20 cm in-row spacing and measured every 2 weeks from 30 June to 15 Aug. at Mount Vernon, WA, in 2022.

Treatment[z]	Canopy Cover (%)			
	4 WAT[y]	6 WAT	8 WAT	10 WAT
Beauregard	5.0 b[x]	17.2 ab	37.2 bc	81.7 abc
Covington	6.7 b	13.7 b	30.9 c	74.6 bc
Monaco	7.6 ab	17.2 ab	39.5 bc	83.6 abc
NC09-122	14.0 a	30.7 a	66.7 a	98.1 a
PI 666141	8.7 ab	30.4 a	57.5 ab	95.7 ab
04-136	4.0 b	6.9 b	24.6 c	62.1 c
04-284	6.8 ab	18.1 ab	39.3 bc	79.4 abc
04-791	3.3 b	9.5 b	36.0 c	82.6 abc
P-value	0.002	< 0.0001	< 0.0001	0.0007

[z]Sweetpotatoes were grown with black polyethylene mulch (1 mil, 1.2 m wide; Filmtech, Allentown, PA).
[y]WAT denotes weeks after transplanting.
[x]Means followed by the same letter in the same column are not significantly different at $P < 0.05$; means were discriminated using Tukey's honestly significant difference.

Table 4. Total, marketable and non-marketable yield, marketable storage root number per plant, jumbo, U.S. no. 1 and U.S. no. 2 yield of eight sweetpotato varieties and breeding lines grown at 20 cm in-row spacing at Mount Vernon, WA, in 2022.

Treatment[z]	Total yield ($t \cdot ha^{-1}$)	Marketable yield ($t \cdot ha^{-1}$)	Non-marketable ($t \cdot ha^{-1}$)	Marketable storage roots (no./plant)	Jumbo ($t \cdot ha^{-1}$)[y]	U.S. No. 1 ($t \cdot ha^{-1}$)[y]	U.S. No. 2 ($t \cdot ha^{-1}$)[y]
Beauregard	34.2 a[x]	28.5 a	5.8 b	4.0 ab	0.0	23.3 a	5.2 b
Covington	30.0 ab	22.8 ab	7.2 ab	4.4 ab	0.0	11.8 bc	11.0 a
Monaco	21.0 b	16.3 bc	4.7 b	3.2 b	0.0	11.3 bc	5.0 b
NC09-122	23.6 ab	8.2 c	15.4 a	1.2 c	0.0	4.8 c	3.4 b
PI 666141	31.3 ab	19.8 ab	11.5 ab	3.0 b	1.2	13.7 b	4.9 b
04-136	19.9 b	16.9 bc	3.0 b	3.1 b	0.0	13.7 b	3.2 b
04-284	28.4 ab	23.6 ab	4.7 b	4.9 a	0.0	18.3 ab	5.3 b
04-791	26.5 ab	23.1 ab	3.4 b	3.5 ab	0.0	19.5 ab	3.7 b
P-value	0.009	0.0001	0.0008	< 0.0001		< 0.0001	0.002

[z]Sweetpotatoes were grown with black polyethylene mulch (1 mil, 1.2 m wide; Filmtech, Allentown, PA).
[y]Jumbo category sorted as >23 cm length and >9 cm diameter. U. S. No. 1 sorted as 7.5–23 cm length and 4–9 cm diameter. U.S. No. 2 sorted as ≥3.8 cm diameter.
[x]Means followed by the same letter in the same column are not significantly different at $P < 0.05$; means were discriminated using Tukey's honestly significant difference.

Table 5. Wireworm damage severity of eight sweetpotato varieties and breeding lines grown at 20 cm in-row spacing at Mount Vernon, WA, in 2022.

Treatment[z]	No scars (%)	1-5 scars (%)	6-10 scars (%)	>10 scars (%)
Beauregard	54.8	27.5	1.7	11.2
Covington	71.9	23.7	1.4	0.0
Monaco	86.4	11.4	1.0	0.0
NC09-122	59.4	40.6	0.0	0.0
PI 666141	73.5	25.0	1.0	0.0
04-136	88.3	11.7	0.0	0.0
04-284	77.6	20.3	1.0	0.0
04-791	98.4	1.6	0.0	0.0
P-value	0.21	0.37	0.33	

[z]Sweetpotatoes were grown with black polyethylene mulch (1 mil, 1.2 m wide; Filmtech, Allentown, PA).

Figure 1. Pre-sprouting of sweetpotatoes.


Figure 2. Sweetpotatoes set up for slip production (left) and slips ready for cutting (right).


Figure 3. Slips collected and stored in a cool and shady area (left) and slips transplanted to the field (right).

Figure 4. Sweetpotato experimental field.

Figure 5. Hand harvesting sweetpotatoes for data collection.

Figure 6. Grading sweetpotatoes.

Figure 7. Sweetpotatoes ready for curing.