PGRs successfully inhibited stem elongation of the three Hibiscus spp. This information, combined with previously identified impacts of photoperiod and temperature on floral initiation of *H. radiatus* and *H. trionum* (Warner and Erwin, 2001) provide a basis for developing production schedules for these species. Further work is needed to understand floral inductive requirements of *H. coccineus.*

Literature cited

Barrett, J.E. and E.J. Holcomb. 1993. Growth regulating chemicals, p. 65–74. In: J.W. White (ed.). Geraniums IV. Ball Publ., Geneva, Ill.

Bickford, E.D. and S. Dunn. 1972. Lighting for plant growth. Kent State Univ. Press. Ashland, Ohio.

Bose, T.K., B.K. Hore, and D. Mukherjee. 1968. Dwarfing of some malvaceous ornamental plants as a nursery practice. HortScience 3:179–180.

Cathey, H.M. 1975. Comparative plant growth-retarding activities of ancymidol with ACPC, phosfan, chlormequat, and SADH on ornamental plant species. HortScience 10:204–216.

Dole, J.M and H.F. Wilkins. 1999. Hibiscus, p. 368–372. In: Floriculture: Principles and species. Prentice Hall, Upper Saddle River, N.J.

Fonteno, W.C. 1992. Geraniums, p. 452–477. In: R.A. Larson (ed.). Introduction to floriculture. 2nd ed. Academic Press Inc., San Diego, Calif.

Gianfaga, T.J. 1995. Natural and synthetic growth regulators and their use in horticultural and agronomic crops, p. 614–635. In: P.J. Davies (ed.). Plant hormones: Physiology, biochemistry, and molecular biology. 2nd ed. Martinus Nijhoff Publ., Dodrecht, Netherlands.

Grossman, K. 1988. Plant growth suspensions for screening and studying the mode of action of plant growth retardants, p. 89–136. In: K. Maraorosch and G. Sato (eds.). Advances in cell culture. Academic Press Inc., San Diego, Calif.

Grossman, K. 1992. Plant growth retardants: their mode of action and benefit for physiological research, p. 788–797. In: C.M. Karssen, L.C. Van Loon, and D. Vreugdenhl (eds.). Progress in plant growth regulation. Kluwer Academic Publ., Dodrecht, Netherlands.

Menhennet, R. 1980. Evidence that daminozide, but not two other growth retardants, modifies the fate of applied gibberellin A_9 in *Chyrsanthemum morifolium* Ramat. J. Expt. Bot. 31:1631–1642.

Rademacher, W. 1991. Inhibitors of gibberellin biosynthesis: applications in agriculture and horticulture, p. 296–310. In: N. Takahashi, B.O. Phinney, and J. MacMillan (eds.). Gibberellins. Springer-Verlag, New York.

Sachs, R.M., A. Lang, C.F. Bretz, and J. Roach. 1960. Shoot histogenesis: subapical meristematic activity in a caulescent plant and the action of gibberellic acid and AMO-1618. Amer. J. Bot. 47:260–266.

Shanks, J.B. 1972. Chemical control of growth and flowering in hibiscus. HortScience 7:574.

Smith, H. 1994. Sensing the light environment: The functions of the phytochrome family, p. 377–416. In: R.E. Kendrick and G.H.M. Kronenberg (eds.). Photomorphogensis in plants. 2nd ed. Kluwer Academic Publ., Dodrecht, Netherlands.

Styer, R.C. and D.S. Koranski. 1998. Plug and transplant production: A grower's guide. Ball Publ., Batavia, Ill.

Takeno, K., R.L. Legge, and R.P. Pharis. 1981. Effect of the growth retardant B-9 (SADH) on endogenous GA level, and transport and conversion of exogenously applied $[H^3]GA_{20}$ in Alaska pea. Plant Physiol. 67(Suppl):581(abstr.).

Tolbert, N.E. 1960. (2-chloroethyl) trimethylammonium chloride and related compounds as plant growth substances II. Effect on growth of wheat. Plant Physiol. 35:380–385.

Wang, S., R.D. Heins, W. Carlson, and A. Cameron. 1998. Forcing perennials: *Hibiscus moscheutos* 'Disco Belle Mixed'. Greenhouse Grower 16(2):29–32.

Wang, Y. and L.L Gregg. 1991. Modification of hibiscus growth by treating unrooted cuttings and potted plants with uniconazole or paclobutrazol. J. Plant Growth Regulat. 10:47–51.

Warner, R.M. and J.E. Erwin. 2001. Variation in flower induction requirements of *Hibiscus* sp. J. Amer. Soc. Hort. Sci. 126:262–268.

Wilkins, H.F. and D. Kotecki. 1982. *Hibiscus rosa-sinensis* L. Minn. State Florists Bul. 31:3–7.

Yield and Quality of Machine Harvested Red Chile Peppers

Marisa M. Wall,[1] Stephanie Walker,[2] Arthur D. Wall,[3] Ed Hughs,[4] and Richard Phillips[5]

ADDITIONAL INDEX WORDS. ***Capsicum annuum*, mechanical harvest, ethephon, paprika, vegetable crops.**

SUMMARY. **In the southwestern U.S. growing region, which includes southern New Mexico, west Texas, and southeastern Arizona, mechanical harvest of chile peppers (*Capsicum annuum*) is increasing because of the high cost of hand labor. Mechanical harvesters have been developed, but there is limited information on the performance of chile cultivars when machine harvested. Four red chile pepper cultivars (New Mexico 6-4, Sonora, B-18, and B-58) were grown in a farmer's field near Las Cruces, N.M., and harvested in October 2000 using a double-helix-type harvester. Ethephon was applied 3 weeks before harvest at 1.5 pt/acre (1.75 L·ha^{-1}) to promote uniform ripening. Ethephon caused fruit of 'B-18' and 'B-58' to drop before harvest, thereby affecting yield results. Treatment with ethylene-releasing compounds is not recommended for these cultivars. 'Sonora' and 'New Mexico 6-4'**

Department of Agronomy and Horticulture, MSC 3Q, Box 30003, New Mexico State University, Las Cruces, NM 88003-0003.

This research was supported by the New Mexico Agricultural Experiment Station, and the New Mexico Chile Pepper Task Force. We thank Steve Lyles for producing the crop; Roy Pennock, Linda Liess and Margery Parossien for technical assistance; Jim McClendon, McClendon Pepper Co., Tulia, Texas, for custom harvest; and Biad Chili Co., Leasburg, N.M., for dehydrating the crop.

[1]Former professor and corresponding author (mwall@pbarc.ars.usda.gov). Current address: U.S. Pacific Basin Agricultural Research Center, USDA–ARS, P.O. Box 4459, Hilo, HI 96720-0459.

[2]Research specialist.

[3]Former assistant professor. Current address: P.O. Box 301, Honomu, HI 96728-0301.

[4]Supervisory agricultural engineer. USDA–ARS, Southwestern Cottoning Ginning Research Laboratory, P.O. Box 578, Mesilla Park, NM 88047.

[5]Project manager, New Mexico Chile Task Force. Department of Extension Plant Sciences, MSC 3AE, Box 30003, New Mexico State University, Las Cruces, NM 88003-0003.

dropped much less fruit than 'B-18' and 'B-58' after the ethephon treatment. Dry weight marketable yield ranged from 1419 to 2589 lb/acre (1590.5 to 2901.8 kg·ha^{-1}), and total yield potential (discounting dropped fruit) ranged from about 2500 to 3100 lb/acre (2802.1 to 3474.6 kg·ha^{-1}), depending on cultivar. Harvest efficiencies of 73% to 83% were observed among the cultivars. Trash content of the harvested chile varied from 25% to 42% of dry weight. Trash was predominantly diseased and off-color fruit, leaves, and small stems. Trash content was highest for 'Sonora'. 'New Mexico 6-4' had the greatest marketable yield and harvest efficiency among the cultivars evaluated in this study.

Chile peppers are a major crop in the southwestern U.S., which includes southern New Mexico, western Texas, and southeastern Arizona. Fabian Garcia developed the modern chile pepper at New Mexico State University (Garcia, 1921). New Mexico is the U.S. center for chile processing, with about 19,000 acres (7689 ha) of chile grown in New Mexico during 2000 (New Mexico Agricultural Statistics Service, 2000). Several types of chile peppers are grown regionally, including long green chile for fresh market and canning, and dried red chile for pungent powder, paprika, and oleoresin. Jalapeño and cayenne peppers also are major crops in this region.

Chile imports into the U.S. have increased dramatically, since the implementation of the North American Free Trade Agreement, the devaluation of the Mexican peso, and the increase in the U.S. minimum wage (Eastman et al., 1997). Mechanical harvest will be necessary for sustainable production of chile peppers in the southwest U.S. growing region because of the high cost of hand harvest. Labor costs account for about 50% of the total production costs when hand harvest is used, but decrease to less than 10% of production costs with machine harvest (Eastman et al., 1997). Presently there are innovative growers, custom harvesters, and equipment manufacturers developing machines to harvest chile with promising results. However, there is limited information on agronomic performance of chile cultivars for machine harvest, on yields and quality of machine harvested chile, and on best management practices for producing chile intended for machine harvest.

Experimental pepper harvesters were first developed in the 1970s, and included a picking head, and collecting, cleaning, and fruit transporting components. A chile pepper harvester built by Ernest Riggs, of Las Cruces, N.M., for Cal-Compack Foods, was in use during 1976 (Gentry et al., 1978). Many different picking mechanisms have been tested, including spring-tines (Gentry et al., 1978), rubber finger rakes (Lenker and Nascimento, 1982), open double-helixes, and forced balanced shakers with stem cutting heads (Marshall, 1986; Wolf and Alper, 1984). Marshall and Boese (1998) reported that 230 machines have been built worldwide, with 30 different pepper removal concepts, harvesting at least 20 different types of peppers.

The different picking mechanisms all work fairly well, depending on crop condition and machine adjustments. Equipment is being improved to reduce the number of fruit dropped on the ground during harvest. Recovery rates of marketable fruit are reported to range between 70% to 90% of full yield potential, with losses attributed to dropped and damaged fruit (Lenker and Nascimento, 1982; Marshall, 1986; Wolf and Alper, 1984). Removal of leaves, stems, trash, and undesirable fruit from machine-picked product remains the greatest obstacle to buyer acceptance of mechanically harvested crops. Cleaning components may include air grading (Marshall et al., 1990), counter-rotating rollers and star wheels (Wolf and Alper, 1984), reflexed rubber-finger shakers (Lenker and Nascimento, 1982), combing belts (Marshall, 1984a) and conveyor belts for hand sorting (Gentry et al., 1978). Improved destemming equipment also will advance mechanical harvest, as many pepper types require hand destemming during the picking operation (Marshall and Boese, 1998).

Plant growth habit has a significant influence on machine harvest efficiency. Higher planting densities that result in taller plants, with narrow branch angles improve harvest. Higher planting density can reduce yield per plant, but increase yield per acre (Cavero et al., 2001; Lenker and Nascimento, 1982; Marshall, 1984a, 1984b, 1997). Also, weed-free fields and well rooted plants are important for machine harvest efficiency (Wolf and Alper, 1984). Direct-seeded plants have fewer branches and less lodging and uprooting than transplants (Cooksey et al., 1994a), and hilling soil around the base of plants during weed cultivation reduces uprooting during machine harvest (Boese and Marshall, 1998; Marshall, 1984b; McCullough et al., 1995).

Several cultivar characteristics improve machine harvest of chile, including an upright plant habit with narrow branch angles, and a dispersed fruit set placed higher on the plant (Marshall, 1984b, 1997; Wolf and Alper, 1984). A small number of basal branches near the soil surface reduces branch breakage during mechanical harvest (Palevitch and Levy, 1984), and cultivars that have larger stem diameters are less susceptible to lodging (Kahn, 1985). Fruit diameter and pedicel diameter are correlated positively with fruit detachment force (Setiamihardja and Knavel, 1990). Long, narrow, pendant fruit with small pedicel scars detach easily from the plant during machine harvest.

We determined the yield, harvest efficiency, and fruit quality of four red chile cultivars following machine harvest in southern New Mexico. The four cultivars are commonly grown in the southwestern U.S. and dehydrated for paprika or mild red chile powder.

Materials and methods

During the 2000 season, a large-scale on-farm trial was conducted. Plots were seeded 4 Apr. 2000 with 5 lb/acre (5.6 kg·ha^{-1}) seed in a single line on 40-inch (101.6-cm) center-to-center beds in a grower's field near Las Cruces, N.M. Four cultivars of chile peppers ('New Mexico 6-4', 'B-18', 'B-58' and 'Sonora') were planted in 12-row plots in a randomized complete block design with four blocks. Plots varied from 924 to 1320 ft long (0.85 to 1.21 acres/plot) [281.6 to 402.3 m long (0.344 to 0.490 ha/plot)], and the entire experimental field was about 16 acres (6.5 ha). Actual acreage for each plot was obtained through a global positioning system (GPS). The field was plowed, disced, listed, and laser leveled before planting. At planting, carbofuran insecticide [Furadan 4F (FMC Corp., Philadelphia, Pa.) at 1 qt/acre (2.3 L·ha^{-1})] and metalaxyl fungicide [Ridomil Gold (Syngenta, Greensboro, N.C.) at 2 fl oz/acre (146 mL·ha^{-1})] treatments were applied in the seedbed. The field was furrow irrigated, and crop management followed standard grower practices as recommended by Bosland et al. (1994). Fertilizer [nitrogen at 150 lb/acre (168.1 kg·ha^{-1}) and phosphorus at 100 lb/acre (112.1 kg·ha^{-1})] was broadcast preplant as ammonium phosphate and in the irrigation water as urea and ammonium nitrate. Irrigations were scheduled biweekly until June, and then weekly until September. Weeds were managed with cultivation and hoeing.

Standard red chile and paprika cultivars were chosen, and represented different plant habit and fruit set patterns. 'New Mexico 6-4' is determinate, with a concentrated fruit set of moderately pungent fruit. 'Sonora' is semideterminate, with a concentrated set of mild fruit. 'B-18' and 'B-58' are indeterminate, with dispersed sets of mild ('B-18') or nonpungent fruit ('B-58'). Plots were thinned in late April to a final plant spacing of 5.6 to 6.0 inches (14.22 to 15.24 cm) between plants [26,000 to 28,000 plants/acre (64,245 to 69,187 plants/ha)].

A ripening and defoliating treatment of 1.5 pt/acre ethephon plus 8 lb/acre (9.0 kg·ha^{-1}) sodium chloride was applied 18 d before harvest (28 Sept.), immediately after plant architecture measurements were made, and before the transect and fruit detachment data were collected. On 26 Sept., 20 plants were randomly sampled from each cultivar per block, for a total of 80 plants per cultivar. Plant heights were obtained in the field by measuring from the soil level to the top of the plant. The plants were then clipped at soil level, placed in plastic bags, and transported immediately to the laboratory, where all fruit were removed from the plants. The total number of red fruit and green fruit was recorded. The length of the main stem was measured from the soil line to the major stem branch position, and the diameter of the main stem was measured 0.4 inch (1 cm) above the soil line. The number of basal lateral branches within 3.9 inches (10 cm) of the soil line was counted, the height to the bottom fruit set was recorded, and the angle of the first major stem branch was measured. Three red fruit were randomly selected from each plant (240 fruit per cultivar), and the length and diameter of the pedicel and the fruit were measured. Pedicel length was measured from the top of the pedicel to the top of the calyx, and pedicel diameter was measured at the top of the pedicel where it detached from the plant. Fruit length was measured from calyx to fruit tip, and fruit width was measured at the widest point.

Several days before harvest (12 to 13 Oct.), 15 sampling locations were randomly selected in each plot, for a total of 60 locations per cultivar. Transects [40 × 60 inches (101.6 × 152.4 cm)] were placed over the row at these locations. All of the red fruit on the ground and the green and red fruit on the plants within the transect were counted. Fruit on the ground were removed from the sampling location at this time, and the location was marked for future identification. The day before harvest, fruit detachment force was measured using a digital force gauge (model DFG51; Omega Engineering, Inc., Stamford, Conn.). Measurements were obtained in the peak tension mode, so that the highest force attained when pulling fruit from the plant was recorded. Fully mature fruit were detached from 20 randomly selected plants for each cultivar per block. Three fruit were detached, from the top, middle, and bottom of each plant (three fruit per plant; 240 total fruit per cultivar).

A mechanical harvester (Peter Piper Pepper; McClendon Pepper Co., Tulia, Texas) was used in the trial. The machine is a self-propelled, open double-helix model, four row harvester, with a self-contained collection basket. The Biad Chili Co. (Leasburg, N.M.) received and dehydrated the harvested material. The processor tared harvest bins, and obtained the wet weight of harvested chile, the wet weight of culled chile, and the dry weight of marketable chile for each cultivar per block.

The crop was harvested on 17 to 19 Oct., before the first freeze. The machine operated at a speed of 1 mile/h (1.6 km·h^{-1}) during this test. As the machine harvested each 12-row plot, six samples of harvested material were obtained directly from the collection basket. Six 5-gal (18.9-L) buckets were used to collect this material. These samples were individually bagged and weighed. Twenty red fruit were randomly sampled to determine dry matter content and extractable color using method 20.1 of the American Spice Trade Assoc. (ASTA, 1985). Material sampled from each plot was dried at 130 °F (54.4 °C), and then sorted into categories to describe the quality of the machine harvested chile. The quality data were expressed as the percentage of the total dry weight of the harvested material. The categories included 1) marketable red fruit, 2) diseased and discolored fruit, 3) green fruit, 4) small trash and leaves, and 5) stems and branches. Fruit classified as marketable were red and defect-free, although fruit classified as diseased or discolored sometimes are not removed as culls by the processors.

The contents of the machine's collection hopper was dumped into preweighed bins, keeping material from each plot separate. Total wet weights were obtained at the chile processing plant. Harvested material for each cultivar per block was processed separately to obtain net dry weights for each plot. The processor also weighed the culled fruit and trash from each plot.

Immediately after harvest, the same transect areas sampled before harvest were located to determine the amount of marketable chile left in the field after machine harvest. All of the red fruit left on the plant and on the ground were gathered from the transect areas, counted, and bagged separately. Fresh and dry weights were obtained for these samples. The total number of plants, and the number of lodged or uprooted plants within the transect area were counted at this time.

Results and discussion

CULTIVAR DIFFERENCES. In late September, 'B-18' plants were taller and had a larger main stem diameter as compared to the other cultivars (Table 1). Also, the height to the primary fruit set was greatest for 'B-18' and 'B-58'. 'Sonora' plants had the widest branch angle and 'New Mexico 6-4' had the most narrow branch angle. Wide branch angles have been associated with branch breakage during harvest, whereas narrow branch angles may facilitate machine harvest with less branch breakage (Marshall, 1984b; Wolf and Alper, 1984). All cultivars had a low number of basal branches, especially 'New Mexico 6-4' and 'Sonora' (Table 1). Dry matter content of marketable red fruit was not significantly different among cultivars, and ranged from 25% for 'Sonora' to

Table 1. Plant characteristics of four cultivars of red chile peppers grown in southern New Mexico.[z]

Cultivar	Plant ht (inches)	Main stem length[y] (inches)	Main stem diam (inches)	Basal branches (no.)	Ht to fruit set (inches)	Primary branch angle (degrees)
B18	36.0 ± 0.64	12.6 ± 0.28	0.58 ± 0.014	1.3 ± 0.15	16.7 ± 0.37	41.8 ± 0.99
B58	30.6 ± 0.55	12.7 ± 0.34	0.54 ± 0.013	1.0 ± 0.12	16.2 ± 0.32	40.8 ± 0.96
NM 6-4	28.4 ± 0.58	9.8 ± 0.25	0.54 ± 0.011	0.2 ± 0.05	13.9 ± 0.35	37.3 ± 0.99
Sonora	29.7 ± 0.60	11.5 ± 0.29	0.55 ± 0.010	0.5 ± 0.09	15.5 ± 0.34	44.1 ± 1.02

[z]All values are means of 80 observations ± SE; 1.0 inch = 2.54 cm.
[y]Measured from the soil to the major stem branch position.

Table 2. Fruit characteristics of four cultivars of red chile peppers grown in southern New Mexico.[z]

Cultivar	Red fruit (no./plant)	Green fruit (no./plant)	Pedicel length (inches)[y]	Pedicel diam (inches)	Fruit length (inches)	Fruit width (inches)	Fruit detachment (kg force)[y]
B18	14.1 ± 0.9	6.7 ± 0.6	1.80 ± 0.020	0.18 ± 0.004	5.76 ± 0.04	1.36 ± 0.02	0.33 ± 0.02
B58	15.2 ± 1.0	8.1 ± 1.0	1.84 ± 0.019	0.22 ± 0.003	5.52 ± 0.07	1.36 ± 0.02	0.29 ± 0.01
NM 6-4	13.0 ± 0.7	3.6 ± 0.4	2.06 ± 0.022	0.21 ± 0.004	6.20 ± 0.07	1.72 ± 0.02	0.93 ± 0.10
Sonora	9.5 ± 0.6	3.3 ± 0.3	1.93 ± 0.022	0.22 ± 0.004	7.52 ± 0.10	1.68 ± 0.02	1.30 ± 0.11

[z]All parameters were measured before ethephon treatment, except for fruit detachment force. Red and green fruit numbers per plant are means of 80 plants ± SE. All remaining values are means of 240 observations ± SE.
[y]1.00 inch = 2.540 cm; 1.00 kg force = 9.807 N = 0.454 lb force.

Table 3. Dry weight of preharvest fruit dropped following ethephon application, postharvest fruit left in the field after mechanical harvest, and final marketable yield of mechanically harvested chile peppers received by processor.

Cultivar	Preharvest fruit drop[z] (lb/acre)	Postharvest fruit drop[y] (lb/acre)	Postharvest fruit on plants[x] (lb/acre)	Postharvest yield loss[w] (lb/acre)	Marketable dry yield[v] (lb/acre)	Harvest efficiency[u] (%)
B18	1233.6	592.3	78.2	670.5	1820.2	73.1
B58	1407.8	426.9	61.9	488.8	1418.6	74.4
NM 6-4	462.8	391.1	131.2	522.3	2588.5	83.2
Sonora	92.0	263.0	162.5	425.5	2078.5	83.0
LSD[t]	276.6	183.0	51.5	234.5	474.9	

[z]Dry weight of marketable red fruit dropped on the ground after ethephon application, but before harvest. Values are means of 60 sampling locations; 1.0 lb/acre = 1.12 kg·ha^{-1}.
[y]Dry weight of marketable red fruit dropped on the ground after mechanical harvest. Values are means of 60 sampling locations.
[x]Dry weight of marketable red fruit left on the plant after mechanical harvest. Values are means of 60 sampling locations.
[w]Total marketable yield left in field (on ground and plants) after mechanical harvest. Does not include preharvest fruit drop. Values are means of 60 sampling locations.
[v]Marketable yield at processor. Values are means of four replications.
[u]Calculated from 100 × [marketable dry yield ÷ (marketable dry yield + postharvest yield loss)].
[t]Least significant difference for comparing means within a column ($P \leq 0.05$).

33% for 'B-18'(data not presented). Before ethephon application and harvest, 'B-58' and 'B-18' had the highest number of red and green fruit per plant, followed by 'New Mexico 6-4' and 'Sonora' (Table 2). The longest fruit [7.5 inches (19.10 cm)] were produced on 'Sonora' plants. Correlations between plant habit and harvest efficiency could not be determined accurately in this study, because preharvest fruit drop reduced yields, as discussed below.

PREHARVEST FRUIT DROP. After ethephon application, a large number of red fruit dropped, contributing to yield losses of 1408 lb/acre (1578.1 kg·ha^{-1}) and 1234 lb/acre (1383.1 kg·ha^{-1}) for 'B-58' and 'B-18', respectively (Table 3). 'New Mexico 6-4' dropped 463 lb/acre (518.9 kg·ha^{-1}), and 'Sonora', a late maturing cultivar with large fruit and high stem detachment force (Table 2), had the lowest fruit drop after the ethephon treatment (Table 3).

Fruit detachment forces at harvest were 0.29 and 0.33 kg [2.844 and 3.236 N (0.639 and 0.728 lb force)] for 'B-58' and 'B-18', respectively, illustrating the negative effect that ethephon had on loosening of fruit stems of these cultivars (Table 2). 'B-18' and 'B-58' plants had smaller, narrower fruit on shorter pedicels, and lower fruit detachment forces, than 'New Mexico 6-4' and 'Sonora' (Table 2). Fruit detachment force has been positively correlated with pedicel length and diameter, and fruit length and diameter in other studies (Setiamihardja and Knavel, 1990). Pedicel diameter was not related to fruit detachment force in the present study. 'New Mexico 6-4' had an intermediate detachment force [0.93 kg (9.120 N or 2.050 lb force)], and the greatest harvest efficiency (83.2%) (Table 3). Marshall (1984b) has suggested that a moderate fruit detachment force is most desirable for mechanical harvest of paprika.

LODGING AND UPROOTING. Before harvest, no differences were found among cultivars for the number of lodged plants. Lodging ranged from 1908 plants/acre (4715 plants/ha) for 'New Mexico 6-4' to 2875 plants/acre

(7104 plants/ha) for 'Sonora'. During mechanical harvest, few plants were uprooted by the machine. The number of uprooted plants per acre was 0, 174, 261, and 653 (0, 430, 645, and 1614 per ha) for 'Sonora', New Mexico 6-4', 'B-58', and 'B-18', respectively. Means for 'Sonora' and 'B-18' were significantly different. Uprooting was relatively low, because the crop was direct-seeded and the soil was hilled around the stem bases early in the season to improve plant support.

YIELD. Dry yield of marketable red fruit delivered to the processor was highest for 'New Mexico 6-4', followed by 'Sonora', 'B-18' and 'B-58' (Table 3). Low yield for 'B-18' and 'B-58' was caused by preharvest fruit drop after ethephon application, which proved to be an unadvisable treatment for these cultivars. When the effects of ethephon were discounted, yield loss attributed to fruit remaining on the plant after harvest and dropped on the ground during harvest was similar for all cultivars, except that 'B-18' yield loss was significantly higher than 'Sonora' yield loss (Table 3).

The total marketable dry yield potential, which includes preharvest fruit drop, fruit remaining in the field after harvest, and net yield at the processor, was 3724, 3574, 3315, and 2596 lb/acre (4174.0, 4005.8, 3715.6, and 2909.7 $kg \cdot ha^{-1}$) for 'B-18', 'New Mexico 6-4', 'B-58', and 'Sonora', respectively. 'Sonora', which is usually grown at lower planting densities [10 to 12 inches (25.4 to 30.5 cm) between plants in 36 to 40 inches (91.4 to 101.6 cm) row spacing;14,500 to 16,000 plants/acre (35,829 to 39,535 plants/ha)], had the lowest total marketable yield potential, presumably because 'Sonora' did not set fruit well at the 26,000 to 28,000 plants/acre (64,245 to 69,187 plants/ha) density used in this study. 'New Mexico 6-4' is often grown at a 14,500 to 16,000 plants/acre (35,829 to 39,535 plants/ha) density, but also performed well at the densities used in this study. This may indicate that 'New Mexico 6-4' has more adaptable plant morphology and fruiting characteristics than 'Sonora'.

Harvest efficiency of these cultivars, when considering only the postharvest yield loss and the marketable dry yield at the processor, was 83.2% for 'New Mexico 6-4', 83% for 'Sonora', 74.4% for 'B-58', and 73% for 'B-18' (Table 3). In previous studies, total fruit recovery rates averaged 75% to 90% for red chile (Marshall, 1979) and 70% to 90% for paprika (Wolf and Alper, 1984) using open helix picking units. Highest recovery rates were achieved when field conditions and machine adjustments were optimal (Wolf and Alper, 1984).

QUALITY OF MACHINE HARVESTED CHILE CULTIVARS. Samples removed from the harvest bin as the machine moved through the field were dried and separated into five categories to determine the quality of harvested material, expressed as a percentage of the total dry weight (Table 4). 'B-18' and 'B-58' had the lowest amount (4%) of small trash and leaves, followed by 'New Mexico 6-4' (6%) and 'Sonora' (8%). The percentage of stems and branches was similar among cultivars and ranged from 1.2% for 'B-58' to 2.3% for 'New Mexico 6-4'. The percentage of green fruit culls was highest for 'B-18' (5%) and 'B-58' (3%), because a large number of red fruit dropped to the ground after the ethephon application. Overall, the machine harvested 'Sonora' had the poorest quality, with 31% diseased and discolored fruit and 58% marketable red fruit. 'New Mexico 6-4' had the highest quality harvested crop, with 16% diseased and discolored fruit and 75% marketable red fruit.

These data differ somewhat from the cull data collected at the processing plant (Table 5), where only wet weights were measured and all diseased or discolored fruit were not necessarily removed before dehydration. In this case, marketable fresh weights ranged from 90% to 93% of the total wet weight received at the dehydration facility. This indicates that processors may not have adequate facilities to sort cull fruit for those cultivars that have a high percentage of cull fruit after mechanical harvest. This is further illustrated by the difference in ASTA extractable color determined by the processor on the final marketable yield, as compared to the ASTA color potentials that were determined on only high quality red fruit sampled from the machine bins. At the processor, extractable color values were 138, 124, and 100 ASTA units for 'B-58', 'B-18', and 'Sonora', respectively. 'New Mexico 6-4' was not evaluated. In contrast, samples from the "marketable red fruit" category from the harvest bins had ASTA color potentials of 224, 191, and 218 for 'B-58', 'B-18', and 'Sonora', respectively.

The processor was able to perform remedial cleaning of trash from this harvest and deemed the machine harvested crops acceptable. Significant improvements in trash removal during harvest will be required to produce crop quality similar to hand harvest, although local growers report that when crop conditions are ideal, machine harvested jalapeños and red chile compare favorably to the quality of hand-picked crops. Some producers mechanically harvest their crops until a hard freeze occurs, when plants become brittle and trash content increases in the machine-harvested material. Hand harvest is then used to finish the late crop. Also, the New Mexico Chile Task Force is devel-

Table 4. Quality of mechanically harvested chile peppers grown in southern New Mexico.[z]

	Percent of total dry wt				
Cultivar	Marketable red fruit	Diseased or discolored	Culled green fruit	Small trash and leaves	Stems and branches
B18	72.6	16.5	5.4	4.0	1.5
B58	70.7	21.2	3.2	3.7	1.2
NM 6-4	75.1	15.5	1.3	5.8	2.3
Sonora	57.8	30.9	1.7	7.9	1.8
LSD[y]	5.2	5.0	2.1	2.7	NS[x]

[z]All values are means of 24 observations. Samples were removed directly from the harvester collection bin before the crop was processed.
[y]Least significant difference for comparing means within a column ($P \leq 0.05$).
[x]Means within the column are not significantly different ($P \geq 0.05$).

Table 5. Fresh weight of mechanically harvested chile peppers and cull material received by processor.[z]

Cultivar	Total fresh wt (lb/acre)	Green fruit and branches (lb/acre)	Small trash and leaves (lb/acre)	Net fresh wt[y] (lb/acre)
B18	6171	402	188	5581
B58	5564	415	151	4998
NM 6-4	9745	500	230	9015
Sonora	8781	386	258	8137
LSD[x]	2264	NS[v]	65	2118

[z]All values are means of four replications. Samples were weighed by the processor before dehydration of crop. 1 lb/acre = 1.1 kg·ha^{-1}.
[y]Net marketable fruit fresh weight.
[x]Least significant difference for comparing means within a column ($P \leq 0.05$).
[v]Means within the column are not significantly different ($P \geq 0.05$).

oping improved cleaning and sorting equipment for field and processor operations.

The experiment was harvested entirely on one day, which may have confounded results, relative to waiting for each cultivar to reach optimal maturity before harvest. These cultivars were grown under the same crop management and plant spacing, whereas optimal management and planting density may vary for each cultivar. 'New Mexico 6-4' was at optimal maturity at the time of ethephon application and harvest. The quality of 'Sonora' may have improved if the harvest had been delayed by one or two weeks. 'B-18' and 'B-58' quality was good, considering the preharvest fruit drop observed for these cultivars. The use of ethephon to concentrate fruit maturity, improve harvestability, and increase marketable yield should be determined for each cultivar in multiple environments. Reports vary on the effectiveness of ethephon as a fruit ripening agent for peppers, depending on cultivar, temperature, rate and maturity (Batal and Granberry, 1982; Cantliff and Goodwin, 1975; Cooksey et al., 1994b; Sims et al., 1974). Premature fruit abscission can occur at high concentrations of ethephon (Cantliffe and Goodwin, 1975), although the rate applied by the grower in the current study was within the recommended amounts. Kahn et al. (1997) increased the percentage of marketable red paprika fruit by applying ethephon once to remove late flowers and green fruit. Also, growers in arid regions typically cease irrigation before harvest to promote fruit ripening and drying for once-over harvest. This practice saves energy at the dehydration plant, and increases fruit dry matter content and color intensity (Palevitch et al., 1975). For some cultivars, such as 'B-18' and 'B-58', this field dry-down may be sufficient preparation for mechanical harvest without the use of ethephon.

Conclusions

The marketable dry yield of machine harvested red chile cultivars was highest for 'New Mexico 6-4', followed by 'Sonora', 'B-18' and 'B-58'. Significant preharvest fruit drop occurred for 'B-18' and 'B-58' following ethephon application. 'B-18' and 'B-58' generally are favored by growers for machine harvest, because the plants are upright with a dispersed fruit set. Ethephon treatment is not recommended for these cultivars. 'Sonora' is not suitable for mechanical harvest, because the plants had high stem detachment forces even after ethephon application. In this study, 'New Mexico 6-4' was at an optimal maturity stage for harvest, and had a desirable combination of narrow branch angles and moderate stem detachment force. The harvest efficiency of the four red chile cultivars ranged from 73% to 83%, when considering only the postharvest yield loss and the marketable dry yield at the processor. These results were achieved using existing varieties, standard cultural practices, and minimal cleaning equipment. The machine used in this study is an advanced version of several earlier models. Machine performance was satisfactory and did not appear to limit harvest efficiency. The current focus of researchers and industry groups is on improving cleaning equipment, optimizing crop management, and breeding cultivars for mechanical harvest.

Literature cited

American Spice Trade Association. 1985. Official analytical methods. 3rd ed. Amer. Spice Trade Assn., Englewood Cliffs, N.J.

Batal, K.M. and D.M. Granberry. 1982. Effects of growth regulators on ripening and abscission of pimiento and paprika peppers. HortScience 17:944–946.

Boese, B.N. and D.E. Marshall. 1998. Breeding capsicum for mechanical harvest, Part 1—Genetics. Proc. 10th Eucarpia Meeting on Genetics and Breeding of Capsicum and Eggplant, Avignon, France. 10:41–45.

Bosland, P.W., A.L. Bailey, and D.J. Cotter. 1994. Growing chiles in New Mexico. N.M. State Univ. Coop. Ext. Serv. Guide H–230.

Cantliffe, D.J. and P. Goodwin. 1975. Red color enhancement of pepper fruits by multiple applications of ethephon. J. Amer. Soc. Hort. Sci. 100:157–161.

Cavero, J., R.G. Ortega, and M. Gutierrez. 2001. Plant density affects yield, yield components, and color of direct-seeded paprika pepper. HortScience 36:76–79.

Cooksey, J.R., B.A. Kahn, and J.E. Motes. 1994a. Plant morphology and yield of paprika pepper in response to method of stand establishment. HortScience 29:1282–1284.

Cooksey, J.R., B.A. Kahn, and J.E. Motes. 1994b. Calcium and ethephon effects on paprika pepper fruit retention and fruit color development. HortScience 29:792–794.

Eastman, C., F. McClellan, and T. Bagwell. 1997. Impact of increasing wages on New Mexico chile production. N.M. Agr. Expt. Sta. Res. Rpt. 714.

Garcia, F. 1921. Improved variety No. 9 of native chile. N.M. College Agr. Mech. Bul. 124.

Gentry, J.P., J.A. Miles, and W.W. Hinz. 1978. Development of a chili pepper harvester. Trans. Amer. Soc. Agr. Eng. Paper 77–1026.

Kahn, B.A. 1985. Characterization of lodging differences in paprika pepper. HortScience 20:207–209.

Kahn, B.A., J.E. Motes, and N.O. Maness. 1997. Use of ethephon as a controlled abscission agent on paprika pepper. HortScience 32:251–255.

Lenker, D.H. and D.F. Nascimento. 1982. Mechanical harvesting and cleaning of chili peppers. Trans. Amer. Soc. Agr. Eng. Paper 80–1533.

Marshall, D.E. 1979. Performance of a mechanical pepper harvester. Amer. Soc. Agr. Eng. Paper 79–1062.

Marshall, D.E. 1984a. Mechanized pepper harvesting and trash removal, p. 276–279. Proc. 1st Int. Conf. on Fruit, Nut and Vegetable Harvesting Mechanization, Bet Dagan, Israel. Amer. Soc. Agr. Eng. Publ. 5–84.

Marshall, D.E. 1984b. Horticultural requirements for mechanical pepper harvesting, p. 389–396. Proc. 1st Intl. Conf. on Fruit, Nut and Vegetable Harvesting Mechanization, Bet Dagan, Israel. Amer. Soc. Agr. Eng. Publ. 5–84.

Marshall, D.E. 1986. Recovery and damage of mechanically harvested peppers. Trans. Amer. Soc. Agr. Eng. 29:398–401.

Marshall, D.E. 1997. Designing a pepper for mechanical harvest. Capsicum Eggplant Nwsltt. 16:15–27.

Marshall, D.E. and B.N. Boese. 1998. Breeding capsicum for mechanical harvest, Part 2—Equipment. Proc. 10th Eucarpia Meeting on Genetics and Breeding of Capsicum and Eggplant, Avignon, France. 10:61–64.

Marshall, D.E., M.G. Pickett, and T.A. Esch. 1990. Using air to convey mechanically harvested peppers. Trans. Amer. Soc. Agr. Eng. 33:47–50.

McCullough, M.D., J.E. Motes, and B.A. Kahn. 1995. Soil bedding treatments improve pepper plant anchorage. HortScience 30:1202–1204.

New Mexico Agricultural Statistics Service. 2000. New Mexico agricultural statistics. N.M. Dept. Agr., Las Cruces.

Palevitch, D.S. Harel, J. Kanner, and I. Ben-Gera. 1975. The effects of pre-harvest dehydration on the composition of once-over harvested sweet paprika. Scientia Hort. 3:143–148.

Palevitch, D. and A. Levy. 1984. Horticultural aspects of mechanized sweet pepper harvesting, p. 397–403. Proc. 1st Int. Conf. on Fruit, Nut and Vegetable Harvesting Mechanization, Bet Dagan, Israel. Amer. Soc. Agr. Eng. Publ. 5–84.

Setiamihardja, R. and D.E. Knavel. 1990. Association of pedicel length and diameter with fruit length and diameter and ease of fruit detachment in pepper. J. Amer. Soc. Hort. Sci. 115:677–681.

Sims, W.L., D. Ririe, R.A. Brendler, M.J. Snyder, D.N. Wright, V.H. Schweers, and P.P. Osterli. 1974. Factors affecting ethephon as an aid in fruit ripening of peppers. Calif. Agr. 28(6):3–4.

Wolf, I. and Y. Alper. 1984. Mechanization of paprika harvest, p. 265–275. Proc. 1st Int. Conf. on Fruit, Nut and Vegetable Harvesting Mechanization. Bet Dagan, Israel. Amer. Soc. Agr. Eng. Publ. 5–84.

Resistance of Hosta Cultivars to Petiole Rot Caused by *Sclerotium rolfsii* var. *delphinii*

Brooke A. Edmunds,
Mark L. Gleason, and
Stephen N. Wegulo

ADDITIONAL INDEX WORDS. **soilborne diseases, herbaceous perennials**

SUMMARY. **Eighteen cultivars of hosta (*Hosta* spp.), selected to represent a wide range of size, leaf shape and color, and genetics, were evaluated for reaction to *Sclerotium rolfsii* var. *delphinii* in a greenhouse in Ames, Iowa in 2000 and 2001. Bare-root, single-eye plants were planted in 15.2-cm (6-inch) pots in a soil-containing (2000) and soilless (2001) mix and grown in a greenhouse for 3 months. Plants were then inoculated by placing a carrot disk infested with mycelium of *S. rolfsii* at the base of the plant. Disease severity was assessed weekly for 6 weeks as percent symptomatic petioles. Disease development varied significantly ($P < 0.05$) among cultivars. Overall, 'Lemon Lime', 'Munchkin', 'Nakaiana', 'Platinum Tiara', and 'Tardiflora' had the most severe symptoms and 'Halcyon' showed the least disease.**

Petiole rot of hosta was once thought to be confined to the southern U.S. Increasing reports of petiole rot in the midwest U.S. during the past decade, however, have caused concern among wholesale producers and homeowners.

Petiole rot, which has many other common names including southern blight, white mold, stalk rot, and crown rot, is caused by one of two fungi depending on location. *Sclerotium rolfsii is* widespread in areas with warm temperate winters such as the southern U.S (Aycock, 1966). A closely related fungus, *Sclerotium rolfsii* var. *delphinii*, is tolerant of cooler temperatures and is found in the northern and midwestern U.S (Harlton et al., 1995). This geographic distribution pattern has been noted through an informal survey of plant pathologists, but a comprehensive assessment of disease distribution has not been done.

The taxonomic status of *Sclerotium rolfsii* var. *delphinii* is not fully resolved. Although it was initially considered to be a separate species, *Sclerotium delphinii*, recent genetic studies suggest that the fungus should be considered a subspecies, *Sclerotium rolfsii* var. *delphinii* (Harlton et al., 1995; Okabe et al., 1998). In another study, Sclerotium rolfsii differed from *Sclerotium rolfsii* var. *delphinii* in optimal growth temperature, host range, colony morphology, and size of sclerotia (Punja and Damiani, 1996). Further studies are needed to conclusively determine the taxonomic designation of this fungus (Harlton et al., 1995; Okabe et al., 1998; Punja and Damiani, 1996). In any case, both fungi produce similar symptoms on hosta and are managed similarly.

Sclerotium rolfsii var. *delphinii* attacks the base of petioles and crown tissue, causing yellowed, wilted, easily detached petioles and, in severe cases, death of entire crowns (Edmunds et al., 2000). Bases of diseased petioles become brown and softened. White mycelium may occur on either the plant tissue or the surface of the surrounding soil. Sclerotia, the overwintering bodies of the fungus, will be present as numerous, 1.1- to 2-mm-diameter (0.04- to 0.08-inch), reddish-brown spheres on the soil or infected tissues. Sclerotia are the most important diagnostic indicator of petiole rot, and enable the fungus to survive in the soil for two or more years (Javed and Coley-Smith, 1973). Sclerotia attached to the crowns are also probably the primary means of long-distance dissemination.

Management of petiole rot is usually directed at preventing dissemination and germination of the sclerotia. Fungicides such as flutolanil and pentachloronitrobenzene (PCNB) can be used, but large volumes are typically necessary (Edmunds et al., 2000; Punja, 1985). Cultural strategies, such as deep burial of the sclerotia and infected plant material and rotation to nonhost species, are only partially effective in managing hosta petiole rot (Punja, 1985). Information on levels of genetic resistance among hosta cultivars is almost nonexistent. Anecdotal

Department of Plant Pathology, Iowa State University, 351 Bessey Hall, Ames IA 50010.