New Mexico Chile Task Force ♦ Report 25

Design and Development of a Prototype Mechanical Gap Sorter for Mechanically Harvested Red Chile

College of Agriculture and Home Economics
Cooperative Extension Service • Agricultural Experiment Station

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 21st century global trade environment.

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Design and Development of a Prototype Mechanical Gap Sorter for Mechanically Harvested Red Chile [1,2]

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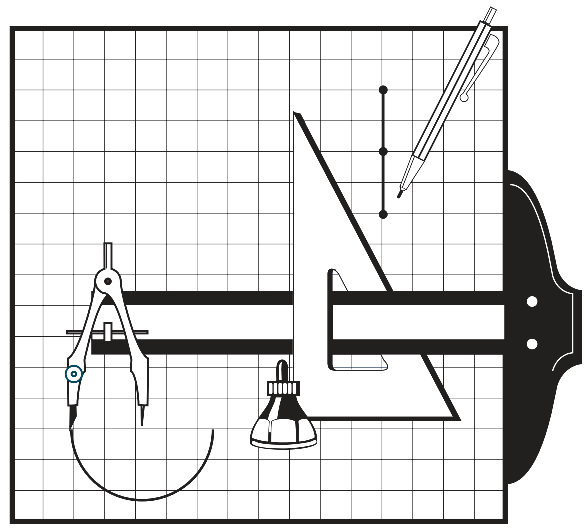

Introduction

At its inception in 1998, the New Mexico Chile Task Force identified widespread adoption of machine harvest technologies as the change most needed to ensure red chile industry survival. Mexican imports, significantly cheaper than U.S. product due to lower hand-labor costs, were threatening the existence of the U.S. industry (Diemer, Phillips & Hillon, 2001). While machine harvesters for red chile were available commercially, their performance was unacceptable to processors because of the volume of trash and sticks that they harvested along with marketable chile pods. Methods existed to remove leaves, dirt, rocks and some short sticks, but longer sticks remained a significant liability.

In October 2001, the task force asked the NMSU College of Engineering's Manufacturing Technology and Engineering Center (M-TEC) to assist in developing an effective mechanical cleaner. M-TEC accepted the project to further its mission of supporting economic development in New Mexico through technical assistance. This report describes the initial development and testing of a prototype gap-belt chile sorter by M-TEC and subsequent testing by task force engineers.

2002 Status of Mechanical Chile Cleaning Technology

The chile industry has employed a number of cleaning methods to remove trash from mechanically harvested chile. The card cleaner is the most successful, used by most processors and is part of three commercial chile harvesting machines. As plastic squares mounted on multiple rotating shafts convey harvested chile across the card cleaner, small-size trash falls through the spaces between the shafts and squares. Task force researchers, working with engineers at the USDA, ARS Southwestern Cotton Ginning Research Laboratory (USDA)

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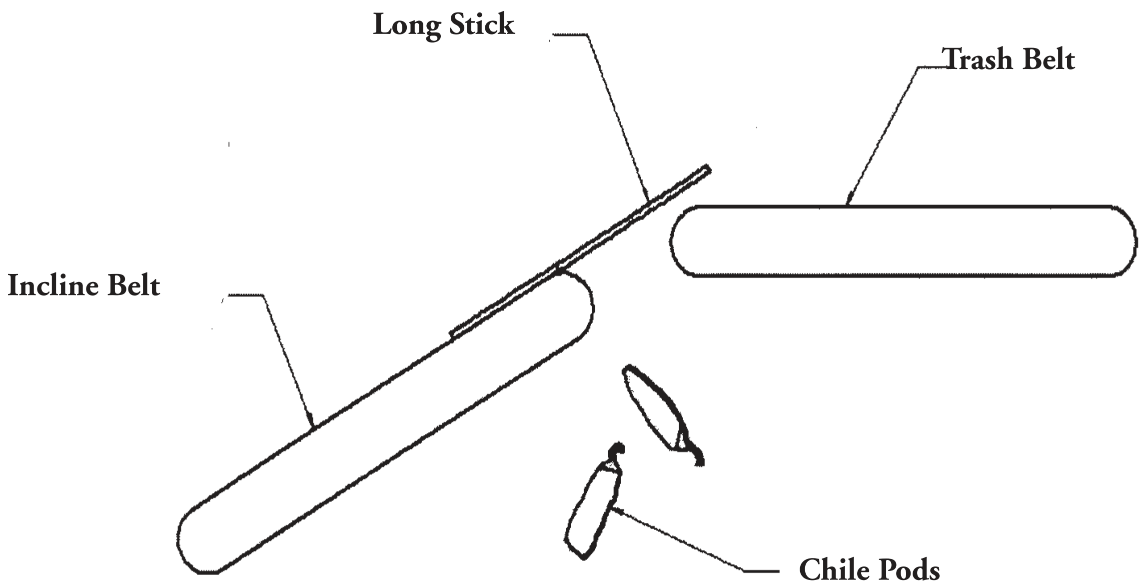

Figure 1. The gap-belt concept

in Las Cruces, experimented with the spacing between the spinning squares. Increasing the spacing from 0.625 inches to 1.625 inches allowed whole plants and sticks with multiple pods attached to be conveyed off the table, while pods and trash smaller than pods fell through the gaps (Abernathy & Hughs, 2002b). However, long straight sticks tended to turn vertically and fall through the spacing along with the pods.

Less common than card cleaners are air blowers, finger rakes and counter-rotating rollers. Success of these methods varies with moisture content of harvested material. Air blowers force a stream of air across harvested material as it falls from a conveyor, diverting lighter material such as leaves into a different container. The air blower method has acceptable results for separating leaf material and pods gutted by insect infestation, but it has not been effective for sorting heavier types of trash (Joel Tellez, personal communication, June 11, 2002). USDA researchers conducted experiments to determine if an air blower could be used to sort sticks from pods based on their relative cross section to the airflow and relative masses. The results were inconclusive, with varying rates of separation effectiveness (Abernathy and Hughs, 2002a). Finger rakes use bolts protruding outward from three counter-rotating drums to strip pods from sticks. Counter rotating rollers detach pods from sticks as harvested material is conveyed through spring-loaded, counter-rotating, rubber-studded rollers operating at 100 rpm.

In 2002, under the auspices of the task force, M-TEC engineers developed a prototype centrifugal blower that combined centrifugal force and an air stream to separate the material within a cylindrical container. In three trials of three random batches of machine-harvested red chile, the prototype failed to adequately sort the material (Herbon, 2003). It was felt that additional concepts should be researched in an attempt to find an acceptable chile cleaning process. It was decided that the machine should address stages of the cleaning process that were not adequately addressed by current cleaning methods. These include sticks that were long and straight as well as sticks that were the same size as chile pods.

The Gap-Belt Concept

In the gap-belt sorter conceptualized by M-TEC engineers, an inclined belt would move harvested material “uphill” toward a second “trash” belt. Material would be oriented parallel to the direction of travel on the belt. Pods would fall through a gap between the inclined belt and the trash belt, while sticks that were longer than the gap between the belts would travel onto the trash belt (fig. 1). The gap belt requires all of the material to be oriented in the same way.

Gap-Belt Design

Researchers decided that the incline belt feeding the gap should be at the maximum possible angle to allow the force of gravity to be overcome by the normal force exerted by the belt. The sticks and pods would be held on the incline belt longer, increasing the possibility of sticks transferring to the trash belt.

The gap belt was designed for ease of testing and manufacture. It allowed adjustment of the horizontal gap distance from 0-10 inches to accommodate different pod sizes. It also allowed the drop-off point from the incline belt to be adjusted over a range of 5 inches above to 5 inches below the pickup for the trash belt. The angle of the incline belt -- the belt feeding the gap -- was designed to be completely adjustable from an angle of 0° to 50° to the horizontal. USDA research showed that the maximum angle at which chile pods would stick to a belt without sliding downhill was 30°. This angle varies according to the material’s moisture content.

The end of the trash belt at the gap interface received special design consideration. It was necessary to ensure that all sticks coming in contact with the belt would be pulled to the trash side. This was accomplished by using the smallest size roller available. Using a small roller increased the number of possible alignments between the incline belt and the trash belt. The factor limiting how small the roller could be was the tightest radius that the food grade conveyor belting and the clips that held the belting together could handle. The manufacturer of the belting recommended a 2-inch diameter minimum roller.

The initial attempt to orient the material in the same way featured use of a conveyor of multiple V-belts, with alternating V-belts traveling at different speeds. This method of alignment has been shown to work in bell pepper processing plants because the faster belt causes one end of the material to be grabbed and pulled while the other end is held in place by the slower belt. This occurs until the material rests solely on either a fast or slow belt and is aligned parallel to the direction of travel (Vince Hernandez, Biad Chili, personal communication, July 16, 2002). To accomplish the speed belt differential, while having a uniform interface at the gap, the shaft at the upper end of the incline had 27 idler pulleys. Bearings pressed into each idler pulley allowed them to spin independently. Two shafts at the bottom of the incline drove the belts. The shafts were set several inches apart, with pulleys set-screwed for every other belt. The belts that were attached to the rear drive shaft were slightly longer than those attached to the front drive shaft. The drive system of the gap belt was designed in accordance with ASAE 211.5 standard for V-belt drives for agricultural machines (American Society of Agricultural Engineers, 2001). A ½-horsepower, variable speed, 180 VDC motor powered each drive shaft.

Strips of Ultra High Molecular Weight (UHMW) plastic were used on the underside of the belts to maintain tension. These strips were crowned so that the belts in the center of the conveyor system were 0.75 inches higher than the belts at the outside of the system. Grooves for each belt were milled in UHMW plastic to keep the alignment of the V-Belts consistent over the entire width.

Integration of the Design Elements

For the purposes of testing, a machine was designed that could be coupled with an electronic color sorter (Herbon, Abernathy and Siddiaih, 2005) and the experimental tumbler cleaning station built by USDA researchers.

The USDA cleaning station features a box dumper that feeds material into the cleaning system. The box dumper turns over a 4 feet x 4 feet x 4 feet, 1,200-pound box of chile to dump its contents. The material flow then is regulated into the cleaning system by a draper, an 8-feet wide metal conveyor that has layering tongs which maintain a constant flow of material into the system. The material travels down a chute to a modified card cleaner with spacing between the rotating squares of 1.625 inches. This gap is large enough to allow the pods and small trash to fall through the spaces while the larger trash and attached pods are conveyed off the end to a trash collection point. The pods that fall through the spaces land on a standard card cleaner (with a spacing of 0.625 inches). This spacing allows small debris and leaves to fall through to a trash collector, while the pods are conveyed off the end of the table. Lastly, pods land on an inclined, cleated belt where they can be conveyed into another box.

The cleaning system developed for the current project took the place of the final collection box on the USDA system. The USDA incline belt dumped the material onto the 24-inch incline belt of the M-TEC-designed gap sorter. Once the material was deposited on the incline belt, the varying speed V-belts aligned it and conveyed it toward the gap. At the gap, the long sticks traveled onto the trash belt that is set apart from the incline belt, while the pods and remaining small trash fell through the gap. The material that fell through the gap landed on a spreader shield, designed to spread the material across the entire 40-inch span of a color sorter belt. (For results of color-sorter testing, see Herbon, Abernathy and Siddiaih, 2005.)

Testing

A standard testing procedure was set up for the gap sorter, using chile pods longer than 6 inches and sticks longer than 8 inches. Twenty batches of machine-harvested chile were sorted using the prototype machine.

The chile-sorting machine testing began with batches, each weighing 10 pounds, randomly taken from the collected material and placed into a bucket. Short sticks were removed from the batches because the gap sorter was not designed to remove them. All sticks with attached pods were removed from the sample before testing so as not to skew results, should the pods become unattached during the test.

A conveyor belt was used to feed batches of material into the chile sorting system at a constant flow rate. Any material that moved onto the trash belt was considered rejected, while material that fell through the gap was considered accepted. The accepted and rejected materials were counted and the amounts of each type of material recorded.

Prior to running the batches, the machine variables (table 1) were optimized in the following order:

1. Incline angle. We hypothesized that the greater the angle of the belt, the longer the time that sample material, both pods and sticks, would be in contact with the belt due to the decreased vertical component to the normal force. In this light, the angle was set to the maximum possible in which the coefficient of static friction between the pods and sticks with the V-belts was great enough to overcome the force of gravity attempting to slide the material downhill.

2. Incline belt speeds. The motor driving the faster alternating V-belts was set, then the slower motor was adjusted until it provided the optimum amount of straightening effect. This was determined by dropping random sticks and chile pods onto the incline belt until the majority of them became oriented in the belt's direction of travel.

3. Gap distances. The gap is the critical variable for successful gap-belt sorter functioning. However, gap size depends on the speed of the incline belt because, as the speed of the incline belt increases, the material velocity and trajectory increase. The vertical drop-off point on the incline belt was set slightly above the catch point on the trash belt to give the longer material a better chance of being caught by the trash belt. The horizontal gap was set by trial and error by placing different length pods and sticks on the operating incline belt, adjusting the gap until the majority of the sticks longer than the pods were reaching the trash belt and the majority of the pods were falling through the gap.

4. Trash belt speed. The speed was adjusted until the majority of the material that touched it was caught and conveyed by it. It was found that when the belt was moving too slowly, material that contacted it would briefly touch it and then fall through the gap. When the trash belt moved too quickly, the material that contacted it would be thrown into the air, flipped over and land back on the incline belt or fall through the gap (table 1).

Table 1. Variables used in the testing of the gap belt.

Variable	Measurement
Slow belt speed	171 FPM
Fast incline belt speed	335 FPM
Vertical gap distance	7 inches
Horizontal gap distance	6 inches
Trash belt speed	437 FPM

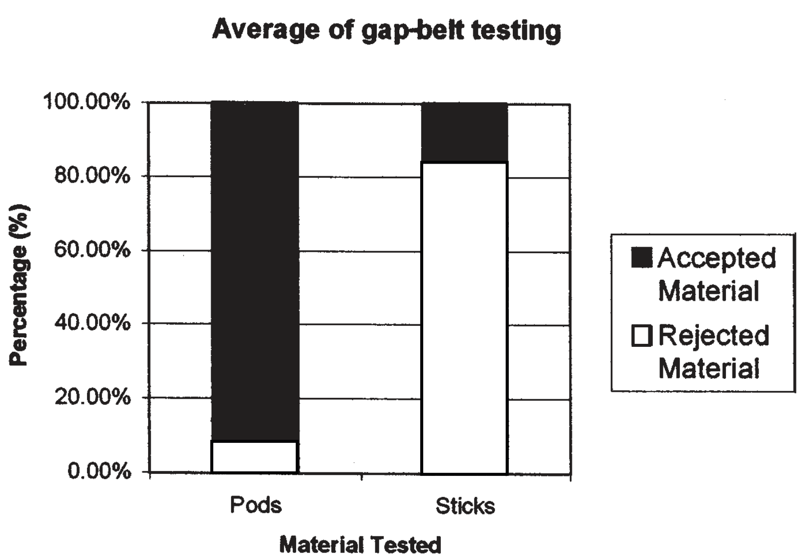

Figure 2. Average results of gap-belt testing.

Table 2. Gap-belt results for removal of sticks longer than 8 inches.

Batch	Sticks Accepted	Sticks Rejected	Percent Sticks Removed
1	6	23	79.31%
2	8	29	78.38%
3	4	24	85.71%
4	4	24	85.71%
5	6	23	79.31%
6	5	20	80.00%
7	8	29	78.38%
8	3	27	90.00%
9	2	19	90.48%
10	7	22	75.86%
11	6	26	81.25%
12	4	32	88.89%
13	6	18	75.00%
14	8	24	75.00%
15	4	26	86.67%
16	6	23	79.31%
17	1	22	95.65%
18	3	27	90.00%
19	2	16	88.89%
20	4	23	85.19%
		Average	**83.45%**
		Standard Deviation	**6.01%**

Table 3. Gap-belt results of chile pods (small sticks removed).

Batch	Pods Accepted	Pods Rejected	Percent Pod Loss
1	11	1	8.33%
2	15	2	11.76%
3	11	1	8.33%
4	16	2	11.11%
5	11	1	8.33%
6	16	3	15.79%
7	9	1	10.00%
8	11	0	0.00%
9	10	2	16.67%
10	8	0	0.00%
11	13	1	7.14%
12	15	0	0.00%
13	11	2	15.38%
14	19	2	9.52%
15	10	1	9.09%
16	14	3	17.65%
17	19	0	0.00%
18	17	3	15.00%
19	14	1	6.67%
20	16	0	0.00%
		Average	**8.54%**
		Standard Deviation	**5.99%**

Results

Data collected through testing the gap belt were used primarily to determine whether the concepts worked well enough to merit further development effort.

In the gap-belt tests, the device rejected 83 percent of sticks with a standard deviation of 6 percent (table 2, fig. 2). This was done with pod loss of 9 percent, with a standard deviation of 6 percent (table 3, fig. 2)

Several observations were made during the gap-belt testing. Foremost was that the sticks' orientation was the key factor in how effectively the cleaner functioned. Sticks that were aligned parallel to the direction of travel were, for the most part, rejected, while those that were not properly aligned were accepted. It also was noted that the sticks that curved down toward the belt seemed to feed through the gap with the "accepted" material, whereas those that curved upward went onto the trash belt.

Two problems were identified during testing in 2002. The variable speed V-belts did not provide the straightening effect required for the gap to work as intended. The belts worked well for heavy, uniformly shaped objects such as screwdrivers but did not straighten all of the chile material. However, testing continued despite this problem, since the gap-belt results had been deemed most important in the test, not the alignment method.

Also, it was found that the strips of Ultra High Molecular Weight (UHMW) Plastic, positioned under the belts to act as a belt-tensioning device and guide, caused the stemmed material to hang up and clog the incline belt. These clogs had to be removed manually to accomplish the gap-belt testing.

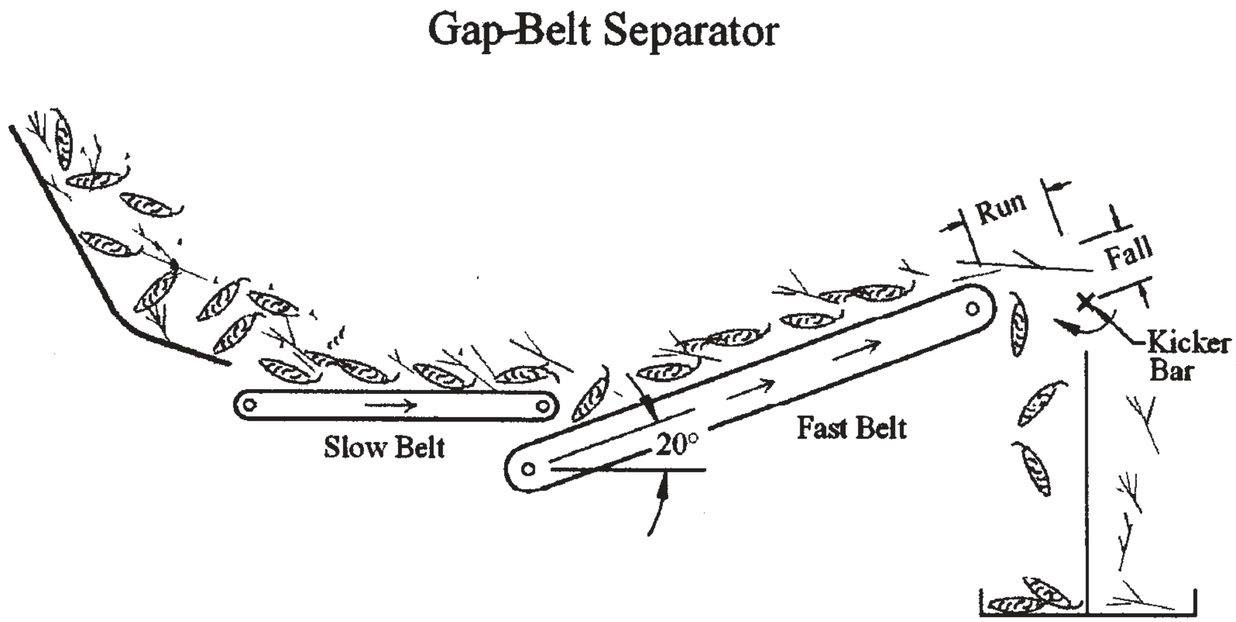

Figure 3. Schematic diagram of a gap-belt chile cleaner. Run and fall are critical dimensions in the operation of the device along with belt speeds and fast-belt angle.

Further Testing

Based on the initial successes of the gap sorter, a second prototype of the concept was designed and built. The idea was improved by the addition of an adjustable kicker bar that makes it possible to regulate cleaning on the fly. A different method of pod and stick alignment also was tested. The new method abandoned the trouble-prone differential speed V-belts in favor of a slow conveyor belt that drops material onto a faster-moving conveyor belt. A schematic of the device is shown in fig. 3

The second prototype was assembled at the USDA during spring 2003. A few exploratory tests were conducted, but other priorities caused delay of the complete evaluation. A fairly complete set of test runs was completed in spring 2004. An air blast was added across the gap to aid in the removal of shorter sticks and other light trash. Test runs are described below in chronological order of their completion.

Alignment test

A sample of pods and sticks was fed through the machine to check operation. The slow belt was 6-8 inches above the fast belt. This was obviously too high as almost no longitudinal orientation occurred on the fast belt. The slow belt was lowered to just clear the fast belt, and since the roller on the slow belt was only 2 inches in diameter material remained in contact with the slow belt while being pulled onto the fast belt. This configuration appeared to operate much better. All the following tests were run with the arrangement.

The first series of tests were designed to evaluate the ability of the slow/fast belt transition to orient material longitudinally. This was done by placing sticks on the slow belt at various angles from 80°-60° from the direction of belt travel, then counting the percent passing over

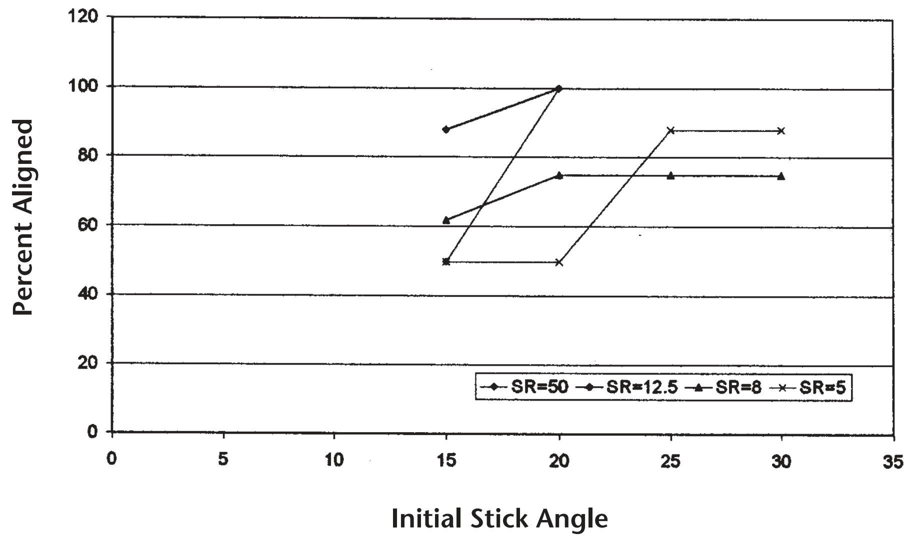

Figure 4. Effect of belt-speed ratio (SR) on alignment of 12-inch sticks where fast belt speed was 100 fpm.

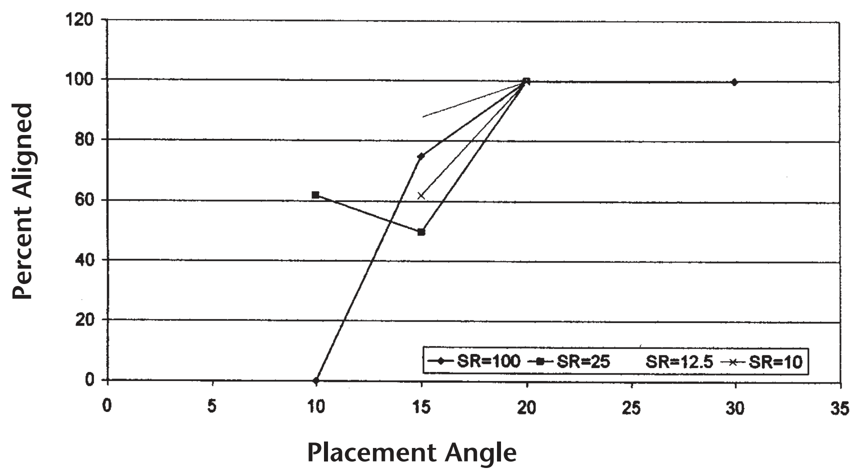

Figure 5. Effect of placement angle and speed ratio on stick alignment where belt speed was 200 fpm.

the gap. It was assumed that those sticks perpendicular to travel (90^o angle) would not be oriented and that those with angles greater than 60^o would be aligned.

Variables in the test were stick placement angle and belt speed for both slow and fast belts (fig. 4). At the fast belt speed of 100 fpm, speed ratios of 8 and 5 resulted in poor stick alignment even at initial placement angles of 25^o and 30^o. Alignment did occur at speed ratios of 12.5 and 50. When the fast belt was operated at 200 fpm (fig. 5), alignment occurred for all sticks placed at 20^o or more from the direction of belt travel for all speed ratios from 1:10 to 1:100.

From these data we conclude that a belt-speed ratio of at least 1:10 is required to align sticks fed from a slow belt to a fast one. Further, the slow-to-fast transition appears weak in aligning sticks that are nearly crosswise on the belt, i.e. placement angles less than 20^o from the direction of travel. Performance may be limited to 80 or 90 percent removal of sticks; however, this would be a vast improvement in many cases.

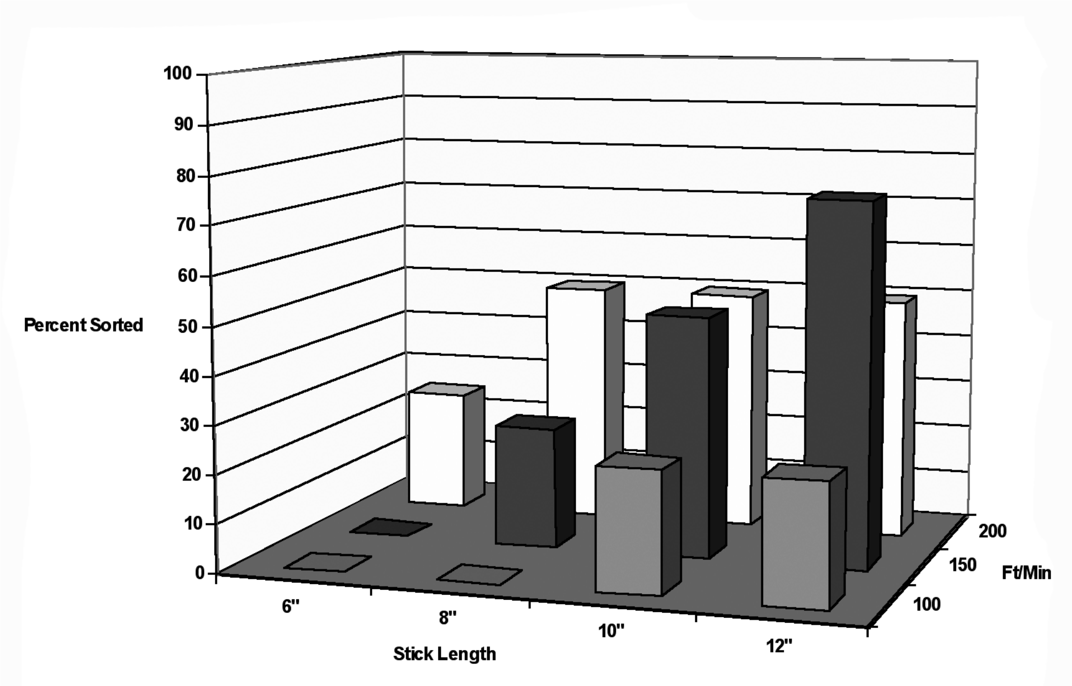

Figure 6. Effect of stick length and fast belt speed on stick rejection with a gap cleaner. Run was about 5.75 inches and fall was about 4 inches.

Stick-length test

The following test was conducted to determine the effect of stick length and fast belt speed on separation. Sticks that were 6, 8, 10 and 12 inches long were placed longitudinally on the fast belt. It was then operated at speeds of 100, 150 or 200 fpm, and the percentage of sticks passing over the kicker bar was determined.

The data (fig. 6) show that faster belt speed increases the rejection of sticks of all lengths and that longer sticks separate better than short ones. The data for 10- and 12-inch sticks at 200 fpm appear lower than they should, probably due to experimental error resulting from a small number of trials.

Kicker bar spacing

Having evaluated stick sorting, the next tests were run on pods. Twenty pods were placed longitudinally on the fast belt, and the belt was operated at speeds of 100, 150 and 200 fpm. In this test, the gap between kicker and the belt discharge was adjusted between 4.75 and 6.5 inches.

Clearly, speed causes a rise in the rejection rate of pods. Few or no pods were lost for speeds of 100 and 150 fpm, while almost all pods were rejected for the narrow gap at 200 fpm. An unacceptable number of pods were lost at 150 fpm and at gap lengths of 5.25 inches or less.

An additional test was run to determine the effect of the kicker on the rejection of 8- and 10-inch sticks. Here the sticks were placed on the fast belt at a 45° angle from the direction of

Table 4. Run and fall dimensions used in tests.

		Run		
		Short	Medium	Long
Fall	Top	3.6 / 4.6*	4.3 / 6.1*	4.6 / 6.8*
	Medium	4.5 / 4.8*	4.9 / 5.8*	5.3 / 6.7*
	Bottom	5.5 / 4.4*	5.7 / 5.1*	6.3 / 6.3*

*First number is fall, second is run.

travel to create a severe test. Separate runs were made for 8-inch and 10-inch sticks, but the data were so similar that the results were combined. At slow speeds such as 100 fpm and 150 fpm, kicker spacing (gap width) seemed to have a random effect on rejection. At 200 fpm, however, a large proportion of sticks were rejected by the narrow gap but few were rejected by the widest gap tested (6.375 inches). This test shows that sticks placed at 45º are very difficult to separate, illustrating the importance of sticks being longitudinally oriented.

The general conclusions we reach from these data are that belt speed and gap width are critical factors so that both must be easily adjustable on the final prototype machine.

Mixed-sample tests

Exploratory research consisted of single-sample tests to determine the limits of operation of the device. Virtually all tests were conducted with sticks or pods. While the information from such tests is valuable, it fails to demonstrate actual operating conditions, where the interaction between sticks and pods may interfere in the separation process.

An adequate supply of chile with sticks was available to conduct a fairly complete evaluation of the gap cleaner at various kicker bar settings. The device would be judged successful if it could be operated to remove 70–80 percent of long sticks without losing more than 5 percent of pods. The following data are the average of two test runs. (Averaging results in more stable findings.)

Tests were run at three different run lengths and at three fall distances (table 4). Note that run is adjustable “on the fly” but fall adjustment requires the repositioning of a bracket. To evaluate the results, material was divided into six categories: pods, small sticks (shorter than pods), medium sticks (those near pod length), long sticks (longer than pods), attached sticks and attached pods.

The effect of kicker bar placement on pod rejection is shown in fig. 7. Pod rejection was excessive for the short value of run and where fall was at the bottom position. Rejection was minimal for the long-run position for both top- and medium-fall positions.

Figure 8 shows the effect of kicker bar placement on the rejection of long sticks. Rejection was best at the short-run position; unfortunately, excessive pods also were rejected at that location. The practical point of operation appears to be medium run and fall. This test demonstrates that the optimum point of operation is included in the range of the points tested and will have to be manually adjusted.

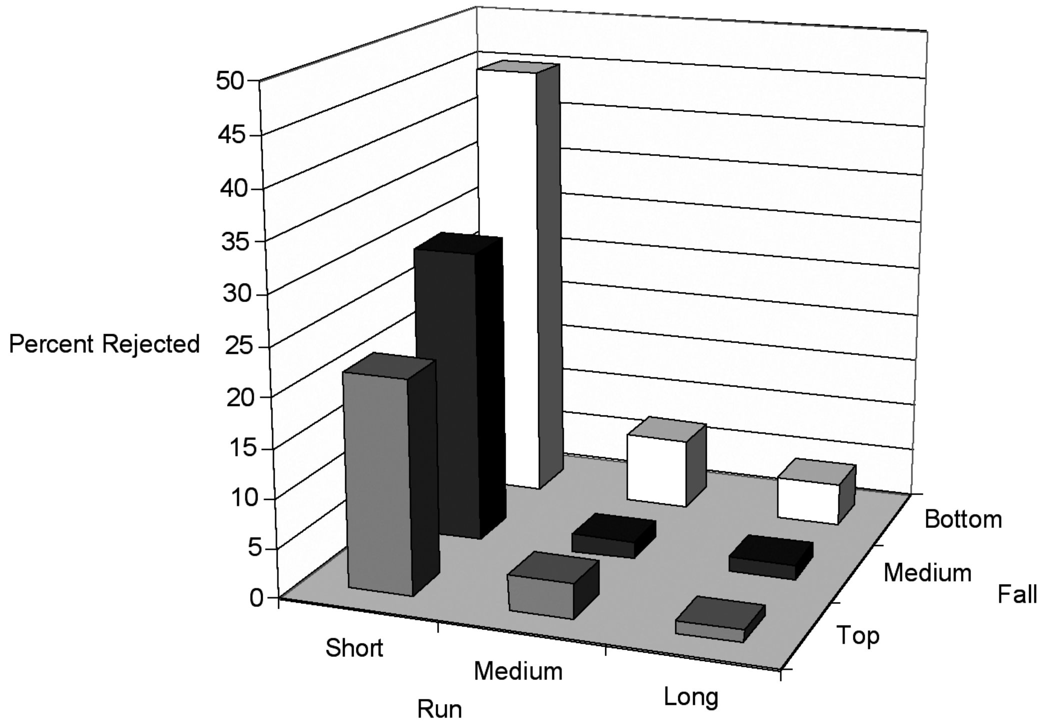

Figure 7. Effect of kicker bar placement on rejection of pods.

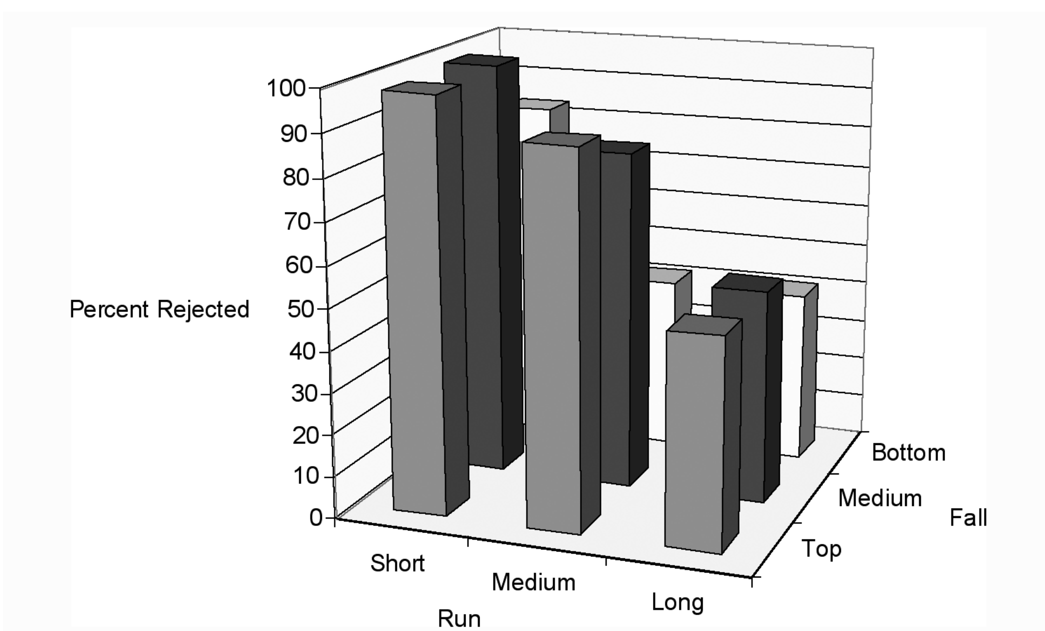

Figure 8. Effect of kicker placement on rejection of long sticks.

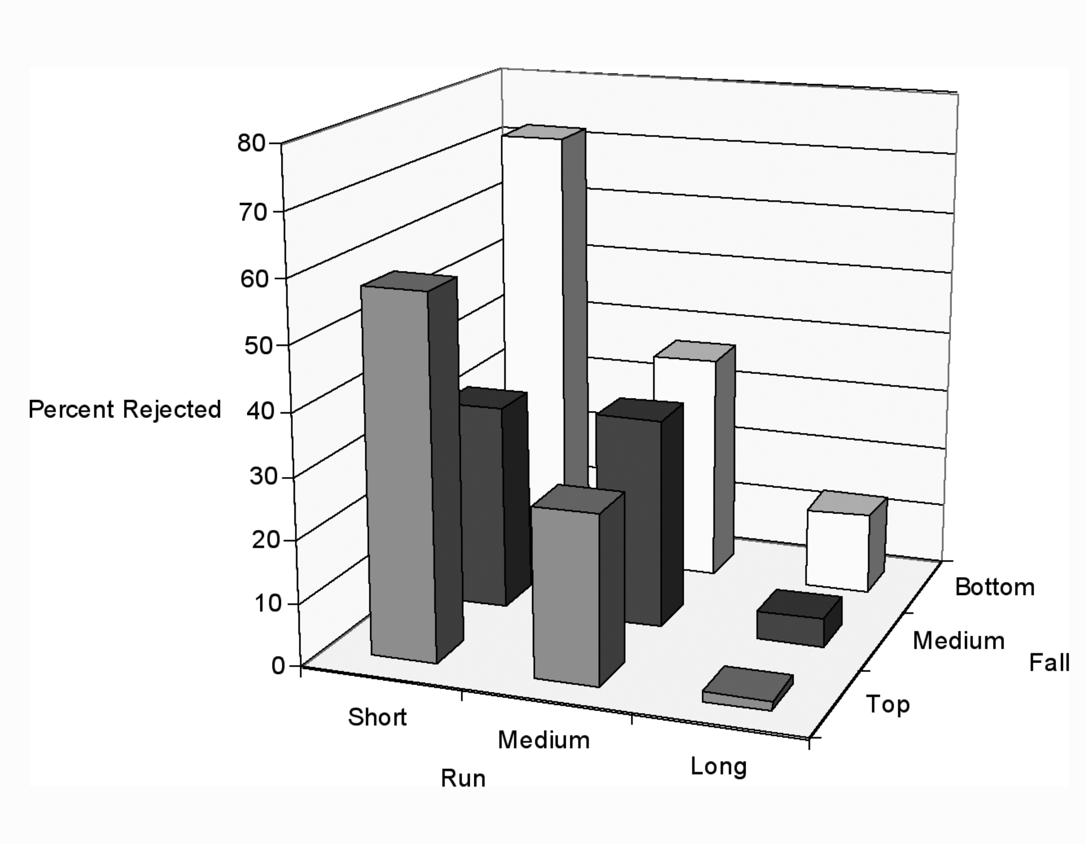

Figure 9. Effect of kicker placement on rejection of medium-length sticks.

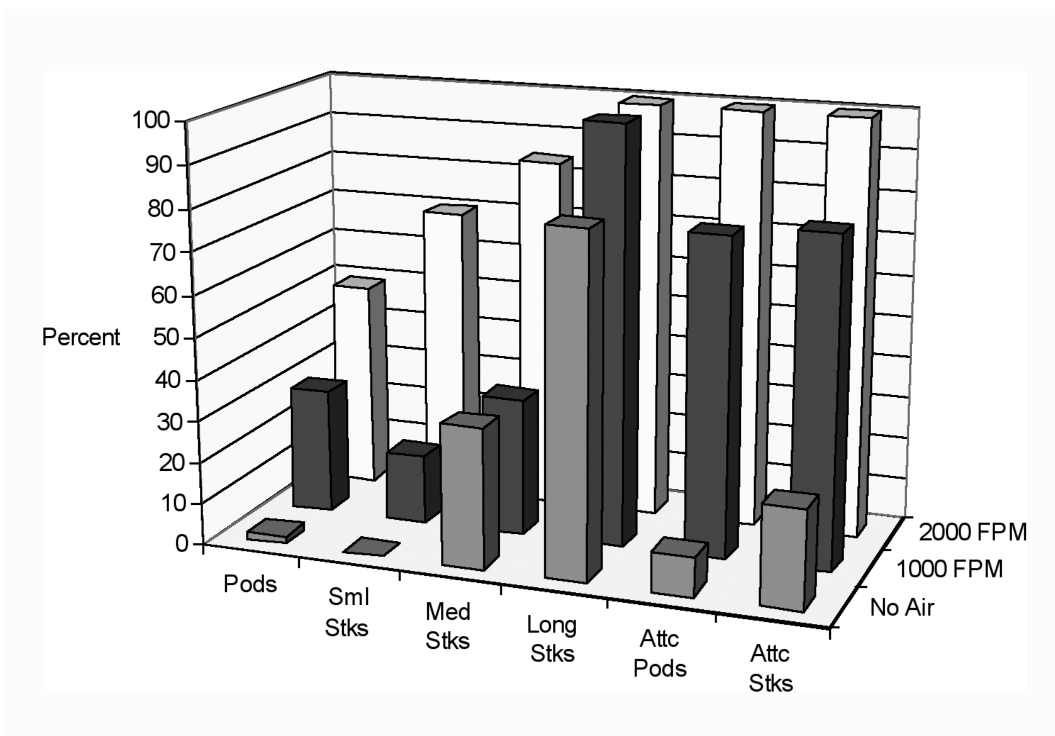

Figure 10. Effect of air flow on rejection of material over a medium-width gap.

The rejection of medium-length sticks (those about pod length) is shown in fig. 9. At the best point of operation for pods and long sticks (medium fall and run), only about 35 percent of medium-length sticks were rejected. Thus, this device is of questionable value in sorting medium-length sticks.

Air assisted separation

An air jet nozzle was installed to apply an upward air blast to the gap. Previous tests by the authors (Abernathy and Hughs, 2002a) had shown that an air blast has more effect on sticks than it does on pods. The air blast is expected to help separate medium- to small-sized sticks while having a minimal effect on pods. This assumption should be fairly valid during that portion of the season when pods are wet and heavy but less valid after frost when pods are dry and light.

Data for a late-season dry sample is presented in fig. 10. Obviously a 2000 fpm velocity air stream was too high since nearly everything was rejected. Even 1,000 fpm caused higher-than-acceptable pod loss. Air flow appeared most useful in sorting attached pods and sticks but will have to be used carefully.

Conclusion

The gap sorter has been shown to effectively remove long straight sticks from mechanically harvested red chile. Further tests should be conducted in a field study to determine if this continues to be the case when the machine is not in a laboratory environment and interactions between pods and sticks come into play. It also must be evaluated relative to a card-cleaner table, with wide spacing to determine which is the most effective and cost-efficient method of removing long straight sticks. Even if the gap cleaner is shown to be more effective at this process, there will still be a place for the widely spaced card cleaner in the removal of pods with attached sticks. The additions of the adjustable kicker bar, and the alignment method of a slow belt feeding a fast belt, provided much improved gap sorter effectiveness and should be implemented on any future versions of the machine.

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Notes

Notes

New Mexico Chile Task Force Publication List

Report 1: An Industry-University Response to Global Competition

Report 2: Chile Seed Germination as Affected by Temperature and Salinity

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Report 9: Economic Impact of Southern New Mexico Vegetable Production and Processing

Report 10: Chile Pepper Growers' Notes: 2003

Report 11: Developing New Marketing Strategies for the Southwestern Chile Industry

Report 12: Incidence of the Beet Leafhopper, *Circulifer teneilus* (*Homoptera: Cicadellidae*), in New Mexico Chile

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