17 Pepper Harvest Technology

Paul A. Funk[1] and Dale E. Marshall[2]
[1]*USDA-ARS, Mesilla Park, New Mexico, USA;* [2]*Holt, Michigan, USA*

17.1 Introduction

Global production and per capita consumption of peppers (*Capsicum* spp.) have been steadily rising. Peppers, especially chilli pepper, are a key ingredient in salsa, which has surpassed ketchup as America's favorite condiment (Diemer *et al.*, 2002). Though mechanization has displaced hand labor for some types, for other pepper types hand labor is the primary harvest method. Mechanical harvesting systems still need to be developed for segments of the pepper industry to help producers manage increasing labor costs and decreasing labor availability.

Increasing cost and scarcity of labor have contributed to displaced production. Production in New Mexico in the USA, as measured by harvested area, declined from 13,962 ha in 1992 (Hall and Skaggs, 2003) to 4324 ha in 2007 (USDA-NASS, 2007). An ever growing domestic demand is increasingly being met by imports (Lucier and Dettmann, 2008).

Harvest labor costs account for about 50% of total production costs in the USA when hand harvest is used (Hawkes and Libbin, 2000), but decrease to less than 10% of production costs with mechanical harvest (Eastman *et al.*, 1997). Though mechanization seems to be an obvious solution, there are several barriers that still need to be addressed.

Peppers are produced as numerous distinct crops, mostly for human consumption. Some production is for ornamental use, pharmaceuticals, spices, or natural dyes. This partial list of common names for commercial varieties is from the taxon *C. annuum* var. *annuum* unless otherwise noted: banana; bell; bird; cayenne; cherry; cone; elongated bell; habanero (*C. chinense*); jalapeño; paprika; pimento; poblano; serrano; tabasco (*C. frutescens*); and various chilli peppers (USDA-ARS, 2010). Each pepper type has its own growing region, production practices, and end use. There are substantial differences in fruit size and shape, with a range in diameter from 1 to 10 cm and shapes ranging from spherical to a 1:15 ratio of diameter to length, and from straight to hook-shaped to curly varieties, and cross sections that range from somewhat flat to round (predominantly two locule) to square (four locule) varieties. A single pepper type may have different production practices and applications. The modern New Mexican-type chilli pepper, developed by Fabian Garcia in 1921 at New Mexico State University (Bosland *et al.*, 1996; Wall *et al.*, 2001), with production still centered in the southwestern USA, is grown as two distinct crops, each including numerous cultivars. They are the New Mexican pod-type red chilli and paprika and New Mexican pod-type long green chilli. Cayenne peppers are a third pod type grown in the southwestern USA that contributes to the overall chilli industry.

Red chilli peppers and paprika are preferentially harvested when physiologically mature, but also partially dried on the plant. Most of the red chilli crop is dried and ground into powder; seed lines are selected to minimize drying energy requirements. Some paprika crops, which include cultivars that are highly pigmented and low in heat, are used to produce oleoresin paprika, a natural red dye used as a food colorant. Selective breeding objectives include control of capsaicin content and maximization of color. Cayenne peppers are harvested when succulent, but physiologically mature. The majority of the cayenne crop is processed into hot sauces. The long green chilli pepper crop is harvested when fruit have reached full size, but are physiologically immature. Green chilli is either processed into a canned or frozen product, or sold directly to consumers (Bosland and Walker, 2004). Most chilli is grown under contracts which specify particular seed lines because modern cultivars are optimized for particular applications. Double cropping (red after green) has become rare for chilli (Roy Pennock, Bueno Foods, El Encanto, Inc., pers. com., 28 January 2010) but continues to be practiced in fresh market bell pepper production.

Each pepper type may require a unique harvester solution. Of the three chilli types grown in the Southwest, green chilli poses the greatest challenge for mechanization because both fresh markets and canning plants find product damage unacceptable (Funk and Walker, 2010). Fresh market bell peppers and green chilli peppers are almost entirely hand harvested, while approximately 80% of the cayenne pepper crop, and nearly all red chilli and paprika peppers, are mechanically harvested (Vince Hernandez, Biad Chile, pers. comm., 29 January 2010). The majority of jalapeños produced in the USA are mechanically harvested. However, 95% of US processing needs are met with imported fruit from countries where jalapeños are hand harvested because they arrive destemmed (Marvin Clary, Border Foods, Inc., pers. comm., 29 January 2010). Only one US company currently uses technology that allows them to process mechanically harvested jalapeños (Henry Rodriguez, pers. comm., 16 February 2010).

No one harvest machine will be optimal considering differences in fruit size and shape, moisture content, density, stem tenacity, plant physiology, and other qualities. Harvest mechanization requires a systems-wide approach, where cultivars are selectively bred and production practices modified to facilitate mechanical harvest, and where processing plant equipment is developed to handle harvests that may have more foreign matter, may arrive in larger quantities, and come with stems still attached (Diemer *et al.*, 2002).

Destemming machines are the most important missing variable still preventing full mechanization because mechanical harvesters only remove fruit from the plant, and do not typically remove the stem, as hand labor crews do. In most processing applications (canning, sauces) the stem and calyx are considered foreign matter, and will either reduce the value of processed chilli or render it unmarketable. The lack of destemming technology has limited acceptance of harvest mechanization because it has merely moved hand labor from the field to the processing plant (Herbon *et al.*, 2009). Attempts to mechanically destem jalapeños in 1977 were unsatisfactory (Dillon, 1981).

Peppers have been traditionally harvested by hand. Workers pull fruit from the plant and snap the stem off, placing the peppers in a plastic bucket (Fig. 17.1). However, hand harvest is not a perfect system. Though statistical data are lacking, growers agree that a portion of the yield is left on the plant as labor crews miss some of the fruit because of foliage or because they skip sections unintentionally or to concentrate their efforts on the highest-yielding areas of a field. Plants may also be missed when slower workers, or workers walking further from the collection point, attempt to catch up with the rest of the harvest crew. Cooper and Cooper (1983) attempted to address this problem with a device that carried two workers near ground level for convenient hand picking, and that had conveyors to elevate fruit from their position into transport containers.

Fig. 17.1. Hand harvest performed by a contract labor crew in a large green chilli field.

Foreign matter can be unintentionally brought to the processing plant with hand-harvested fruit or due to incentives to fill buckets quickly. As recently as 2009 cleaning machines have been placed at the end of the field to reduce foreign material in hand harvested chilli. Hand-harvest crews carry buckets to a mobile collection point, typically chilli boxes stacked on trailers that are pulled by a tractor at the pace of harvest, with the labor crew working several rows on either side (Fig. 17.2). Physical damage occurs during bulk bin loading as peppers drop on to the hard bin bottom, causing bruising or splitting (Jones *et al.*, 2000). As with any harvest method, additional damage can occur during transport if peppers are not shielded from the sun. Because peppers (*Capsicum* spp.) are indeterminate, flowering over a period of several weeks, a plant will have both mature and immature fruit. Hand-harvest crews may enter a field several times; generally over a period of 2 or 3 weeks in field production, or for several months in greenhouse conditions, selectively harvesting fruit at the desired stage of development. The decision to harvest a field is influenced by contract obligation, processing plant capacity, and market needs and by weather, field, plant, and fruit condition.

17.2 Harvest Mechanization

Principles

Mechanical harvesting consists of several distinct steps: divide, remove, catch and convey, clean and transport.

Divide

A crop divider is necessary to lift branches that are near the ground, separate entangled plants from each other, and protect plants from the harvest apparatus. Though it may sound trivial, a poorly designed or improperly located crop divider can result in substantial yield loss by knocking fruit to the ground where there is no mechanism to catch and convey it. Since many cultivars have not yet been optimized for mechanical harvest, lifting fruit that hangs near the ground may

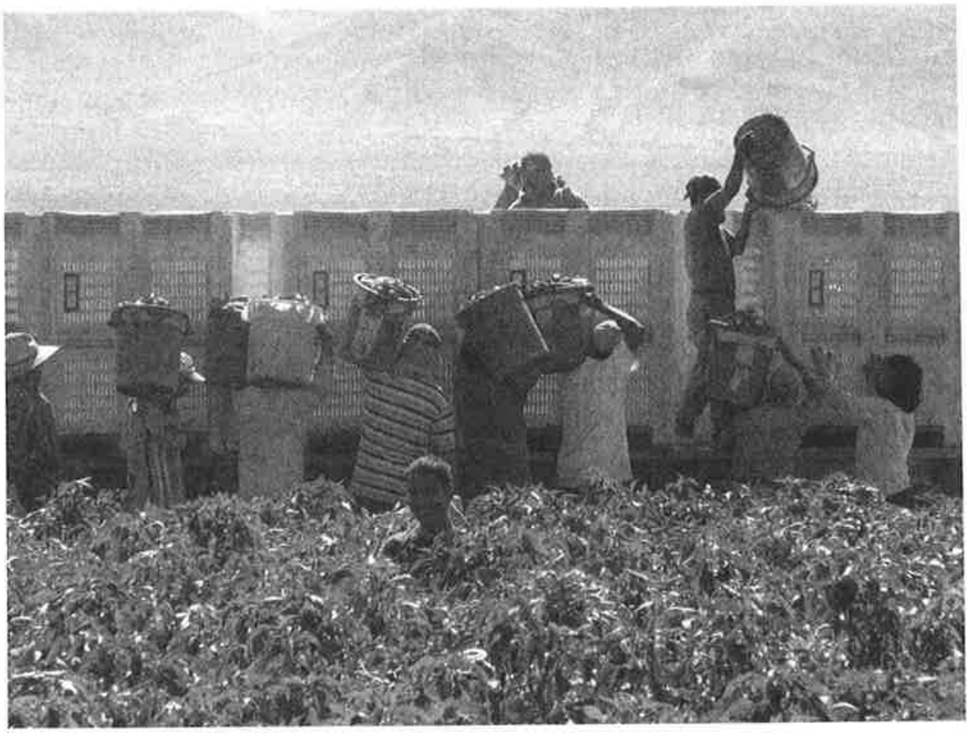

Fig. 17.2. Labor crew members carrying filled buckets to a mobile collection point.

also increase harvest efficiency. One system devised to assist with this consists of snouts with slotted drums that allow rotating fingers to protrude into the crop area where they help feed the picking mechanism (Boese, 2002).

Remove

Removing fruit from a pepper plant can be accomplished by shaking, pulling, or lifting. Shakers were being developed to harvest bell peppers in Florida as early as 1973 (Fowler and Shaw, 1975; Shaw, 1975; Shaw and Ozaki, 1976). Though the 5g shaker harvester removed 100% of the fruit and only damaged 20%, once-over harvest was not considered practical then due to plant indeterminacy. The shaker was abandoned in favor of a combing apparatus (based on an oblique side-delivery hay rake) capable of selective harvest. However, the shaking principle is presently used for plant/fruit separation by mechanical pepper harvesters that cut the plant at ground level and convey material to an oscillating, forced balance shaker drum lined with tines. Pik Rite (Lewisburg, PA) currently offers a machine for harvest of fresh bell, banana, jalapeño and hot cherry peppers. A list of available harvesters is presented in the "current status" section, below.

The stem naturally resists the downward pull of gravity and lateral forces caused by wind. Miles *et al.* (1978) investigated stem attachment forces and found that rotating the fruit in a vertical plane about the attachment point significantly reduced removal force. The vertical force required to remove a mature, green New Mexico 6-4 chilli ranged from 4.5 to 40N (Newtons) with a mean of 21N; the force was higher with dry red fruit of the same variety (frequently 65N), but bending the stem reduced the force required for detachment to 4N. Generally harvesters primarily lift the fruit to bend the stem, taking advantage of the resulting order of magnitude reduction in detachment force.

The first mechanical harvest of chilli peppers was attempted in New Mexico in 1965 using two parallel inclined shafts with counter-rotating brushes or rubber flaps (Riggs, 1971), similar to a cotton stripper harvester. Whitney *et al.* (1997) reported on using a cotton stripper modified to harvest dry paprika for food dye in Oklahoma. An important innovation was the device that fed plants into the harvest mechanism. They had the most success with three pairs of powered disk brushes. Five experimental harvest mechanisms (helical brush; closed helix; short rubber bats; long split rubber bats; and combined bats and brushes) were tested. They attained harvest efficiencies of between 94% and 98% with cotton stripper rolls (short and long bats) turning at from 200 to 560 rpm. Less trash was included when the harvest mechanism speed was 200 rpm. Additionally, they found that using a forage fan for conveyance caused fruit damage.

Gentry *et al.* (1978) described a novel chilli harvester that was 80% effective when harvesting green and red Arizona chilli (with appropriate changes to tine spacing) consisting of plastic-tipped horizontal steel rods that combed upward from both sides of the crop canopy (Fig. 17.3). The chains that moved the tine mounting bars were inclined rearward to synchronize the tine's apparent motion with harvester ground speed, resulting in a purely vertical path.

Urich and Urich (1999) described an offset double crank apparatus for harvesting peppers of various types. Their apparatus had rubber fingers carried on elongated opposing bars which are inclined relative to the ground and moved through a circular path by disks (spider wheels) with an axis perpendicular to the ground (hay-rake type assembly), such that opposing fingers engage and lift plants as the harvester moves forward, separating fruit. The effective motion of the fingers was parallel to the ground and perpendicular to the direction of travel. Fruit separation was caused by the forward movement of the harvester through the plant while the fingers were engaged. Massey and Massey (2005) built two self-propelled three-row

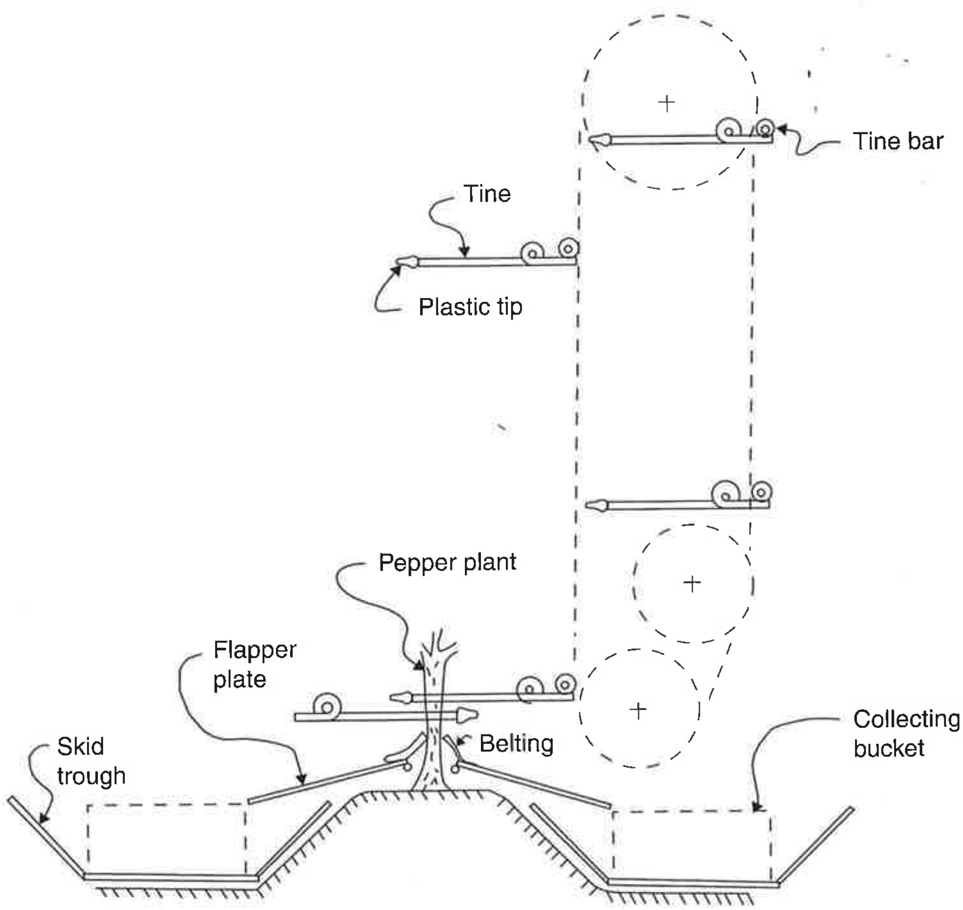

Fig. 17.3. Arizona chilli harvester consisting of plastic-tipped horizontal steel rods (Gentry *et al.*, 1978).

jalapeño harvesters using this principle. These have been called "Colorado head" harvesters; versions with metal fingers were tested by Wilhoit *et al.* (1990). Eaton developed a similar harvest mechanism for the New Mexico State University Chile Task Force (ca. 2004). The Eaton design, like the Massey, had two disks turning four bars with a plurality of rubber fingers mirrored on either side of the crop row. It had the same drive mechanism, but the axis of rotation was parallel to the ground so that finger motion was primarily vertical, lifting the peppers from the plants when engaged, and returning downward when withdrawn. A compact version of this mechanism was tested in 2008 (Funk and Walker, 2010). Results were confounded by limited mechanical clearance, which caused excessive fruit damage.

Lenker and Nascimento (1982) described a harvest machine for dry red chilli having a pair of belts facing each other on either side of the crop row, inclined at 45° with respect to the ground, moving several rows of 7.6 cm rubber fingers spaced 4.4 cm on center upward through the plant as the harvester moved forward. It attained a harvest efficiency of from 78 to 86%. Belt-mounted rubber fingers are in use today on the Pik Rite (Lewisburg, PA) chilli pepper harvester (different from their pepper harvester). On the chilli pepper harvester, sometimes called the "Texas head," the belts move in a vertical path. The harvester is able to recover dropped fruit by sweeping the ground.

A vertical helix mechanism was patented by Creager (1971) and again by Cosimati (1998). The Creager harvester used vertical open-helixes formed of 13 mm diameter steel rod in a 4.5 turn coil 20 cm in diameter by 66 cm tall on each side of the plant. Each row's head housed eight counter-rotating open-helixes, four on each side, in an orthogonal pattern. Gerhareus Swart, Wilcox, Arizona, developed a similar vertical open-helix mechanical harvester with interchangeable helices, mounted on a Pik Rite Chile Pepper Harvester. It can harvest fruit selectively by first picking fruit only from the bottom of plant, then can be reconfigured with 12 inch removable sections to pick the bottom and middle, and then the entire plant, or the middle and top if fruit is already turning red in the lower section (pers. comm., 19 February 2010).

The first inclined counter-rotating open-helix used was by Fullilove and Futral in 1968, followed by Creager in 1971 and Suggs in 1972. The first patent was awarded to McClendon (1981) with improvements by Boese (1999, 2002). Both McClendon and Boese presently produce pepper harvesters. Marshall (1979) asserted that every type of pepper grown in the USA can be mechanically harvested with the inclined counter-rotating open-helix design. He added that 80 to 90% harvest efficiency was possible with as little as 1 to 10% fruit damage. Dillon (1981) reported 90 to 95% removal when harvesting jalapeños with a 15 cm diameter open helix and 18 cm diameter rubber bats. Marshall (1981) measured recovery of banana, bell, and cherry peppers as a function of ground and helix speed. Harvest efficiency increased with helix rotational speed (from 152 to 758 rpm) and decreased with harvester ground speed. Damage was independent of helix rpm but increased with ground speed.

Wolf and Alper (1984) chronicled development of a mechanical harvest system in Israel, starting in 1968. They credit Fullilove and Futral (1972) with the inclined counter-rotating open-helix concept that proved successful in harvesting pimento peppers. They tested three inclined (30°) counter-rotating double open-helixes with a 4 cm gap between elements. The elements were operated 90° out of phase to increase fruit removal by shaking. Operating with a linear velocity of 4 to 5 m s^{-1} they obtained the same result with 20, 10, and 6.5 cm diameter helixes. Harvest efficiencies between 70 and 90% were obtained at 3 km h^{-1} field speed (0.1 to 0.3 ha h^{-1}) using a 10 cm helix made of 1.2 cm pipe with a 30° wind. This apparatus was patented (Wolf and Alper, 1985) and is currently available from Yung-Etgar (Bet-Lehem-Hglilit, Israel). The Yung-Etgar head has air cylinders that press the helixes together, providing a constant compressive force while still letting the helixes spread apart to accommodate thicker foliage.

Other mechanisms for pepper harvest include a shaft above and parallel to the crop row with either a large rotating helix

(Rodriguez, 1980) or a series of arms (Cosimati, 1985, 1993), or a shaft perpendicular to the row (Rodriguez, 2002, 2009), in all cases fitted with loops or hooks that catch and lift fruit from the plants.

Catch and convey

Often great attention is paid to the design of the mechanism that removes fruit, but not as much consideration is given to subsequent steps. Ground fall is as much a yield loss as failing to remove fruit from the plant. Harvest mechanisms may toss fruit forward (Dillon, 1981), necessitating extending the collection and conveyance apparatus. The gap that allows plants to flow into the harvesting area without being uprooted needs to be narrow enough to prevent fruit loss and flexible enough to accommodate navigation errors. The section where plants exit also needs to be sealed against fruit loss. Watenpaugh (1983) combined the vertical and inclined helix principles in a single machine for field-harvesting peppers, with star wheels to lift low-hanging fruit and branches. Their patent claims included nylon brush aprons to prevent ground loss.

Gentry *et al.* (1978) mentioned the challenge of dealing with yields which can be 38,000 kg ha^{-1}; even with narrow production rows (0.75 m) at low speeds (0.8 km h^{-1}) the conveying system for each row must collect and convey 40 kg min^{-1}. Today yields up to 74,000 kg ha^{-1} are not unheard of, and, at higher ground speeds (3.2 km h^{-1}) with a 1 m row spacing, conveying and cleaning systems will need to handle well over 400 kg min^{-1}. The volume associated with that mass flow depends on fruit density, size, and shape.

The most important consideration for conveying systems is minimizing crop damage. Augers may be acceptable for spherical fruit, but they can damage elongated peppers. Paddles can break peppers if they pass shear points, and discharging from a height can result in bruising. One of the principles elucidated from harvester trials (Funk and Walker, 2010) was the importance of providing a clear product path for fruit conveyance after removal, with no opportunity for mechanical parts to cause damage.

Post-removal product loss also must be avoided. Cleaning gaps need to be smaller than fruit size, and spill shields may be required where there are directional changes. Small details can make a big difference. Branches tend to bridge across any space where conveying systems narrow or change direction. By maintaining operator access and minimizing bottlenecks, choke-ups can be more easily cleared – or avoided. Conveying systems may also include material separation. Frequently conveyor belts are made of parallel rods to allow soil and small trash to drop out. Avoiding surfaces where soil and sand will accumulate and eventually interfere with moving parts can reduce machine wear and fruit abrasion.

Clean and transport

Field cleaning reduces the amount of material transported to processors, lowers shipping costs, reduces the amount of industrial waste that must be disposed of by processors, and decreases processing plant labor costs. Dillon (1981) reported on jalapeño cleaning systems that used air, cleated combing belts, and counter-rotating helical wire rollers. An inclined, vibrating belt was developed to clean dry red chilli. It walked peppers downward over small fingers while leaves and sticks trapped between the fingers were conveyed upward (Lenker and Nascimento, 1983).

Wolf and Alper (1984) invented the card cleaner, "a series of unidirectionally revolving shafts with square rubber cards and eight-fingered rubber star-wheels, of 150 mm diameter." A similar device on which are stacked 150 mm square plastic (UHMW or polypropylene) cards 5 mm thick was developed by Jim McClendon of Tulia, Texas. Inter-card spaces of from 15 to 25 mm are used to separate leaves and other smaller material. Inter-card spaces of from 40 to 80 mm carry branches to a discharge point while dropping fruit on to another conveyor. Inter-shaft spacing allows cards on adjacent shafts to overlap (Eaton and Wilson, 2005).

The helical coil cleaner, developed by Wondel Creager of Salem, New Mexico, consists of several 100 mm coils made of 10 mm wire with 10 mm spaces between. Trash and sticks are pulled down between coils as harvested material flows axially across downward-sloped coils. New Mexico field trials operating card and coil cleaners in tandem removed 60 to 75% of foreign material, resulting in dry red chilli that contained less than 10% branches in most cases, a small enough quantity that the processing plant's existing hand crew was able to remove them (Eaton and Wilson, 2005).

Fans have been used for air separation on several commercial machines, with adjustments in fan speed and opening size to accommodate changes in leaf or product density through the field and through the day. Many systems also have conveyor belt sorting tables where workers remove bad fruit and foreign material. These systems can have a large influence on the amount of labor required. Harvester labor requirements were measured for 13 mechanical harvesters; six four-row harvesters averaged 5.9 man-h ha^{-1} while the seven two-row harvesters averaged 3.6 man-h ha^{-1} (Abernathy and Hughs, 2006).

Discharge conveyors typically load dry fruit into bulk truck trailers (live bottom or dump), farm trailers, or pallet boxes on flat farm trailers. Fresh fruit are loaded in pallet boxes only. With pallet boxes, labor is required to pack them evenly. With all transport systems, at least one tractor and driver are employed to pull the trailer(s) beside the harvester.

Production practices

Production practices that suit mechanization should result in low fruit attachment force and slender, well-rooted plants having few branches producing fruit well above the ground (Wolf and Alper, 1984). Palevitch and Levy (1984) recommended increasing plant population up to 10 plants m^{-1}. This reduced side shoots and increased stem length from soil surface to main branch. These results were confirmed by Paroissien and Flynn (2004), who recommend no less than 100,000 plants ha^{-1} or 10 plants m^{-1} to reduce main fork angle and increase fruit height. Marshall (1984a) found that yields increased and fruit were borne higher as in-row plant spacing approached 15 cm.

Ethephon (Ethrel, Bayer Crop Science, Research Triangle Park, North Carolina) has long been used with hand harvest to help synchronize ripening, as a defoliant, and to facilitate picking by reducing fruit attachment force. The use of ethephon with mechanical harvesting can be counter-productive with certain chilli cultivars due to resultant preharvest fruit drop from plants (Wall *et al.*, 2003).

Current status

Marshall (1984b) observed that commercial machines from four manufacturers, all using the open helix mechanism, had been available as early as 1978. Sales appeared limited due to an abundance of hand labor. He mentioned the 1980 import of an Israeli chilli harvester to New Mexico. He also cautioned that field cleaning apparatuses need to be customized to pepper size and shape. He summarized two decades of chilli harvester research listing over 130 harvesters built by 59 research groups employing a dozen principles. Ten years later he identified 195 pepper harvesters by 75 different groups (Marshall, 1994). The count was revised upwards a third time to 230 machines worldwide employing 30 concepts covered by 14 patents in an attempt to harvest 20 pepper types (Marshall and Boese, 1998). Mechanical harvesters are available today from (in alphabetical order):

- Boese Harvester Co. (2929 River Street, Saginaw, MI 48601; (989) 754-2990; www.boese.ws) manufactures chilli harvesters that use the inclined double open helix removal principle, in both pull-behind (two-row) and self-propelled (four-row) versions. Both units have field cleaning systems and provision for manual sorting (Fig. 17.4).
- Crown Farming Systems Inc. (2005 Burke Rd., Las Cruces, NM 88007; (575) 524-4972) is currently offering for sale a two-row harvester and related patents (Cosimati, 1998) that uses vertical open helixes on either side of the crop row.

Fig. 17.4. Boese Harvester picking four rows of dry red chilli near Hatch, New Mexico.

This self-propelled harvester includes rotating-drum field cleaning.

- Massey Pepper Harvester, LLC (PO Box 316, Animas, NM, 88020; (575) 548-2434) has developed a harvester for jalapeños (Massey and Massey, 2005). This self-propelled unit uses rubber fingers moving in an orbital path and includes field cleaning with provision for manual sorting. Two machines are available: a three-row unit that stores fruit on board for delivery to a collection point at the edge of the field, and a four-row unit that discharges fruit into trailers that are pulled alongside (Fig. 17.5).
- McClendon Pepper Co. (301 Southwest Second St., Tulia, TX, 79088; (806) 681-9949, www.mcclendonpepper.com) is currently producing self-propelled units in two-, four-, and six-row configurations with two different heads, an inclined double open-helix for green chilli, and rubber fingers on two parallel inclined counter-rotating shafts for dry chilli. The harvesters use air for conveying and cleaning, and also have card-type field cleaning systems (Fig. 17.6).
- Pik Rite Inc. (101 Fairfield Rd., Lewisburg, PA, 17837; (800) 326-9763; www.pikrite.com) offers a mechanical Pepper Harvester for fresh bell, banana, jalapeño, and hot cherry peppers, and a mechanical Chili Pepper Harvester for dry red peppers (Fig. 17.7a). The pepper harvester uses a forced balance drum shaker to separate fresh fruit from plant material. The chilli pepper harvester combs dried fruit from plants with belt-mounted rubber fingers (Fig. 17.7b). Both units are two-row pull-behind designs with field cleaning and provision for manual sorting.
- Rodriguez Co. (1448 Hwy 338, Animas, NM, 88020; (575) 548-2243) offers custom harvesting with self-propelled mechanical harvesting machines they developed that have rotating picking elements (Rodriguez, 2009). This two-row device has on-board field cleaning (Fig. 17.8).
- Yung-Etgar, Bet-Lehem-Hglilit, Israel produces an inclined double open-helix head (in two- and four-row versions) for green and dry chilli, mounted on the GH-80 frame and sold through Oxbo

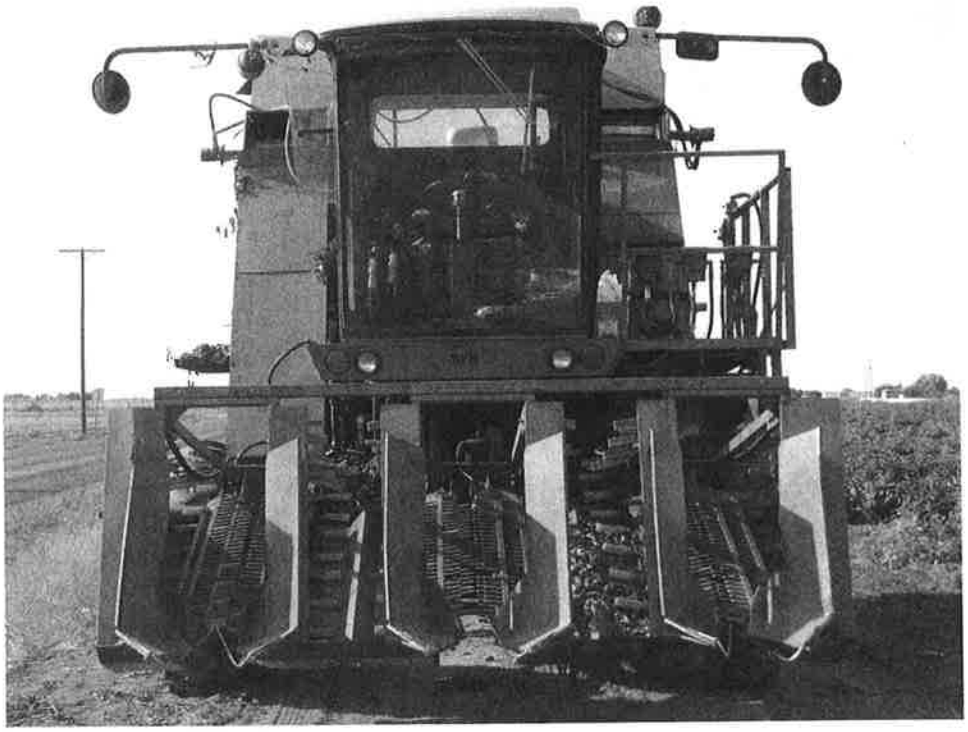

Fig. 17.5. Massey Harvester picks three rows of jalapeño peppers, near Deming, New Mexico.

Fig. 17.6. McClendon Harvester picking four rows of dry red chilli near Hatch, New Mexico.

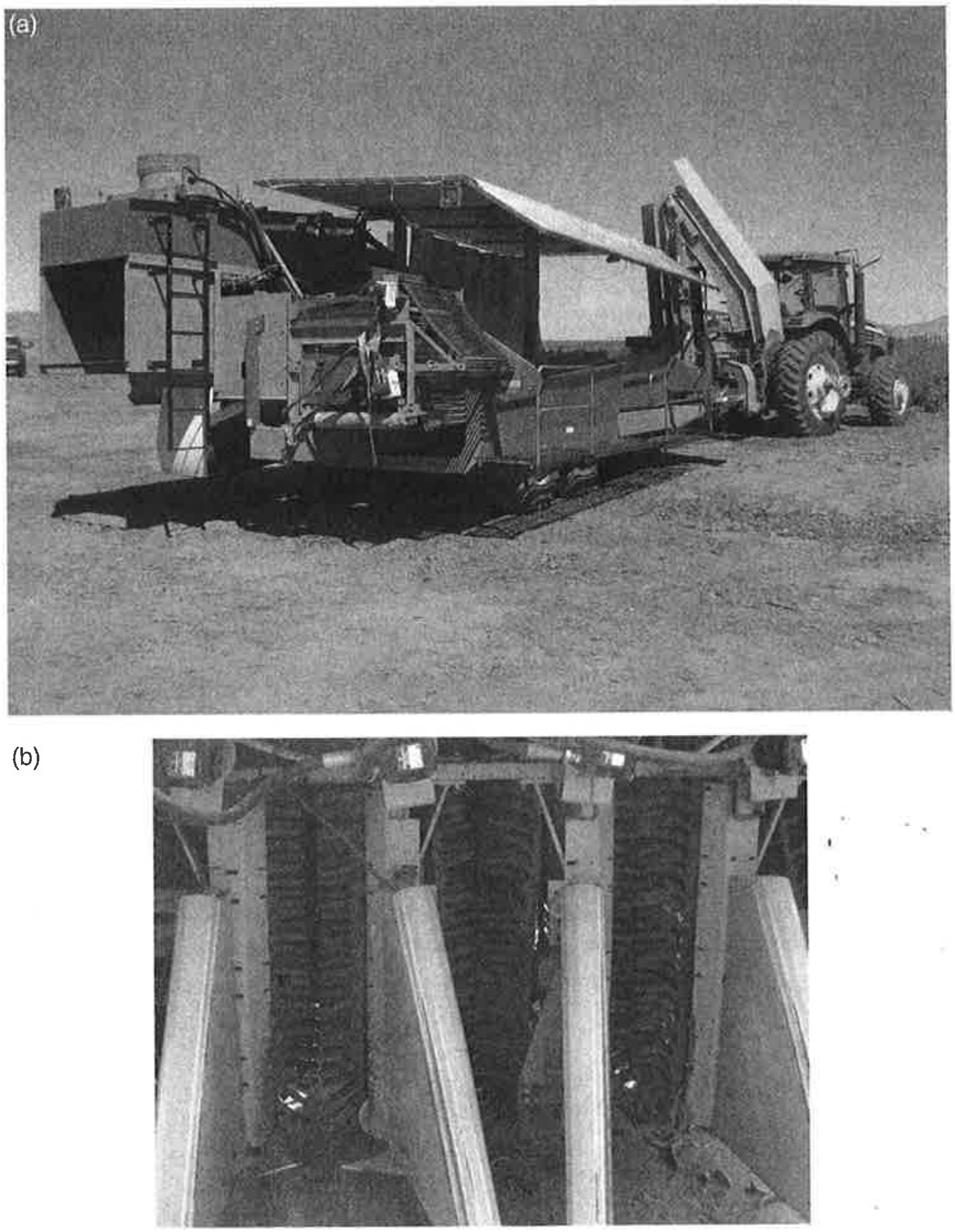

Fig. 17.7. (a) Pik Rite Harvester picks two rows of fresh green chilli near Wilcox, Arizona; (b) Pik Rite Harvester "Texas" head (for dry chilli) near Portales, New Mexico.

Corp. (formerly Pixall) (100 Bean St, Clear Lake, WI, 54005; (715) 263-2112; www.oxbocorp.com). Newer units include field cleaning (Fig. 17.9).

Paprika breeding efforts have already begun to select for traits compatible with mechanical harvest such as fruit set and detachment force (Walker *et al.*, 2004). Yet there is more research to be done in the area of pepper harvest mechanization. Few existing studies evaluated fresh market (bell, green chilli) peppers. Irrigation and fertilizer timing may influence determinacy and root strength, facilitating mechanical harvest. New pepper types such as non-pungent jalapeño used in salsa products that have pedicels that can be easily removed with no, or minimal, damage to pods present opportunities for development of equipment to service this portion of the industry.

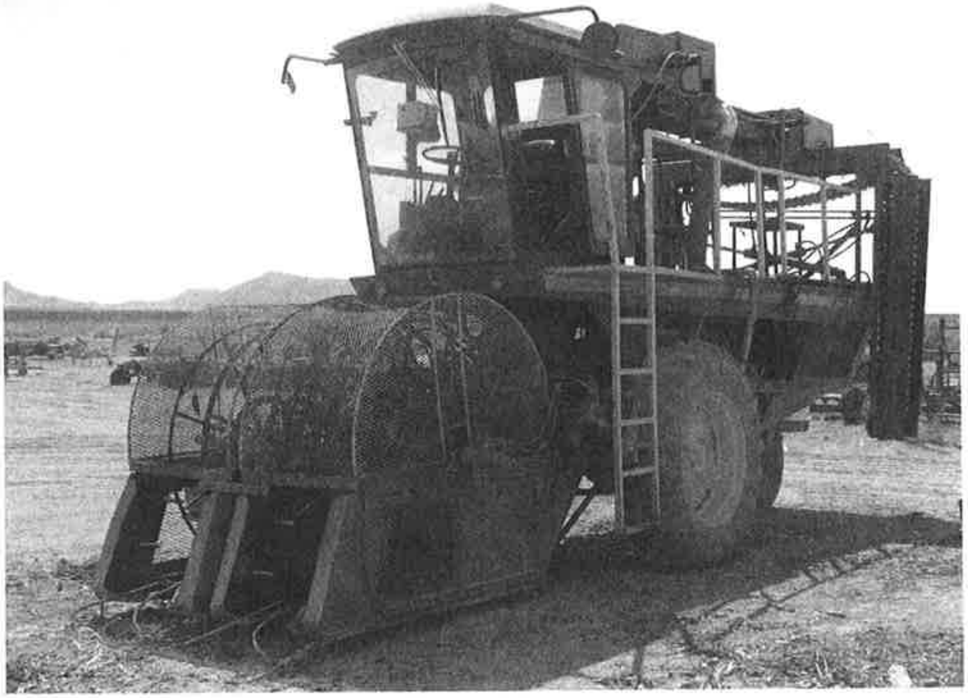

Fig. 17.8. Rodriguez Harvester picks two rows of jalapeños, near Waterloo, New Mexico.

Fig. 17.9. Yung-Etgar/Oxbo Harvester for four rows of dry or fresh chilli (Oxbo Corp.).

References

Abernathy, G. and Hughs, E. (2006) Chile machine harvesting observations: 2004. New Mexico Chile Task Force Report 24. Available at: http://aces.nmsu.edu/pubs/ taskforce/#chile/ (accessed 8 November 2010).

Boese, G.M. (1999) Vegetable harvester. US Patent No. 6,003,293.

Boese, G.M. (2002) Vegetable harvester. US Patent No. 6,419,093.

Bosland, P.W. and Walker, S. (2004) Growing chiles in New Mexico. *New Mexico State University, Cooperative Extension Service Guide H-230*.

Bosland, P.W., Bailey, A.L. and Iglesias-Olivas, J. (1996) *Capsicum* pepper varieties and classification. *New Mexico State University Cooperative Extension Service Circular 530*.

Cooper, D. and Cooper, R.D. (1983) Pepper harvesting apparatus. US Patent No. 4,395,867.

Cosimati, R.O. (1985) Chili pepper harvester. US Patent No. 4,546,602.

Cosimati, R.O. (1993) Chili harvester. US Patent No. 5,210,999.

Cosimati, R.O. (1998) Chili harvester with adjustable spiral picker units. US Patent No. 5,709,071.

Creager, W.G. (1971) Chili harvester. US Patent No. 3,568,419.

Diemer, J.A., Phillips, R. and Hillon, M. (2002) An industry-university response to global competition. New Mexico Chile Task Force Report 1. Available at: http://aces.nmsu.edu/pubs/taskforce/#chile/ (accessed 8 November 2010).

Dillon, R.C., Jr (1981) Harvesting, length sizing and destemming jalapeno peppers. *ASAE Paper No. 81-1068*. ASABE, St Joseph, Michigan, 28 pp.

Eastman, C., McClellan, F. and Bagwell, T. (1997) Impact of increasing wages on New Mexico chile production. *New Mexico Agricultural Experiment Station Research Report No. 714*.

Eaton, F.E. and Wilson, C. (2005) Refinement and testing of mechanical cleaners for red chile. New Mexico Chile Task Force Report 22. Available at: http://aces.nmsu.edu/pubs/taskforce/#chile/ (accessed 8 November 2010).

Fowler, W.E., Jr and Shaw, L.N. (1975) Inertial removal of bell peppers with a vertical snapping motion produced by a double crank mechanism. *Transactions of the ASAE* 18(5), 614–617.

Fullilove, H.M., III and Futral, J.G. (1968) Progress in the development of a pimiento pepper harvester. *Proceedings of the Association of Southern Agricultural Workers* 66, 73 (Abstract).

Fullilove, H.M., III and Futral, J.G. (1972) A mechanical harvester for pimiento peppers. *ASAE Paper No. 72-148*. ASAE, St Joseph, Michigan, 6 pp.

Funk, P.A. and Walker, S.J. (2010). Evaluation of five green chile cultivars utilizing five different harvest mechanisms. *Applied Engineering in Agriculture* 26 (6), 955–964.

Gentry, J.P., Miles, J.A. and Hinz, W.W. (1978) Development of a chili harvester. *Transactions of the ASAE* 21(1), 52–54.

Hall, T.Y. and Skaggs, R.K. (2003) Economic impact of southern New Mexico vegetable production and processing. New Mexico Chile Task Force Report 9. Available at: http://aces.nmsu.edu/pubs/taskforce/#chile/ (accessed 8 November 2010).

Hawkes, J. and Libbin, J.D. (2000) *Crop Cost and Return Estimates in New Mexico, 1998*. New Mexico Agricultural Experiment Station, Las Cruces, New Mexico.

Herbon, R., Cillessen, D., Gamillo, E. and Hyde, A. (2009) Engineering a machine to remove stems from chile peppers – a critical need for the New Mexico chile industry. *Proceedings of the 2009 ASABE Annual International Meeting*, Reno, Nevada, 21–24 June.

Jones, T., Bessin, R., Strang, J., Rowell, B. and Spalding, D. (2000) Kentucky pepper integrated crop management grower manual. University of Kentucky Cooperative Extension Service bulletin IPM-13. Available at: www.uky.edu/Ag/IPM/ manuals/ipm13pep.pdf (accessed 8 November 2010).

Lenker, D.H. and Nascimento, D.F. (1982) Mechanical harvesting and cleaning of chili peppers. *Transactions of the ASAE* 25(1), 42–46.

Lenker, D.H. and Nascimento, D.F. (1983) Vibrating separator. US Patent No. 4,385,702.

Lucier, G. and Dettmann, R.L. (2008) Table 13 Vegetables, fresh market: US imports of major vegetables, 1979–2007. In: *Vegetables and Melons Situation and Outlook Yearbook*. Electronic Outlook Report from the Economic Research Service, USDA, VGS-2008, 15 May, p. 28.

Marshall, D.E. (1979) Performance of a (twin, double open helix) mechanical pepper harvester. *ASAE Paper No. 79-1062*. ASABE, St Joseph, Michigan, 23 pp.

Marshall, D.E. (1981) Performance of an open-helix mechanical harvester in processing peppers. *ASAE Paper No. 81-1069*. ASABE, St Joseph, Michigan, 11 pp.

Marshall, D.E. (1984a) Horticultural requirements for mechanical pepper harvesting. In: *Proceedings of the 1st International Conference on Fruit, Nut and Vegetable Harvesting Mechanization*, Bet Dagan, Israel, October 1983. ASAE, St Joseph, Michigan, pp. 265–275.

Marshall, D.E. (1984b) Mechanized pepper harvesting and trash removal. In: *Proceedings of the 1st International Conference on Fruit, Nut and Vegetable Harvesting Mechanization*, Bet Dagan, Israel, October 1983. ASABE, St Joseph, Michigan.

Marshall, D.E. (1994) Status of mechanical pepper harvesting. *ASAE Paper No. 94-1578*. ASABE, St Joseph, Michigan, 7 pp.

Marshall, D.E. and Boese, B.N. (1998) Breeding Capsicum for mechanical harvest, Part 2 – Equipment. In: *Proceedings of the 10th Eucarpia Meeting on Genetics and Breeding of* Capsicum *and Eggplant*, Avignon, France 10, 61–64.

Massey, R.A. and Massey, B.F. (2005) Pepper harvester. US Patent Application No. 2005/0210853; A1.

McClendon, J.R. (1981) Apparatus and process for field harvesting of peppers. US Patent No. 4,257,217.

Miles, J.A., Hinz, W.W. and Pike, W.H. (1978) Development of a mechanism for picking chile peppers. *Transactions of the ASAE* 21(3), 419–421.

Palevitch, D. and Levy, A. (1984) Horticultural aspects of mechanized sweet pepper harvesting. In: *Proceedings of the 1st International Conference on Fruit, Nut and Vegetable Harvesting Mechanization*, Bet Dagan, Israel, October 1983. ASABE, St Joseph, Michigan.

Paroissien, M. and Flynn, R. (2004) Plant spacing/plant population for machine harvest. New Mexico State University Chile Task Force Report 13. Available at: http://aces.nmsu.edu/pubs/taskforce/#chile/ (accessed 8 November 2010).

Riggs, E. (1971) Harvester for peppers and other crops. US Patent No. 3,613,339.

Rodriguez, H. (1980) Mechanized harvesting machine. US Patent No. 4,196,570.

Rodriguez, H. (2002) Mechanized harvesting machine with rotating picking elements. US Patent No. 6,338,236.

Rodriguez, H. (2009) Mechanized harvesting machine with rotating picking elements. US Patent No. 7,568,332.

Shaw, L.N. (1975) The application of an offset double crank mechanism in a selective bell pepper harvester. *Transactions of the ASAE* 18(4), 606–609.

Shaw, L.N. and Ozaki, H.Y. (1976) Mechanical pepper harvester research in Florida. *Soil and Crop Science Society of Florida Proceedings* 35, 64–67.

Suggs, C.W. (1972) Mechanical harvesting of flue cured tobacco (with twin, double helix), leaf removing devices. *Tobacco Science* 16, 35–39.

Urich, O.D. and Urich, D.W. (1999) Harvesting apparatus. US Patent No. 5,930,987.

USDA-ARS (2010) National Genetic Resources Program. Germplasm Resources Information Network - (GRIN) [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. Available at: www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?8904 (accessed 8 November 2010).

USDA-NASS (2007) Census of agriculture-state data. Table 30; Vegetables, potatoes and melons harvested for sale: 2007 and 2002. Available at: www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_US_State_Level/st99_2_030_030.pdf (accessed 8 November 2010).

Walker, S., Wall, M.M. and Bosland, P.W. (2004) "NuMex Garnet" paprika. *HortScience* 39, 629–630.

Wall, M.M., Walker, S., Wall, A.D., Hughs, E. and Phillips, R. (2001) Yield and quality of machine-harvested red chile peppers. New Mexico Chile Task Force Report 3. Available at: http://aces.nmsu.edu/pubs/taskforce/#chile/ (accessed 8 November 2010).

Wall, M.M., Walker, S., Wall, A.D., Hughs, E. and Phillips, R. (2003) Yield and quality of machine harvested red chile peppers. *HortTechnology* 13(2), 296–302.

Watenpaugh, N.H. (1983) Pepper harvesting machine. US Patent No. 4,402,175.

Whitney, R.W., Solie, J.B. and Motes, J.E. (1997) Pepper harvester from modified cotton stripper. *Applied Engineering in Agriculture* 13(4), 435–441.

Wilhoit, J.H., Duncan, G.A. and Wells, L.G. (1990) Elliptical combing motion for harvesting bell peppers. *Applied Engineering in Agriculture* 6(6), 673–678.

Wolf, I. and Alper, Y. (1984) Mechanization of paprika harvest. In: *Proceedings of the 1st International Conference on Fruit, Nut and Vegetable Harvesting Mechanization*, Bet Dagan, Israel, October 1983. ASAE Publication No. 5-84. ASABE, St Joseph, Michigan, pp. 265–275.

Wolf, I. and Alper, Y. (1985) Apparatus for harvesting and separation of produce. US Patent No. 4,507,911.

CABI is a trading name of CAB International

CABI
Nosworthy Way
Wallingford
Oxfordshire OX10 8DE
UK

Tel: +44 (0)1491 832111
Fax: +44 (0)1491 833508
E-mail: cabi@cabi.org
Website: www.cabi.org

CABI
875 Massachusetts Avenue
7th Floor
Cambridge, MA 02139
USA

Tel: +1 617 395 4056
Fax: +1 617 354 6875
E-mail: cabi-nao@cabi.org

A catalogue record for this book is available from the British Library, London, UK.

Library of Congress Cataloging-in-Publication Data

Peppers : botany, production and uses/Vincent M. Russo, editor.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-84593-767-6 (alk. paper)
1. Peppers. 2. Peppers--Utilization. I. Russo, Vincent M. II. Title.

SB351.P4P47 2011
635'.643--dc23

2011028633

ISBN-13: 978 1 84593 767 6

Commissioning editor: Sarah Hulbert
Editorial assistant: Gwenan Spearing
Production editor: Shankari Wilford

Typeset by SPi, Pondicherry, India.
Printed and bound in the UK by CPI Group (UK) Ltd, Croydon, CR0 4YY.