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Grading Criteria for Judging Potatoes for Chip Quality and Yield

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Summary. Grading criteria are proposed for judging potatoes (*Solanum tuberosum*) for chip quality and yield. The criteria were derived from a decision-making scheme developed from expert opinions, U.S. Dept. of Agriculture grades, and a statistical evaluation of stored potatoes. The criteria are presented as ranges of acceptable values for a limited set of variables found to be important for chip quality and yield. These variables include bruising, cracks, cuts, fusarium dry rot, lesions, and scab. The proposed criteria, besides being a practical decision-making tool for processors, could serve as a knowledge base for potato expert systems and the development of mechanized sorting equipment.

The extent to which chipping quality of raw potatoes deteriorates during storage depends on many factors, including cultivar,

growing season, maturity at harvest, quality after harvest, curing practices, and storage conditions. A processor must evaluate each lot of potatoes and make decisions about how long to store them, and then modify the decision based on the deterioration of the potatoes during storage. Although processors rely on experience to predict which cultivars and storage conditions are most likely to result in long-term retention of quality, the variability from year to year and from one growing area to another makes such decisions risky.

One popular approach for determining quality and minimizing the risk of making decisions with stored produce is the use of grading systems. A grading system identifies variables important to the yield and quality of a crop and organizes the values for each variable into a logical framework for decision-making. In defining the ranges of variable values that are "acceptable" for a particular use, a grading system strikes a compromise between "ideal" and "reject" quality. An effective grading system should have stringent criteria for those variables that dramatically quality and less stringent criteria for those that do not. A grading system for potatoes intended for storage and processing, for example, should have low tolerances for defects and diseases that are known to cause substantial shrinkage during storage or that have a negative effect on the quality of the processed product. However, potatoes intended for processing could be graded less harshly for cosmetic defects that would be removed or otherwise become unimportant after processing.

In this paper, we propose grading criteria for judging the quality of stored potatoes. The proposed criteria are derived from a previously developed decision-making scheme (Russo et al.,

1988), U.S. Dept. of Agriculture (USDA) standards (USDA, 1983), and experimental data on stored potatoes.

Collection of commercial potato samples

Potatoes were sampled from two commercial storages during the 1985-86 and 1986-87 storage seasons. The bin storage consisted of bulk bins supplied with heating and ventilation. The pallet storage consisted of temperature- and humidity-controlled rooms, with the potatoes stored in pallet boxes. Each lot of potatoes was sampled upon receipt at the storage facility, typically within 1 week of harvest, and at 2- to 3-week intervals throughout the storage season. The origin of the lots used, the storage conditions, and the initial and final sampling dates are summarized in Table 1. Twenty potatoes were sampled from the top of each bin or pallet on each sampling date during the 1985-86 storage season. At the start of the 1986-87 storage season, samples of 30 potatoes each in bin storage were counted, weighed, and buried in mesh bags in the bin so that weight loss during storage could be recorded at each subsequent sampling time.

Potato tuber quality, defects, and diseases, and chip quality and yield characteristics were recorded for samples from each lot at each sampling time. All variables except chip quality and yield were measured on individual potatoes. Defects and diseases were identified using the U.S. standards for potatoes (USDA, 1983) and other USDA publications (USDA, 1978, 1982). Surface and internal defects and diseases were scored by dividing the potato into 20 sections (four longitudinal and five radial) and examining the outside and cut surfaces of each section. When USDA grades specified maximum percent waste, our measurements of percent surface area or percent volume (estimated from examining cut surfaces) were interpreted based on the assumptions listed in Table 2.

For compositional analyses, sections representing the central third of the potato longitudinally were peeled, frozen immediately in liquid N₂, freeze dried, and stored frozen until analyses could be performed. Discolored and diseased tissues were not included in the frozen samples. Sugars were extracted by homogenization of 20 g of

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of 10% may be more suitable (Table 4). For fusarium dry rot, silver scurf, sprouts, and internal bruising, our data indicated that the criteria should be more stringent than those in the USDA grades. Fusarium dry rot was associated with weight loss and the weight of defective chips. We recommend a maximum of 2% surface fusarium dry rot, since more than that would be associated with >1% defective chips and >2% weight loss during storage. Silver scurf was not included in the USDA grades. We found that it had a significant effect on chip color, particularly if the incidence was >5%. We therefore recommend an acceptable

range of 0% to 5% of the surface area. Sprouting occurred late in storage. The problems it might cause during processing were not detectable by our methods, so we recommend the minimum tolerance proposed by experts. Internal bruising and internal fusarium dry rot at 5% internal volume had a negative effect on chip color. Although the effect on overall chip color would be small if these defects were present at 1% to 2% internal volume, we recommend the experts' more-stringent values, because the defects they cause in the chips are so objectionable.

Specific gravity and reducing-

sugar content of raw potatoes are commonly used as predictors of yield and quality (Gould and Plimpton, 1985). Even though the specific gravity of 98% in our samples was in the acceptable range (Table 2), this was still the most important variable (highest F value) in models predicting chip yield. While only 6% of the chip samples were very dark (PC/SFA rating >2, Table 2), glucose content was an important variable (second-highest F value) in models predicting Agtron score (data not shown). Specific gravity and reducing sugars are not listed in Table 3, because the ranges of values obtained in our samples were too narrow to add

Table 2. Comparison between expert opinion and U.S. Dept. of Agriculture (USDA) grades for general, surface, and chip variable values defining acceptable ranges and the percentage of sampled potatoes falling within those ranges.

Variable	Range of acceptable values		Commercial samples within range (%) ^c		Assumptions and comments
	Expert units ^a	USDA units ^a	Expert	USDA	
General					
Shape	0.61-1	---	98	---	Shape = diameter/length
Specific gravity	1.061-1.110	---	98	---	
Second growth no.	0-1	0-5	100	100	Assumes one second growth gives at least 5% Waste
Surface					
Infected lenticels	0-1	0-5	83	100	5% Waste = 10% surface area
Blackleg	0-0.5	0-5	100	100	5% Waste = 5% surface area
Bruises	0-1	0-5	38	94	
Cracks	0-2	0-10	81	100	
cuts	0-1	0-10	66	100	
Discoloration	0-4	---	99	---	
Fusarium	0-0.5	0-5	18	98	5% Waste = 5% surface area
Greening	0-2	0-5	55	100	5% Waste = 5% surface area
Holes	0-0.5	0-5	89	100	5% Waste = 5% surface area
Lesions	0-0.5	---	75	---	
Rhizoctonia	0-1	0-10	31	98	
Pinkeye	0-1	---	100	---	Not included in expert survey; values set by comparison with similar disorders
Scab	0-1	0-25	66	100	
Shriveling	0-1	---	93	---	See comment for pinkeye
Silver scurf	0-1	---	21	---	
Skinning	0-5	---	88	---	See comment for pinkeye
Sprouts	0-0.5	---	94	---	
Sunburn	0-0.5	0-5	100	100	
Chip characteristics ^b					
Chip yield	2-higher	---	80	---	
Chip color	55-higher	---	32	---	Agtron measurement
Chip color	1-2	---	94	---	PC/SFA measurement ^v
Oil content	28-34	---	82	---	
Moisture content	1.26-1.55	---	46	---	

^aPercentage of 142 means (each sampling of each lot) that were in the acceptable range.

^bDefects expressed as percentage of surface area.

^cFor U.S. No. 1, USDA defects are expressed as percent Waste, except surface cracks, cuts, Rhizoctonia, and scab are expressed as percent surface area. Dashes indicate that no criteria were specified.

^dAll but yield were determined from line-fried chips. N = 135.

^ePC/SFA = Potato Chip and Snack Food Assn.

Table 3. *Comparison between expert opinion and U.S. Dept. of Agriculture (USDA) grades for internal variable values defining acceptable ranges and the percentage of sampled potatoes falling within those ranges.*

Variable	Range of acceptable values		Samples within range (%) ^c		Assumptions and comments
	Expert units	USDA units ^a	Expert	USDA	
Bacterial soft rot	0–0.25	0	92	90	Tolerance = 2% by weight
Blackheart	0–0.25	0	100	100	Tolerance = 2% by weight
Blackleg	0–0.25	0	91	93	Tolerance = 2% by weight
Late blight	0–0.25	0	100	100	Tolerance = 2% by weight
Rotted tissue	0–0.25	0	99	99	Tolerance = 2% by weight
Bruises	0–0.5	0–5	41	74	5% Waste = 2% volume
Cracks	0–1	0–5	98	100	5% Waste = 2% volume
cuts	0–0.5	0–5	99	100	5% Waste = 2% volume
Fusarium	0–0.25	0–5	18	60	5% Waste = 2% volume
Greening	0–0.5	0–5	85	99	5% Waste = 4% volume
Stem-end browning	0–0.5	0–5	91	100	5% Waste = 4% volume
Vascular discoloration	0–0.5	0–5	92	89	5% Waste = 4% volume
Blackspot (brownspot)	0–0.5	0–0.5	98	98	Maximum spot diameter transformed to volume using specific gravity = 1.084
Discoloration			81	81	See comment for blackspot
Holes			98	99	See comment for blackspot
Hollow heart			94	99	See comment for blackspot
Internal sprouts			100	100	See comment for blackspot
Tissue necrosis			89	100	See comment for blackspot
All variables			0	89	

^aPercentage of 142 means (each sampling of each lot) that were in the acceptable range.

^bDefects expressed as percent surface area or percent internal volume.

^cFor U.S. No. 1, USDA defects are expressed as percent waste. Dashes indicate that no criteria were specified.

Table 4. *Recommended ranges of acceptable values for selected variables judged to be important for chip quality and yield. The table includes the source of the recommended ranges and the assumptions and comments for choosing a particular range.*

Variable	Recommended range	Source	Assumptions and comments
Surface			
Infected lenticels	0–10	USDA	5% Waste = 10% surface area
Bruising	0–5	USDA	5% Waste = 5% surface area
Cracks	0–10	USDA	
cuts	0–10	USDA	Smooth cuts only
Fusarium dry rot	0–2	Data	Assumes up to 1% defective chips is tolerable
Greening	0–5	USDA	5% Waste = 5% surface area
Holes	0–5	USDA	5% Waste = 5% surface area
Lesions	0–5	USDA	5% Waste = 5% surface area
Rhizoctonia	0–10	USDA	
Scab	0–25	USDA	Surface (common) scab only
Silver scurf	0–5	Data	Associated with darker chip color
Sprouts	0–0.5	Expert	USDA grades disallow “loose sprouts”
Internal			
Bruising	0–0.5	Expert	Associated with darker chip color
Fusarium dry rot	0–0.25	Expert	Associated with darker chip color

^aValues expressed as percent area for surface variables and percent volume for internal variables.

to current information on these variables.

It should be noted that many variables are correlated with others. For example, internal bruising was correlated with glucose, surface bruising, fusarium dry rot, silver scurf, and specific gravity. Thus, when one variable is measured, others can be indirectly estimated as well. This covariation makes it difficult to determine the precise nature of relationships among variables but does not preclude their use in decision-making tools, since the consistency of the relationship is more important than its nature.

The proposed grading criteria improves information currently available to potato processors by bringing together grading systems, expert opinions, and experimental data. As a refined decision-making tool, the criteria accurately reflect the variable values that are the most reliable for judging chip quality and yield. The criteria described here could be combined with other proven criteria, such as specific gravity and reducing-sugar content, to

improve decision-making. The grading criteria can be updated according to the demands of a decisionmaker as processing requirements for potatoes change, as existing variables take on new importance, or as regional differences in preferences or performance arise.

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An Effective System for Brushing Vegetable Transplants for Height Control

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Additional index words. mechanical stress, conditioning, growth regulation

Summary. A brushing system for vegetable transplants that is adjustable, easy to use, and provides uniform brushing action was designed and constructed. Using this system, the height of several species and cultivars of vegetable transplants was reduced 15% to 50%. Quality and uniformity also were improved, and edge effects on growth were reduced.

Due to the recent restrictions regarding the use of chemical growth regulators on vegetable transplants, the development of alternative methods of practical growth control and conditioning of transplants is necessary. Growers currently are limited to using water/fertilizer restriction or temperature adjustment to control the growth of transplants. However, physiological stress due to water and nutrient restriction may affect long-term crop productivity (McKee, 1981). Temperature regulation, especially imposition of day/night temperature differentials (DIF) (Heins and Erwin, 1990), can be very effective in controlling plant height but has resulted in transplants of poor quality (Ferretti, 1990). Under southern conditions, it is difficult to obtain temperature differentials large enough to provide sufficient growth control of spring transplants. Brushing of trans-

plants is a nonchemical means of controlling growth that improves the overall quality of the transplants (Latimer, 1991a).

With the growing interest in brushing as a means of height control in transplants, a practical, uniform method of treatment is needed. Previous experiments using various materials for the application of mechanical stress have given mixed results. Cardboard sheets gave good growth control, but since the brushing was applied free-hand, the chance for inconsistent application was high (Fig. 1). Folded sheets of paper worked well on small transplants (Biddington, 1986), but as the stems grew stronger, stimulation of the plants was insufficient to maintain effective height control (unpublished data). Both paper and cardboard deteriorated when exposed to plant guttation. We tried using a drafting brush on tomato transplants, but the brush and leaves became entangled, resulting in plant damage. All of these materials limit treatment application to only a few plants at any one time. Beyl and Mitchell (1977) devised an automated system for applying a combined shaking-touching mechanical stress to reduce stem elongation of potted chrysanthemum. This device was cumbersome and unsuitable for the growth habit and intensive production of vegetable transplants. A brushing device consisting of polyvinylchloride (PVC) pipe was used to reduce shoot growth of tomato transplants (Latimer and Thomas, 1991), but under wet or very humid conditions or with very soft plant material, leaves adhere to the plastic, causing undesirable friction that may damage the transplants (Fig. 2).

Therefore, we designed and constructed a prototype of a brushing apparatus based on three major goals: 1) the brushing apparatus had to be lightweight and easy to use; 2) the height of the brushing bar had to be infinitely adjustable to "grow" with the transplants; and 3) the brushing action had to be consistently uniform.

Our brushing apparatus consisted of a 3-cm-diameter wooden closet rod attached to a lightweight frame made of PVC pipe (Fig. 3). The wooden closet rod was cut ≈30 cm longer than the width of the bench to provide a "handle" and was sanded until smooth to prevent damage to the transplants. Height adjustment was achieved by

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Fig. 1. Brushing tomato plants with a cardboard sheet gave effective growth control, but consistency of the treatment across the flat varied with the applicator and size of the plants. The cardboard deteriorated when wetted by plant guttation.

Fig. 2. Under very humid conditions or with soft plant material, leaves adhere to the polyvinylchloride pipe, resulting in torn leaves and damaged plants.

sliding the brushing bar up or down the frame, visually leveling the bar against the plants, and then tightening the clamp to hold the bar firmly at the optimum level for brushing (to brush the top quarter to third of the plants). The apparatus rests in a wooden track treated with three coats of a gloss polyurethane varnish to provide a smooth finish and protect the system from water damage. A final spray of silicone ensured that the bar runners glided smoothly over the track. The silicone was reapplied about every 2 weeks to maintain a smooth surface.

The brushing apparatus is very lightweight, allowing one person to apply the treatments and move the

apparatus from bench to bench, provided that the benches are standard in size (Fig. 4). In our system, the benches were 1.5 m wide. This may be the maximum width comfortably treated with this brushing apparatus. With very large plants or a wider bench, two people may be required to operate the brushing bar. In addition, longer spans may result in the wooden bar sagging in the center. Potentially, an aluminum bar may replace the wooden bar. The weight and rigidity of the wooden bar make it easy to handle over this and smaller bench widths.

Testing the response of at least two cultivars of each crop, the brushing treatment reduced transplant

height of tomato 50% (Fig. 5), eggplant 35% (Fig. 6), cucumber 25%, and squash 15% to 25%. Broccoli and cabbage cultivars varied in responsiveness to brushing (Table 1). Tomato plants were brushed for 40 cycles (back and forth across the flat equals one cycle) twice daily, and all other crops were brushed for 20 cycles twice daily. Data presented are for brushing treatments initiated at the cotyledonary stage of development.

Although previous experience suggested that eggplant would be easily damaged by brushing (Latimer et al., 1986), two cultivars responded well to this treatment. No damage was evident in either cultivar, perhaps because the treatment primarily contacted leaves instead of terminal stem tissue. Uniformity of the transplants was improved over a freehand method of application even when different operators applied the treatments. Since all the plants on a bench received the same stimulation, edge effects on growth were reduced. This system provides flexible brushing treatment,

Table 1. Response of various cultivars of vegetable transplants to brushing initiated at the cotyledonary stage of development.

Crop/cultivar	Stem length (cm)	
	Nontreated	Brushed
Tomato		
Sunny	20.4	9.6*
Celebrity	19.0	9.5*
Eggplant		
Black Beauty	14.6	9.2*
Ping Tung Long	9.4	6.2*
Cucumber		
Suyo Long	23.0	16.0*
Sweet Success	26.6	20.5*
Squash		
Dixie	9.6	8.0*
All Seasons	7.0	6.0*
Cream of the Crop	7.3	5.5*
Broccoli		
Early Dawn	8.0	6.9*
Green Duke	7.8	7.3*
Symphony	6.4	6.2
Premium Crop	5.6	5.8
Green Comet	4.9	4.8
Cabbage		
Conquest	5.6	5.0*
A&C #5	4.3	4.0
Rio Verde	4.1	4.1
Gourmet	4.9	4.9
Market Prize	4.3	3.9*

*Significantly different from respective nontreated control, $P < 0.05$.

Fig. 3. The brushing apparatus, consisting of a wooden rod attached to a polyvinylchloride (PVC) pipe frame, rests on a wooden track attached to both sides of the bench. For each side of the bench, two 30-cm pieces of 1.9-cm-diameter PVC pipe were connected to form the runners. A 45-cm section of 1.2-cm PVC pipe was connected to each T-joint to form the upright posts of the frame. For added stability, a section of 1.2-cm PVC pipe cut to the width between the centers of the tracks was attached to the tops of the two upright poles with PVC elbows. A 3-cm hose clamp was fastened to each end of the bar. A 2.5-cm hose clamp was looped through each larger clamp and then fastened around the upright sections of the PVC frame. The track consisted of high-quality pine boards (2.2 × 9.8 cm) of the maximum length available (4.9 m) attached to both sides of the woodframe bench by nails or screws, leaving »5 cm extending beyond the bench frame. To minimize contact resistance, corner molding was attached to the inside corners of the pine boards with finishing nails. To keep the bar runners from falling off the track, 0.6 × 1.2-cm wooden lattice strips were attached to the outside edges of the track.

since the height can be adjusted rapidly for various species. It is important that plants treated at any one time be of the same approximate height (Latimer, 1991b). On a small or research scale, this may be achieved by placing wooden strips under the flats of shorter cultivars to obtain equivalent shoot heights.

The cost of building this system was about \$12 for the brushing apparatus and about \$35 for the track for each 5.0 m of bench length. If more than 5.0 m of bench is to be used for this track system, take care to ensure

Fig. 4. Brushing 3-week-old tomato transplants.

Fig. 5. Three-week-old 'Celebrity' tomato plants brushed for 40 cycles twice daily for 13 days. Treatment was initiated at the cotyledonary leaf stage.

Fig. 6. Five-week-old 'Black Beauty' eggplant transplants brushed for 20 cycles twice daily for 27 days beginning at the cotyledonary leaf stage.

that all connections between the wooden sections are made as smoothly as possible to prevent the brushing apparatus from "resisting" as it is moved back and forth over the transplants.

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Growth of Container-grown Trees Transplanted from the Field or Grow-bags

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Summary. Crape myrtle (*Lagerstroemia* L. × 'Natchez'), live oak (*Quercus virginiana* Mill.), and Chinese pistachio (*Pistacia chinensis* Bunge) were planted into a sandy loam soil directly in the field or in grow-bags. Root and top growth were measured in March and July of the second year. Some of the trees were transplanted to 20-gal (76-liter) containers in March or July and grown for 3 months. Chinese pistachio developed a poor root system in field soil and was not ready for harvest in March or July. There was no difference in height, caliper, or top fresh weight for crape myrtle. Caliper and top fresh weight were similar for live oak trees. However, live oaks grown by traditional field production methods were taller than trees produced in grow-bags. With March transplanting, both crape myrtle and live oak trees from traditional field plantings were taller than trees transplanted from grow-bags 3 months after transplanting into containers. Tree top weight, caliper, and root ratings were similar for March-transplanted crape myrtle. Live oak trees transplanted from grow-bags had similar caliper and top weight but a higher

root rating. July-transplanted crape myrtle trees had similar values for all variables 3 months later. All live oaks died when transplanted from traditional field plantings to containers in July. All live oaks grown in grow-bags survived transplanting.

Grow-bags (Root Control Bags; Root Control, Oklahoma City, Okla.) are a significant and controversial introduction to the nursery industry. They are the result of research by Reiger and Whitcomb (1983).

With traditional field production, 92% to 98% of the roots are removed when plants are harvested (Watson and Himelick, 1982). The grow-bag system constricts the root tips as they penetrate through the small holes in the fabric, resulting in root pruning and root branching. As with containers, grow-bags confine a large portion of the roots within a limited space. Some reports indicate that more roots are harvested from a grow-bag than from traditional field-production rootballs (Fuller and Meadows, 1987; Ingram et al., 1987). Another report indicates that the growth response is species-specific for root reduction within a grow-bag (Chong et al., 1987). This positive aspect of grow-bags for some trees facilitates year-round harvesting. Landscaping has become a year-round business, with demand for plant materials that will tolerate transplanting during extremely stressful conditions.

Grow-bags are not perceived as being as attractive as traditional containers. Consumers prefer plastic containers over the grow-bag and the grow-bag over ball-and-burlap material (Purvis et al., 1991). Some nursery producers transplant trees to containers to provide retailers with a more aesthetically desirable product. Limited data are available on transplanting grow-bag-grown trees to containers.

Our research compared tree growth under traditional field production and grow-bag systems in the sandy soils of southern Alabama where traditional field harvesting methods are more difficult. We also compared the performance of trees transplanted from the two production systems to 20-gal (76-liter) containers in March (dormant trees) or July (actively growing trees).

Materials and Methods

Liners of 'Natchez' crape myrtle and Chinese pistachio were transplanted on 24 Mar. 1988 from 1-qt containers. Live oak was transplanted from 4 × 4 × 12-inch tree containers. Live oak was selected because of its reputation for being difficult to transplant, while crape myrtle is a tree that traditionally transplants easily. Chinese pistachio transplants easily, but due to slow root growth, field-planted or grow-bag trees were not ready to harvest. Therefore, this tree was omitted from the study and is probably not a good selection for this production method.

Tree liners were planted in a Malbis fine sandy loam soil at the Gulf Coast Research Substation, Fairhope, Ala. Crape myrtle and live oak trees were planted either in 18-inch-diameter (46-cm) grow-bags, backfilled with native soil, or directly in the field. Holes were dug using a 20-inch (51-cm) auger. Each tree was topdressed with 1 tbsp (18 g) of Osmocote 17N-3P-10K (Grace-Sierra Horticultural Products, Milpitas, Calif.) at planting and again on 13 Apr. 1989. On 21 July 1988 and 12 May 1989, 1 tbsp of 12N-2.6P-5K was applied. Plants were watered every 28 h for 2 h with drip irrigation emitters supplying 2 gal of water at each irrigation. Irrigation was turned off during rainy days. A 3-ft-wide (0.9-m) weed-free strip was maintained around the trees using metolachlor (Dual; Ciba-Geigy, Greensboro, N.C.) and simazine (Princep; Ciba-Geigy) at labeled rates in April of each year. Spot spraying with glyphosate (Round-up; Monsanto, St Louis) as needed and hand weeding around tree trunks completed the weed control program.

The experiment was arranged in a randomized complete block design with six replicates of five plants each. Plants were spaced 6 ft (1.8 m) within rows and 10 ft (9.0 m) between rows.

Height and caliper were measured on 17 Oct. 1988 and 1 Mar. 1990. The caliper of crape myrtle trees was measured by taking the average of the largest three trunks of the multi-stemmed trees. On 17 Mar. 1990, one tree from each block and treatment (24 trees, 12 of each species) was selected at random and harvested. A 20-inch-diameter (51-cm) rootball was dug by hand for 5.8-ft (175-cm) caliper crape myrtle trees and 1.4-inch

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(36- mm) caliper live oak trees. These were traditionally field-produced trees dug according to American Standards of Nursery Stock (American Association of Nurserymen, 1990). Grow-bag-grown trees were removed from the field in their bags. The 24 trees were cut at ground level and fresh top weight was determined. Rootballs were washed, roots were severed from the original rootball, and fresh root weight was recorded.

Two additional trees from each block and treatment (24 trees of each species) were dug by hand and transplanted to 20-gal (76-liter) containers filled with 100% pine bark (grow-bags were removed from trees). Trees were fertilized by topdressing with 5.3 oz (150 g) Osmocote 17N-2.6P-10K plus minor nutrients/pot. Trees were placed under 50% shade, syringed three to four times a day for 1 week, and then moved to the production area under overhead irrigation.

On 11 July 1990, 4 months after transplanting, containerized trees were measured for caliper, height, and fresh weight. Twelve rootballs of each species were slipped from the containers and evaluated for the percentage of the rootball surface covered with roots. Rootballs were rated from 1 to 5 (1 = no roots on rootball surface, 3 = moderate, and 5 = dense matting) (Keever et al., 1985). Oak roots were washed, and the root growth extending into the pine bark from the severed roots of the original rootball was cut and weighed. Crape myrtle root systems were too dense to separate the container medium from the roots.

On the same date (11 July), the

remaining 24 trees (12 of each species) were measured, dug, and transplanted to 20-gal (76-liter) containers using the same procedures described earlier. This step was used to evaluate transplanting success during stressful conditions. The July-planted containerized trees were harvested 3 Oct. 1990 and fresh weight and root ratings were recorded.

Results and Discussion

Growth was similar for both tree species grown in both tree production systems (Table 1). Exceptions were 1990 live oak height and 1988 live oak caliper, where trees (60 measured) in traditional field production were 18 cm (7 inches) taller than trees grown in grow-bags and 1 mm (0.04 inch) larger in caliper, respectively. However, this difference was not reflected in the other growth variables and was very small. This concurs with other research on grow-bags (Tilt and Dickerson, 1987). Chong et al. (1991) reported reduction in growth due to the grow-bag, but indicated the reduction was not economically significant and attributed it to restriction of root growth by the bag or the initial hydrophobic nature of the fabric bag.

Neither caliper nor top weight of crape myrtle or live oak trees differed as a result of transplanting the dormant trees to containers in Mar. 1990. However, live oak and crape myrtle trees produced without bags, dug by hand, and grown in containers for 9 months were 42 and 17 cm (16.5 and 6.7 inches) taller, respectively, than trees in grow-bags. Live oak root regeneration expressed by the root rating system was enhanced in plants in grow-bags.

Growth was similar for March-transplanted/July-harvested and July-transplanted/October-harvested crape myrtle trees when comparing grow-bag and traditional field production. Live oaks produced by traditional field production and transplanted to the 20-gal containers in July died. Live oaks grown in grow-bags survived and continued to grow until the October harvest. Additional root growth was exhibited by March-transplanted/July-harvested trees (root rating 3.5) grown in grow-bags compared to traditionally field-produced trees harvested and transplanted on the same dates (root rating 2.6). This result may explain the survival of July-transplanted live oaks harvested from grow-bags in October and the death of traditionally field-produced trees.

Grow-bags offer an alternative to producing more difficult-to-transplant species, especially in sandy soils where traditional field production is not practiced. Advantages gained from using the grow-bags vary with the species grown.

A niche has been established in the industry for the production and use of plants produced in grow-bags. Grow-bags meet the landscaper's need for trees in mid-summer. As evidenced by the results of transplanting crape myrtle trees, all trees may not benefit from the grow-bag system. The system is a hybrid between traditional field production and container production and requires the development of cultural and marketing practices that are significantly different from the other two systems. Our research, as well as that of others, shows that many

Table 1. Effect of production system on 2 years of growth and final weights of *Lagerstroemia* × 'Natchez' and *Quercus virginiana* harvested from the field and transplanted to containers.

Production system	Field						Container							
	Caliper (mm)		Ht (cm)		Top fresh wt (kg)	Root wt (g)	Caliper (mm)		Ht (cm)		Top fresh wt (kg)		Root rating	
	1988	1990	1988	1990	1990	1990	July	Oct.	July	Oct.	July	Oct.	July	Oct.
<i>Lagerstroemia</i> × 'Natchez'														
Field	----	23	105	175	2.4	276	29	32	206 a ^y	193	3.9	4.7	4.3	4.1 ^x
Grow-bag	---	28	105	176	2.6	353	29	31	189 b	178	4.1	3.3	4.1	4.0
<i>Quercus virginiana</i>														
Field	16 a	36	132	211 a	2.2	262	47	---	252 a	---	3.1	---	2.6 a	---
Grow-bag	15 b	36	127	193 b	2.0	260	43	44	210 b	211	3.3	2.5	3.5 b	2.5

^xData not available for caliper in 1988.

^yMeans within columns for each species separated by Duncan's multiple range test, $P = 0.05$. Means not followed by the same letter differ significantly from one another; all other comparisons are nonsignificant.

^zTrees were transplanted to 20-gal containers from the field in Mar. and July 1990 and harvested in July and October. Root rating: 1 = no roots on outside of container rootball, 5 = matted (24 trees for each species, each transplant date).

plants can be grown as well in grow-bags as by traditional field-production methods. Live oaks and possibly other difficult-to-transplant trees can have increased success in the landscape when produced in grow-bags, especially where sandy soil conditions prevail.

One major limitation to the system is that no standards or specifications for the use of grow-bags by landscape architects and designers have been developed and published by the American Association of Nurserymen. This failing hinders the market potential of grow-bags.

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High-temperature Inhibition of Seed Germination and Seedling Emergence of Broccoli

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Summary. High summer temperatures may reduce plant stands of direct-seeded fall broccoli (*Brassica oleracea* var. *italica* Plenck). The influence of constant and diurnally alternating temperatures in the range of 5 to 42C on germination and emergence of 'Packman' broccoli was evaluated. Germination was defined as protrusion of the radicle from the seedcoat, and emergence as 10 mm elongation of the radicle. The range of constant temperatures from 10 to 30C for 14 days was satisfactory for 90% germination and 75% emergence. However, alternating temperatures extended the acceptable emergence range to 5/17 through 20/32C. Since soil temperatures in warm climates often exceed 20/32C during the summer, high-temperature inhibition of seed germination and seedling emergence is a potentially important factor limiting direct-seeded broccoli stands.

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Efforts to produce direct-seeded fall broccoli in Virginia and other warm climates have resulted in poor stand establishment. Many factors affect stand establishment of a direct-seeded crop, including soil temperature, soil moisture, planting depth, seed size, and seed vigor. Since fall broccoli is direct-seeded in July and August, when soil surface temperatures often exceed 35C, high soil temperatures may have a significant influence on germination and emergence of broccoli.

Harrington and Minges (1956) and Wagenvoort and Bierhuizen (1977) evaluated the influence of temperature on many vegetables. However, neither of these studies included broccoli.

Wagenvoort and Bierhuizen (1977) defined the "practical" germination temperature range as the temperature extremes ($T_{p_{min}}$, and $T_{p_{max}}$) between which a predetermined acceptable germination percentage is achieved in a limited period of time. For example, the germination percentage of red cabbage (*Brassica oleracea* var. *purpurea*) was $\geq 75\%$ between 5 and 25C after 2 weeks. Below the $T_{p_{min}}$ (5C) and above $T_{p_{max}}$ (25C), germination was reduced to $< 75\%$.

Hegarty (1975, 1977, 1978) investigated numerous aspects of broccoli germination and emergence. However, his temperature studies did not exceed 25C. If the "practical" germination temperature maximum of 25C for red cabbage (Wagenvoort and Bierhuizen, 1977) approximates the limits for other *Brassica oleracea* varieties, high soil temperatures would limit stand establishment of fall broccoli during hot weather.

Hegarty (1975) has shown that diurnally alternating temperatures increased the germination of broccoli. Alternating temperatures are more representative of field conditions and have been shown to increase germination in many crops (Ellis et al., 1982; Hegarty, 1975; Logendra, 1984; Probert and Smith, 1986; Thompson and Fox, 1976). As a result, alternating temperatures may increase germination and emergence at high temperatures.

The objective of this study was to determine the constant and diurnally alternating temperature limits for acceptable germination and emergence of broccoli. Germination does not necessarily equate with emergence,