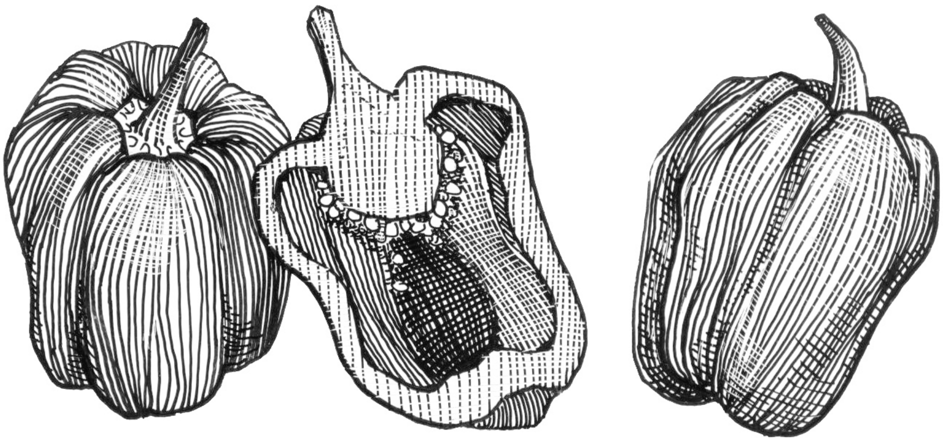
PEPPER SEED PRODUCTION

An organic seed production manual for seed growers in the Mid-Atlantic and South.



For updates and additional resources, visit www.savingourseeds.org
For comments, suggestions, or distribution information contact:

Jeffrey H. McCormack, Ph.D.
Saving our Seeds
www.savingourseeds.org
Charlottesville, VA 22911

Funding for this project was provided by USDA-CREES (Cooperative State Research, Education, and Extension Service) through Southern SARE (Sustainable Agriculture Research and Education).

TABLE OF CONTENTS

SCOPE OF THIS MANUAL

The scope of this manual is devoted mainly to the major cultivars of peppers, *Capsicum annuum* var. *annuum*. Four other domesticated species of the genus *Capsicum* are also discussed, mainly with reference to their botanical characteristics, pollination and isolation distance requirements. Other species are included because of their increasing popularity and distribution.

PEPPER SEED PRODUCTION

BOTANICAL CLASSIFICATION

Botanical classification of commonly cultivated species of peppers:
Family: Solanaceae (Nightshade family)

Common name or representative type	Scientific name	Horticultural Group
Bell pepper	*Capsicum annuum* var. *annuum*	Grossum
Cone pepper	*Capsicum annuum* var. *annuum*	Conoides
Cherry pepper	*Capsicum annuum* var. *annuum*	Cerasiforme
Cayenne (Red cluster pepper)	*Capsicum annuum* var. *annuum*	Fasciculatum
Chili pepper	*Capsicum annuum* var. *annuum*	Longum
Bird pepper	*Capsicum annuum* var. *aviculare*	
Aji pepper	*Capsicum baccatum* var. *baccatum*	Baccatum
Aji pepper	*Capsicum baccatum* var. *pendulum*	Pendulum
Tabasco and Squash pepper	*Capsicum frutescens*	
Habanero	*Capsicum chinense*	
Rocoto and Manzano	*Capsicum pubescens*	

SPECIES CHARACTERISTICS AND IDENTIFICATION

General:

The common names for domesticated peppers vary from region to region, and among different ethnic groups; therefore use of common names may not be a reliable indicator of species. There are also regional differences in use of the common name "pepper." For example, "chili" is the generic name for pepper (regardless of whether sweet or hot) in Mexico and Central America. The name "chili" is derived from the Nahuatl dialect of Mexico. Throughout South America, the generic name for pepper is "aji" or "axi," and the Quechuan word "ucha" is still used by some Indian groups of Inca origin. These regional names can provide clues to the geographic origins of some of the less commonly cultivated peppers (for example, 'Kellu Uchu,' which originates from Peru). When the species identification is in question, the grower should consult a dichotomous key in order to make proper identification. Even when a key is used, it is important to note that the taxonomic classification of peppers is a study in progress, especially as modern research methods such as molecular biology are employed. Traditional methods of identifying the relationships between species are based primarily on flower characteristics. The following is a brief description of the major domesticated species with some of their identifying characteristics.

Capsicum annuum* var. *annuum
The species name (specific epithet) "annuum" means annual, but the name is misleading because all species of *Capsicum* are perennials when grown under favorable (semi-tropical or tropical) conditions. Of the five domesticated species, this is the most economically important and widely cultivated species, both for gardeners and commercial production. The flowers are usually solitary, creamy white, and seeds are straw colored. Virtually all of the large-fruited peppers belong to this species.

Capsicum baccatum
The specific epithet "baccatum" means "berried" or "berry-like." There are two subspecies: "*C. baccatum* var. *baccatum*" and "*C. baccatum* var. *pendulum,"* The later previously confused with the common bird pepper. Both subspecies are found in the lowlands and middle elevations of Bolivia, but "baccatum" ranges southward into Argentina whereas "*pendulum*" ranges northward into Peru. In South America, where *C. baccatum* is widely grown, this pepper is referred to as "aji." The wrinkled fruits of "aji" are distinctively fruity, aromatic, and colorful. The plants have large leaves. The flowers are solitary and the corollas creamy white (with diffuse white spots at the bases of lobes). Seeds are straw colored. Examples of this species include 'Aji Dulce' and 'Kellu Uchu.

Capsicum frutescens
The specific epithet "*frutescens*" means "shrubby" or "bushy." Its center of origin is the Amazon basin and lowlands of Columbia and Peru. In the United States it more commonly cultivated in the South. Flower corollas are usually greenish-white (without diffuse spots), solitary (occasionally 2 or more), the seeds are straw colored, and fruit flesh often soft. Some of the better-known representatives of this species include the 'Tabasco' pepper, and squash peppers that are distinctive for their hot, fiery flavor.

Capsicum chinense
The specific epithet "*chinense*" is misleading: it does not come from China. It originates from the Amazon region where it is the most widely grown species. This species is quite variable and is distinguished from *Capsicum frutescens* either by a constriction below the calyx of the flower, or is distinguished on the basis of a combination of characteristics rather than a single character. Flowers often number 2 per node (sometimes solitary), corollas are greenish-white (sometimes milky white or purple) and without diffuse spots at the base of lobes, flesh is firm, and seeds are straw colored. As the variability of this species becomes more widely known, and taxonomic methods improve, the emerging consensus of researchers is that this species should be considered as subgrouping of *Capsicum frutescens*. Well-known representatives of this species include the hot peppers 'Habanero,' 'Yellow Squash,' and 'Scotch Bonnet.'

Capsicum pubescens
The specific epithet means "downy" or "hairy." This species is found in the higher elevations of Mexico, Central America, and the Andes Mountains. This is the most distinctive of the five cultivated species. The leaves are usually pubescent along the veins. The flowers have purple corollas (sometimes with white margins), and the seeds are dark brown or black, somewhat wrinkled and rough-textured (rugose). Examples include 'Rocoto,' 'Locoto,' and 'Manzano.'

CLIMATE AND SOIL REQUIREMENTS

Climate:

Because peppers evolved in the climate of Central and South America they are tropical and subtropical in climate preference, and therefore thrive as perennials when grown in suitably warm climates. Evidence of their cultivation by native peoples can be traced back to at least 5000 BCE. With the European discovery of the New World in 1492, peppers were rapidly distributed along post-Columbian trade routes to Africa, India, the Far East and southern Europe, so that by 1600 they had achieved a worldwide subtropical and tropical distribution. So many different kinds of peppers made their way to India that at one time, India was considered (incorrectly) to be the center of origin for peppers. As peppers were brought into cultivation in the cooler temperate climates, there was (and continues to be) increasing selection for varieties that have less sensitivity to day length, and greater ability to grow and mature at cooler temperatures.

Temperature:

The tropical and subtropical origins of peppers continue to be expressed in their slow germination time, higher germination temperature requirement (the optimum is 81°F (27°C)), warm-temperature requirement for rapid growth, and for some varieties, sensitivity to day length (which affects flowering). Their requirement for warm temperatures is highest during the period from germination through early seedling growth. In seedlings and young plants (prior to flowering) the optimum day temperature for growth is 75 to 85°F (24 to 29°C) with the night optimum in the range of 50 to 60°F (10 to 16°C). By the time the plant enters flowering, the best temperature for fruit set is between 64 and 81°F (18 and 27°C). Plants will not set fruit well during periods of extended hot weather. Temperatures above 86°F (30°C) can cause developmental abnormalities in both the flower and the fruit of some varieties. Even in the Deep South, peppers are started in seedbeds or cell packs and set out for transplanting. Peppers need a growing season of at least 150 to 180 days for maximum production of fruit and seed. Day-length sensitivity continues to be an issue for the successful culture of some varieties, for example, 'Rocoto' (*Capsicum pubescens*).

Soil and moisture:

Peppers do not respond well to dry growing conditions or compacted soil. Good drainage and an adequate and steady supply of moisture are essential for good production. The preferred soil is a fertile sandy loam with pH maintained in the range of 5.5 to 6.8. Though clay soils are common (and sometimes despised) throughout the Mid-Atlantic and South, clay makes an excellent base soil with high production potential. This is due to its excellent mineral retention capacity. Clay-based soils must be liberally supplemented with organic matter to maintain aeration, increase drainage, buffer pH, and to encourage beneficial organisms such as earthworms. Sandy soils are preferred for early plants because the soil warms up rapidly. Pepper plants do not like "wet feet" and likewise, the seeds themselves do not germinate well unless the germination medium is well aerated and well drained. During the growing season, plants should receive the equivalent of at least 1 inch of rainfall, and during flowering and fruit set 1-½ inches of rainfall will give better fruit set. In large commercial plantings, growers use drip lines buried 2 to 10 inches deep in the soil, sometimes supplemented with drip irrigation tapes on the surface.

Culture:

Peppers have cultural requirements similar to tomatoes, though there are some noteworthy differences. Cultivation should be shallow to avoid root pruning. The plants themselves are brittle, especially as they age. Stems are easily broken by cultivation equipment when working between rows. For this reason, the inter-row spacing should be a minimum of 36" for most varieties. Some of the smaller, early dwarf varieties can be grown in rows spaced 24" apart. Mulching is preferred over cultivating between the rows, but mulch should not be applied until the soil has warmed considerably, typically the end of June or early July. In the Mid-Atlantic and South, strong winds from thunderstorms or the remnants of hurricanes can easily cause fruit-laden plants to lodge. Another factor affecting lodging is the amount of organic matter in the soil. In my experience, when the organic matter content exceeds 6% or more, top-heavy plants may not anchor well during high winds. To prevent lodging and stem breakage, plants should be caged rather than staked in order to minimize damage to the structure of the plant. Peppers are also very sensitive to high nitrogen levels, a factor that may have an effect in keeping the plant in vegetative phase, thus delaying the onset of flowering.

PLANT CHARACTERISTICS

General:

Peppers are perennial woody plants, grown as herbaceous annuals in temperate areas. Most species and varieties range between 2 and 4 feet tall. The branching system is dichotomous, so above the first division of the branch there is no main stem.

Roots:

Roots of large mature pepper plants form a dense network within a spread of 2 feet around and below the root crown. The total lateral spread may have a diameter of 3 feet, and in loose soil, the root depth may reach 3 feet.

Leaves:

The leaves of the most commonly cultivated pepper (*Capsicum annuum*) are characteristically flat, glabrous (smooth, without hairs), and simple or entire, though they vary in shape from ovate to elongate depending on the variety. Sweet peppers typically have a larger leaf size than hot peppers.

Inflorescence:

As noted in the section on species identification, *Capsicum annuum,* the flower is solitary, but in some other species, notably *C. chinense* and *C. frutescens,* the flowers are borne in a cymule (a more or less flat-topped, determinate flower cluster containing several flowers with the central flower opening first). The flowers are usually white or occasionally tinged with purple, and are borne in the axils of the leaves or branches. The five-part, bell-shaped corolla is 3/8 to 5/8" across, and the calyx is minutely lobed. Normally there are five stamens with bluish anthers united to the base of the corolla, but the stamens are not united as in the tomato. The stamens dehisce (split) longitudinally, exposing the pollen. The style is single and often longer than the stamens, especially in hot peppers. The stigma is club-shaped and the ovary has two locules in wild forms, but in domesticated forms the number of locules may vary between two and four or more. It is not unusual for there to be a variation of locules in the same plant.

Peppers tend to be short-day plants, with a tendency to blossom and set fruit earlier when the day length is short. For some species, this short-day condition can present problems when those species are grown in more northern latitudes. I have found that it is possible to "trick" some short-day varieties into blooming when they otherwise wouldn't. For example, in Virginia, 'Rocoto' (*Capsicum pubescens*) normally won't bloom until late in the summer, too late in the season to develop mature fruit (much less develop fruit that is half-normal size). I found that I could get 'Rocoto' to flower and produce fruit normally by planting it in a north-south row between rows of corn with about a 3-foot distance from the rows of corn. The mechanism for the success of this method is probably based on the fact that the day length is "shortened" by shading the pepper plants from both the early morning and late afternoon sun. Another explanation is that the corn filters the sunlight, changing the ratio of red to far-red light, which in itself may affect flower initiation. Though the yield of peppers is reduced using this method, it is possible to mature a decent crop of day-length sensitive peppers. Other species or varieties with a less stringent short-day requirement may be handled in a similar way, though may be grown more in the open by shielding the plants from early morning or late afternoon sun, for example by growing in the partial shade of a building or line of trees.

Pollination:

Pepper flowers continue to open for up to 2 hours after sunrise, though the anthers of most do not dehisce (open) until 30 minutes to 5 hours later (in some cases as late as 10 or more hours later, depending on the variety and species). The corollas close by approximately 6:30 to 7:30 p.m. and then reopen the following morning. The corollas drop from the plant on about the 3rd to 5th day. Stigma receptivity has not been well studied, but is thought to be receptive for less than 24 hours. The difference in timing between when the stigma is receptive and when pollen is shed favors cross-pollination during the early part of the day, primarily between 7 a.m. and 11 a.m., with the peak between 8 a.m. and 10 a.m. Field observations have confirmed that the stigma of the flower is frequently covered with pollen before the anthers have dehisced. These studies and observations indicate that cross-pollination is favored and is the natural condition.

Relative to other types of flowers, pepper flowers are often not as attractive to bees that may be attracted to more strongly-scented or more brightly-colored flowers (in terms of bee vision), or flowers that have richer sources of pollen. Pepper flowers do not produce a noticeable odor, but they do produce nectar that accumulates in the nectary at the base of the flower. The quantity of nectar depends on the variety and species, as well as a number of other factors. The primary pollinators of peppers are honeybees, bumblebees, and wild native bees.

Strangely for a major food crop, relatively few vigorous studies have been conducted on the rate of natural cross-pollination of peppers (NCP). Such studies are not easy to conduct because of the multitude of factors that affect natural cross-pollination (NCP). In 1941 Odland and Porter wrote: "Plant breeders and seedsmen disagree considerably in their opinions relative to the amount of natural cross-pollination in the cultivated pepper in seed production, knowledge relative to natural crossing is a great aid in determining the isolation necessary in the seed plots." The lack of information is due partly to the number of variables affecting NCP such as location, time of year, changes in insect populations, and climatic factors. Several seed saving guides recommend isolation distances ranging from "several feet" to "50 feet," to "separation of the length of the garden," to "separation as far as practical," to "500 feet," to "¼ mile or more".

Odland and Porter's 1941 study using *Capsicum frutescens* demonstrated that NCP values ranged from 9 to 38% depending on the variety of pepper tested. They did not determine the amount of isolation required to keep varieties pure. A 1984 study by Tanksley reported results of experiments conducted over a two-year period in five commercial fields in New Mexico. Tester plants were placed 12" from adjacent plants of a commercial variety. The average NCP was found to be 42% with individual plants having a NCP value as high as 91%. The plants experiencing NCP in these studies were grown in close proximity, but high values of NCP can also be expected when the two varieties are grown a short distance apart, especially when growing plants organically in a biodiverse environment. In my experience, I have had peppers cross in plantings 6, 15, and 25 feet apart.

The following chart shows the recommended isolation distances for peppers grown organically for seed in the Mid-Atlantic and South:

Seed Crop	Min. for home use	Min. w/ barriers *	Min. w/o barriers *	Comments
Peppers (*Capsicum annuum*)	40-75'	75-150'	300-600' depending on variety	A larger isolation is required between hot peppers that have a longer style. Population size, pollinator pressure, and biodiversity should be considered.

The isolation distances recommended above take into consideration a number of factors that are too numerous to mention here. For a thorough discussion of the physical, biological and ecological factors that affect isolation distance recommendations for peppers and other crops, see the companion manual titled: "Isolation Distances: Principles and Practices." This manual also provides methods and strategies for modifying recommended isolation distances based on the importance of certain variables.

One factor that is especially important to mention is that many hot peppers, as well as wild peppers, tend to have an elongated style. The longer the style, the less likely self-pollination will occur and the more likely cross-pollination may occur. For this reason, I recommend that hot peppers have at least twice as much isolation distance from each other (and from sweet peppers). The most important rule to remember about determining or modifying isolation distance recommendations is that every doubling of the isolation distance decreases the chance of cross-pollination by a factor of four.

Fruit:

The fruit is a pod-shaped berry that is attached by a short, thick peduncle. Young fruit is usually borne in an erect position, but in some varieties it turns downward into a pendant position as it grows. Fruit size varies from small, berry-like fruits to large fruits such as 'California Wonder.' Shape varies from long and slender, and tapering, to flattened and oblate. The pericarp (fruit walls) varies from thin to thick. It is the combination of these various characteristics that comprise the array of numerous varieties of peppers available.

Though fruit size and shape are genetically pre-determined, environmental conditions (such as light, temperature, and nutrient status) modify the expression of the genes that code for shape and size. Daytime temperatures over 100ºF (38ºC) in combination with low humidity cause the development of poorly shaped, off-type fruit. At the end of the growing season in temperate zones, I have observed that bell peppers have a tendency to become more elongated. Because there is so much parallel variation in *Capsicum* species, fruit color, shape, and size are of little taxonomic value in classifying non-domesticated peppers, but within domesticated species, fruit shape and size can be reliably used to distinguish between most varieties. Floral characteristics are the most reliable characteristics for taxonomic purposes.

Seed:

The seed is borne on the placenta, mostly on the basal end of the fruit. Seeds have a flattened disk-like shape, and are usually creamy tan or dark tan in color. The seed lacks pubescence except for *Capsicum pubescens* (which has distinctive dark brown seeds). The number of seeds per ounce varies according to species, variety, and growing conditions. On average, the number of seeds per ounce for *Capsicum annuum* is 4,500 to 4,700 seeds.

The federal standard for pepper seed germination is 55%. This low standard probably incorporates the germination response of less-domesticated species of *Capsicum* that have a naturally lower, more erratic germination. Dormancy is a survival mechanism in wild plants that ensures that seeds germinate at different times in order to ensure survival under adverse conditions. Briefly stated, it is a strategy that avoids putting all eggs in the same basket. Even freshly harvested seed of some varieties of *C. annuum* have low germination. Such seed requires a period of "after-ripening" during which dormancy is overcome and the seed is physiologically prepared for germination. The lower germination of freshly harvested seed can be improved by after-ripening the seed by storing the seed at a cool temperature for 6 months. Germination typically requires 12 to 21 days at 70ºF (21ºC), or up to 30 days or longer for some varieties and species.

Pungency and flavor:

The pungency of hot peppers is not due to a single molecule, but rather closely related capsaicin molecules that differ from each other principally in the structure of their acid side chains. Capsaicin is virtually odorless and flavorless: it is experienced physiologically as a burning sensation and is so potent that it can be detected at the level of 1 part in a million. The amount of "heat" in a pepper is expressed in Scoville Heat units which range from 0 units (as in sweet peppers) to 80,000 units in some 'Tabasco' peppers. The test is based on the Scoville Organoleptic Test of 1912 that uses human "guinea pigs" as a taste panel. The level of capsaicin is primarily a variety characteristic, but can be greatly influenced by environmental conditions and maturity of the fruit. Nearly all the capsaicin is produced in the placental partition of the fruit and is controlled by a single dominant gene. Seeds acquire their pungency only through contact with the placenta. Capsaicin is a useful genetic marker for determining minimum isolation distance recommendations when separating a pungent from non-pungent variety of pepper.

The flavor of peppers is experienced separately from pungency and involves the senses of smell, taste and touch (tactile sense), and is due to the presence of small amounts of several aromatic substances. These flavor components are associated with the presence of carotenoid pigments. Flavor and color are strongly linked which can be easily verified by sampling fruit at different stages of color development. The flavor components are located throughout the outer wall of the fruit.

Reponses to air drying:

Some species of *Capsicum* are very difficult to air dry, for example, *C. chinense*, *C. pubescens*, and some varieties of *C. annuum* (for example 'Jalapeno'). Where climate permits, peppers are best dried on the plant, rather than being picked when ripe and succulent, but the hot-humid climate of the Mid-Atlantic precludes use of this method for drying. Color is best retained when peppers are dried under cool conditions. Storage temperature is more important than light.

SEED PRODUCTION METHODS

Minimum population size:

The flowers of peppers are perfect, self-pollinated, and self-fertilized, but the sequence of floral development strongly favors cross-pollination by insects. Although they are highly cross-pollinated, there is no inbreeding depression within domesticated peppers.

If a variety of pepper has been badly mismanaged when first acquired, start with a minimum population size of about 200 plants and rogue out at least one-third of the plants the first year. When selecting during the first year, the priority should be on selecting out those plants with low vigor. Be careful about selecting for high vigor which may be due to accidental crossing. Later selections can focus more on off-type vegetative characteristics, reproductive maladies, and off-color fruits. If the seed stock has been well maintained, the minimum population size for saving seed should generally be in the range of 40 to 75 plants. The higher end of that range is suggested is for certain ethnic, family heirloom, and heterozygous varieties. A minimum population size of 25 plants may be sufficient for retaining most of the heterozygosity of uniform varieties. When doing intensive selection to develop pure line selections that will later be pooled or massed, the minimum population size of the single line selections can be smaller.

Rouging:

Peppers are easier to rougue than tomatoes because unlike many tomato varieties, the characteristics of the plant, foliage, and fruit are more distinct. Rouging is usually not necessary when peppers are grown from quality seed stock. That said, when working with ethnic and family heirloom varieties of peppers you should first have a good idea of how much variation to expect within the population of plants that you are growing for seed. Most commercial varieties will have good uniformity, but when working with ethnic varieties and family heirloom varieties, there may be significantly more plant-to-plant variation in fruit characteristics. The amount of expected variation should be ascertained before rouging the seed crop.

The earliest rouging of sweet peppers should be based on low vigor and leaf size before plants begin to flower. Because small-leafed plants tend to be pungent, they are likely the result of a cross of a sweet pepper with a hot pepper. The second stage of rouging is based on fruit shape, before fruit reach edible maturity, so that the seeds don't contribute to the gene pool, and also to prevent further cross-pollination. Note: it is not uncommon to have some variation in shape of individual fruits on a single plant. Therefore rouging should be based on the appearance of all the fruit on a plant, rather than the presence of one or several off-type fruits on a plant. The third stage of rouging is done when the fruits begin to turn their mature color: individual plants with off-color fruit should be pulled.

Harvest:

The best quality, highest germination seed is obtained from fully ripened fruits. Peppers are fully ripe when color development is complete and uniform over the surface of the fruit. Many pepper varieties are red when ripe, but some are yellow, orange, purple, or brown, (though at least one variety, 'Permagreen' remains green when ripe). Regardless of the color, do not let ripe fruits remain on the plants, and do not harvest seed from peppers showing signs of disease, especially mosaic virus which can be carried in the seed.

When peppers are grown for seed in the Mid-Atlantic and South, certain pepper varieties may develop a cream-colored fungus in the seed cavity at peak ripeness or slightly afterward. In my experience, this problem seems to be associated with certain varieties that were developed for more northern climates, for example, 'Merrimack Wonder,' 'Midway,' and 'Yellow Belle.' The solution to this problem is to harvest before peak ripeness. For example, if harvesting from a red pepper, you may have to harvest from fruits that are mostly red, but still show a trace of green somewhere on the fruit. If you harvest too early the germination will be lower, but if you harvest too late, the seed will not be useable. Working with fungus-susceptible varieties leaves a small harvest window, but the method requires only slightly more attention than working with non-susceptible varieties.

At the end of the growing season when frost threatens to kill the crop, harvest the mature-green, and red- and green-streaked peppers and ripen indoors or outdoors (as described below). To hasten the ripening of green fruits, the practice I follow is to load 5-gallon buckets with mature-green peppers combined with peppers that that have some red streaks. The 5-gallon buckets are then covered with a lid and kept in a cool, fully shaded location outside. The purpose of using lids on the buckets is to help retain ethylene, a volatile hormone released by ripening fruits. It is possible that adding a few ripe apples may hasten the process, but I have not performed a controlled experiment. The only drawback to the covered bucket-ripening method is that the fruits respire and the moisture collects in the buckets, requiring that the peppers be periodically dried and reloaded into the buckets. Keeping the buckets cool presents a trade-off; peppers are kept in good condition, but the cool temperature may slow the ripening process.

Seeds harvested from mature-green fruits may germinate less than 10%, but seed extracted from peppers ripened off the vine often germinate as high as 90%. What I have not tested is the storage life of pepper seed extracted from fruits ripened off the vine. When tomato seed is extracted from fruits that are ripened off the vine, the germination is as good as the seed obtained from vine ripened tomatoes, but the storage life is shorter. Whether this is also true of peppers needs to be determined.

Extraction methods

Basically there are three approaches to pepper seed extraction: (1) dry extraction, (2) wet processing, and (3) wet processing with brief fermentation. The process of extracting seed from peppers is similar to that for tomatoes except that the fermentation process (when used) is about 24 hours instead of 72 hours. In exceptional cases, I have allowed fermentation to proceed for a longer period of time, up to 36 to 40 hours.

Wet seed processing methods have the advantage of enabling the separation of good seed from poor-quality seed, thus yielding better quality seed. When good quality, freshly extracted seed is added to, or extracted in water, the good quality seed sinks to the bottom because the seed is denser. Poor quality seed is less dense because the seed is immature or not well filled out, and being less dense, it tends to float off with the wash water. A potential problem with the wet processing methods is that some good quality seed may float due to the fact that tiny air bubbles stick to the seed causing them to become buoyant during the washing procedure. This is a problem with certain species such as *Capsicum pubescens*, which has rough-textured (rugose) seeds. It can also be a problem with certain varieties of peppers, but the seed buoyancy problem is more often due to the washing technique than the variety of pepper. Floating of good seed can be avoided by not introducing air into the wash water. Instead of spraying wash water into the container from a hose nozzle (which introduces air bubbles into the mash), water should be added beneath the surface of the mash in such a way to avoid introducing air. If there is a problem with air sticking to the seeds, a solution is to take the palm of your hand and gently push the seeds down under the water surface. This will cause many of the good seeds to sink to the bottom. Using this technique it is possible to recover some good seed that would otherwise be washed away. One other important aspect of the wet processing technique is that the mash should be well diluted prior to pouring off the wash. If the mash is not well diluted the specific gravity of the mash may be too high causing some good seed to be lost in the wash.

Though the dry seed extraction method involves fewer steps, it may not be as efficient in separating good quality seed from poor quality seed. That said, it is still possible to get some separation of good and poor quality seed by using an acceptable winnowing or air separation technique. Whether using water or air separation, the principle is the same because both techniques are based on buoyancy.

The extraction method used (either wet or dry) depends largely on the how much seed is to be processed, what type of seed quality is desired, the type of equipment available, fruit characteristics such as fruit size and pungency, and perhaps personal preference, which is influenced by the other factors. My recommendation is to use wet processing with a 24-hour fermentation period. The fermentation serves several purposes: (1) it loosens bits of placenta and other debris from the seed coat, (2) it gives cleaner seed by breaking down plant material making the separation and washing easier, and (3) it gives higher germination seed when the seed is properly washed. The 24-hour fermentation may not be long enough (typically a 72-hour process) to kill certain diseases, but since fermentation is also used as a sanitizing step, this is a step in the right direction in the goal of providing quality seed.

When washing the seed after fermentation, it is important to add lots of water to the pulp or mash (especially on the first wash), otherwise the dissolved soluble solids in the mash will raise the specific gravity of the liquid thereby reducing the efficiency of seed separation and may cause loss of some good seed.

For the sake of completeness, I have described several methods of seed extraction based on the scale of operation and the type of equipment that can be used. In most cases the advantages and disadvantages of each method are also described.

Large-scale extraction methods (hundreds of pounds of seed)

Large-scale commercial processing method:

The fruit is cut and macerated by machines that are used for almost any wet-processed fruit such as tomatoes. The macerated fruit is discharged from the rollers onto a large rotating screen where the seed is washed free of the larger pieces of pulp, stem fragments, and skin. The fruit is then fermented for 24 hours in large vats, though fermentation of pepper seed is not practiced as much as in the past, possibly because chemicals are used to kill disease organisms, or to reduce costs.

Small-scale extraction methods (ounces to several pounds of seed)

Dried core hand-extraction method:

Remove the seed-bearing cores of the fruits and let them air dry. In using this method in the humid Mid-Atlantic and South, it essential that the cores dry in a well-ventilated, air-conditioned location, otherwise the seeds may become moldy, discolored, and useless as commercial grade seed. Once the core has dried, simply rub off the seeds. This method is adequate for small batches of sweet pepper seed, for example seed extracted from a few plants for seed increase, breeding purposes, or for seed saved for home use. For commercial grade seed, a final air separation stage is recommended.

Wet core hand-extraction method:

Cut the core out of the pepper, grasp the core with one hand, submerge in a pan of water, and rub the seeds from the core using the other hand. When finished extracting seed from a number of cores, pick large pieces of debris from the water, and then carefully pour off the floating debris. Good quality seeds will sink to the bottom of the container, and the immature and poor-quality seeds will float off with the debris. The remaining good-quality seeds should be submerged in water and washed well before being collected in a strainer. The washed seeds are then air-dried in a thin layer (no more than ¼" thick) on the top of folded paper towels, cloth, or window screen. A variation on this method is to put the seed-bearing cores in a small volume of water, and let cores ferment for up to 24 hours. This will help loosen the seed, and this method gives better quality seed than the dried core method, but is a little bit more labor intensive.

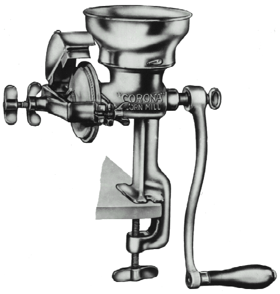
Food processor method:

This method works best for small-fruited, cherry-type, sweet peppers, and especially for small-fruited hot peppers (for example, 'Amazzo'). In selecting a blade, use only a blunt-edge, plastic, square-edge blade (1/8" thickness) as shown here (Figure 1). Do not use a sharp metal blade because it will cut some of the seed — unless your timing and technique is exquisite. To extract seed of sweet peppers, remove the stem and place the cores in the food processor. Add enough water to cover the cores completely. If not enough water is added the seeds may become bruised from the blade hitting the seed. The ideal process is to let the turbulence of the water pull the seeds off the core rather than beating the seeds off the core with the blade. Keep the processing time to a minimum, just enough time to separate the seed from the fruit. Pour the mash into a container and let it ferment for 24 hours. Then wash the seed to remove pulp, debris, and low quality seed. The seed is collected in a strainer, washed a final time and then laid out in thin layers to dry. When processing hot peppers, use rubber gloves when cutting off the stems completely. Stem fragments are heavy and may have to be hand picked from washed seed. Make sure the equipment is washed thoroughly after each use. The primary advantage of using the food processor is to avoid handling pungent fruits. The disadvantage is that bruising or cutting of the seed may impair the germination. I have compared germination of seed extracted by this method with other methods. It certainly does yield good quality seed. Based on physical inspection of the seed I would estimate that germination impairment might be relatively small, say at most a 5% reduction in viability, depending on technique and type of food processor.

Medium to larger-scale extraction methods (several pounds of seed)

Corona grain-mill method:

Adjust the rotating plate on the grain mill so that the grinding plates are approximately ¼" apart. This is just enough distance to separate the seed from the pulp without grinding the seed. Because the hopper capacity on the grain mill is small, large-fruited varieties will need to be cut into sections so that the sections feed easily down onto the rotating auger that pushes the cores through the grinder. Small-fruited peppers can be added directly to the hopper, though they need to be pushed down onto the auger with enough pressure to force them between the auger threads. A wooden stick (1-½ x ½") or large diameter dowel is used to push the fruits into the grinding chamber (Figure 2). When processing hot peppers it is important to label the "hot" end of the stick because the capsaicin will penetrate the wood and will be transferred to the skin if the wrong end is handled days or weeks later. You may not notice the contamination on your hands, but you will if you rub your face. At the end of the grinding process, transfer the mash to a bucket and add enough water to make a loose slurry. The slurry is allowed to ferment for 24 hours as described previously. The disadvantage of this method is that the grain mill can be difficult to clean. The mill must be totally disassembled and washed when changing varieties, and seed must be picked out of the crevasses in the grinder plates and other parts of the mill.



Figures 2 and 3: Illustration of a Corona grain mill, and photo of a Corona mill being used to extract the seed of a small-fruited hot pepper ('Amazzo'). The wooded "push rod" is used to force the uncut fruit into the throat of the hopper and between the threads of the auger. Small hot peppers do not need to be cored or sliced. The mash is caught in a large tray and later transferred to a bucket for fermentation. When working with small-fruited varieties, quite a bit of seed (ounces to pounds) can be extracted this way.

Wheelbarrow/hoe chopping/mashing method:

Figure 4.

This method works well for large hot peppers or large quantities of whole sweet peppers. Add the fruit and a small amount of water to a wheelbarrow. Chop the fruits with a hoe until fruits are thoroughly cut up, and then mash with a mortar mixer. A mortar mixer (shown in Figure 4) looks like an oversized potato masher. Dump the mash into a clean trashcan or 5-gallon bucket to ferment. A similar method is to core the sweet peppers and then add the fleshless cores to a 5-gallon bucket. Add enough water to cover the cores, ferment for 24 hours and then mash the cores. By doing the fermentation first, the seeds slip more easily from the cores and the mashing process is easier.

Figure 5. Hoe, wheel-barrow and hand mortar mixer for chopping and mashing peppers

Apple grinder/press method:

Illinois seed grower Merlyn Niedens has explored this method. The grinder that he uses (Figure 6) is similar to the one shown at the right (Figure 7), though his grinder was made from a kit in about 1980. The grinder throat (Figure 9) consists of a wooden cylinder and seven long L-shaped metal brackets screwed to the wooden cylinder. The rotation of the cylinder within the grinder housing causes the contents to shred. He has used it successfully to extract seed of tomatoes, peppers, eggplant, and watermelon. He does not use the press. Instead, the wooden barrel is replaced by a 5-gallon bucket to catch the pulp. Use of the press might be helpful in the extraction of eggplant seed, but isn't necessary for pepper seed extraction. Small peppers (less than ¾" wide) are best extracted using the Corona mill. Seed of large peppers is best extracted using the grinder. Extraction may require two or three passes through the mill, depending on the mill design.

Figure 6. Grinder made from a kit.
Photo courtesy of Merlyn Niedens.

Figure 7. Apple grinder/press

Figure 8. Throat of an apple grinder/press. Photo courtesy of Pleasant Hill Grain.

Figure 9. Throat of an apple grinder made from a kit. Photo courtesy of Merlyn Niedens.

Drying the seed:

After seed has been fermented and washed clean, it is spread in thin layers on window screen and allowed to dry in a shady well-ventilated place. If screens are not available use cloth towels, or absorbent material to wick water away (but don't use newspaper). If not dried in an air-conditioned environment, turn the seed often to hasten the drying process or place the seeds under a ceiling fan or in front of an air conditioner. Keep seeds far enough away from fans to avoid blowing seeds away as they dry. Once dried, cure the seed by letting it air dry for four to six weeks before placing in moisture-proof containers. When pepper seed has sufficiently dried, the seeds will break rather than bend when folded. For additional in-depth information, see the companion manual in this series titled: "Seed Storage and Processing."

Cleaning:

After fermentation and washing, pepper seed requires very little cleaning except perhaps screening to remove small seeds. Seed extracted by the dry core method is also fairly clean, but may require some hand picking and screening to remove seed with pieces of placenta attached.

Seed yield:

Pepper seed yields are highly variety dependent, and the seed yield per acre is low. Reported average seed yields of sweet peppers from large-scale commercial sources vary from 35 to 50 pounds per acre (0.8 to 1.15 pounds/1000 square feet). Small-scale growers can achieve much higher yields. Data from my records are shown in Table 1.

Table 1: Pepper seed yields from the author's seed production records during the years 1988 to 1993 (includes some grower data).

Type of pepper	Number of plants needed to produce one pound of seed	Average number of plants per acre	Average yield of seed per acre (pounds)
Sweet varieties	128 to 256	9,680	38 to 75
Hot varieties	32 to 128	14,520	113 to 453

Breeding priorities:

Compared to tomatoes, there has been much less breeding work done on peppers, yet there is a great deal of unexplored potential for breeding new varieties, especially varieties suited for organic growers in the Mid-Atlantic and South. My opinion is that much of the modern commercial breeding efforts have focused on improvements that have had little significance for home gardeners and small-scale organic growers. Two notable exceptions are 'Charleston Belle' and 'Carolina Wonder' first introduced in 1998 and 1999. These were developed by Drs. Fery, Duke, and Thies at the USDA ARS in Charleston, South Carolina. They were the first nematode-resistant bell peppers, and these varieties represent a great step forward for organic sweet pepper growers in the South. Other than these introductions, much of the novel and more useful genetic material, from my perspective, has come from family heirloom and ethnic varieties of *C. capsicum* as well as other species. This is a fertile area of exploration for the breeder and small-scale organic seed grower focused on crop improvement, especially in the Mid-Atlantic and South. Much of the emphasis should be placed on breeding peppers resistant or tolerant of diseases.

DISEASES AND DISEASE MANAGEMENT

Unless otherwise noted below, many diseases can be minimized or controlled by maintaining good soil health and proper pH, composting or burying crop residues, using drip irrigation instead of overhead irrigation, maintaining good air circulation around plants, and practicing a 3-year crop rotation with other Solanaceae (nightshade family). Rotation with cereal crops provides the best defense against bacterial, fungal, and viral pathogens. Certain regulated copper products may be used for control of fungus diseases, provided they are used in an approved manner and do not accumulate in the soil. Check with your organic certifier and obtain approval before using any copper product for disease control.

Southern blight (*Sclerotium rolfsii*): This fungus disease affects many vegetables, especially southern grown peppers. Symptoms are characterized by sudden yellowing and wilting of the plant. The fungus attacks the root crown and if a plant is pulled up, a white fungal mycelium will be observed on the roots. In the mycelium are tiny brown sclerotia (fungal reproductive structures which overwinter in the soil). Since many other crops are affected by this fungus, rotation with cereal crops is recommended because cereals do not serve as host plants.

Bacterial leaf spot (*Xanthomonas vesicatoria*): This seed-borne bacterial disease first appears as small irregular water-soaked areas that enlarge up to ¼ inch in diameter. The disease spots have black centers and yellow halos. The spots are depressed on the upper leaf surface, whereas on the lower surface the spots are raised and scab-like. Heavily infected leaves may develop ragged edges on the leaf margins causing deformed leaf growth. The leaves eventually turn yellow and drop off, leaving fruit susceptible to sunscald. Symptoms on the fruit appear as raised-scabby spots. The principle sources of infection are seed, infected transplants, and crop residues. The bacterium can survive up to one year in infected crop residues. Moist conditions encourage disease development.

Cercospora leaf spot (*Cercospora capsici*): This seed-borne fungus disease is promoted by extended warm, wet conditions. The fungus may survive up to one year in infected crop residues and infected seedbeds. The disease is characterized by the appearance of water-soaked areas that enlarge up to ¼ inch in diameter, symptoms later presenting as circular or oval-shaped spots with light-gray centers and brown margins. In severe infections, leaves may turn yellow and defoliation may occur.

Anthracnose (*Colletotrichum piperatum* and *C. capsici*): These two seed-borne fungal diseases do not seriously affect the vegetative growth, but do affect the fruit. Symptoms appear on both unripe and ripe fruit and are characterized by sunken, more-or-less circular spots that can grow up to 1 inch in diameter or larger. In moist conditions, pinkish or yellowish spore masses may appear, often accompanied by setae (dark hair-like structures produced in association with the fungal spores). The disease is promoted by warm temperatures, over 90ºF (32ºC), and high moisture (dew, fog, rain, frequent overhead irrigation, and poor air circulation among the plants). The fungus overwinters in plant debris and seeds. Provided that seed is harvested only from healthy fruit, and fermentation and washing is carried out without contamination from diseased fruits, the harvested seed lot should be fairly clean. Approved chlorine materials may be applied to healthy fruits prior to seed extraction to reduce possibility of contamination. Check with your organic certifier first. The chlorine levels in the wash water should not exceed the residual disinfectant limit under the Safe Drinking Water Act.

Phytophthora blight (*Phytophthora capsici*): This fungal disease is promoted by warm, wet weather, and is most frequently observed in the wettest areas of a field. All parts of the plant are affected. Symptoms include leaf blight, fruit rot, root rot, and stem canker. Affected areas are often bordered by a white mold. In addition to control practices mentioned above, plants should be grown in well-drained soil.

Mosaic viruses: Infection may be caused by a number of viruses which include: cucumber mosaic (CMV), tobacco mosaic virus (TMV), potato virus Y (PVY), tobacco etch virus (TEV), and alfalfa mosaic (AMV). Symptoms vary according to the type of virus and strain, time of year, and environmental conditions. Symptoms may include leaf mottling, curling, puckering, streaking of stems and petioles, spotted or mottled fruit, stunted plants, and dropping of blossoms and fruit. TMV is highly infectious and persistent, and is also carried by tobacco in cigarettes. Smokers should not be allowed within proximity of the crop, nor should they handle seeds, tools, or anything that comes in contact with the crop. TMV is heat-resistant, and can persist in a dried state for many years though it attenuates over time. TMV is killed by milk. After handling infected plants in the field, disinfect hands or tools with milk. Fortunately, TMV resistance has been bred into a number of modern cultivars, though resistance may not be present in some heirloom or ethnic varieties. Of the viral diseases of pepper, CMV is the most important viral disease because it is so widespread and no level of tolerance is available in any commercial variety. Aphids, especially the green peach aphid and potato aphid are the most important vectors. Aphids can be controlled by soap sprays and oils, but unfortunately the virus has already been transmitted by the time an outbreak of aphids has been detected. Check with your organic certifier before using any treatments. Viruses often overwinter in infected perennial plants, notably poke. Other hosts include catnip, members of the Solanaceae (nightshade family), wild lettuce, mallow, and chickweed. CMV virus infects more than 775 species! Where possible grow resistant varieties, use good cultural and disease control practices, protect young plants from aphids with floating row cover, plant a barrier crop of a non-susceptible small-grain cereal crop or sweet corn, and keep plants away from weedy border areas.

Physiological diseases (abiotic diseases): Physiological diseases are not true diseases caused by infectious organisms. They are caused by environmental conditions or metabolic imbalances. Examples include blossom end rot and sunscald. Blossom end rot is due to a transient deficiency of calcium in the developing fruit, and is often due to moisture stress. Sunscald can be a serious problem in some varieties of peppers (especially sweet peppers) grown in the southern latitudes. Sunscald can be prevented by growing varieties with good foliage cover. Many hot peppers are resistant to sunscald.

For additional information: Though not oriented toward organic growers, the online resources cited below offer useful in-depth information on diseases and pest control.

- **Vegetable MD Online** (http://vegetablemdonline.ppath.cornell.edu) This is an excellent website containing detailed disease descriptions, photographs, and suggested control measures.
- **UC IPM Online** (http://www.ipm.ucdavis.edu) A comprehensive site containing detailed disease descriptions, photographs, and control measures. Also includes a photo gallery of common weeds.

INSECT PESTS AND PEST MANAGEMENT

Although a number of insects attack peppers, only two insects are of much significance for the region covered by this publication. As mentioned previously, aphids are a problem in that they are vectors for viruses. Flea beetles are a nuisance when peppers are in the seedling stage. The major destructive pests are covered below.

Nematodes: Nematodes are microscopic, eel-like roundworms that live in the soil and feed on roots. The most destructive is the root knot nematode (*Meloidogyne* sp.) They are difficult to control and are easily spread from place to place on tools, equipment, shoes, and plant roots. Root knot nematodes cause distinctive swellings, called galls. The nematodes develop and feed within the galls that can swell to a large size, up to an inch in diameter on some host plants, but are much smaller on the roots of peppers (see Figure 7). The galls interfere with nutrient and water transport in the roots, thus weakening the plants. Sometimes the galls break open providing an entry for opportunistic disease organisms. Nematodes can make gardening and farming difficult in warm, sandy, irrigated soils in the South.

Figure 7: Pepper roots with extensive galling. Photo by Scott Bauer ARS USDA

The most effective controls are soil solarization, crop rotation, sanitation, fallowing, and use of resistant varieties (for example 'Carolina Wonder' and "Charleston Belle'). A 2004 study by one of the developers of 'Charleston Belle' showed that not only did it repel nematodes, it also protected subsequently planted (double-cropped) susceptible squash and cucumber crops. In a USDA ARS study, cucumber yields were 87% heavier and numbers of fruit were 85% higher when grown after ‘Charleston Belle’ than after ‘Keystone.’ Squash yields were 55% heavier, with 50% more fruit. This finding has very important implications for organic growers dealing with nematode problems.

When using soil solarization for control, the clear plastic ground cover must be in place for at least 6 weeks during the hottest part of the summer. This technique is not effective in cool, coastal southern areas where the daytime temperature is less than 80ºF (27ºC). When controlling nematodes by means of crop rotation, use nematode-resistant varieties, and small cereal grains. Certain marigolds when planted as a solid cover crop will suppress root knot nematodes. Marigold varieties that are most effective include 'Nemagold,' 'Petite Blanc,' 'Queen Sophia,' and 'Tangerine.' Soil should be well supplied with organic matter to increase water-holding capacity. Though this doesn’t decrease the number of nematodes it decreases the damage to the plants by reducing water stress.

Pepper maggot (*Zonosemata electa*): The pepper maggot is a major pest of peppers and is often difficult to detect, usually not until the fruit has been harvested. The adult form is about 8 mm long and is shown in Figure 8. The female lays its eggs in the flesh of the fruit leaving only a very small dimple (oviposition scar) in the wall of the fruit. The eggs hatch into translucent white maggots that feed in the seed cavity just under the pericarp (walls of the fruit). Infected fruits tend to ripen prematurely and when harvested, the stem cap often separates from the fruit. Because the integrity of the fruit is breached, the seed cavity may occasionally be colonized by opportunistic fungi that make seed harvest questionable. Control relies principally on crop rotation and sanitation. Adult flies are attracted to rotting fruit. Oddly in trapping studies, the adult flies prefer certain non-host habitats (such as maple trees), except when they are laying their eggs. Yellow sticky traps (baited with liquid ammonium hydroxide) are used to monitor infestations. Traps placed at crop height within the crop catch very few flies, but traps placed at tree line at about 20 feet are very effective in monitoring infestations. Fruit oviposition scars are the only other method of detecting an infestation.

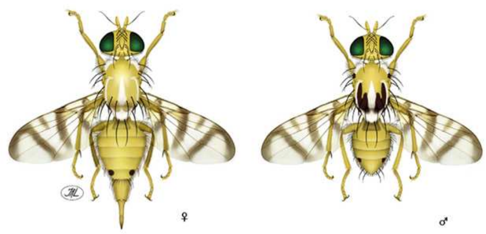


Figure 8: Adult female and male flies
Source: USDA

SELECTED BIBLIOGRAPHY AND LITERATURE CITED

Ashworth, Suzanne. 2002. Seed to Seed: Seed Saving and Growing Techniques for Vegetable Gardeners. Seed Savers Exchange, Decorah, IA

Hawthorn, Leslie. R. and Leonard H. Pollard. 1954. Vegetable and Flower Seed Production. The Blakiston Co., Inc. Garden City, NY

Heiser, Charles. B., Jr. 1969. Nightshades: The Paradoxical Plants. W.H. Freeman and Co., San Francisco, CA

Smith, Jean A. 1984. Peppers: The Domesticated Capsicums. University of Texas Press, Austin, TX.

Smith, R., Hartz, T., Aguiar, J. and R. Molinar. 1998. Chile pepper production in California. University of California Publication 7244

Lorenz, Oscar A. and Donald N. Maynard. 1980. Knott's Handbook for Vegetable Growers (2^{nd} edition). Wiley and Sons, NY

MacNab, A. A., Sherf, A. F. and J.K Springer. 1983. Identifying Diseases of Vegetables. Pennsylvania State University, University Park, PA

McCormack, Jeff 1986. "Guidelines for maintaining purity in pepper varieties" (pp. 242-246) in Seed Savers Exchange: The First Ten Years. Seed Saver Publications, Decorah, IA

McCormack, Jeff. 1989. Southern Exposure Seed Exchange catalog. Earlysville, VA

McGregor, S.E. 1976. Insect Pollination of Cultivated Crop Plants. U.S. Department of Agriculture Research Service. Agriculture Handbook No. 496

Odland, M. L. and A.M. Porter. 1941. A study of natural crossing in peppers (*Capsicum frutescens*). Amer. Soc. Hort. Sci. Pro. 38: 585-588.

Tanksley, S. D. 1984. High rates of cross-pollination in chile pepper. HortScience 19: (4): 580-582.

Villalon, Ben. 1984. Texas Agricultural Experiment Station, Weslaco, TX (personal communication)

OTHER REFERENCES OR RESOURCES

Due to the dynamic and ever-changing nature of resources available on the World Wide Web, Internet resources cited in this publication may not remain current. If the address has changed, try using the base URL for locating information that has moved to a new address.

Any reference to commercial products, trade or brand names is for information only, and no endorsement or approval is intended.

CREDITS

Front matter illustration is from botanical illustrator, Lucia ("Cinder") Stanton, Charlottesville, VA

DISTRIBUTION AND LICENSING INFORMATION