Fig. 2. Chimera rating scale.

Table 1. Simple linear regression analysis slope estimates for total mutations between three generations of sweetpotato storage roots.

Model		Slope estimate ($\pm$ SE)	Prob > T	r ²
Total mutations	Total mutations			
1991	= 1992 ²	-0.0280 $\pm$ 0.0335	0.4226	0.0653
Total mutations	Total mutations			
1992	= 1993 ²	-0.00144 $\pm$ 0.0073	0.8494	0.0012

²Results of the progeny from the degree-3 (high degree of chimeras) parent roots.

size of the mutations.

The Mississippi sweetpotato foundation program will continue to slice each seed root selected for bedding. Each root will be examined for flesh color, pests, diseases, and the presence of somatic mutations in the flesh color. However, the small spots that caused the seed root to be rejected in previous years will not cause the rejection of the seed root beginning in 1994.

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The Certified Sweetpotato Seed Program in North Carolina

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Additional index words. *Ipomoea batatas*, breeder seed, foundation seed, registered seed, russet crack, disease, pathogen, feathery mottle virus, micropropagation, virus-indexed

Sweetpotato is the most valuable vegetable crop produced in North Carolina, having farm gate returns of about \$40 million in 1992 (North Carolina Agricultural Statistics, 1993). The certified sweetpotato seed program in North Carolina serves a large industry to provide high-quality seed of varieties that are true-to-type and free from pests. This program annually includes 700 acres and provides more than 150,000 bushels of seed roots. Certified seed helps maximize root quality such as shape and skin and flesh color, while also providing the opportunity to achieve high yields.

As new varieties are developed and released by the North Carolina Agricultural Research Service (NCARS) and other breeding programs, they must be increased carefully to maintain desirable characteristics initially developed by the plant breeder. At the same time, established varieties

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This research was funded in part by the North Carolina Agricultural Research Service (NCARS Project No. NC6187) Raleigh, NC 27695–7643, and the North Carolina Sweetpotato Certified Seed Producers' Assn. We gratefully acknowledge the assistance of W.R. Jester (Area Specialized Agent) and the technical assistance of D.E. Adams and J.G. Driver. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

must be maintained so that varietal identity and purity are preserved. Sweetpotatoes are genetically unstable and likely to mutate. Because sweetpotatoes are asexually propagated, they are more prone to accumulate disease-causing pathogens than sexually propagated crops. The percentage of roots with mutated tissue increases with succeeding generations if left unchecked. Diseases and insects threaten sweetpotato seed production, while varietal mixtures can result from careless handling.

Mixtures, mutations, and roots harboring pathogens and insects decrease the advantages for which a variety was released. Seed certification provides a program of planned production, limited generations, rigid standards, and unbiased field and storage inspections for orderly increase and maintenance and distribution of varieties. The North Carolina Crop Improvement Assn. (NCCIA); the North Carolina Foundation Seed Producers, Inc.; the North Carolina Certified Sweetpotato Seed Growers Assn.; and the NCARS work together to provide this assurance of variety purity and high-quality sweetpotato seed roots.

There are four classes or generations included in the North Carolina certified sweetpotato seed program (Fig. 1). The classes are breeder, foundation, registered, and certified seed.

Breeder seed. Breeder seed roots are produced under the supervision of the plant breeder. Seed varieties *not* released by the NCARS are maintained by the originating institution/breeder using the protocols of their respective programs. These varieties developed outside of North Carolina are obtained as needed by the North Carolina Foundation Seed Program from these institutions and then increased as described below. Breeder seed of varieties released only by the NCARS is provided and maintained by the sweetpotato breeder at North Carolina State Univ.

For North Carolina-released varieties, each root exterior is examined visually, and only those true-to-type and free of defects are bedded. Any roots showing diseases or characteristics not typical of the variety are discarded. Breeder seed is grown in cooperation with the North Carolina Dept. of Agriculture on a research station in isolation from commercial sweetpotato production.

Once plants are established in the field and have started vine growth, they are inspected visually by the plant breeder to detect off-type plants within a variety. Production practices throughout the growing season are similar to commercial production practices (Wilson et al., 1989). At harvest, seed roots are brought to the soil surface

with a chain digger. Based on production needs, a specific quantity of seed roots is selected individually to serve as bedding stock for producing the following year's breeder seed. Every 2 to 3 years, hill selections are made to maintain high yields of well-shaped roots. The remaining breeder seed roots are placed in new containers and delivered to the North Carolina Foundation Seed Producers, Inc., where they are cured, stored, and used for the production of foundation seed. The breeder retains hill-selected seed, which is cured and stored on the research station.

Foundation seed. Foundation seed is one vegetative generation from breeder seed. Only disease-free roots with true-to-variety characteristics are bedded. To ensure high-quality seed, each root is nicked ≈ 1 cm deep on the proximal end and examined for characteristic flesh color prior to bedding. Roots are sprayed with a fungicide just prior to covering with soil.

Registered seed and certified seed. Registered seed and certified seed roots are produced by members of the NCCIA. The former class is two vegetative generations, the later three generations, from breeder seed.

At bedding and at harvest, roots with mutations or disease symptoms are discarded. Seed is

Fig. 1. North Carolina certified sweetpotato seed program with proposed hill selection, virus elimination, evaluation, and delivery.

treated with a recommended fungicide at soil bedding. If certified plants are sold, the propagation beds must be fumigated with a broad-spectrum fumigant or evidence provided that the beds are free of serious soil insects and pathogens.

To avoid the incidence of scurf, black rot, and disease from soil-borne pathogens, plants are never pulled for breeder, foundation, registered, and certified seed (Wilson et al., 1989). Vine cuttings must be used to propagate foundation seed, whereas registered and certified seed may be propagated also from cut plants from sweetpotato beds. Plants produced for registered and certified seed must be cut from the bed using an upward motion with a knife to avoid soil contact. Plant beds must be inspected if certified plants are to be sold. As with breeder seed, fields of foundation, registered, and certified seed are inspected at least once by a representative from the NCCIA.

Land requirements specify a 4-year crop rotation in which sweetpotatoes must not be produced on the land for at least 3 consecutive years. During this time, the land must not have received manure or sweetpotato residue. The land must not be subject to drainage from any fields in the above-mentioned categories.

At harvest, seed roots are inspected, and defective roots discarded. The remaining roots are cured and stored according to good commercial production practices (Wilson et al., 1989). Seed for certification must be stored separately from commercial sweetpotatoes, unless the commercial crop was produced from certified seed or cut plants. The seed must be isolated to avoid contact with dust from a commercial packing area.

Samples from each seed lot of stored foundation, registered, and certified seed are inspected annually in January by the NCCIA. Inspections are limited due to the large quantity of seed and limited access to seed in storage rooms. However, a sample of roots as representative as possible is inspected for skin mutations, diseases, insects, and trueness-to-variety characteristics. Each root is sliced into ≈300-mm slices and evaluated for internal color and mutations, as well as internal diseases and disorders. The inspector may reject seed lots containing variety mixtures, atypical color mutations, or serious diseases or insects according to published standards (North Carolina Crop Improvement Assn., 1990) (Table 1).

All classes of certified seed must be cleaned and graded to conform to the standards for U.S. No. 1 grade, except size (USDA, 1963). Seed is usually graded prior to storage, but may be graded before shipment. The roots are separated into two categories, according to diameter: small (2.5 to 5.1 cm) and medium (5.1 to 7.6 cm). Root length must be a minimum of 7.6 cm and a maximum of 25.4 cm for both size categories. The seed must be offered for sale in new containers that have net weight stamped, stenciled, or printed on the tag, which must be attached to each container. These tags also must state the specific class of seed or

Table 1. *Standards for foundation, registered, and certified sweetpotato seed (adapted from North Carolina Crop Improvement Assn., 1990).*

Standards	Foundation	Registered	Certified
Plant beds ²			
Blackrot	None	None	None
Scurf	None	None	None
Wilt	None	None	None
Other varieties	None	None	None
Field standards			
SSR-Pox ³	None	None	None
Wilt	None	None	0.1%
Mosaic-Georgia	None	None	None
Other varieties	None	None	None
Seed standards			
Blackrot	None	None	None
Scurf	None	None	None
Wilt	None	None	0.1%
Internal cork ⁴	---	---	---
Nematodes ⁵	None	0.2%	0.5%
Wireworms ⁶	1.0%	2.0%	5.0%
Sweetpotato weevil	None	None	None
SSR-Pox ³	None	5.0%	5.0%
Other varieties	None	None	None
Common storage rots	None	None	None

²Seed should be treated with a recommended fungicide.

³Any area of a field in which *Streptomyces soil rot (pox)* is found will be rejected and separated by a buffer zone.

⁴If serious, will cause rejection.

⁵Tolerance applied to severely infected roots.

⁶Seed with pox will be labeled *Streptomyces soil rot (pox)* below 5%.

plants—foundation, registered, or certified.

Future considerations. As mentioned earlier, high-quality seed is crucial for producing a top-yielding commercial sweetpotato crop that is of high quality (Fig. 2). Although the North Carolina certified sweetpotato seed program takes great care to produce high-quality seed, it does not provide seed that is free of viruses and possibly other pathogens. Feathery mottle virus is widespread in most commercially available seed (Clark

and Moyer, 1988), and causes leaf blemishes, internal cork, and russet crack (Cali and Moyer, 1981; Hammond and Daines, 1974; Martin, 1970).

In recent years, some commercial growers in Tennessee (D.W. Monks, personal communication) and South Carolina (W.R. Jester, personal communication) have had crop failures with 'Beauregard' sweetpotatoes. Harvested roots showed russet crack symptoms that rendered roots unsalable (Fig. 3). Some evidence indicates that

Fig. 2. Box packed with high-quality 'Beauregard' roots with uniform shape and size.

Fig. 3. 'Beauregard' roots exhibiting severe symptoms with large, open longitudinal cracks. Less-severe symptoms appear as short longitudinal cracks in circular bands on the root exterior.

this cracking disorder in 'Beauregard' may be due to the feathery mottle virus because these symptoms were seed- and graft-transmitted and not soil-transmitted (Jester et al., 1994). To date, the russet crack problem is largely confined to 'Beauregard', but has been observed on 'Sweet Red'. About 2% to 3% of 'Beauregard' roots typically have been reported by North Carolina growers to have cracking symptoms when examined in packing houses. For one grower in North Carolina, cracking symptoms were reported on 20% to 25% of his 1993 'Beauregard' sweetpotato crop (personal communication).

California has used hill selection and tissue culture to eliminate the feathery mottle virus and other pathogens, and to produce superior planting stock for its sweetpotato seed program for more than 25 years (Dangler et al., 1994). The North Carolina Cooperative Extension Service; NCARS; NCCIA; North Carolina Foundation Seed Producers, Inc.; and the North Carolina Certified Sweetpotato Seed Growers Assn. are working together to improve further the seed quality of North Carolina certified sweetpotato seed.

Tests have been conducted since 1989 in North Carolina to evaluate the effects on yield and root quality of virus-free, micropropagated plants (VFM) with virus-infected, nonmicropropagated plants from various sources (VINM) (Averre et al., 1993). In 1993, additional comparisons were made between VFM and naturally reinfected VFM plants (VFM-R), plants obtained at various stages of the North Carolina certified seed program (foundation vs. registered seed), and plants from foundation vs. grower seed (seed not part of the North Carolina certified seed program, VFM, or VFM-R). 'Beauregard' yields from VFM were as good or better than yields from VINM plants (Schultheis et al., 1994; Schultheis, 1994). Of equal or more significance was the reduction of the cracking

symptoms from 13.0% in VINM to 0.2% in VFM plants (Table 2). No differences in cracking were found between VFM (0.2%) and VFM-R (2.3%) plants. No significant difference in cracking was found when foundation seed was used instead of registered seed (10.4% vs. 5.9%); however, grower seed had more cracking (22.8%) than either foundation or registered seed.

These results (Table 2), coupled with the knowledge that the cracking symptoms are seed-transmissible (Jester et al., 1994), caused concern that cracking could become a financial hardship for more commercial growers if additional actions/

Table 2. Percent of No. 1 grade sweetpotato roots with symptoms of cracking.

Seed source	Cracking (%)
VFM ²	0.2
VIM-R ³	2.3
VINM ⁴	13.0
Foundation	5.9
Registered	10.4
Grower	22.8
Contrasts	
VFM vs. VINM	**
VFM vs. VFM-R	NS
Foundation vs. registered	NS
Foundation vs. grower	**
Registered vs. grower	**

²Plant stock was micropropagated and virus-indexed and did not contain virus at planting.

³Plant stock was micropropagated and virus-indexed, but was naturally reinfected with virus from previous growing seasons and contained virus at planting.

⁴Plant stock contained virus at planting and originated from seed that was from foundation, registered, and a grower source (not micropropagated).

*,** F-test significant at the 0.01 level or nonsignificant, respectively.

precautions were not taken within the North Carolina certified seed program. The use of hill-selected, virus-indexed, micropropagated plants is being incorporated into the North Carolina certified sweetpotato seed program. A likely scheme would produce VFM plants for the foundation seed production stage (Fig. 1). The tentative protocol for obtaining VFM plants is:

- 1) Select superior roots by hill.
- 2) Eliminate virus/pathogens using tissue culture.
- 3) Evaluate and select superior virus-tested clones.
- 4) Deliver virus tested stocks for production of foundation, registered, and certified seed.

We expect commercial growers to benefit from the use of VFM root stocks by having reduced root cracking, reduced incidence of disease, and potentially more consistent yields of quality roots. The number of hills selected for VFM root stock would be reduced significantly compared with the number of hills selected for breeder seed. Another potential benefit might be the reduction in labor required in hill selection for obtaining breeder seed. This could reduce the workload of the sweetpotato breeder and make it easier to incorporate more varieties into the certified seed program because only a few superior hills would need to be selected prior to multiplication. The use of micropropagation in North Carolina certified sweetpotato seed production also could provide a mechanism for the rapid increase in planting stock of newly released varieties. The amount of seed introduced from sweetpotato weevil infested regions also could be reduced, and the potential of importing the sweetpotato weevil minimized. However, one concern is the possible production of quantities of off-type seed should hills be selected improperly. Another concern is the occurrence of mutations during micropropagation. To avoid these problems, virus-free stock must be evaluated carefully before increase and delivery to the seed certification program.

The use of hill-selected, virus-free, micropropagated seed roots appears to offer an opportunity for improvement in the North Carolina sweetpotato seed certification program. Ornamental, industrial, and food crops, such as asparagus, cauliflower, potato, and rhubarb, have benefited using virus indexing and micropropagation to improve seed or plant sources (Fordham and Biggs, 1985). Although such a program offers promise, it does not replace good seed management practices on the part of the grower.

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Foundation Sweetpotato Seed Program in Virginia

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Additional index words. *Ipomoea batatas*, sectorial chimera

Summary. A procedure is described for maintaining root quality in a foundation seed program that serves a primarily processing industry. Trueness-to-cultivar root type and color is maintained through hill selections within the prefoundation seed at harvest. Internal color is examined after sprout production, but prior to planting. Each root of the prefoundation seed is lifted and cut. If any sectorial chimeras are visible or the internal color is lighter than expected for that cultivar, all sprouts from that root are discarded. Otherwise, sprouts are planted to generate prefoundation seed. Prefoundation roots not selected by hill selection are given to designated growers for production of foundation seed. Contracts with growers for foundation seed and seed distribution are the responsibility of the Virginia Crop Improvement Assn. (P.O. Box 78, Mt. Holly, VA 22524). Hill selection of 'Hayman', a white-skinned, white-fleshed cultivar, over the past 20 years has essentially eliminated strings and nonenlarged roots. Improved root shape and smoothness has resulted in increased regional consumer demand for this specialty crop.

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These studies were supported, in part, by the Virginia Sweet Potato Board, Onley, Va. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

The sweetpotato foundation seed program in Virginia, like the industry it serves, is small, but focused, on maintenance or improvement of root quality. Because the majority of the orange-fleshed sweetpotato crop in Virginia is processed, the availability of "seed" roots with uniform, consistent internal color, free of chimeras or color breaks, is considered critical by Virginia growers. Most of the crop is harvested mechanically, graded primarily to remove roots with insect damage, and shipped field-run to the processor.

The management demands of producing sprouts combined with the declining availability of labor has made purchased southern-grown sprouts an attractive alternative until recently. Now, increased transportation costs for sprouts, along with dockage for light, off-color roots at harvest, have encouraged Virginia growers to produce more sprouts locally using Virginia foundation seed. 'Beauregard' is currently the primary orange-fleshed cultivar in the foundation seed program, although 'Jewel' is also maintained in very limited quantities.

For the foundation seed program, prefoundation seed are maintained at the Eastern Shore Agricultural Research and Extension Center, Painter, Va. At harvest, hill selections are made within each cultivar using the procedure described by Watts (1956). All rows of a given cultivar are dug with a turn plow and scratched out, keeping all roots of the same hill together on top of the plowed furrow. The criteria for hill selection include trueness to root type and external color, root yield, uniformity, earliness, and number of roots set per hill. These roots are designated *select roots* and sprouts from these roots are used to produce the next generation of select and prefoundation seed.

After the hill selections for select roots have been made, the remainder of the small roots [1 to 2.5 inches or (2.5 to 6.3 cm)] are classified as prefoundation roots and, the following spring, are given to the grower contracted by the Virginia Crop Improvement Assn. for the production of foundation roots. When sprouts from the select roots are ready for planting, roots are lifted carefully from the beds, keeping all sprouts attached to their respective root. Each root is cut in transverse sections ≈1 cm (0.5 inch) thick to check for acceptable internal color and freedom from sectorial chimeras (Fig. 1). If any sectorial chimera tissue is visible within the select root, or the overall flesh color is less than acceptable, then all the sprouts from that root are discarded. All sprouts that can not be identified with the corresponding mother root are also discarded.

Sectorial chimeras may vary in shape from prominent wedges to narrow streaks of light tissue. In a 3-year study, the annual mutation rate of 'Jewel' varied from 33% to 40% of the roots cut. The size of the sectorial chimeras appeared to be reduced by annual cutting and evaluation of the select roots when sprouts were pulled for planting