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Mass Selection for Low Oxidation in Sweetpotato¹

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Abstract. Mass selection for low oxidation of root flesh was initiated in the fourth generation of an open-pollinated sweetpotato [*Ipomoea batatas* (L.) Lam.] population. Two selection schemes were followed which provided different selection pressures by varying effective population sizes. In one (population A), selected plants were randomly intercrossed by insects each cycle. In the other (population D), approximately 10% of the randomly intercrossing population were selected each cycle and their true seed used to plant the next generation. After 2 cycles of selection in A and 3 in D, they were compared to appropriate generations of the base population. Results were in agreement with selection theory and closely paralleled those obtained with other crops. More rapid advance was made with A, which requires 2 seasons per cycle for any trait not measured in the seedling stage. Good advance was made with D, which allows 1 cycle per season. Study of 21 other traits indicated more changes in unselected traits in A than in D, thus favoring the method of D in early generations of mass selection in sweetpotato. The rapid increase of low oxidizing plants in this study suggests that selection for low oxidizing cvs. may reduce associated processing problems.

In 1963, meiotic data were collected from 40 sweetpotato [*Ipomoea batatas* (L.) Lam.] breeding lines and first year seedlings (3). Nineteen of the best flowering lines were used to initiate a population suitable for quantitative genetic studies. Ultimate objectives were to develop improved breeding procedures for sweetpotatoes (2) and to provide plant materials suitable for use in such procedures, i.e. free flowering types. Studies to date have presented cytological and fertility data of the originating plants (3), reported the morphological variability

of early generations (4, 9, 11), characterized the phenotypic, genotypic, and environmental variances and correlations displayed in the base population (5, 6, 7, 8, 10), documented the additive and non-additive genetic effects of 21 traits (5, 6, 10), and observed the fertility and morphological changes of the first 7 open-pollinated generations (9, 11).

This report deals with the next phase of these exploratory studies of sweetpotato genetics, the effects of controlled selection. Two mass selection schemes of practical interest to breeders were considered. Although previous reports (2, 3, 4, 5, 6, 7, 8, 9, 10, 11) have indicated the suitability of mass selection for sweetpotato improvement, no information from actual selection experiments is available.

Materials and Methods

Selection for low oxidation was based on the reaction of cut roots to the oxidizing agent catechol. After dipping the cut

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Table 1. Distributions (%) of root flesh oxidation scores as recorded at time of selection, the numbers of plants evaluated the percent selected and means of all plants and of the selected plants.

Population and generation	Root flesh oxidation score ^z					No. plants	% selected	Mean Score	
	1	2	3	4	5			Pop.	Sel.
C/3	4	22	42	18	14	472	0	3.2	—
C/4	4	36	37	22	1	166	30	2.8	1.9
A/5	11	39	37	10	3	332	10	2.5	1.0
D/5	6	15	33	26	20	419	10	3.4	1.4
A/6	6	24	37	25	8	211	10	3.0	1.4
D/6	10	44	36	6	4	259	10	2.5	1.0

^zScores obtained in different years; 1 = no oxidation, 5 = severe blackening after treatment with 0.25 molar catechol for 10 minutes.

roots in a 0.25 M catechol solution for 10 min, the degree of oxidation was coded 1-5 with 1 representing no appreciable darkening and 5 representing complete blackening. Selection for reduced oxidation was first imposed on material extracted from generation 4 of the base population (C/4). Plants of C/4 were evaluated to obtain 50 with scores of 1 or 2 (Table 1) and 2 different selection schemes were followed thereafter; mass selection with control over both parents and mass selection on the basis of female performance. In population A the selected clones were transplanted (4 replicates) to an area isolated from other sweetpotatoes and open-pollinated by insects to produce seed for A/5. Seedlings of A/5 were evaluated as they were pulled from the greenhouse bench. The selected plants were set in a replicated crossing block to produce seed for A/6. Thus, selection was imposed on both male and female parents in population A. In population D open-pollinated seedlings from the same 50 selected C/4 plants were started in the greenhouse and later moved outside to an isolated crossing block (D/5). At harvest, roots were evaluated for their response to the oxidizing agent and open-pollinated seed from selected plants were bulked for use as D/6. Repetition of the procedure the following season produced seed for D/7. Therefore, in population D selection was on the female phenotype only.

In order to assess what changes had occurred during these early generations of selection, remnant seed were used for a comparative test which included A/5, A/6, D/7, C/2 to C/7 and 4 cultivar checks: 'Goldrush', 'Georgia Red', 'Porto Rico', and 'Tinian' (PI 153655). Nine replications were grown in 1968 at Tifton, Georgia, as previously described (9).

Duncan Multiple Range techniques were used to test for mean differences in degree of root flesh oxidation of C/2 to

C/7, A/5, A/6, and D/7; and to detect mean changes in the other 21 traits of C/4, C/7, A/5, A/6, and D/7. Estimates of phenotypic variances were taken from total mean squares of the 9 replications, and were used to monitor variance changes which occurred with and without selection for decreased root flesh oxidation. The average phenotypic variances of the 4 cvs. were also used for comparative purposes.

Tests of distributional differences of populations and generations were obtained by conversion of all values to percentages and use of standard Chi-squares techniques. Since about 150 observations were made for most traits of each population, this procedure provided conservative tests. Interest was in detection of gross population changes, thus this conservative test was deemed appropriate.

Results

The original plan was to start with 50 plants from C/5, and thereafter to select 10% of 500 plants each cycle under each selection system. As with many such studies, various problems did not allow strict adherence to this plan. Population sizes were much less than the planned 500 (Table 1). Seed of A/7 were not available in time for inclusion in the test. Since measurable differences were evident in A/6, the omission of A/7 probably had little effect on interpretations. In population A, plants were replicated to assure sufficient seed for subsequent generations and there apparently was no selection for increased flowering (buds per cyme). In C and D, since no seed set problems were anticipated, the plantings were not replicated and considerable selection obviously occurred for increased flowering (Table 3).

No mean change in root flesh oxidation occurred in the first 7 generations of the base population (C/2 to C/7, Table 2).

Table 2. Root flesh oxidation distributions, means and phenotypic variances of generations 2 to 7 of the base population C, the selected populations A/5, A/6, D/7 and cvs.

Population and generation	Root flesh oxidation classes (%)					Mean score ^z	No. plants scored	Phenotypic variance
	1	2	3	4	5			
C/2	1	41	27	15	16	3.03a	160	1.11
C/3	4	30	32	15	19	3.15a	162	1.31
C/4	3	38	23	14	22	3.15a	153	1.42
C/5	5	32	35	15	13	3.00ab	157	1.10
C/6	3	34	23	14	26	3.28a	150	1.59
C/7	3	25	35	18	19	3.27a	160	1.26
Sel. Pop.								
D/7	7	46	24	13	10	2.73b	150	1.09
A/5	8	58	23	6	5	2.40c	144	0.83
A/6	17	53	22	6	2	2.24c	157	0.79
Checks								
Goldrush	31	66	3	0	0	1.72	178	0.25
Georgia Red	3	73	23	1	0	2.21	177	0.19
Porto Rico	0	7	60	22	10	3.36	98	0.50
Tinian	0	0	0	3	97	4.98	152	0.02

^zPopulation means not followed by the same letter are different at .01 significance level. Cultivar data are from clonal material analyzed separately. Each cv. mean was different from the other 3 at the .01 significance level.

Table 3. Means, variances, and distributional comparisons of unselected traits in populations with and without selection for root flesh oxidation.

Trait (units)	Statistic ^y	Population & Generation ^z				Cv. average ^x
		C/4	C/7	D/7	A/6	
Buds per cyme (Number)	Mean	3.9c	4.8b	5.5a	3.8c	0.0
	σ_p^2	6.48	6.50	6.07	6.72	—
	Prob. C/4	—	0.003	0.02 ⁻⁷	0.169	—
	Prob. C/7	—	—	0.076	0.02 ⁻³	—
Root flesh color (Code 1-5)	Mean	3.4b	3.1c	3.5b	3.9a	3.2
	σ_p^2	1.01	1.16	0.75	0.64	0.06
	Prob. C/4	—	0.008	0.069	0.01 ⁻³	—
	Prob. C/7	—	—	0.02 ⁻²	0.02 ⁻⁸	—
Leaf vein purp. (Code 1-6)	Mean	2.8a	2.7a	3.1a	1.8b	5.5
	σ_p^2	2.88	1.82	2.36	1.13	0.00
	Prob. C/4	—	0.001	0.032	0.04 ⁻⁵	—
	Prob. C/7	—	—	0.004	0.01 ⁻¹⁰	—
Vine purpling (Code 1-5)	Mean	1.6a	1.9a	1.6a	1.1b	4.2
	σ_p^2	1.50	2.23	1.40	0.36	0.06
	Prob. C/4	—	0.010	0.455	0.03 ⁻³	—
	Prob. C/7	—	—	0.035	0.07 ⁻⁴	—
Leaf length (cm)	Mean	10.9a	10.4ab	10.1b	10.4ab	11.30
	σ_p^2	2.94	3.80	3.93	2.64	1.59
	Prob. C/4	—	0.079	0.015	0.319	—
	Prob. C/7	—	—	0.385	0.185	—
Root shape (Code 1-5)	Mean	2.5a	2.4ab	2.3b	2.4ab	2.5
	σ_p^2	0.75	0.81	0.58	0.57	0.38
	Prob. C/4	—	0.125	0.003	0.110	—
	Prob. C/7	—	—	0.304	0.265	—
Root growth cracks (Code 1-4)	Mean	1.6ab	1.6ab	1.4b	1.7a	1.0
	σ_p^2	1.02	0.90	0.74	0.91	0.05
	Prob. C/4	—	0.836	0.343	0.006	—
	Prob. C/7	—	—	0.525	0.055	—
Root skin color (Code 1-25)	Mean	11.7ab	11.4b	13.3a	10.3b	19.2
	σ_p^2	44.6	55.1	41.7	36.3	1.4
	Prob. C/4	—	0.043	0.114	0.011	—
	Prob. C/7	—	—	0.04 ⁻²	0.08 ⁻⁴	—
Root skin purp. (Code 1-10)	Mean	2.9ab	2.9ab	3.3a	2.3b	5.3
	σ_p^2	4.50	5.98	4.06	3.47	0.41
	Prob. C/4	—	0.006	0.04 ⁻⁴	0.006	—
	Prob. C/7	—	—	0.02 ⁻³	0.027	—
Root weight (lbs. per hill)	Mean	2.6a	2.2b	2.7a	2.2b	2.6
	σ_p^2	2.94	2.35	3.61	2.47	1.42
	Prob. C/4	—	0.411	0.001	0.493	—
	Prob. C/7	—	—	0.044	0.390	—
Vine diameter (Code 1-5)	Mean	3.4ab	3.2b	3.3b	3.5a	3.3
	σ_p^2	0.56	0.73	0.63	0.59	0.44
	Prob. C/4	—	0.127	0.660	0.621	—
	Prob. C/7	—	—	0.354	0.098	—
Leaf type (Code 1-3)	Mean	1.8a	1.7a	1.8a	1.8a	1.7
	σ_p^2	0.72	0.60	0.61	0.82	0.10
	Prob. C/4	—	0.043	0.036	0.045	—
	Prob. C/7	—	—	0.811	0.04 ⁻³	—
Root skin texture (Code 1-5)	Mean	2.2a	2.4a	2.1a	2.2a	1.7
	σ_p^2	1.03	1.22	0.98	0.98	0.41
	Prob. C/4	—	0.158	0.775	0.06 ⁻²	—
	Prob. C/7	—	—	0.242	0.05 ⁻²	—
Leaf whorl purp. (Code 1-5)	Mean	1.4a	1.2a	1.2a	1.4a	1.9
	σ_p^2	1.02	0.33	0.40	1.09	0.10
	Prob. C/4	—	0.126	0.134	0.205	—
	Prob. C/7	—	—	0.483	0.01 ⁻⁵	—
Edible roots (No. per hill)	Mean	4.6a	4.1a	4.3a	4.5a	3.9
	σ_p^2	7.86	5.53	6.66	7.70	2.78
	Prob. C/4	—	0.304	0.752	0.640	—
	Prob. C/7	—	—	0.203	0.038	—
Root cortex (mm)	Mean	3.1a	2.8a	2.8a	2.9a	2.6
	σ_p^2	1.80	1.00	1.05	1.18	0.42
	Prob. C/4	—	0.143	0.06 ⁻²	0.262	—
	Prob. C/7	—	—	0.001	0.020	—
Root veining (Code 1-4)	Mean	1.5a	1.5a	1.5a	1.3a	1.3
	σ_p^2	0.64	0.58	0.74	0.51	0.17
	Prob. C/4	—	0.168	0.164	0.164	—
	Prob. C/7	—	—	0.050	0.106	—
Internode length (cm)	Mean	3.5a	3.5a	3.4a	3.5a	3.7
	σ_p^2	1.93	2.32	1.74	2.31	0.92
	Prob. C/4	—	0.362	0.514	0.065	—
	Prob. C/7	—	—	0.226	0.491	—

Table 3 continued.

Trait (units)	Statistic ^y	Population & Generation ^z				Cv. average ^x
		C/4	C/7	D/7	A/6	
Plant pubescence (Code 1-5)	Mean	2.9a	2.9a	2.7a	2.7a	2.0
	σ_p^2	1.16	1.08	1.04	1.08	0.24
	Prob. C/4	—	0.796	0.731	0.471	—
	Prob. C/7	—	—	0.325	0.286	—
Vine length (feet)	Mean	3.0a	3.0a	2.8a	3.1a	2.9
	σ_p^2	1.06	0.94	0.88	1.32	0.65
	Prob. C/4	—	0.128	0.395	0.858	—
	Prob. C/7	—	—	0.245	0.552	—
Root flesh purp. (Code 1-5)	Mean	1.05a	1.01a	1.02a	1.01a	1.00
	σ_p^2	0.09	0.01	0.06	0.01	—

^zC/4 = fourth generation of base population in which selection was initiated.

C/7 = seventh generation of base population, no selection.

D/7 = seventh generation; selection, on basis of female phenotype, initiated in fourth generation (C/4 = D/4) for low oxidation.

A/6 = sixth generation, selection initiated in fourth generation (C/4, selection = A/4) for low oxidation with selected plants open-pollinated.

^yMeans not followed by the same letter are different at the .01 level. σ_p^2 = phenotypic variances estimated from total mean squares of 9 replications.

Prob. C/4, Prob. C/7 = probabilities of larger Chi-squares for comparison of frequency distributions to that of C/4 or C/7.

^xAverage values of 4 cvs. as a comparative estimate of variance in clonal material.

After 3 cycles of selection on the female phenotype (D/7, Table 2), there was a mean reduction accompanied by increases of plants in classes 1 and 2. Variance, however, remained equivalent to that in the base population. After only 2 cycles of selection on the phenotype of both parents (A/6, Table 2) the mean was reduced even further than in D/7, about 70% of the population fell in classes 1 and 2, and the variance was decreased.

Insight into the kinds of population changes expected by the 2 procedures followed can be obtained from the means and distributional shifts observed (Table 3). Comparison of C/4 and C/7 shows 3 mean changes where there was no selection on flesh oxidation. One of these, number of buds per cyme, was probably due to field plot technique. Comparison of C/4 vs. D/7 also shows 3 mean changes. Flowering changed in similar manner to that in C/7 but to a different degree. Means of the other 2 traits, leaf length and root shape, were not different from those of C/7 or A/6. Thus, these 2 changes can also be considered as changes in degree. There were 4 mean changes in A/6 vs. C/4, 3 differed in kind from those observed in C/7 vs. C/4. Thus, there appeared to be more mean changes of greater magnitude in A/6 than in D/7. Nine mean differences between A/6 and D/7 demonstrate the widely different outcomes from the 2 selection schemes.

Since significant distributional shifts can occur with no appreciable mean change, consideration of distributional changes are also important in comparison of the 2 selection schemes. At the .01 probability level the number of distributional shifts detected between C/4 and C/7 was 5, between C/4 and D/7 was 5, between C/4 and A/6 was 7, between C/7 and D/7 was 5, and between C/7 and A/6 was 8 (Table 3). Thus, more distributional shifts were observed with the procedure of A even though measurements were taken one generation earlier than with procedure D.

Discussion

This test was designed to study changes in a particular character after the first few cycles of selection. Two different selection schemes were followed which, by altering the effective population size, provided considerably different selection pressures. Flesh oxidation was chosen for study because it was easy to measure, was relatively free of environmental influences (10), had desirable types allowing truncation selection, and resulting plants could be expected to have practical breeding

value. Differential effects of the 2 selection schemes on unselected traits were provided by data from 21 other traits (Table 3). Comparisons were made to the unselected base population. The primary objective of the study was to measure the kinds and magnitudes of changes that occurred and to relate these to breeding procedure. Thus, the particular changes in the unselected traits are of secondary importance and probably would not be duplicated in similar studies with other materials. Rather, they represent a sample of those traits not considered by the breeder but which might become important later in the breeding program. The traits studied were used to provide continuity with previous studies made with materials of the same origin.

Results of selection for low oxidation were in keeping with expectations based on previously determined heritability estimates (10). As expected, there was a greater mean reduction per cycle in population A than in D (Table 2). Because of its smaller population size one would expect more changes in unselected traits in A than in D. Comparisons of means and distributions indicate that this did occur (Table 3). The changes in vine, leaf vein, and root flesh colors observed in A/6 are in keeping with previous predictions (8), but predicted changes in skin color were not realized. Interpretation of mean and distributional changes in population D are complicated by the increased flowering which may have offset some of the effects noted in A through opposite correlations with numbers of buds (8), or by contributing to a breakage of genetic correlations with low oxidation.

Root flesh color appeared to be directly related to selection for low oxidation. The decrease in flesh color of C/7 may be related to increased flowering. However, this effect was offset in D/7 by a genetic correlation with low oxidation (7, 8). In A/6, where there was no selection for flowering, a notable increase in orange flesh color was accompanied by a decrease in variance due to a sharp reduction of plants with white or cream flesh (7% in A/6 vs. 38.8% in C/7).

Thus, there was a more rapid improvement in the selected trait with the smaller population size (population A) than with the larger population size (population D). More changes in other traits tended to occur in A than in D. These results are in accord with selection theory and changes in the selected trait closely parallel those from mass selection in alfalfa (1).

The procedure followed in A requires 2 seasons unless selection is for characters measured in seedlings. One cycle of

selection is possible each year in the procedure followed in D. Thus, the advantage of more rapid advance per cycle in A is partially offset by the increased time per cycle. This factor, plus the greater chance of loss by genetic drift or correlation of unselected traits in method A, favors the method of D (assuming similar selection intensities) in early stages of sweetpotato improvement through mass selection. The method of A may be more appropriate when short term gains have high priority or with traits easily measured in the seedling stage (allowing a complete cycle each season). Larger population size than used in this study would be desirable as further assurance against loss of potentially valuable variation. These results further confirm the suitability of mass selection techniques for sweetpotato improvement. The rapid increase in percentages of plants in the selected populations with low oxidation suggests that new cvs. may reduce processing problems associated with root flesh oxidation.

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Organic and Mineral Fertilizers Compared by Yield, Quality, and Composition of Spinach¹

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Abstract. Mineral fertilizers increased yield and concn of N in leaf tissue more than organic fertilizers when nutrients were applied to make mineral and organic rates identical. All 3 types of fertilizer treatments increased N concn in plant tissues over the control plots. Organic fertilizer resulted in significantly higher P concn in plant tissue than did MF or MFSN for every crop. Mineral fertilizer increased Ca uptake the 1st and 3rd crops, but significantly reversed those results in the 2nd (overwintered) crop. Organic fertilizers increased Fe uptake significantly over MF the 2nd and 3rd crops and significantly increased Na uptake more than either MF or MFSN every crop. Of the 13 variables studied, concn of 10 variables was greater in the overwintered crop than in the spring planted crops.

Spinach (*Spinacia oleracea* L.), an annual, cool-season plant, is popular as a green, leafy vegetable fresh, canned, or frozen. It can be grown both spring and fall, giving high yields in a short time. The most important potherb grown in the United States, it is a rich source of chlorophyll (3), which gives it a dark green color, color quality, and consumer acceptance. It is high in nutritional quality due to its unusually high Fe and Vitamin A content (7). Except for work of Greig et al. (11), little has been done to test fertility treatment effects on color quality and nutritional quality expressed as Fe and Ca concn.

Mineral fertilizers are highly soluble and, therefore, difficult to use efficiently (21), particularly N and K on sandy soils as shown by lysimeter studies (6). Organic fertilizers (OF) like manure are not soluble and release nutrients slowly. The most common and plentiful OF in the Midwest is feedlot manure which also is a possible source of pollution. About 10

million cattle are in large feedlots, of 3,200 to 32,000 head in the United States (24). A 15,000 head feedlot would produce about 170 MT (metric tons) of manure per day. If OF is a good source of plant nutrients that contribute to high yields of quality food, it might be an asset rather than a pollution problem.

Nutritional studies with human beings the past 2 decades have shown repeatedly that inadequate intakes of Ca, Fe, ascorbic acid, and vitamin A occur among all age groups (7). More leafy green vegetables like spinach in diets could help solve such dietary problems, especially if Fe content could be maintained at normal or above normal levels. Studies have shown that Fe content varies (4).

We recycled OF back to the land as the sole nutrient source to determine its effects on yield, composition, and quality of spinach compared with effects of mineral fertilizers.

Materials and Methods

Three crops of spinach (*Spinacia oleracea* L., cv. Bloomsdale L.S.) were grown during 2 years on a Hayne fine sandy loam under a RCB design. Organic fertilizer was the sole nutrient source in a comparison with (a) MF (mineral fertilizer), and (b) MFSN (mineral fertilizer with split N application). Four rates of 22.4, 44.8, 67.2, and 89.6 MT/ha of OF (45% water content) were applied, as were NPK equivalents of those 4 OF rates. Soil

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