



# Yield and Quality of Machine-Harvested Red Chile Peppers

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In November 1998, the New Mexico Chile Task Force was formed to identify and implement ways to keep chile pepper production profitable in New Mexico and to maintain and enhance the research and development partnership between the New Mexico chile industry and New Mexico State University.

Chile Task Force reports will be issued periodically to consider issues of concern to the industry and to document the Task Force's progress in developing techniques and technologies to improve industry competitiveness in the 21<sup>st</sup> century global trade environment.



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**Report 3:** Yield and Quality of  
Machine-Harvested Red Chile Peppers



# Yield and Quality of Machine-Harvested Red Chile Peppers<sup>1,2</sup>

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## Introduction

Chile peppers (*Capsicum annuum L.*) are a major crop in the southwestern United States, especially in southern New Mexico, western Texas and southeastern Arizona. Several chile types are grown regionally, including long, green chile for fresh market and canning; dried, red chile for pungent powder, paprika and oleoresin; jalapeños; and cayenne peppers. Fabian Garcia developed the modern chile pepper at New Mexico State University (Garcia, 1921). Today, New Mexico is the Southwest's chile processing center. In addition, New Mexico growers produced approximately 19,000 acres (7,695 ha) of chile during 2000 (New Mexico Agricultural Statistics Service, 2000).

During the last decade, the high cost of hand labor in the region, compared with that of competing Latin American, African and Asian markets, has threatened the Southwestern chile industry. To sustain the industry, growers increasingly favor mechanical harvesting of chile crops. Innovative growers, custom harvesters and equipment manufacturers are developing chile harvest machines with promising results (fig. 1). However, information is lacking on agronomic performance of chile cultivars for machine harvest, yields and quality of



Figure 1. Peter Piper pepper harvester, manufactured by McClendon Pepper Co., Tulia, Texas, used to harvest chile for this trial.

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machine-harvested chile, and best management practices for producing chile intended for machine harvest.

## Mechanical harvesting history and research

In the 1970s, experimental chile harvesters were developed that included picking heads and collecting, cleaning and fruit transporting components. Ernest Riggs, of Las Cruces, N.M., built a pepper harvester for Cal-Compac Foods that was used during 1976 (Gentry, Miles and Hines, 1978). Many different picking mechanisms have been tested, including spring-tines (Gentry et al., 1978), rubber-finger rakes (Lenker and Nascimento, 1982), open double-helices 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, using 30 different pepper removal concepts to harvest at least 20 different pepper types. Use of the open double-helix, rubber-finger rake and forced-balanced shaker harvester types is expanding in the Southwest.

The different picking mechanisms all work fairly well, depending on crop condition and machine adjustments. Equipment is being improved to reduce the number of fruits dropped on the ground during harvest. Recovery rates of marketable fruits range between 70-90% of full yield potential, with losses attributed to dropped and damaged fruit (Lenker and Nascimento, 1982; Marshall, 1986; Wolf and Alper, 1984). Removing 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, Picket and Esch, 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, Miles and Hinz, 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 significantly influences 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, Orton and Gutierrez, 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 deeper root systems, fewer branches and less lodging and uprooting than transplants (Kahn, 1992). Hilling soil around the base of plants during weed cultivation reduces lodging and uprooting during machine harvest (Boese and Marshall, 1998; Marshall, 1984b).

Several chile cultivar characteristics improve machine harvest. These include 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). Fewer basal branches near the soil surface reduce branch breakage during mechanical harvest (Palevitch and Levy, 1984). Cultivars that have larger stem diameters are less susceptible to lodging (Kahn, 1985).

## Yield and quality of machine-harvested red chile pepper

During the 2000 season, we conducted a large-scale trial to investigate the effect of an ethylene-releasing compound (ethephon) and machine harvest on yield, harvest efficiency and quality of four red chile cultivars commonly grown in the Southwest and dehydrated for paprika or mild red chile powder. Yield and quality of the cultivars were compared following mechanical harvest and dehydration.

## Materials and methods

Plots were seeded in March 2000 with 5 lbs/acre ( $\approx$  5.6 kg/ha) seed in a single line on 40-inch (102-cm) 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 1,320 ft long (0.85-1.21 acres/plot). The entire experimental field was about 16 acres (6.5 ha). Actual acreage for each plot was obtained through a global positioning (GPS) satellite system.

Standard red chile and paprika cultivars, which represented different plant habit and fruit set patterns, were chosen. '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 (fig. 2). 'B-18' and 'B-58' are indeterminate with dispersed sets of mild ('B-18') or nonpungent fruit ('B-58') (fig. 3). Plots were thinned in late April to a final plant spacing of 5.6 to 6.0 inches (14.2 to 15.2 cm) between plants (26,000-28,000 plants/acre). The field was furrow irrigated and crop management followed normal grower practices as recommended by Bosland, Bailey and Cotter (1994).

A single ripening and defoliating treatment of 1.5 pts/acre ethephon plus 8 lbs/acre sodium chloride was applied 18 days before harvest (Sept. 28), immediately after plant architecture measurements were made and before the transect and fruit detachment data were collected. On Sept. 26, 20 plants from each cultivar were randomly sampled 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 then were clipped at soil level, placed in plastic bags and transported



Figure 2. 'Sonora' with leaves removed to show branching habit and concentrated fruit set.

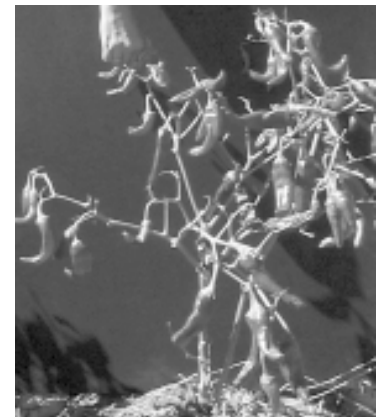


Figure 3. 'B-58' with leaves removed to show branching habit and dispersed fruit set.



Figure 4. Example of a 40 x 60 in. transect used to collect chile samples at 15 randomly selected locations in each of four plots.

immediately to the laboratory, where all fruits were removed from the plants. The total number of red and green fruits was recorded. The main stem's length was measured from the soil line to the major stem branch position, and the diameter of the main stem was measured 0.5 inch (1.3 cm) above the soil line. Researchers counted the number of basal lateral branches within 4 inches (10 cm) of the soil line, recorded the height to the bottom fruit set and measured the angle of the first major stem branch. Three red fruits were selected randomly from each plant (a total of 240 fruits per cultivar) and the pedicels' and fruits' lengths and widths were measured. Pedicel length was measured from the top of the pedicel to the top of the calyx. 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 prior to harvest (Oct. 12-13), 15 sampling locations were selected randomly in each plot, for a total of 60 locations per cultivar. Transects (40 x 60 inches) were placed over the rows at these locations (fig. 4). Researchers counted all of the red fruits on the ground and the green and red fruits on the plants within the transects. Fruits on the ground were removed from the sampling location at this time, which was marked for future identification.

The day before harvest, fruit detachment force was measured using an Omega 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 fruits were detached from 20 randomly selected plants for each cultivar per block. Three fruits were detached from the top, middle and bottom of each plant.

A Peter Piper Pepper harvester (McClendon Pepper Co., Tulia, Texas) was used to harvest the chile during this trial. The machine is a self-propelled, open double-helix, 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 Oct. 17-19, prior to the first freeze. The machine operated at a speed of 1 mph during this test. As the machine harvested each 12-row plot, researchers collected six samples of harvested material directly from the collection basket using six 5-gallon buckets. These samples were bagged and weighed individually. Twenty red fruits were sampled randomly to determine dry matter content and extractable color using method 20.1 of the American Spice Trade Association (ASTA) (1985). Material harvested from each plot was dried at 130°F

(54°C) and sorted into categories to describe the quality of the machine-harvested chile. The quality data were expressed as percentages of the harvested material's total dry weight. The categories were marketable red fruit, diseased and discolored fruit, green fruit, small trash and leaves, and stems and branches. Fruits classified as marketable were red and defect free, although fruits classified as diseased or discolored are not always culled by processors.

The machine's collection hopper contents were 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 fruits 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 areas were counted at this time.

**Table 1. Plant characteristics of four red chile cultivars grown in southern New Mexico.**

Cultivar	Plant height (in.)	Main stem length (in.)	Main stem diameter (in.)	Basal branches (no.)	Height to fruit set (in.)	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

All values are means of 80 observations ± standard error.

**Table 2. Fruit characteristics of four red chile pepper cultivars grown in southern New Mexico.**

Cultivar	Red fruit (no./plant)	Green fruit (no./plant)	Pedicle length (in.)	Pedicle width (in.)	Fruit length (in.)	Fruit width (in.)	Fruit detachment force (kg)
'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 64'	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

All values are means of 80 observations ± standard error. All parameters were measured before ethephon treatment, except for fruit detachment 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 <sup>z</sup> (lb/acre)	Postharvest fruit drop <sup>y</sup> (lb/acre)	Postharvest fruit on plants <sup>x</sup> (lb/acre)	Postharvest yield loss <sup>w</sup> (lb/acre)	Marketable dry yield <sup>v</sup> (lb/acre)	Harvest efficiency <sup>a</sup> (%)
'B18'	1,233.6	592.3	78.2	670.5	1,820.2	73.1
'B58'	1,407.8	426.9	61.9	488.8	1,418.6	74.4
'NM 6-4'	462.8	391.1	131.2	522.3	2,588.5	83.2
'Sonora'	92.0	263.0	162.5	425.5	2,078.5	83.0
LSD <sup>d</sup> (0.05)	276.6	183.0	51.5	234.5	474.9	

<sup>z</sup>Dry weight of marketable red fruit dropped on the ground after ethephon application but before harvest. Values are means of 60 observations.

<sup>y</sup>Dry weight of marketable red fruit dropped on the ground after mechanical harvest. Values are means of 60 observations.

<sup>x</sup>Dry weight of marketable red fruit left on the plant after mechanical harvest. Values are means of 60 replications.

<sup>v</sup>Total marketable yield left in field (on ground and plants) after mechanical harvest. Does not include preharvest fruit drop.

Values are means of 60 replications.

<sup>w</sup>Marketable yield at processor. Values are means of four replications.

<sup>a</sup>Calculated from:  $100 \times [\text{marketable dry yield} / (\text{marketable dry yield} + \text{postharvest yield loss})]$ .

<sup>d</sup>Least statistical difference.

## Results and discussion

**Cultivar differences.** In late September, 'B-18' plants were taller and had larger main stem diameters 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 angles, and 'New Mexico 6-4' had the narrowest. 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. It ranged from 25% for 'Sonora' to 33% for 'B-18'. Prior to ethephon application and harvest, 'B-58' and 'B-18' had the highest number of red and green fruits per plant, followed by 'New Mexico 6-4' and 'Sonora' (table 2). The longest fruits (7.52 in.) 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 fruits dropped, contributing to yield losses of 1,408 lbs/acre ( $\approx 1,577$  kg/ha) and 1,234 lbs/acre ( $\approx 1,382$  kg/ha) for 'B-58' and 'B-18', respectively (table 3). 'New Mexico 6-4' dropped 463 lbs/acre ( $\approx 519$  kg/ha). '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 0.29-0.33 kg for 'B-58' and 'B-18', respectively, illustrating the negative effect that ethephon had on loosening the

**Table 4. Quality of machine-harvested chile peppers grown in southern New Mexico.**

Cultivar	Percent of total dry weight				
	Marketable red fruit	Diseased or discolored	Culled or 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 <sup>1</sup> (0.05)	5.2	5.0	2.1	2.7	NS <sup>2</sup>

All values are means of 24 observations. Samples were removed directly from the harvester collection bin before the crop was processed.

<sup>1</sup>Least statistical difference.

<sup>2</sup>Not studied.

cultivars' fruit stems (table 2). 'New Mexico 6-4' had an intermediate detachment force (0.93 kg) and the greatest harvest efficiency (83.2%) (table 3). Marshall (1984b) suggested that a moderate fruit detachment force is most desirable for mechanical paprika harvest.

**Lodging and uprooting.** Before harvest, no differences were found among cultivars for the number of lodged plants. Lodging ranged from 1,908 plants/acre (4,713 plants/ha) for 'New Mexico 6-4' to 2,875 plants/acre (7,101 plants/ha) for 'Sonora'. During mechanical harvest, the machine uprooted few plants. The number of uprooted plants per acre was 0, 174, 261 and 653 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.

**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 stems and branches percentages were 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 fruits dropped to the ground after the ethephon application. Overall, the machine-harvested 'Sonora' had the poorest quality, with 31% diseased and discolored fruits and 58% marketable red fruits. 'New Mexico 6-4' had the highest quality harvested crop with 16% diseased and discolored fruits and 75% marketable red fruits.

These data differ somewhat from the cull data collected at the processing plant (table 5), where only wet weights were measured and not all diseased or discolored fruits were removed prior to dehydration. In this case, marketable fresh weights ranged from 90% to 93% of the total fresh weight received at the dehydration facility. This

**Table 5. Fresh weight of machine-harvested chile peppers and cull material received by processor.**

Cultivar	Total fresh weight (lb/acre)	Green fruit and branches (lb/acre)	Small trash and leaves (lb/acre)	Net fresh weight (lb/acre)
'B18'	6,171	402	188	5,581
'B58'	5,564	415	151	4,998
'NM 6-4'	9,745	500	230	9,015
'Sonora'	8,781	386	258	8,137
LSD <sup>1</sup> (0.05)	2,264	NS <sup>2</sup>	65	2,118

All values are means of four replications. Processor weighed samples before crop dehydration.

<sup>1</sup>Least statistical difference.

<sup>2</sup>Not studied.

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.

'New Mexico 6-4' was at optimal maturity in this field at the time of ethephon application and harvest. The quality of 'Sonora' may have improved if harvest had been delayed one to two weeks. The quality of 'B-18' and 'B-58' was good, considering the preharvest fruit drop observed for these cultivars.

**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 ethephon's effects were discounted, yield loss attributed to fruit that remained on the plant after harvest and that dropped on the ground during harvest was similar for all cultivars. However, '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 3,724, 3,574, 3,315 and 2,596 lbs/acre ( $\approx$ 4,171, 4,003, 3,713 and 2,908 kg/ha) for 'B-18', 'New Mexico 6-4', 'B-58' and 'Sonora', respectively. 'Sonora', which usually is grown at lower planting densities (10-12 in. between plants in 36-40 in. row spacing; 14,500-16,000 plants/acre), had the lowest total marketable yield potential, presumably because 'Sonora' did not set fruit well at the 26,000-28,000 plants/acre density used in this study. 'New Mexico 6-4' often is grown at a 14,500-16,000 plants/acre density, but it 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, relative to '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). Low harvest efficiency of 'B-18' and 'B-58' is attributed to preharvest fruit drop after the ethephon application.

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. However, local growers report that when crop conditions are ideal, machine-harvested jalapeños and red chile compare favorably to the quality of hand-picked crops.

The experiment was harvested entirely on one day, which may have confounded results relative to waiting for each cultivar to reach optimal maturity prior to harvest. These cultivars were grown under the same crop management and plant spacing, whereas optimal management and planting density may vary for each cultivar. For instance, ethephon application seemed to improve the harvestability and net yield of 'Sonora' and 'New Mexico 6-4', but significantly reduced net yield of 'B-18' and 'B-58'.

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