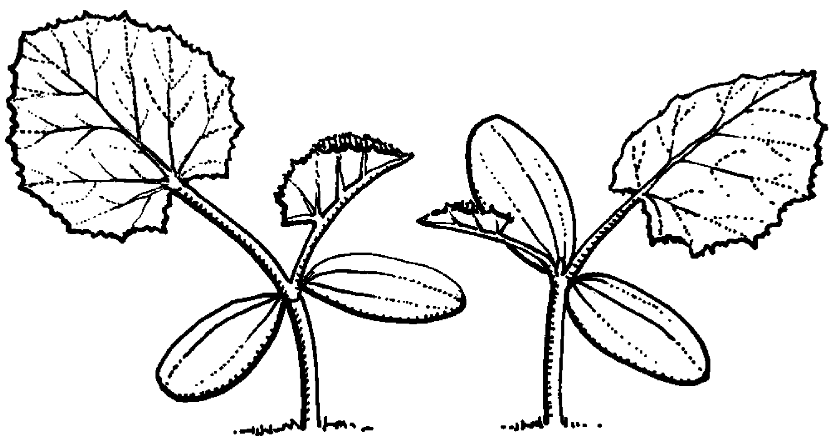
CUCURBIT SEED PRODUCTION

An organic seed production manual for seed growers in the Mid-Atlantic and Southern U.S.



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SCOPE OF THIS MANUAL

The scope of this manual is mainly devoted to the major domesticated culinary species of cucumber (*Cucumis sativus*), muskmelon (*Cucumis melo*), watermelon (*Citrullus lanatus*), and four species of squash (*Cucurbita pepo, Cucurbita maxima, Cucurbita moschata, and Cucurbita argyrosperma* (formerly *classified as Cucurbita mixta).*

CUCURBIT SEED PRODUCTION
BOTANICAL CLASSIFICATION

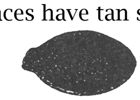
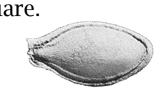
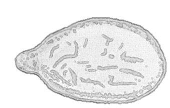
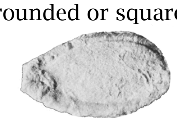
Botanical classification of commonly cultivated species of *Cucurbitaceae*:
Family: Cucurbitaceae (Gourd family)

Common name or representative type	Scientific name	Horticultural Group
Wax gourd (white pumpkin, ash gourd)	*Benincasa hispida*	
Watermelon	*Citrullus lanatus*	
Citron (preserving melon)	*Citrullus lanatus* var. *citroides*	Citroides
West Indian gherkin (bur cucumber)	*Cucumis anguria*	
Asian pickling melon (Shiru-Uri, Golden Crispy)	*Cucumis melo* var. *conomon*	Conomon
True cantaloupe (rare in U.S.)	*Cucumis melo* var. *cantalupensis*	Cantalupensis
Mango melon, Lemon melon, Vine peach	*Cucumis melo* var. *chito*	Chito
Pocket melon, Plum granny, Dudaim melon	*Cucumis melo* var. *dudaim*	Dudaim
Snake melon (Armenian cucumber)	*Cucumis melo* var. *flexuosus*	Flexuosus
Winter melon (Casaba, Crenshaw, Honeydew)	*Cucumis melo* var. *inodorus*	Inodorus
Phoot (aka Fuut), snap melon	*Cucumis melo* var. *momorida*	Momordica
Muskmelon, cantaloupe (U.S), Persian	*Cucumis melo* var. *reticulatus*	Reticulatus
African horned cucumber	*Cucumis metuliferus*	
Cucumber	*Cucumis sativus*	
Malabar Gourd (Fig Leaf Gourd)	*Cucurbita ficifolia*	
Buffalo Gourd	*Cucurbita foetidissima*	
Squash – winter varieties: (Banana, Buttercup, Delicious, Hubbard, Marrow, Show, Turban)	*Cucurbita maxima*	
Squash - winter types and for seed: (Cushaw, silver-seeded gourds)	*Cucurbita argyrosperma* (formerly *Cucurbita mixta)*	
Squash: (Butternut, Cheese, Large Crookneck)	*Cucurbita moschata*	
Squash – summer and winter types (acorn, crookneck, straightneck, scallop, cocozelle, pumpkin, zucchini, vegetable marrow)	*Cucurbita pepo*	
Gourd, hard-shelled (Bottle Gourd, Calabash)	*Lagenaria siceraria*	
Gourd, angled luffa (Chinese okra)	*Luffa acutangula*	
Gourd, smooth luffa (sponge gourd)	*Luffa aegyptiaca*	
Balsam pear, southern	*Momordica* var. *balsamina*	Balsamina
Balsam pear, bitter melon	*Momordica* var. *charantia*	Charantia
Chayote (vegetable pear)	*Sechium edule*	
Casabanana	*Sicana odorifera*	
Gourd, serpent	*Trichosanthes anguina*	

Note: Regarding melon classification, see the discussion under Melons on page 17.

SQUASH

Table 1. Identifying characteristics of five species of *Cucurbita*

Species and representative cultivars	*Vegetative Characteristics*	*Fruit Characteristics*	*Seed Characteristics*
C. ficifolia Chilacayote Figleaf gourd Malabar gourd	Perennial. Root not tuberous as in many perennials, but thicker than roots of annual cucurbits. Leaves are lobed and almost round. Hard, smooth angled, slightly flared stem.	Superficially looks like a watermelon. Has white flesh - never yellow because it doesn't produce carotene. Mostly day-length sensitive, except for day-neutral types selected to produce seed in northern areas.	Seed is small and has a pitted coat. Most cultivars have black-colored seeds. Land races have tan seeds. 
C. pepo Acorn Cocozelle Crookneck Delicata Patty Pan Pumpkin, pie-type Scallop Straightneck Zucchini Vegetable marrow	The pendunce (fruit stalk) is hard and angular (with five distinct angles). The peduncle is usually not swollen. Stems and leaves have stiff, large trichomes that irritate the skin when working the crop. Many cultivars (though not all) have a high degree of lobing of the leaves (3- to 7-lobed).	Lots of diversity in form and color in this species. Greatest diversity of *C. pepo* is in Europe and especially along the eastern seaboard of the U.S. Less diversity in Mexico. The subspecies *pepo* is probably of Mexican origin whereas subspecies *ovifera* is likely of eastern U.S. origin.	Seeds are dull white to tan. The smooth seed margin is generally the same color as the seed. Oblong seed shape. In modern cultivars the seed length and seed margin is smaller. Seed scar is round or square. 
C. maxima Banana Buttercup Delicious Hubbard Turban Giant pumpkins	Has a soft peduncle (round in cross section) that swells during development of the fruit, and is fairly swollen and corky. Leaf blades are generally kidney-shaped, and only slightly indented between the rounded lobes. Rough hairs on plants. Vines generally more vigorous than *C. moschata* and *C. pepo*, but less than *C. ficifolia*.	Fruits generally grow quite large. Unlike other species this was domesticated in South America, not Mexico. Flesh is fine textured with good flavor.	Seed is thick, color ranges from cream to dark tan. Seed surface wrinkled, or sometimes split. Seed margins are narrow. Oblique seed scar. 
***C. argyrosperma* (*C. mixta*)** Cushaws Silver Seed	Stem/penduncle is hard, somewhat grooved, and smoothly angular. The pendunce doesn't flare as much as it does in *C. moschata*. Selected primarily for seed production. Sometimes more easily distinguished from *C. moschata* by the seed.	Fruits are large with a somewhat coarse texture, and are less sweet and flavorful than *C. maxima* and *C. moschata*. Western Mexico has the most diverse forms. The more common eastern forms from Mexico have green-mottled stripes.	Seed is white, sometimes creamy tan with a pale or light margin. The seed surface sometimes covered small irregular cracks, and covered with a cellophane-like membrane. 
C. moschata Butternut Big Cheese	Stems, leaves, and peduncles have long, very soft hairs. Stem/peduncle is hard and smoothly angular at the fruit. Usually the sepals are expanded and leafy – not rounded. Leaves are usually large with 3- to 5-lobed blades, often with white spots at the vein intersections. Soft hairs on the vines, petioles, and blades.	Lots of diversity in form and color, especially in Mexico. Pendunce swells just before it connects with the fruit. Fruit is usually buff-colored.	Seed is dull white to tan. Some pitting and cracking of the seed is normal during and after development. Generally the seed margin is wrinkly, and dark beige to brown depending on the cultivar. Seed from Central America and South America may be light brown. Seed scar rounded or square. 

General plant characteristics:

When growing squash for seed, it is essential that the grower be able to identify and distinguish between the five main species of domesticated squash. Unfortunately, the terms “squash” and “pumpkin” (and modifiers such as “summer,” “winter,” “crookneck,” and “straightneck”) provide little guidance as to species affiliation. Any relationship between the common name and species is rather loose or non-existent. For example, the term “cushaw” usually provides a good indication that the species is *C. argyrosperma (*previously *C. mixta),* but ”winter squash” can refer to any one of four species. Pumpkin pie can be made from *C. pepo, C. maxima,* or *C. moschata.* Unlike some other types of vegetables where common names can provide some guidance, common names are often unhelpful. In any case, it is always necessary to confirm the species before growing it for seed. The identifying vegetative, fruit, and seed characteristics of five species of squash are described above in Table 1. The flower characteristics are also useful for identification, but require a more trained eye.

Figure 1. *Cucurbita pepo* diversity.
Photo © by Bryan Connolly.

Figure 2. *Cucurbita. moschata* diversity.
Photo © by Bryan Connolly.

Each species of squash has associated cultural and culinary uses as summarized in Table 2 below.

Table 2. Cultural characteristics and uses of five species of *Cucurbita*

Species and representative cultivars	***Culture Notes***	***Culinary Uses of the Fruit and Seed***
C. ficifolia	Perennial. Vigorous, fast growing, long-vined plant. Doesn’t survive light frost. Prefers moist soil. Tolerates nutritionally poor soil. Most accessions are day-length sensitive, but some day-neutral types have been selected to produce seed in northern areas.	Flesh is cut and boiled with sugar for a long time to make “dulce,” a sweet candy. Mature fruit can be stored for two years during which time it becomes sweeter. Hard rind of fruit can be used as container. Seeds oily and sweet.
C. pepo	Annual, vine or bush. Most bush types are modern cultivars that are sensitive to vine borers and are best planted in succession. Most varieties are not good keepers when mature.	Flesh is mild flavored and quality declines quickly in storage. Usually eaten in the immature stage. Usually prepared by baking, boiling, or frying.
C. maxima	Annual. Mostly vining types. Bush types are modern cultivars. Generally tender and sensitive to wilts, vine borers, and other insects. This species is more tolerant of cool temperatures than other cucurbits. Matures between 100 and 120 days.	The seed is not generally used for culinary purposes. Fruits keep well in storage, some varieties for up to a year.
***C. argyrosperma* (*C. mixta*)**	Annual. Mostly vining types, grown primarily in the South. Good resistance to vine borers and cucumber beetles once beyond the seedling stage. Best drought tolerance of the cultivated *Cucurbita* species. Matures in 100+ days.	Often grown for its seed that is roasted and eaten. The seed is sometimes used to make a sauce: the seed coat is removed and the seed is ground. Because the flesh is often stringy and watery, and not very flavorful as other species, it is cooked with sweeteners.
C. moschata	Annual. Needs warm night temperatures above 60°F (16°C) to grow well. Good resistance to vine borers and cucumber beetles once beyond the seedling stage. This species is the best adapted to hot, humid conditions. Matures in 90 to 120 days.	Flesh is often flavorful, sweet and fragrant. Excellent keeper for winter use. Often used for pies, cakes, or boiled.

Climate and soil requirements:

All of the domesticated cucurbits are frost-sensitive, but squash thrives more readily than muskmelon and watermelon when the environment is moist and cool. Most cultivars require a period of warm weather, but not extreme heat in order to mature fruit. Cucurbits will grow well on almost any soil, but for late crops maturing in the fall, good air drainage and planting on the high end of a slope is recommended so that plants avoid frost pockets. *Cucurbita pepo* is the most cold tolerant of the squash species. Though frost-sensitive, *C. pepo* has many cultivars that will mature in cool and short season climates. Most cucurbits fail to thrive in soils that are compacted and poorly aerated: the plants wilt and become stunted when grown in soil that is consistently waterlogged. Soil pH should be in the range of 5.6 to 6.8. Liberal addition of organic matter improves both the aeration and water holding capacity of the soil. In addition, organic matter buffers pH changes, adds nutrients, and promotes the growth of beneficial soil organisms. Full sun is required for maximum production, though partial shade is well tolerated, as for example when planting in the traditional Native American method where hills of squash and corn are interplanted.

Roots:

The lateral roots of all cultivated squash species are highly branched and grow primarily in the upper foot of soil, and rarely below 2 feet deep. Some long-season vining varieties will also develop taproots that can extend to a depth of 6 feet in loose soils. Many vining types (notably *C. moschata* and *C. argyrosperma*) develop adventitious roots as the vines spread over the surface of the soil. This growth habit confers additional drought tolerance and resistance to vine borer. In some cases vines may be killed at their origin by vine borers, but the plant may survive and produce fruit because of a large number of root nodes along the length of the vine.

Inflorescence:

The four major domesticated species are all monoecious, that is, the male and female flowers are both present on the same plant, but borne separately and singly in the leaf axils. At the beginning of the growing season, the staminate (male) flowers develop, mature, and shed their pollen before the female flowers develop. This sequence of floral development helps ensure that cross-pollination will occur early in the plant's development.

The male and female flowers of squash are generally similar in structure to those of other cucurbits, but are much larger (up to 3"), a characteristic that allows for ease of hand pollination. Both male and female flowers are nectar producing and have corollas divided into five-pointed lobes. The male flowers have long thin peduncles (flower stalks) and united filaments and anthers that produce relatively large pollen grains. The female flowers are easily recognized: the ovary looks like an undeveloped fruit that is borne on a short, thick peduncle that becomes the fruit stalk (Figure 3). The style is three-lobed which corresponds to the three chambers of the ovary. Rudimentary, non-functional stamens may be present. Depending on the species, flower color ranges from light creamy-yellow to deep orange-yellow. A diagram of the generalized flower morphology is shown in Figure 4.

The time of day when squash flowers open depends a lot on the species and variety. Generally, flowers open as early as 5:00 a.m. and close by noon, with the peak pollinator visitation between 8:00 and 9:00 a.m. (though the pollination peak is different according to the species of bee). Some varieties may close as late as 2:00 to 5:00 p.m., but these are exceptions. When the weather is hot, some varieties may start to close as early as 10:30 a.m.

Most, but not all varieties of squash produce male flowers before producing female flowers, but this does not necessarily ensure that cross-pollination will occur early in plant development, since they continue to produce male flowers after female flowering commences. For those varieties producing female flowers first, it does ensure that cross-pollination will occur early when they have no male flowers (Robinson, 2005, personal communication).

Figure 3. Male (left) and female (right) squash flowers. Note that the ovary of the female looks like a miniature fruit.
Photo © Bryan Connolly.

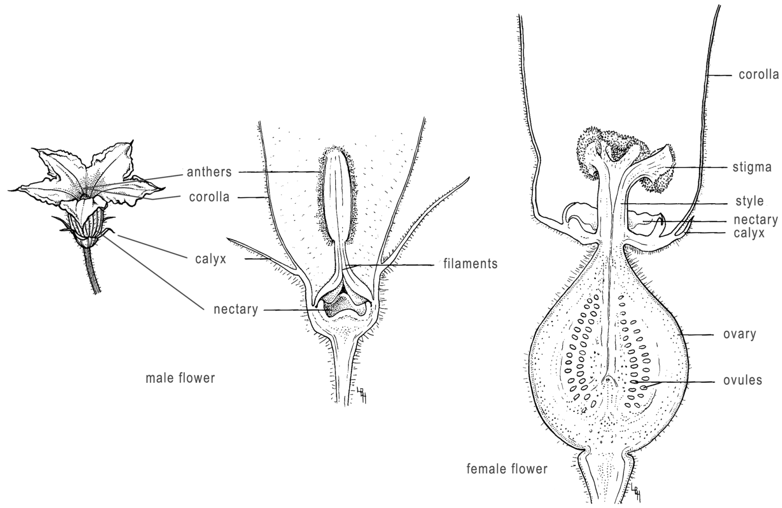


Figure 4. Diagram of squash flowers illustrating floral parts. The staminate or male flowers are shown on the left, and a longitudinal section of the pistillate or female flower is show on the right. (The longitudinal sections are modified from McGregor, 1976; the male flower has been modified from Stanton, 1991 as first published in Southern Exposure Seed Exchange, 1992)

Male and female flower development in relation to genetic and environmental factors:

Environmental conditions can play a large role in influencing sex expression and the developmental ratio of male to female flowers. Temperature and day length influence how long the plant remains in the male phase, as well as the ratio of male to female flowers. High temperatures, high light intensity, and long days favor the production of male flowers. This leads to a longer male phase and a larger number of male flowers relative to female flowers. Low temperatures, low light intensity, and short days favor the development of female flowers.

Both species and cultivars differ in whether male or female flowers are produced first. Most squash varieties produce male flowers first. There are some notable exceptions. Squash breeder and seed grower, Glenn Drowns reports that *C. moschata* typically produces female flowers first in his location in Iowa. Bryan Connolly, seed saver and squash breeder in Connecticut reports that vigorously growing bush varieties of *C. pepo* (zucchini and patty pan types), and some bush *C. argyrosperma* occasionally produce female flowers first. Dr. R.W. Robinson at Cornell University notes that most summer squash (*C. pepo*) varieties produce male flowers first, but when planted early, some varieties initially produce female flowers. He also notes that it is not uncommon for *C. moschata* to bear female flowers first. An informal survey of squash growers in Virginia, Missouri, and Arizona yielded reports that only male flowers were produced first – locations where light intensity and temperatures are higher. As the growing season progresses, especially at the end of the season, temperatures become lower, and days shorter, thus causing the number of female flowers to increase relative to male flowers. Another factor affecting the flower ratio is the number of developing fruits already present.

The developing flower buds of all monoecious species are hermaphroditic initially, but the hormonal status at the flower node determines which sex is expressed (i.e. either female or male development is arrested thereby leading to production of a male or female flower). Very rarely are there hermaphroditic flowers in squash, but there are some notable exceptions, such as in *C. moschata* where the incidence is fairly high. For example, the variety 'Butternut' expresses this tendency, in which case either the female or the male portion of the hermaphroditic flower is inviable. Sometimes, both male and female are parts are viable.

In conclusion, it appears that production of male or female flowers and their sex ratio is determined by a complex interplay between genetics and environment and that for *Cucurbita* in particular, sex expression is more malleable than for many other monoecious plants. It is tempting to speculate on the significance of this in terms of interspecies crossing and survival value in certain environments, and possible evolutionary implications. At the very least, differences in sex expression and the large diversity of fruit forms within the genus *Cucurbita* demonstrate that there is quite a bit of variability within this genus compared to other food crops. It is important that the breeder and seed grower be familiar with such nuances of crop biology because these are more than matters of curiosity.

Pollination:

Though most squash cultivars produce male and female flowers, the development of female flowers is delayed, thus favoring cross-pollination. Or, as noted before, some cultivars produce female flowers first. In either case, the mechanical transfer of pollen by pollinators is essential for fruit set.

Pollinators:

The most common pollinators are bees, though flies, moths, and some beetles (notably cucumber beetles) are also capable of pollination, though to a lesser degree. Of these, bees are by far the most significant, especially wild bees such as *Peponapsis* spp. and *Xenoglossa* spp., and the European honeybee, *Apis mellifera*. The corolla of squash flower reflects ultraviolet light which helps make the flower more visible to bees.

Wild bees are the most efficient pollinators because they co-evolved with squash in Central and South America. In fact, cucurbits provide the primary, and in some cases the only source of pollen for *Peponapsis* spp. and *Xenoglossa* spp. (collectively referred to as "squash bees" or "digger bees"). Squash bees are able to fly at low temperatures and very low light intensities with the result that their flight is synchronized with the opening of squash flowers before dawn. In addition, squash bees have modified pollen baskets and specialized dense hairs distributed on their bodies in locations that are especially adaptive for carrying the large spiny pollen grains. Male squash bees habitually spend the late afternoon and night in the closed male flowers of cucurbits, chewing their way through the closed flowers and emerging covered with pollen. Squash bees have an extraordinary ability to find flowers on the basis of odor. An entomologist documented a case of squash bees flying seven miles over open water to a new squash planting on Penikese Island (2.2 square miles) off the coast of Massachusetts to forage on pollen! Squash had not been grown there for at least several years prior to this observation (Dr. Gerald Stage, personal communication). Needless to say, the presence of squash bees in cucurbit plantings can have important implications regarding isolation distance recommendations.

Honeybees were introduced to the Americas from Europe, and are therefore late arrivals in the evolutionary interplay between squash and bees. Honeybees scrape the pollen from squash flowers with difficulty; their pollen loads are very small compared to squash bees and their pollination efficiency is lower. However, squash bees and other wild bees have become scarce where large-scale monoculture is practiced, and therefore honeybees have come to be considered the primary pollinator in industrialized agriculture. Small-scale organic growers using planting techniques that favor biodiversity will find that wild bees may be the primary pollinators. In the absence of honeybees and squash bees, other bees such as bumblebees, carpenter bees, stingless bees, and halictid or sweat bees may account for much of the pollination.

If there is a dearth of natural pollinators, a hive of bees should be placed at the periphery of the planting to increase seed yield. Usually one hive per acre is sufficient to achieve good results. For best results, hives should be placed near the planting when 5 to 10% of the plants have flowers. Small-scale organic growers usually do not have to rely on supplemental pollination.

Fertilization:

All squash varieties, as well as other *Cucurbita*, are self-compatible. There have been of reports self-incompatibility dating from 1890 through the early 1900's, but it is now generally accepted that self-incompatibility is not characteristic of any species of *Cucurbita*. The more likely explanation for these reports is that occasional plants may exhibit male sterility, or some of form of sterility (Robinson, 2005, personal communication).

There is not a lot of information available about length of pollen viability, but is believed to be about 12 hours or less. This needs to be investigated more closely, especially in light of the observation that squash bees may reside in the male flowers overnight. When the pollen is viable and fertilization has taken place, the event is noticeable to the naked eye: the stigma will acquire a more liquid appearance and will start to deteriorate; otherwise the stigma will remain intact and glistening or shiny if fertilization has not taken place. The ovary will dehisce and fall off if fertilization does not occur.

Fruit:

Regardless of whether the squash is a winter or summer squash, both are handled the same way for seed production: they are left to fully mature. Squash fruits grow in a great variation of colors, sizes, shapes, surface textures (smooth, warty, ridged, and creased), and flesh colors which may be any of the following: white, yellow, salmon, orange, light or dark green, gray, any combination of colors, including their intermediates and even striping of colors.

Seed:

Though squash species can often be distinguished on the basis of seed characteristics, (see Table 1) most varieties have seed that are indistinguishable from another. Squash seed, compared to cucumber and muskmelon seed, has a rougher surface texture. There are approximately 100 to 400 seeds per ounce, depending on the species and the variety. The Federal Germination Standard for commercial squash seed is 75%.

Culture:

Growing squash for seed is similar to growing winter squash for market in that the fruit is grown to an advanced stage of maturity. Squash grows relatively well under dry conditions but will thrive when given an ample supply of moisture. Though many cultivars don't need a long growing season, a period of warm days and nights is needed to mature the fruits properly. Plan on adding at least 30 additional days to the growing season when growing summer squash for seed. Because squash roots grow primarily in the upper foot of soil, it is important not to cultivate too deeply. Bush varieties are spaced approximately 3 feet apart in the row and spaced 4 to 5 feet between rows. Vining types are spaced approximately 3 feet apart in the row and 8 to 12 feet between rows. Some of the most vigorous varieties will fill the space between the rows even at the widest spacing.

Roguing:

Because of the large number of squash varieties available, the seed grower should be familiar with the most common varieties before growing for seed. Off-type plants should first be rouged at the vegetative stage, paying particular attention to low vigor and off-type growth habit. For example, when a bush-type variety produces one or more plants with runners, remove those plants before flowering occurs. Likewise, remove bush plants from a planting of squash that normally produces vines. Be especially observant when plants first start to flower: pay attention to the shape of the earliest fruits. Off-type fruits may be detected at the ovary stage even before the flower opens. As long as the population size is large enough, the appearance of an off-type plant after flowering is not a cause for concern as long as the off-type is removed promptly. As with roguing other crops, remember that occasionally a fruit will be deformed (usually for environmental reasons), in which case the fruit is still usable for seed provided that the other fruits borne on the same plant are true to type. If you are unsure about exactly which fruit is coming from which plant, do not use the seed.

Interspecific crossing and isolation:

All varieties of squash within the same species can in some instances cross with certain other squash species. Those that can cross with each other produce partially fertile hybrids, as shown in Figure 5. It should be noted that most interspecies crosses could be difficult to make. In instances where crossing occurs, the cross is highly cultivar dependent. For example, some varieties of *C. pepo* cross readily with Butternut (*C. moschata*), but most do not (Robinson, 2005 – personal communication).

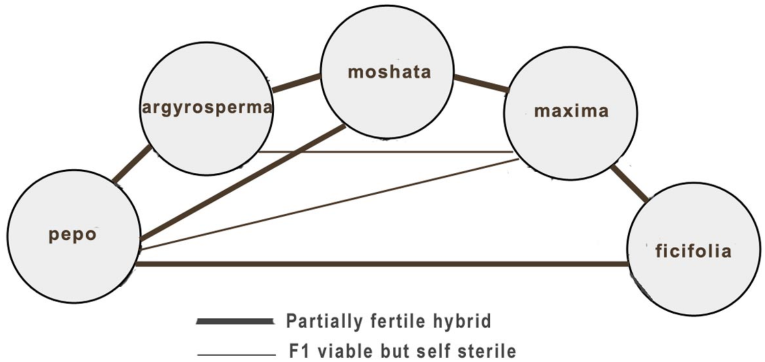


Figure 5. Sex and the single cucurbit: this simplified crossability polygon illustrates the potential crossing relationships between different species of cultivated *Cucurbita.* Such crossings are highly cultivar dependent and usually produce few viable seed. (Diagram adapted from Robinson and Decker-Walters, 1999.)

Figure 6. An example of an interspecific cross between *C. moschata* 'Butternut' and *C. maxima* ' Buttercup.' Hand pollination was used to make this cross.
Photo © by Bryan Connolly

Production of partially fertile hybrids can occur when two taxonomically related species (for example, *C. maxima* and *C. moschata)* (Figure 6) are planted in close proximity and subjected to high pollinator pressure under conducive environmental conditions (or more likely as a result of hand pollination). Regardless, the percentage of successful fertilization is small, typically resulting in a small seed yield (about five viable seeds per fruit according to Bryan Connolly). The remainder of the seed is inviable. The degree of success in attempting experimental (or accidental) crossing depends on the compatibility of the cultivars themselves. Glenn Drowns, seedsman and squash breeder in Iowa, reported approximately 10% crossing of *C. maxima* and *C. moschata* in adjacent plantings, which is a surprisingly high percentage that deserves further investigation. Though the risk of interspecific crossing is generally small, certain cultivars of squash should not be grown in adjacent rows or plots. The recommended isolation distance for avoiding interspecific crossing is not known, and depends on a number of factors, but would be substantially less than the recommended isolation distance between cultivars of the same species. One result of planting two species in close proximity is that pollen from one species can stimulate the production of parthenocarpic fruit in the recipient species, and though this doesn't result in contaminated seed, it has the effect of reducing the total seed yield.

The diagram in Figure 5 illustrates the potential for crossing, but in practical terms such crosses are normally difficult to make. The highest potential for interspecies crossing exists between *C. maxima* and *C. moschata*, especially if *C. moschata* is the maternal parent. Compatibility is highly cultivar dependent. For example, Japanese seedsmen have found that certain cultivars are more amenable to interspecies crossing and have been successful in marketing the F1 seed commercially. In such crosses, both parental species are monoecious, but the F1 generation is gynoecious (produces mostly female flowers). Regarding the potential for other types of interspecies crossing, a cross between *C. pepo* and *C. moschata* is difficult, though not impossible to make. One practical result has been the incorporation of the gene for the bush growth habit into *C. moschata* (Robinson and Decker-Walters, 1999).

Intraspecific crossing of cultivated and wild cucurbits:

Intraspecific (within species) crossing of squash with wild cucurbits can create a serious problem for seed growers (and seed companies). It can be an especially serious problem in the Southeast, Southwest and Deep South, especially Mississippi, Florida and Texas. Cotton and sorghum fields in the Southeast have become a haven for troublesome feral and wild cucurbits. The Dudaim Group melon can cross with melon (muskmelon), and the bitter ornamental or wild gourd (*Cucurbita pepo* ssp. *ovifera*) can cross with *C. pepo* squash. In Mississippi cotton yields have been affected, and machinery has been broken (Robinson and Decker-Walters, 1999). Also contamination of cultivated squash by wild cucurbits has become a serious problem for farmers in Mexico where wild species may be present. In Dr. Gary Nabhan's book "Gathering the Desert" there is mention of introgression of bitterness into cultivated *C. argyrosperma*. (Bryan Connolly, personal communication). Wild cucurbits have an extremely bitter flesh, and the consequences of a cross with a cultivated species results in a squash with bitter flesh causing the squash to be unpalatable at best, and dangerous at worst. Even one mouthful of cooked squash containing cucurbitacins can induce nausea and vomiting, and can cause a drastic purgative action on the intestinal tract (Claus et al., 1970). Severe cramping of the stomach can follow for three days, and diarrhea can continue even longer (Nabhan, 1985). In addition to the culinary and health implications, there are horticultural implications as well – the bitter squash are more attractive to the cucumber beetle.

Cucurbitacins are resinous compounds of a complex chemical nature consisting of oxygenated tetracyclic triterpenes. These are intensely bitter substances that can be tasted in one part per billion parts water (Nabhan 1984). These undesirable compounds are often under the control of a dominant gene. Where wild cucurbits are present within (and somewhat beyond) the recommended isolation distance, the seed grower should be alert for the possibility of crosses. Bees, especially squash and gourd bees, as noted in the section on "pollinators," can bring cucurbit pollen from great distances causing contamination, even in isolated squash seed production fields. If the grow-out of the subsequent generation has some shorter, rounder fruits with warts, and a different colored rind than typical for the cultivar, a cross should be suspected. The squash-gourd hybrid should be rogued; otherwise the bitterness can persist in succeeding generations if bees distribute the pollen from the squash-gourd hybrid plants before the plants are rogued (Robinson and Decker-Walters, 1999). Suspected off-type individual plants can be hand-pollinated, the fruits of which are tested for bitterness, and if there is no bitterness the seed can be used. But if there is some contamination of the seed crop, it may be better to plow the crop under and start over with pure seed stock. As a routine precaution, the seed grower should self-pollinate a number of individual plants each season, and save the seed which can later be pooled as elite seed stock for future grow-outs (Robinson and Decker-Walters, 1999).

A few years ago, nearly all the wholesale quantities of 'Delicata' squash were genetically contaminated from a cross that resulted in a seed crop that produced a significant amount of bitter fruit. In 2004, the Washington State Department of Health (Anderberg, 2005) reported that nine people had become very ill after eating only a bite-sized portion of genetically contaminated 'Delicata.' In 2003, Cricket Rakita (at Southern Exposure Seed Exchange) had a similar problem with a crop of 'Navajo Hubbard' squash (*C. maxima*) which produced a small percentage of bitter fruits. In this case it is not clear if the bitter trait originated from a mutation or was present to a small degree in the stock seed. There are other examples, such as the winter squash 'Jersey Golden Acorn' and the summer squash 'Castle Verde' that were taken off the market because they had been contaminated by a bitter gene that probably came from pollination with a bitter ornamental gourd (Robinson, 2005 – personal communication).

Dr. Robinson (2005, personal communication) notes that cross-pollination with bitter gourds can cause a problem with bitterness in any area of the country, not just the South. In the South, the likely culprit is the wild gourd (*C. pepo* ssp. *ovifera* var. *texana*). Some, but not all ornamental gourds (*C. pepo* ssp. *ovifera*) that are cultivated throughout the U.S. are bitter, and can cause severe contamination problems with *C. pepo* throughout the U.S. It should be emphasized that the bitter gene is dominant, but will not be expressed in the fruit because the fruit (except for the seeds) is maternal tissue; the bitterness will not be expressed until the next generation.

Isolation distance:

For a detailed understanding of how isolation distances are determined and utilized for various seed crops, refer to the manual in this series titled: "Isolation Distances: Principles and Practices." It also provides guidelines for adjusting and interpreting isolation distance recommendations within the context of the grower's environment, especially conditions related to organic agriculture.

The discussion here is limited to the recommended isolation distances for cultivated *Cucurbita*. In the "Isolation Distances" manual, the isolation distance recommendations for different crops are based on the intended use of the seed which specifies the level of purity required. Three different isolation distances are given below, depending on the intended uses which are defined as (1) home-saved seed, (2) seed saved for exchange, and (3) seed grown for commercial use. In this manual we are focused primarily on the production of commercial grade seed.

The chart below summarizes the minimum recommended isolation distances for cucurbit crops based on intended use of the seed:

Type of crop	Minimum for home use only	Minimum with barriers	Minimum without barriers	Comments
All cucurbit crops	600'	0.25 mi	0.50 mi	Subject to variables below

When *Cucurbita* seed crops are grown within range of large commercial plantings, the recommended distances above should be doubled. As a general rule, every doubling of isolation distance decreases the amount of cross-pollination by a factor of four. Pollination barriers should consist of flowers (annuals and perennials) and/or physical barriers (trees, shrubs and dense tall plantings). When growing organic seed near plots of genetically modified seed, the distances may need to be increased further, as discussed in the "Isolation Distances" manual. Also, the recommended distances may need to be increased if there are large populations of squash and gourd bees. The distances can be decreased when separating two different species that are capable of crossing (see Figure 5). Acceptable strategies for decreasing recommended isolation distances are discussed in the "Isolation Distances" manual.

Hand pollination:

In some cases it is impossible to achieve the recommended isolation distance for the purposed of maintaining or breeding a cultivar. One way to isolate varieties is to do controlled crosses by transferring the pollen by hand. The usual technique is to bag the flowers to exclude bees, but it isn't necessary to bag squash flowers because the flower itself can be made into a natural bag. The male and female flowers can be closed the night before they open by using twist-ties, yarn, tape, rubber bands, or adhesive tape placed over the tip of the flower. It is important to tie the male flowers as well, so that they are not contaminated with foreign pollen. The first task is to identify the male and female flowers and to learn when the flowers are ready to open the next day. Flowers that are about to open show some yellow color along the seams and the flower tip may be slightly separated (Figure 8). Because it can be difficult to locate the tied flowers the following morning, fluorescent survey flags are placed in the ground next to the tied or taped blossoms. In the morning after the dew has dried, pick two or three taped male flowers, open them, and use them as a paintbrush to deposit pollen on the stigma of the female flower. Usually two male flowers are used for each female in order to ensure good pollination, though Dr. Robinson (2005, personal communication) reports that in most cases, a single male flower is sufficient. After opening the female flower, work quickly and keep an eye out for bees that can quickly enter the flower. After the female has been hand pollinated, the blossom is re-tied or taped to prevent entry by bees, which incidentally, are very good at finding small openings. The pollinated female is then marked by tying a ribbon or yarn on the flower stem. Colored rubber bands and poultry bands (available from animal feed stores) are also good as markers because they expand as the flower stem grows. Another way to record the pollination (along with data about the cross) is to make a durable label by taking a 5" plastic plant label, and by using a hole punch, punch a hole in one end of the label. Thread a twist-tie through the hole, and record the data using a pencil or waterproof marker. Fasten the label to the flower stem and use a survey flag to mark the location. Differently colored flags are useful for locating recent and past hand pollinations, as well as different types of crosses. Because bumblebees will sometimes chew holes through the side of a tied flower, it is a good idea to inspect tied flowers for forced entry, which if it occurs, will render the pollination useless. If there are a lot of bumblebees, or if you don't have the time to inspect the tied flowers for forced entry, it might be safer to bag the flowers, especially when doing breeding work.

Figure 7. Female zucchini flower taped shut the previous day and now ready to open for cross-pollination.
Photo © by Bryan Connolly.

Figure 8. Male flower ready to be taped to prevent cross-pollination. The bright yellow color and the slightly open tip indicate that the flower will open the following day. In this example, the flower tip is open, but that is not always the case.
Photo by Jeff McCormack.

When making crosses in the field, environmental conditions can greatly affect the success rate; it is not unusual for only 25% of the crosses to be successful, especially during a drought (when the success rate may drop to 10%). Otherwise, the success rate will be much higher (approximately 75%) when the plants are not under moisture stress, when pollinations are done early in the season, and when there is not a lot of fruit set on the plant. When hand pollination is done in a greenhouse, the success rate is much higher, approximately 85%.

Breeding:

Many varieties of squash listed in seed catalogs in the 1930's are still available today (for example, 'Connecticut Field,' 'Small Sugar,' 'Hubbard,' 'Table Queen,' 'Cocozelle,' and 'Summer Crookneck'). Some trace back to colonial times. A number of these older varieties were developed by selection alone. A problem for squash growers and breeders is the amount of variation in older seed stocks that has resulted from natural crossing. Several times I have observed off-types of squash in grow-outs of commercial seed from reputable sources. This problem appears to be more common with older varieties, probably because there is less commercial incentive to invest time in properly roguing open-pollinated varieties. This observation suggests that it is important for the small-scale seed grower to rogue vigorously and perhaps to consider using a planned program of inbreeding to maintain desirable characteristics (such as fruit shape and flesh texture). This can help the grower develop a market niche, and reputation for quality. Several long-term studies (up to 10 generations) of controlled inbreeding using carefully controlled pollination have shown that it is possible to maintain pure stocks without loss of vigor. Because some family heirloom or ethnic varieties tend to have more variability, these varieties often present an opportunity to develop new lines on the basis of selection and hand pollination alone. The selection techniques that are used are relatively uncomplicated — it is primarily a matter of selecting for the desired characteristics, and in some cases, hand pollination (crossing) of desirable parents.

Some desirable performance characteristics of cucurbits, such as earliness, yield, fruit color, and environmental adaptiveness are influenced by a number of genes. In order to improve on these characteristics, breeding success requires growing out larger populations, use of good experimental design, and careful analysis of the data. Figures 7 and 8 show Bryan Connolly's results of breeding for powdery mildew resistance in 'Woods Prolific' squash.

When the objective is breeding for disease resistance, the previously mentioned strategies are useful, but a fast-track approach is to use backcrossing. This involves crossing a disease-resistant variety or breeding line with another variety or line that lacks desired resistance. The selected progeny of subsequent generations are then backcrossed with the disease-resistant parent. For organic growers, this represents another opportunity to further organic agriculture on a large scale, and to develop a niche on a small scale.

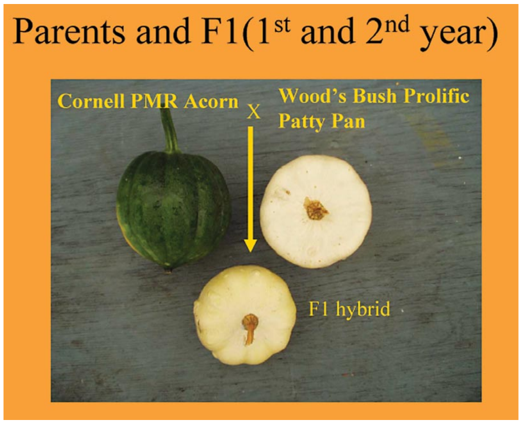


Figure 9. Parents and F1 generation of cross between 'Cornell PMR Acorn' with 'Woods Prolific' squash to confer powdery mildew resistance.(PMR) in a patty pan squash.
Photo © by Bryan Connolly.

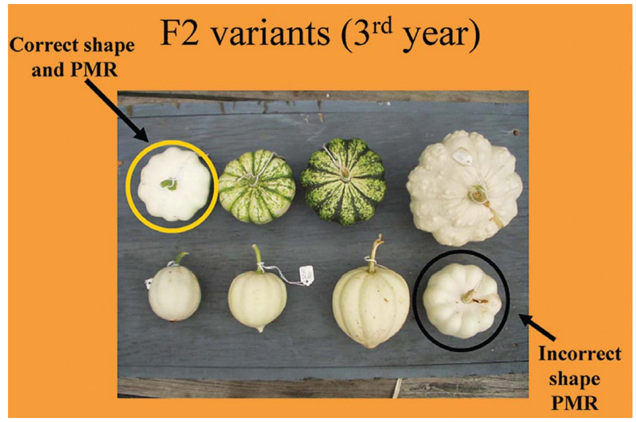


Figure 10. F2 generation segregates from a grow-out from the F1 generation. Note the variation in the F2 generation including one variant with the proper shape and powdery mildew resistance (PMR).
Photo © by Bryan Connolly.

When the objective is breeding for insect resistance, Robinson and Decker-Walters (1999) suggested that it is possible to breed for multiple insect resistance using a single cross. For example, 'Butternut' (*C. moschata*) has resistance to vine borer, squash bug, cucumber beetles, pickleworm, melonworm, and leaf miner.

Harvest:

Squash fruits are allowed to fully mature before being harvested for seed. You should not be able to dent the flesh with your thumbnail and the penduncle should be dry. Research at Arizona State University demonstrated that if fruits of squash are allowed to remain on the vine 20 days past maturity, the seed increases in size and quality. If the fruit are harvested at maturity, they should be allowed to after-ripen for at least 20 days before harvesting the seed. The after-ripening can occur while the fruits are on the vine, with one exception. For example, in the South, where the growing season is longer and the days are hotter, seed quality can decline after peak maturity if temperatures are high and the fruits become sunburned. Sunburned fruit can be an indication that seed may be damaged due to high fruit temperatures. In a situation where sunburn can occur it is better to harvest the fruits from the vine at maturity and then bring them under cover where they can continue to after-ripen before extracting the seed. In the Mid-Atlantic, sunburned fruit is less of an issue, and the later-maturing fruit can be left in the field until a frost has killed the foliage (which makes the fruit easier to see in a large planting). If you use this method, care should be taken during the harvest as black widow spiders will often hide under the fruits when the weather is cool. The harvest period is a final opportunity to rogue out off-type fruit.

Seed extraction:

In large commercial operations, fruit is mechanically crushed and macerated to release the seed, or the fruits are cut in half and the seeds are scooped out by hand. The seeds and pulp are put in a storage hopper and from there they are augured into bins for transport to a shaker washer or onto rotating drum screens where the seeds are sprayed with water.

In smaller-scale operations, the fruit is segregated by maturity of the fruit. The fruits are cut in half and the seed scooped out. It is advisable to cut the fruit around the seed cavity with a utility-knife or other short bladed knife to avoid cutting the seed. Seed should then be washed and dried promptly after extraction from the fruit because microbial fermentation begins immediately. At elevated temperatures the seed can be damaged, resulting in low vigor. The seed is then washed in a colander or similar metal container that has drain holes. The seed is loosened from the pulp by hand separation. In larger seed washing operations, ¼" hardware cloth can be used as the base for holding the seed and pulp while the seed/pulp mixture is gently rubbed across the screen. A forceful spray of water from a hose nozzle helps force the pulp through the screen, leaving clean seed. Seed separates from the pulp in some varieties much easier than others. The seed should then be dried as soon as the washing operation has been completed.

Fermentation:

Fermentation is risky, and if practiced it must be done very carefully and kept to the shortest duration possible, just enough time to help separate the seed from the placenta. In no case should fermentation go longer then 24 hours, which may be long enough to damage seed of some varieties. Seed of *C. maxima* should never be fermented because the seed is likely to be damaged and discolored. *Cucurbita pepo* tolerates fermentation better than *C. argyrosperma,* but again, fermentation should be practiced for the minimum amount of time. Fermentation can introduce beneficial fungi, and in some cases, may help overcome and prevent detrimental bacteria.

Drying:

Seed should be spread out in a thin layer on screen-bottomed trays to dry in layers approximately one seed thick. Air should be able to freely move through the screen. Though sun drying is common in dry western states, in the Mid-Atlantic and South, drying is best done under cover with forced air circulation. If the temperature is mild and the air is dry, seeds may be sun dried, but if the seeds are wet, the temperature should be below 90ºF (32ºC). Seed may also be dried on cloth towels which help wick away the water. Newsprint should never be used because the seeds may stick to the paper and the ink will come off on the seed. Nobody wants to read the daily news on the surface of a seed. Whatever method is used, the seed should dry as soon as possible. The final seed moisture content ranges between 6 and 8%. Seed with higher moisture content will not store well, and below 5% moisture content seed may be damaged by over-drying.

Milling and winnowing:

Winnowing is very helpful for removing immature seeds and those that are not well filled out. Winnowing also has the effect of enhancing the germination of the seed lot. Techniques for drying and winnowing are described in the companion manual in this series titled: "Seed Processing and Storage: Principles and Practices."

Seed yields:

As expected, there is quite a large range of seed size in squash. Seed yields vary according to the species, variety, pollination efficiency, area of the country, and growing conditions. Seed yields can be expected to be in the range between 200 to 800 pounds of seed per acre. The "average" yield is typically around 300 to 500 pounds, which is equivalent to 5 to 18 pounds per 1000 square feet. A squash flower needs only one pollination to produce a fruit, but it is believed that up to 40 visits by pollinating insects will have a positive impact on the seed yield.

CUCUMBER
Cucumis sativis

General plant characteristics:

The ancestor of the modern cucumber is unknown in the wild, though the closely affiliated species *Cucumis sativus* var. *hardwickii* occurs in the foothills of Nepal. The progenitor of the modern cucumber is a daylength-sensitive, highly branched, rough-stemmed, monoecious, annual vine that produces an impressive amount of bitter fruit. The cucumber has come a long way since its first domestication in India well over 3,000 years ago, and from a secondary center of domestication in Asia over 2,000 years ago. Modern fruits now range in size from small, stubby types to slender, elongate forms about 18" or longer. The flesh ranges from green to white, with smooth or rough skin, and with fine white or black spines. Cucumbers are classified according to culinary use, primarily as slicing (salad types) or pickling types. The latter tend to be short wartier fruits with a 3:1 length to width ratio. Picklers are fresh packed, but they are more often brined or fermented. The two types have been developed for their specific uses and differ somewhat in their production methods. In the U.S, North Carolina, Florida, and Michigan, are major areas of cucumber production.

Prior to the 1880's, cucumbers existed as a number of varied cultivars, but as seed companies developed in the latter half of the 1800's, breeders began to focus on selecting cultivars for a number of desirable characteristics and adaptability for local conditions and diseases. With regard to seed production, the cucumber is easy to grow, but production of good quality seed of specialty varieties can test the skill of the seed grower

Climate and soil requirements:

Growth requirements are similar to squash as described previously. Cucumbers grow best when the temperature ranges between 65 to 75ºF (18 to 24ºC) at a minimum temperature of 60ºF (16ºC). When preparing for spring planting, the plants should be started late enough to avoid prolonged temperatures below 55ºF (13ºC) which can cause cold injury that is characterized by pitting, water-soaked spots and decay. In the piedmont region of the Mid-Atlantic, the healthiest crops result from plantings made in May. The maximum temperature for good growth of mature vegetative plants is 90ºF (32ºC). Later sowings (in late July) miss the hottest weather during fruit production, but the vines are more vulnerable to disease because of sustained higher humidity and temperatures, and build up of pathogens in the environment.

Culture:

Culture of cucumber is similar to that of fruit grown for market with two exceptions: (1) another month is required to mature the fruit for seed – a growing season of at least 100 days is required for most varieties; and (2), wider spacing is needed – seedlings should be thinned to 12 to 18" within the row and spaced 6 feet between rows. When seeds are started indoors, the seed-starting medium should be well drained and kept moist, not wet. Seed germination is inhibited at temperatures below 60ºF (15ºC). The optimum is 95ºF (35ºC), though the temperature response can vary significantly among varieties. Seeds are sown directly in the field or as transplants not more than three weeks old.

Roots:

Cucumbers develop a strong taproot that can grow as much as an inch a day under good conditions. The taproot can reach a depth of 2 to 3 feet, but most of the laterals develop in the first 8 inches of soil and their length can reach 1 to 2 feet. A few of these laterals may abruptly turn nearly at a right angle and grow downward as deep as the taproot.

Inflorescence:

Most cucumbers are monoecious, bearing male and female flowers on the same plant. Exceptions include the heirloom 'Lemon' cucumber and as well as some modern cultivars bred to be andromonoecious or gynoecious. 'Lemon' cucumber is an example of an andromonoecious variety meaning that it bears both male flowers and hermaphroditic flowers. Gynoecious means that flowers are predominately female. Such varieties are often used for the production of hybrid seed, and for pickle production when sown with about 10% seed of monoecious varieties. The greater concentration of female flowers produces a more rapid and uniform seed set for mechanical harvesting.

The male flowers of cucumber are borne mostly in clusters of five in the leaf axils of vines. The female flowers are borne in the first leaf axils of the fruiting (secondary) branches. Occasionally these are borne in a cluster of two to three flowers. The male flowers usually appear about 10 days before the first female flowers. The ratio of male to female flowers is strongly influenced by day length. In the summer, the male flowers outnumber the female flowers by approximately 10 to 1, but the ratio has been known to reach 100 to 1. This is especially useful to know before attempting to hand pollinate cucumbers. The male flowers are easily recognized by the absence of an inferior ovary as shown in Figure 11 below.

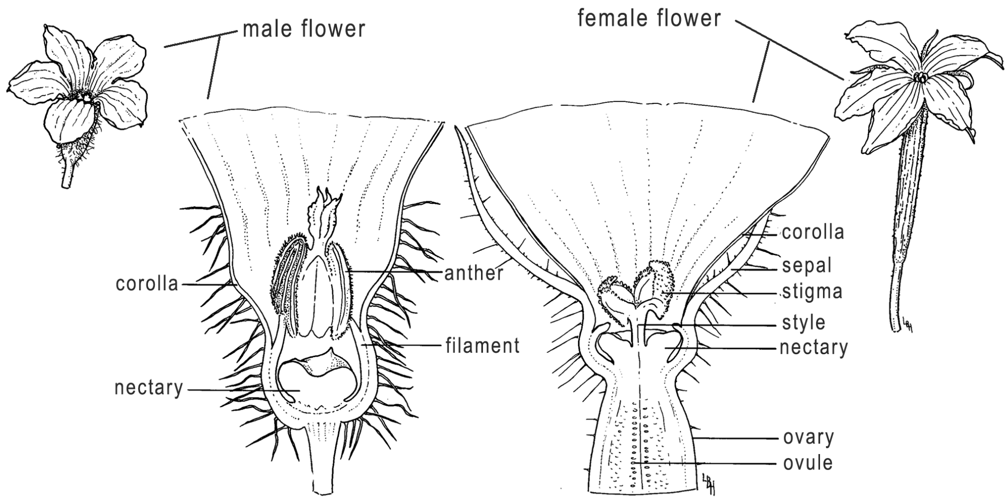


Figure 11. Male and female cucumber flowers, a cross section of the male flower and a cross section of the upper portion of the female flower. (Modified from McGregor, 1976.)

Pollinators and pollination:

In large seed production plots, cucumbers are pollinated primarily by honeybees. These are by far the most important pollinators. The most practical recommendation for the number of honeybees required for pollination was suggested by Hughes (1971) who stated that on a clear day when you walk into a cucumber field you should be able to count 30 to 40 bees within a 30 foot diameter circle. If you cannot hear a noticeable buzz or hum, you need more bees. This translates into about one bee per 100 flowers, or at least one colony of bees per acre, though two colonies are more desirable. If too few bees are present, seed yield will be low.

Small-scale organic seed producers growing cucumbers in biodiverse environments will also find that in addition to honey bees, there will be other insect visitors such as halictid bees, wasps, and cucumber beetles. Though halictid bees and cucumber beetles are not very efficient pollinators, the wild bee *Melissodes communis* is an efficient pollinator. Also squash and gourd bees may be found as pollinators as well, but they prefer to pollinate squash flowers if available.

Like squash flowers, cucumber flowers open in the early morning and pollination is complete by noon. Cross-pollination between plants is the norm with about 30 to 35% of the pollinations being self-pollinations.

Hand pollination:

The technique for hand pollinating cucumbers is essentially the same as that for squash with a few variations. The flowers are smaller, only about ½ to 1" in diameter, and more dexterity is required than for hand pollinating squash. When tying off blossoms that are due to open the following day, twist-ties are easier to use than tape or yarn. A cotton swab can be used to transfer the pollen from the male flower to the female. A swab is preferable to a camel's hair brush because there is less chance of contamination and better control of the pollen load. The cotton swab technique simply involves opening the male flower and twirling the swab against the anthers of the male flower. Cucumber pollen is light colored and not easy to see without a hand lens. The swab is twirled on the stigma of the opened female flower and the flower is then taped shut. Better results will be achieved if at least two male flowers are used, but once you are familiar with the technique the success rate will be approximately 80%. Although cucumbers are self-fertile, better success will be obtained by using the male flowers from another plant for cross-pollination. Best times to attempt hand pollination is during shorter days when there are more female flowers, and when plants are not stressed by high temperatures or drought which can cause fruits to abort. Another technique for hand pollination involves picking the male flower and carefully removing the petals to expose the stamens. Thus exposed, the male flower is then inserted into the female blossom to make contact with the stigma.

The anthers of the male are then gently twirled against the stigma of the female. The stigma will now appear dull or satiny instead of glossy.

Occasionally cucumber beetles may chew a hole through the corolla of the flower and contaminate the stigma with the pollen of another variety. If this is a problem, cover the closed female flower with a piece of used nylon stocking and secure it with a twist-tie.

Fertilization:

Cucumbers are self-compatible. Normally in a well-pollinated flower, fertilization leads to the development of about 400 to 600 seeds per fruit.

Isolation distances:

The isolation distance recommendations for maintaining purity of cultivars are the same as that for squash. Cucumber does not need to be isolated from squash, muskmelon or watermelon, but because pollen from other species of *Cucurbita* can stimulate production of parthenocarpic fruit, seed yields may be reduced when cucumber is planted adjacent to other *Cucurbita.* Pollination by melon pollen (*Cucumis melo*) can result in seedless cucumbers.

Roguing:

As with any crop grown for its fruit, most roguing should first be done while the plant is in the vegetative stage. Once fruit production commences, any plant with off-type fruit should be removed as soon as possible to prevent further contamination from its pollen. Spine color (white or black) should be consistent, and any plants with the wrong spine color should be rogued. Differences in spine color become very apparent when fruit are ripe since spine color is linked to ripe fruit color. Knowledge of other varieties is helpful for intelligent roguing.

Fruit harvest and seed extraction:

The mature fruits of slicing varieties usually have white spines (which are more apparent during the immature stage) and the fruit is pale yellow, or yellow. In the South, white-spined pickling varieties have been popular, whereas in the North, popular pickling varieties usually have black spines. Black-spined pickling mature to an orange or orange-brown color. A cross-section of the cucumber fruit is rounded-triangular in shape corresponding to the three locules of the ovary. At maturity, the cavity of the locule is filled with seeds and translucent placental tissue. The seeds should be well filled out. The area between the placenta and the rind is white or greenish white. In some long-fruited varieties, such as ‘Suyo Long’, the locules occupy only one end of the fruit so that at maturity only a portion of the fruit is swollen from seed development. When judging maturity in such varieties, the color of the swollen blossom end gives the best indication of maturity. The wall of a mature fruit will give slightly under gentle thumb pressure. Because the seeds continue to develop after harvest, fruits should be held long enough to develop a fully mature color that is accompanied by softness in the fruit wall. They should not be held so long that the fruit wall begins to break down.

When cucumbers have reached the mature state, the fruits are sliced open longitudinally, and the seeds are scraped out with a spoon into five-gallon buckets. Slice the fruit close to one edge so that the seeds can be exposed without being damaged by the blade. At this stage, the seed will not separate cleanly from the pulp. Large commercial operations use one of three methods to extract the seed: mechanical methods, fermentation, and chemical extraction. Small-scale organic seed growers should use fermentation, which when done properly yields a high-quality product.

Fermentation:

Fermentation is a process that occurs naturally to some extent when fruit decomposes. Details of the fermentation process for wet-seed processed seed crops have been discussed in the companion volume in this series: “Seed Processing and Storage.” One of the goals of the seed producer is to control this in such a way as to give the highest quality seed. When properly done, fermentation helps to remove seed cleanly from the pulp, removes germination inhibitors, and inhibits or kills certain disease organisms. The usual length of fermentation depends on the temperature and the variety, but typically the process is complete in about three days at a temperature of 70 to 75^{o}F (21 to 24^{o}C). High temperatures speed up fermentation and low temperatures slow fermentation. When the fermentation temperature is below 60ºF (16ºC) seed may be damaged. The mash (mixture of seed and pulp) should be stirred at least twice daily (preferably three times), to prevent the formation of mold on top of the mash which may blacken or discolor the seed, thus reducing the quality of the seed lot. During the fermentation process the seed separates from the pulp: the good seed sinks to the bottom of the container and poor-quality seed floats to the top. Good quality seed is dense and well filled out. Stirring the mash daily also circulates nutrients through the mash, thereby aiding the fermentation while allowing good seed to settle to the bottom of the container.

Washing:

Once fermentation is complete, the mash is diluted with water. Pulp and poor-quality seeds float to the top and are poured off leaving good quality seeds at the bottom of the container. The seeds are washed again until they are clean.

Drying, milling and winnowing:

Seeds are dried in a manner similar to that used for squash. The seed layer should not be more than one seed thick so that the seeds dry quickly. Stirring and forced air circulation helps to speed the drying process. Artificial dryers can be used, but the temperature should not exceed 100ºF (38ºC). At this stage the seed moisture content should be reduced to at least 12%. Properly dried seed will break rather then bend when force is applied. As a final step, the seed should be cleaned with an air separation technique to help remove seed that is not well filled out.

Seed and seed yield:

Mature seed is ovate in shape with pointed ends, and is well filled out, meaning flat or slightly curved when viewed from the edge. The seed coat is thick, and the surface is smooth and cream-colored. Immature seed appears sunken and has a thin seed coat. The number of seeds per ounce depends on the variety, averaging 985 seeds per ounce. The Federal Germination Standard for commercial seed is 80%. It takes about 45 fruits of the average slicing variety to produce a pound of seed.

MELON (MUSKMELON)
Cucumis melo

General plant characteristics:

The muskmelon is an annual that produces vines from 4 to 12 feet long. Muskmelon is believed to have been first domesticated in northwest Africa (primarily Egypt) over 4,500 years ago. A second area of domestication is in the Middle East, principally Afghanistan and Iran. To date, their direct wild ancestors have not been identified, though a number of feral and wild inedible species have been noted in southwestern Asia. Most of the thick-fleshed forms that we know today were developed by the 1600's and by then had worldwide distribution along trade routes. The cucumber and the closely related muskmelon probably moved through the same channels of trade.

The term muskmelon includes a variety of types and forms that include the smooth-skinned honeydews and the rough-rind cantaloupes (and variations such as banana, snake, and casaba melons). The leaf lobes and stems of most varieties, compared to cucumber, are more rounded. Unlike the cucumber, fruit and seed maturity occur at the same time.

Muskmelon is a hot weather plant, requiring higher temperatures for optimum growth than cucumbers. Fruits mature in 65 to 120 days depending on variety, climate, and conditions of growth.

Classification of cultivar groups:

There are two basic classification schemes with several variations depending on the classification method. One method is based on horticultural characteristics and uses. The other method is based on botanical characteristics that may include considerations of phylogeny or molecular biology. Some authors are "lumpers" and others are "splitters." Lumpers tend to consolidate variation, whereas splitters parse out variation into separate groups. For example, a lumper would classify the Reticulatis Group as part of the Cantalupensis Group, and the Chito Group as part of the Dudaim Group. In Table 2 below, I have chosen to parse out the variations, since I was not entirely able to reconcile the various classification schemes from different sources.

Table 2. Horticultural and botanical groups of melons.

Common name or representative type	Scientific name	Group
Asian or Oriental pickling melon (Shiru-Uri, Golden Crispy, Chekiang melon, Chinese white cucumber)	*Cucumis melo* var. *conomon*	Conomon
True cantaloupe (Charentais): has a rough and warty skin, not netted. Rare in the U.S.	*Cucumis melo* var. *cantalupensis*	Cantalupensis
Mango melon, Lemon melon, Vine peach, Garden lemon, Apple melon (see also Dudaim)	*Cucumis melo* var. *chito*	Chito
Queen Anne's pocket melon, Plum granny, Vine pomegranate, Apple melon, Dudaim melon	*Cucumis melo* var. *dudaim*	Dudaim
Snake melon (Armenian cucumber, Oriental cucumber, Serpent melon)	*Cucumis melo* var. *flexuosus*	Flexuosus
Winter melon (Casaba, Crenshaw, Honeydew) These have smooth rinds, and do not have a musky odor.	*Cucumis melo* var. *inodorus*	Inodorus
Snap melon, Fuut (fruit bursts or splits open as maturity approaches) Rare in the U.S.	*Cucumis melo* var. *momordica*	Momordica
Cantaloupe (U.S), Muskmelon, Nutmeg (popular melons of U.S. commerce)	*Cucumis melo* var. *reticulatus*	Reticulatus

The purpose of the table above is to associate common names of various melons with their botanical or horticultural grouping and to give some additional background regarding common names. Regardless of how the various groups of melons are classified, the seed grower needs to know basically two things: (1) that all of these melons will cross with each other, and (2) that cucumber types, such as the Armenian cucumber, is a melon, not a cucumber.

Climate and soil requirements:

Melons grow best in sandy loam soils well supplemented with organic matter. Such light, well-drained soils give earlier crops, though with reduced yields compared to clay loam. Minimum soil temperature for direct seeding should be 65ºF (18ºC). Transplants should be set out when the plants are about three weeks old. Soil pH should between 6.0 and 6.7. Melon seed germinates poorly below 60ºF (16ºC). The optimum temperature range for germination is 75 to 95ºF (24 to 35ºC), with the germination optimum at 90ºF (32ºC). Muskmelon grows best at moderately high air temperatures, the optimum range for growth is 70ºF (21ºC) and 95ºF (35ºC). Melons like other cucurbits, do not tolerate "cold feet." Root-zone temperatures (below 68ºF (20ºC)) make the plants more susceptible to disease and less able to take up water due to a decrease in root permeability. Even when there is ample water in the soil, cold root temperatures may injure the plant.

Roots:

The root structure is similar to cucumbers with two notable differences: (1) the taproot grows deeper, and (2) the lateral root system can be quite extensive such that when growing in good conditions, the laterals may extend at a foot or two beyond the lateral branches.

Inflorescence:

The male and female flowers of the melon are very similar to that of the cucumber. The male flowers are borne in clusters of three to five, and the female flowers borne singly in the first or second axil of the vine branches. Most American varieties of muskmelon are andromonoecious, meaning that the vines bear both male and hermaphroditic flowers as shown in Figure 12.

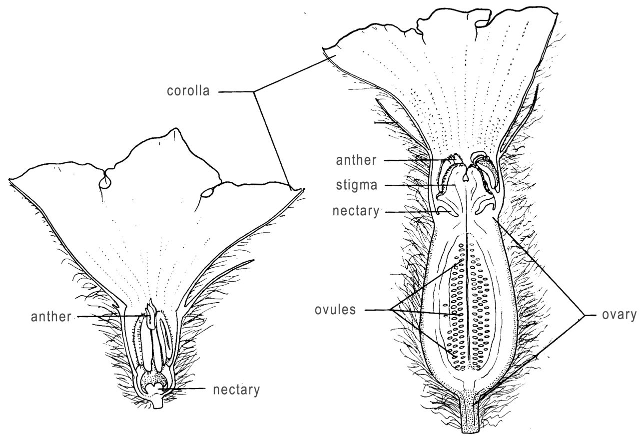


Figure 12. Male and hermaphroditic flower of muskmelon (Modified from McGregor, 1976.)

Pollination:

The pollinators and pollination dynamics of muskmelon flowers are similar to that of cucumber. Though muskmelon has hermaphroditic (perfect) flowers that are self-fertile and capable of self-pollination, cross-pollination is common due to the activities of bees which transfer pollen from one perfect flower to another. There is also a structural difference in the orientation of the stamens in hermaphroditic flowers: the stamens shed their pollen to the outside (away from the stigma) rather than toward the stigma.

When transporting hives of honeybees to melon crops, the hive is placed in the center rather than at the edge of the planting because the flowers are not as attractive to bees as other cultivated cucurbits.

Culture:

Melons are grown for seed in a manner similar to melons grown for market. Plants are spaced about 18" apart in the row in rows spaced 6 to 8 feet apart, depending on the variety. In the South, there may be a benefit from using higher-density plantings that provide better foliage cover, resulting in less sunburned fruits and greater yields. The trade-off in using closer spacing is that roguing is more difficult.

Roguing:

Roguing melons is similar to roguing cucumbers except that the shape of off-type fruits of melons are more easily spotted when half-grown. This is because a melon with elongated fruit has proportionally more length than a spherical melon early in development. Melons also need to be rogued for the quality of their flesh. Unfortunately this can be a destructive procedure and is usually done only if an off-type is suspected: the melon is cut and a plug is taken for examination. The task of roguing some older varieties can be complicated by the number of variety synonyms. For example, 'Rocky Ford' had as many as 55 different synonyms by 1950. When working with heirloom varieties, a broad knowledge of varieties can be helpful in working with a crop that is so easily cross-pollinated.

Fruit harvesting, seed extraction, and processing:

Unlike cucumbers, melons mature their seed at the same time that the fruit reaches edible maturity. For melons that are members of the Reticulatus Group, harvest occurs when the fruit "slips" from the vine, either by itself or by applying gentle thumb pressure to the place of attachment of the stem to the fruit. Melons that are members of the Inodorus Group do not have an abscission layer and must be cut from the vine. Once mature, the fruits can be held until there are enough to justify extracting the seed from a batch of melons.

The process of seed extraction is done in a manner similar to cucumbers. The fruits are cut in half, and the seeds with their attached placental material are scooped out into a container. The fermentation, washing, drying, and milling process is the same as the procedure for cucumber.

Seed yield:

There are approximately 1,300 seeds per ounce, depending on the variety. The Federal Germination Standard for commercial melon seed is 75%. An acre of melons plants will yield on average, 200 to 300 pounds of seed, which is equivalent to 4.6 to 6.9 pounds per 1000 square feet.

WATERMELON and CITRON

Citrullus lanatus* var. *lanatus* and *Citrullus lanatus* var. *citroides

General plant characteristics:

Watermelon has been in cultivation for over 4,000 years. Thought to have been first domesticated in Central Africa, watermelon has also been used as a water source during times of drought, both during and prior to domestication. The flesh of watermelon is typically yellow or red, but may be white or orange. Most are sweet flavored, but there are land races that may have bitter or light-green flesh. The seeds, like those of squash, can be quite varied in size and color, usually black, brown, mottled brown, white, and less common, reddish black or light green. Seed characteristics can be very useful for variety identification.

The fruits typically range from 8 to 50 pounds depending on the variety and the area where grown. Jumbo sizes have been produced in the range of 100 to 262 pounds. Most watermelons are grown for their sweet flesh, though in China, for over 200 years, varieties have been bred for their black seeds that are baked or roasted.

Watermelon is a slender, sprawling, hairy, frost-tender annual vine with tendrils. It is usually monoecious, though a Georgia grower reported that it can be briefly gynomonoecious (with female flowers having sterile male parts). The stems are angular in cross-section and individual vines may extend from 4-½ to 18 feet. The leaves are "pinnatifid" (i.e. pinnately lobed – the lobes themselves may be lobed and toothed). Fruit size, shape, and color vary according to the cultivar.

The citron melon (preserving melon) is used primarily for pickling or to make conserves. It is not palatable in the raw state, and the fruit is opened with difficulty. Many contemporary gardeners are unfamiliar with it, but seed growers need to be aware that it has escaped from cultivation in some areas. It has become a serious weed in cotton and sorghum fields and especially in watermelon seed fields where it can readily pollinate watermelon causing serious contamination. The fruit of citron resembles a small globe-shaped watermelon. The rind is green with irregular light green striping and the flesh is firm, bland, or slightly bitter, and white or light green in color. The fruits typically weigh 8 to 14 pounds. Seed color is typically red or green.

Climate and soil requirements:

Watermelon requires a long, warm growing season for fruit development and good yield. Two-thirds of watermelon seed production comes from only four states Georgia, South Carolina, Florida, and Texas. Other watermelon production areas such as coastal Virginia, North Carolina, South Carolina, Alabama, and Missouri also offer long warm growing seasons. In the Mid-Atlantic, shorter season (65 to 75 day) varieties such as 'Black Tail Mountain' and 'Sugar Baby'' do well in areas that have shorter growing seasons or at higher elevations. Watermelon does best on a rich sandy loam, but will grow in most soil types provided the soil is well drained. The plants are drought resistant and prefer full sun, and hot, dry air. Humid, moist climates put the plants at greater risk for disease, and for that reason, long periods of crop rotation in moist climates are key for maintaining healthy crops. This is especially important in seed production as many watermelon diseases are seed borne.

Roots:

The root system of watermelon is similar to muskmelon. The principal difference is that like most plants of arid climate origin, the main root system is shallower, more extensively branched and longer. One report indicated that a lateral branch extended as far as 21 feet from the base of a well-grown plant.

Inflorescence:

Most varieties of watermelon are monoecious. Unlike muskmelon, the flowers are borne singly and the male, female and hermaphroditic flowers are essentially similar to muskmelon, though slightly smaller. Flowers are pale yellow to greenish colored. A few varieties bear hermaphroditic flowers instead of female flowers. On average, the ratio of male to female flowers is about seven to one. Under certain environmental conditions (as described for squash), plants may bear female flowers before bearing male flowers, though when this occurs male flowers appear two to three nodes later. Most open female flowers are found 12 to 18 inches from the tip of the branches.

Pollination and pollinators:

Watermelon flowers open one to two hours after sunrise. The stigma is receptive throughout the day, but most pollination occurs before noon. The flowers close in the afternoon whether pollinated or not.

The flowers are attractive to honeybees for nectar and pollen, but are not as attractive as the flowers of competing crops. For that reason, when honeybees are used for pollinating large plantings, pollination is more effective when hives are placed in the center of the planting. Large plantings should be no further than 250 yards from a hive.

At least 1,000 pollen grains, evenly deposited on the three-lobed stigma, are required in order to produce a symmetrical melon. Unequal pollen distribution may cause development of a lopsided fruit that is small on either end. This is important to bear in mind when roguing watermelon not to mistake off-type watermelons for those that inadequately pollinated. When hand-pollinating watermelons, pollen from at least three male flowers should be used to ensure adequate pollination. The highest success rate from hand pollination occurs between 9:00 a.m. and 10:00 a.m. Success rate also depends on the physiological state of the plant, amount of stress, and number of melons already on the vine. Though the flowers are small, hand pollination is relatively easy and is successful at least 50% of the time under favorable conditions.

Culture:

Watermelon grown for seed is grown in the same manner as watermelon grown for market, the main difference being the row spacing. When grown for seed, plants should be spaced 24 to 36" within the row, in rows spaced at least 6 feet apart for short-season varieties, and 8 to 12 feet or apart for long-season varieties. The extra space between plants will assist in determining which plant is mother to which fruit during rouging. Because watermelon has an extensive root system, supplemental irrigation is often unnecessary once the plants are well established.

Watermelon grows best at a soil pH of 5.6 to 7.0, but will tolerate a pH as low as 5.0. In low pH soils, manganese toxicity can be an issue. The minimum temperature for seed germination is 60ºF (16ºC) and the optimum is 95ºF (35ºC). The optimum air temperature range for growth is between 75 and 86ºF (21 and 30ºC).

Roguing:

Much of the roguing process used for other cucurbits is also applicable to watermelon. Because there are so many different watermelon varieties, the seed grower should have a general working knowledge of the common watermelon cultivars. Roguing should be first practiced on the basis of spotting and removing off-type plants before flowering occurs. Thereafter roguing is based on the characteristics of all the fruits on the plant, not just individual off-type fruits, which may differ from the others due to developmental abnormality. Additional roguing for hollow heart and off-type flesh can also be practiced during seed extraction. The flesh at the center of the melon normally has the deepest color. If the center is pale or white, or is hollow, these are defects called "white heart" and "hollow heart." Fruits having either of these conditions should be rogued out.

Fruit harvest:

It takes some practice to be able to judge when a watermelon is mature enough to harvest at the edible stage. Unlike muskmelon, the fruit doesn't slip from the vine. The edible maturity stage is judged by several factors: (1) the spot in contact with the soil turns a yellowish color, (2) the tendril on the vine nearest the point of fruit attachment is dried up, (3) the rind has a dull or rough appearance compared to smooth, glossier, immature fruit, and (4) the fruit ripeness is detected by the classic method of thumping the fruit with knuckles or extended fingers. The sound of a ripe melon is comparable to the sound of thumping your chest (or according to Mark Twain, a "punk" sound, as compared to a "pink" or "punk" sound). When under-ripe, it sounds like rapping your knuckles on your head (a sharp or metallic "pink" sound). When over-ripe (for eating, but not for seed harvest) it sounds like slapping your stomach ("pank" sound).

Though seeds are ready to harvest at the edible maturity stage, seeds continue to mature in the fruit for several weeks, a process called "after-ripening." Allowing the seed to after-ripen gives a higher quality seed. For this reason, seed extraction is best delayed for several weeks. For the best quality seed, the best time to extract the seed is between 10 and 30 days past edible maturity. Seed extraction can be delayed until late November, or even December for some varieties, however the fruits should be stored at a temperature not less that 50ºF (12ºC) nor more than 68ºF (20ºC) for long-term storage.

Fruit left in the field to after-ripen is susceptible to injury and disease, especially anthracnose that may be latent in the field. If foliage cover is sparse, there is risk of sunscald and possible reduction of seed quality, especially in hot southern areas. Illinois seed grower Merlyn Niedens sometimes tapes paper plates over his watermelons, or uses a light covering of straw to prevent sunscald. This can be a useful technique when the grower is short of storage space before the seeds are extracted.

Fruits should be harvested in the late afternoon rather than evening. Fruits harvested in the morning are more turgid and prone to splitting during handling and transport. When transporting watermelons over rough terrain, they should be packed in straw to minimize splitting.

Seed extraction:

Watermelon seed can be extracted by cutting the melon in half and scooping out the seed into five-gallon buckets or other suitable containers used for fermentation. The seed is then either macerated by hand or by use of a hand mortar mixer that resembles an oversized potato masher. Another method is to slice the fruit into wedges and rub the wedges over a ½" hardware cloth stretched on a wooden frame that is placed on top of a wheelbarrow used to catch the pulp and seed. A third method is to run slices of the wedges through an apple grinder. The apple grinder method works well on most watermelon varieties, and has been described in the companion manual in this series: "Pepper Seed Production."

Some seed production manuals state that small amounts of seed can be obtained by eating the watermelons (as a single or community effort) and spitting out the seed into bowls. This method is impractical for anything but seed saved for home use. More importantly, the seed quality is adversely affected for several reasons: (1) some seed, especially that of small-seeded varieties (e.g. 'Sugar Baby') is easily injured by accidentally biting the seed, (2) this method does not break down the germination inhibitors on the seed coat, resulting in delayed or poor germination, and (3) the seed does not benefit from fermentation which inhibits or kills some watermelon diseases. I have found dramatic differences in seed germination tests comparing the quality of seed from "oral extraction" versus fermentation. Fermentation is the only acceptable method.

Fermentation:

After the rough extraction is complete, the mixture of seed and pulp should be allowed to ferment for two to three days. The ideal fermentation time and temperature is about 70ºF (68ºC) for three days, or two days at a higher temperature. After fermentation is complete, add water to the mixture and pour off the ferment and the pulp. The good seed will sink to the bottom and the immature seed will float off the top with the pulp. Watermelon is one of the few wet-processed fruits that has some exceptions to the rule that good seed sinks to the bottom. There are a few varieties that have a high percentage of good quality, low-density seed that may float on the water surface. When washing seed of these cultivars it is easier to wash the seed by pouring the fermented mash onto a ¼" hardware cloth screen and spraying the surface of the screen with a water spray from a hose to force large pieces of mash through the screen. This leaves clean seed on the surface of the screen. Seed that is not well filled out is removed primarily by air-separation rather than washing. The air separation step is especially important for varieties that have low-density seed (seed that tends to float during the washing process).

Seed yield:

There are approximately 175 to 300 seeds per ounce, depending on the variety of watermelon. The Federal Germination Standard for commercial melon seed is 75%. An acre of watermelon plants will yield on average, 200 to 250 pounds of seed, which is equivalent to 4.6 to 5.7 pounds per 1000 square feet.

DISEASES AND DISEASE MANAGEMENT

Disease prevention and control strategies:

Many fungal diseases are encouraged by high humidity, use of overhead sprinklers (especially late in the day leaving moisture on leaves), poor sanitation and failure to remove crop residues, use of disease contaminated seed, failure to use a minimum three-year crop rotation, and improper soil pH. Crops should be located where the early morning sun can quickly evaporate the morning dew. Use of cereal crops in the rotation scheme gives significantly better control than rotation with non-cucurbit vegetable crops. By late summer/early fall, crop residues should be removed as soon as possible and composted. Seeding a winter cover crop helps to eliminate weeds and insects that harbor disease. Generally recommended cover crops are annual or winter rye. The latter does a better job of drying out the soil in the spring. Clover makes an excellent winter cover crop if started soon enough to get established, and can often be sown with a thin seeding of a buckwheat nurse crop that is later killed by frost. Finally, and perhaps foremost, be a good crop manager and scout frequently for signs of disease. Check with your organic certifier to determine what treatments are approved for control of fungal diseases.

Remember that the most successful strategy for dealing with disease is to use resistant varieties. The most progress has been made with cucumbers, where sources of resistance have been found for most of the major pathogens (Robinson and Decker-Walters, 1999). In the discussion of diseases below, specific open pollinated varieties with resistance to certain diseases have been cited. These recommendations come largely from Robinson and Decker-Walters (1999).

Grafting as a means of disease control:

Grafting susceptible scions onto resistant rootstock can be very effective, and has been practiced in Japan and Korea for over 50 years (Robinson and Decker-Walters, 1999). Vegetable grafting is also practiced in some Mediterranean and European countries.

In the late 1970's I was successful in grafting peppers onto tomatoes and vice versa. The experiment was conducted on 18 to 24" tall, potted plants growing indoors under a combination of natural and artificial light. Though the procedure was successful, the experiment was discontinued after about 6 to 8 weeks because it was too late in the season to set the large plants outside. Because the grafts were performed on medium-sized plants, rather than on seedlings, differences in growth habit between the tomato-pepper grafts might have caused structural problems later in the season. Nevertheless, the results were intriguing, especially because these were grafts of two different genera. It is worth repeating this experiment at different developmental stages (seedlings and mature plants), allowing the grafted plants to grow for a longer period of time.

Grafts involving two different cultivars of the same species can be useful for conferring insect and disease resistance. Some people are surprised to learn that vegetables can be grafted, but I found vegetable grafting easier than grafting fruit trees. The basic procedure that I used is fairly simple. A razor blade or X-acto knife is used to make a "v-shaped" cleft in the severed rootstock. A short section of scion is then severed and the severed end is cut into a matching "v-shape" (top wedge) and inserted into the cleft of the rootstock. Another technique used was a type of whip graft where the scion and rootstock were each cut at a shallow angle across the stem so that each overlapping whip was the same length and at least ½" long. The scion and rootstock tongues were then matched together and held with Parafilm (trade name of a common thermoplastic film). The Parafilm is cut to a length of about two inches, and a width that is ½" wider than the width of the graft. The film is then stretched and wound around the graft to form a seal that is impermeable to water.

Robinson and Decker-Walters (1999) describe some cucurbit grafting techniques in their book, "Cucurbits." There are many types of grafting techniques, and a detailed discussion of vegetable grafting can be found in Lee (1994). The techniques are briefly summarized here. Cucurbits are grafted before the first true leaves have fully expanded on both the scion and rootstock. Tongue grafting is practiced in cucumbers because they have sturdy hypocotyls. "Cleft grafting" is used with older seedlings that have several sets of leaves. "Hole insertion grafting" is used for watermelon seedlings because they are of small size. This technique involves cutting the apical bud out of the rootstock and then cutting the scion just above the roots. The scion is inserted into the hole (between the cotyledons) in rootstock. Grafts are inspected for their integrity a week to 10 days after grafting.

Though somewhat labor intensive, the process can be used for small-scale seed production. Grafting can be useful for rescuing certain cultivars that normally would be susceptible to disease, or for maintaining a valuable genetic trait. It is also another option for organic growers to explore when there are no other organic options. Automated methods of grafting are currently under development.

Disease overview:

There are quite a few diseases that affect cucurbits in various stages of development from germinating seed to stored fruit. The diseases described below are some of the most important ones. Note that some of these diseases can be prevented by controlling insect pests, especially cucumber beetles as discussed later. Do not sell or trade seed if seed-borne diseases are observed during production.

BACTERIAL DISEASES

Angular leaf spot (*Pseudomonas syringae* pv. *lachrymans*): [seed-borne]
This disease primarily affects cucumber, but also affects other commonly cultivated cucurbits. The infection enters through stomata or wounds. Symptoms first appear as water-soaked spots on the underside of leaves. The spots turn tan and drop out leaving ragged or angular holes. The disease over-winters on plant debris, soil, and on the seed. Resistant cucumbers include 'Poinsett 76,' 'Edmonson,' and 'Little Leaf H-19.'

Bacterial wilt (*Erwinia tracheiphila*):
This is primarily a disease of cucumber and muskmelon, though it affects squash at a lower incidence. Individual leaves or the entire plant wilt on successive sunny days even though there is ample water in the soil. The usual diagnostic test is to use a knife to cut a wilted branch near the crown and then check for the presence of a sticky white exudate. When the exudate is touched with the knife blade, it will form a thread that adheres to the blade as it is drawn away. The disease is transmitted by cucumber beetles that feed on the plant. Prevention includes controlling cucumber beetles, especially by use of trap crops, and where possible, use of non-bitter cultivars (for example, 'Marketmore 80') that aren't attractive to cucumber beetles.

Bacterial leaf spot (*Xanthomonas campestris* pv. *cucurbitae*): [seed-borne]
The host plants are primarily squash, though cucumber and other cucurbits may be affected. This disease infects the plant primarily through the stomata giving rise to small brown lesions about 1/8th inch in size. These are surrounded by yellow halos that coalesce and form dead areas. The disease is favored by high humidity and overhead irrigation. Some *Cucurbita moschata* have resistance.

Bacterial fruit blotch (*Acidovorax avenae* ssp. *citrulli*): [seed-borne]
Now a serious disease of watermelon primarily in southern states (especially Florida), it was introduced on foreign-grown seed. The practice of out-sourcing seed production to other countries often results in a false economy and underscores the importance of relying on local and regional seed

production. The disease has become so serious that some seed companies no longer carry watermelon seed, or they limit the amount of seed sold, or sell it only with a liability waiver. Symptoms appear as water-soaked lesions on the foliage and stems. Later these become necrotic spots with yellow margins. Lesions can also appear on the fruit accompanied by cracking and an exudate. The disease is promoted by high temperature, high humidity, and overhead irrigation. Prevention involves growing watermelon where cucurbits and solanaceous crops (primarily eggplant) have not been grown for at least four years, or growing on virgin soil at least ¼ to ½ mile from infected fields. Some control can be achieved by use of copper-based fungicides. Check with your organic certifier for approved control options.

FUNGAL DISEASES

Alternaria leaf spot (*Alternaria cucumerina*): [seed-borne]

Also called Alternaria leaf blight, it occurs primarily on cucumber, but also on muskmelon and other cucurbits. Weak and senescing plants are more affected than vigorous plants. Symptoms start as circular water-soaked leaf spots on leaves and fruit. These later enlarge up to ½' in diameter and become light brown with dark concentric rings. These coalesce affecting large areas of the leaf, leading to defoliation. Resistant watermelon varieties include 'Sugar Baby' and 'Calhoun Grey' (not commercially available, and may only be available from seed exchanges now). Resistant melons include 'Edisto 47.'

Anthracnose (*Colletotrichum lagenarium*): [seed-borne]

Anthracnose primarily affects watermelon, and to a lesser extent cucumbers, melons, and other cucurbits. The disease is most prevalent in hot, humid areas with frequent rains. The disease begins rapidly as water-soaked or yellow areas in the leaf that rapidly enlarge, turn into tan, brown, or black lesions that often have ragged holes or rips within the lesions. Fruits are also affected, developing sunken cankers with dark borders, sometimes producing pink or salmon-colored spore masses when sufficient moisture is present. Prevention includes hot-water treatment of seed, and use of resistant cultivars such as 'Charleston Grey' and 'Crimson Sweet' watermelon, and 'Poinsett' cucumber.

Downy mildew (*Pseudoperonospora cubensis*):

Common to the southeastern U.S., downy mildew affects primarily cucumber and muskmelon, though squash and watermelon are susceptible. Symptoms first appear as small yellow spots on the upper leaf surface and under moist conditions as a purple mildew (spores) on the underside of leaf spots. Wider plant spacing increases air circulation and is an important prevention. Resistant cucumber varieties include 'Ashley,' 'Marketmore 76,' 'Marketmore 80,' and 'Little Leaf H-19.' Resistant melon varieties include 'Edisto 47.'

Gummy stem blight/black rot (*Didymelia bryoniae*): [seed-borne]

These two diseases are caused by the same fungus, but with differing symptom expression in different species of cucurbits. On squash, the symptoms show as a black rot that first starts as tan lesions on the fruits and foliage. Of the squash species, *Cucurbita. pepo* is affected the most: the fungus penetrates the rind causing a dry rot that is accompanied by opportunistic fungi that cause a wet rot. In *C. moschata* the fruit symptoms appear as irregular spots or rings without dry rot. The symptoms in cucumber and watermelon at the advanced stage of the disease show as streaks (appearing first at the nodes) extending along the stems. The streaks are accompanied by a gummy exudate. Associated leaves on the affected vine yellow and die. 'Congo' watermelon has some resistance, but there aren't many options regarding resistant varieties.

Fusarium wilt (*Fusarium oxysporum* spp.): [seed-borne]

Fusarium wilt affects mostly watermelon and melon, and cucumber to a lesser extent. Symptoms are first expressed by wilting of one or more vine tips due to an impaired vascular system that is no longer able to transport water and nutrients. Wilting and die back continues along the vines. Browning of the vascular tissue is one of the diagnostic signs of fusarium disease. (By diagnostic, do you mean it is only caused by Fusarium?). The fungus is introduced via the root system. This soil-borne disease needs a long rotation period of six to eight years. Grasses and legumes, not vegetable crops should not be grown in the rotation area, and soil solarization may be helpful. The fungus exists in different races. Resistant varieties of open-pollinated watermelon include 'Charleston Grey.' Melons having resistance to one or more races include 'Delicious 51,' 'Harvest Queen,' 'Honey Dew,' and 'Iroquois.'

Phytophthora root and crown rot (*Phytophthora capsici*):
This fungus causes rapid wilting and death, usually at the fruiting stage. Symptoms appear as black lesions on the crown, and the roots have a brown or black decay. This disease is more common on compacted wet soil. An important prevention measure is to increase the drainage in the soil by adding composted organic matter, using shorter irrigation periods, or growing on soil ridges or raised beds.

Powdery mildew (*Sphaerotheca fuliginea* and *Erysiphe cichoracearum*):
This fungus appears as a white powdery overgrowth on the leaves that starts out as circular white spots that coalesce to cover most of the leaf. Symptoms first appear on the crown leaves, and as the disease progresses, the leaves yellow and die. The disease is favored by high temperatures. Most of the fungus grows on the surface of the leaf. Mycelia and spores are vulnerable to being washed away by heavy rains (Robinson and Decker-Walters, 1999).

Figure 13. Powdery mildew on squash. (Photo © by Bryan Connolly.)

Septoria leaf spot (*Septoria cucurbitacearum*): [seed-borne]
Septoria leaf spot affects mostly melons and squash. Disease development is promoted by cool, rainy weather when the temperatures are in the low 60's (16 to 19ºC). Symptoms appear on both leaves and fruit. Disease expression on the leaves is characterized by the presence of small white spots with brown halos. Later, black spores (pycnidia) develop within the lesions.

Target leaf spot (*Corynespora cassicola*):
Cucumbers are particularly susceptible. Symptoms initially resemble downy mildew: lesions first develop as small yellow flecks or spots, averaging about ¼" across. The disease becomes more distinctive when the spots turn tan to light brown with dark borders. Coalescing lesions become dry and necrotic, causing tissue to drop out giving a shredded appearance to the leaf.

Verticilium wilt (*Verticillium dahliae* and *V. albo-atrum*):
Symptoms are similar to that of fusarium wilt. Whereas fusarium is promoted by higher soil temperatures, verticillium is more of a problem in northern areas where soil temperatures are cooler. Like fusarium, the fungus has a long persistence in the soil. A long rotation of at least 8 years is suggested using legumes or grasses, which in most cases effectively means abandoning the soil for use in cucurbit production. 'Honey Dew' and 'PMR 45' have some resistance.

VIRAL DISEASES

Figure 14. Virus-infected leaf. Note stringy appearance and islands of green tissue.
Photo © by Bryan Connolly.

There are over 30 viral diseases of cultivated cucurbits, nine of which can be carried on the seed (Robinson and Decker-Walters, 1999). The three most important are cucumber mosaic virus (CMV), squash mosaic virus (SqMV), and watermelon mosaic (WMV). Unfortunately CMV may infect many vegetables and a host of unrelated genera and species, and is also spread by cucumber beetles as well as aphids. WMV is spread by aphids and affects legumes as well as cucurbits; therefore grasses should be used in rotation instead of legumes. SqMV is spread by cucumber beetles, and can be transmitted in squash and melon seed. A good discussion of the various virus diseases can be found in Robinson and Decker-Walters (1999). The basic symptoms of virus diseases often share some basic similarities which include leaf distortion, mottling, a stringy appearance to the leaves, and "green islands" (areas of green tissue surrounded by yellow tissue). For CMV, control of weeds and cucumber beetle is important. Fortunately most modern cucumber cultivars have CMV resistance, though most melon cultivars are susceptible. The use of row covers is useful for reducing cucumber beetle visitation during the vegetative stage of growth.

NEMATODES

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. Sometimes the galls break open providing an entry for opportunistic disease organisms. Nematodes can make gardening and farming difficult especially in warm, sandy, irrigated soils in the South.

The most effective controls are soil solarization, crop rotation, sanitation, fallowing, and by double cropping with resistant tomato or pepper varieties (for example ‘Carolina Wonder’ and “Charleston Belle’ peppers). 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 the 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. Including castor beans, rye, or velvet beans in the rotation will drastically reduce nematode pressure.

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.

INSECT PESTS

The principles of integrated pest management are appropriate for organic growers, one of the main differences being that control measures of last resort involve only approved substances. Control of pests is the natural outcome of prevention. Prevention begins with an understanding of how to grow healthy plants with a minimum of stress. The basic cultural and management methods (especially sanitation and crop rotation) used for prevention of disease are equally applicable to the prevention of damage by pests. Prevention also begins with early scouting, knowledge of the habits of major pests and their life cycles, times of emergence, their preferred hosts (including both crops and weeds), their natural enemies, and their behavior on host plants. Another important component of prevention involves maintenance of biodiversity and ecological complexity. It has become very clear from my own experience that maintaining borders of annual and perennial flowers around seed production areas is important for providing food resources for beneficials throughout the growing season. Within the growing area, the use of trap crops is also beneficial. Row cover may be used to exclude or reduce populations of pests up to the flowering stage. Thereafter, the covers must be removed to allow pollination. When these prevention methods fail, the last resort involves use of biological controls (microbial and beneficials). Lastly, as in disease prevention, the use of resistant varieties is recommended. Unfortunately there aren’t many cucurbits that have been bred for insect resistance. Notable exceptions are cultivars (e.g. ‘Marketmore 80’ cucumber) bred to be free of cucurbitacins (bitter compounds in cucurbits that attract cucumber beetles). The trade-off is that the bitter-free cultivars are now more susceptible to spider mites, aphids, thrips, and cucurbit caterpillar (Robinson and Decker-Walters, 1999).

When preventative methods are not sufficient to control serious pest outbreaks, certain botanical pesticides may be used in conjunction with a biorational pest management program, and must be used in the least ecologically disruptive way possible. Allowed substances include certain essential oils, garlic, and non-synthetic regulated botanical pesticides such as neem, pyrethrum, rotenone, ryania, and sabadilla. Consult your organic certifier before using any of these controls. Remember that insecticides derived from natural sources are nevertheless toxic and must be used with care and precaution, including adherence to EPA label restrictions.

For an excellent discussion of the use of levels of control in certified organic production, I highly recommend: *Organic Crops Workbook: A Guide to Sustainable and Allowed Practices.* This publication is available as a PDF download from the National Center for Appropriate Technology: See the section on Internet Resources on page 33**.** A related publication titled Farmscaping to Enhance Biological Control is also recommended.

A number of insects attack cucurbits and often cause more damage than diseases or in the case of cucumber beetles and melon aphids are disease vectors. The discussion below is limited primarily to major insect pests of the Mid-Atlantic and South.

Cucumber beetles (*Diabrotica* spp.):

Figure 15. Spotted cucumber beetle.
Photo by Jeff McCormack

Cucumber beetles are the most destructive of the cucurbits either because of direct damage due to feeding on plant parts, especially during the seedling stage, or by spreading plant diseases at any developmental stage of plant growth. There are two species, the spotted and the striped cucumber beetle. It is thought that cucumber beetles co-evolved with cucurbits, and that in the wild they serve to regulate population densities of cucurbit seedlings by reducing competition for scare resources such as water (Nabhan 1985).

The striped cucumber beetle is more common in most areas, and emergence is at about the same time that cucumber seedlings emerge from the soil. Adult beetles are about 3/16" long. They lay their eggs in the soil at the base of the plant. The eggs hatch out into larvae that grow approximately ½" long.

The adults feed on the leaves and stems. In the Mid-Atlantic there are two to three generations a season and in the South, up to four generations. Cucumber beetles are also common on corn and eggplant. The natural predator is the tachinid fly (*Celatoria diabrotica*). Other predators include soldier beetles, brachonid wasps, and bats, through they may not be in sufficiently high numbers to control outbreaks. In addition to the preventive measures discussed above use amaranth as a trap crop near cucurbit plantings.

In 1990 when we moved our seed gardens to one area that had been planted to corn three years earlier, we had large populations of this pest. I discovered by accident that the striped cucumber beetle (the major pest of our cucurbits) was strongly attracted to amaranth, especially 'Mayo Indian' amaranth that we were also growing as a seed crop. During the first year, the amaranth was covered with cucumber beetles and severely defoliated (see Figure 16**)**. To control cucumber beetles the following year, volunteers of amaranth were transplanted to the edges of cucurbit plantings, and biodiverse borders of perennial flowers were planted around the edges of our seed production areas. Within three years, cucumber beetle populations were diminished to the extent that no control measures were needed except to set out some cucurbits as transplants rather than direct seeding early in the season.

Figure 16. Striped cucumber beetle feeding on a trap crop of 'Mayo Indian' amaranth.
Photograph by Jeff McCormack

Interestingly the technique of using amaranth as a trap crop may not always be effective. Seed saver and squash breeder, Bryan Connolly in Connecticut reports that the striped cucumber beetle is not strongly attracted to his amaranth (which has also hybridized in his seed plots with the native green amaranth). There may be several reasons for the non-preference of amaranth in his location: either the ecotype of striped cucumber beetle in his area has different feeding preferences, or the cultivated amaranth that has hybridized with native amaranth is not as attractive to the beetles. Exploring this idea further in another discussion it was noted that the feeding preferences of Japanese beetle in his area were directly the opposite of the preferences in Virginia (i.e. apple family preferred in Virginia, but not in Connecticut, and primrose family preferred in Connecticut, but not Virginia). Since the ecotypes of the cultivated species of plants differ little between the two locations, we speculated that the insect pests had different ecotypes that were expressed in their feeding preferences. So the use of 'Mayo Indian' amaranth as a trap crop may not have the same results in all regions. Nevertheless, the combination of biodiverse flower borders and an amaranth trap crop is worth exploring as part of the organic strategy because it has been successful in our location.

Squash vine borer (*Melittia cucurbitae*):

The squash vine borer is a major pest of squash and in fact prefers squash, especially *C. pepo.* It can also damage cucumber, watermelon, and melon, but may not complete its life cycle on these hosts (Robinson and Decker-Walters, 1999). If squash is present, it will likely avoid other cucurbits. *Cucurbita moschata* and *C. argyrosperma* are resistant. It has been suggested that resistance is associated with its hard woody stem, and that volatile chemicals of the host plant influence oviposition. I have found that any variety of squash that produces adventitious roots along the vine confers some resistance. Even though the original plant may be destroyed, rooted vines can continue to grow and produce in the absence of the original plant. The process can be facilitated by hilling some soil over the vine at the nodes to stimulate production of adventitious roots.

The adult moth resembles a wasp, about 5/8" long. The forewings are orange and black and the rear wings are transparent. It is active during the day, laying dark, reddish brown eggs mostly on the stem or leaf petioles at the base of the plant. The larvae hatch and burrow into the stem and feed for four to six weeks. Their feeding activity destroys the vascular tissue and causes the plant to wilt or die. A sticky mass of excrement (frass) that resembles sawdust may be seen at the base of the plant. The white larvae have a brownish-black head and may grow up to an inch long. After feeding the larvae leave the stem, pupate, and over-winter in the soil. Adult moths can fly about ½ mile from the site of pupation.

Because the borer lives inside the stem it is more difficult to control organically. When growing melons and cucumbers, a few squash plants can be used as a trap crop, or a planting of another species of cucurbit can be interplanted in the seed crop. Floating row cover can be used for early season control. Natural predators include robber flies and ground beetles, and at least one egg parasitoid has been discovered. Biological control requires early scouting to be effective. Borers can be removed from the stem by making a slit along the affected stem. Liquid suspensions of predatory nematodes or *Bacillus thuringiensis* var. *kurstaki* (Bt) may be injected into the stem by using a syringe. Also the soil around the base of the plant should be hilled to allow the plant to promote development of adventitious roots. Because most of these organic options are labor intensive, early scouting is important. A pheromone lure and trap is available, and although this does not control populations it serves to alert the grower that moths are active. The base of the plant can be sprayed with pyrethrum but this often requires repeated applications, and may require approval from the organic certifier. Many old farmers claim that mixing a handful of hardwood ash into each hill before seeding will deter the vine borer. Past experience has taught me to pay close attention to such anecdotal reports. It is certainly worth doing a controlled experiment to test this further.

Squash bug (*Anasa tristis*):

Planning for squash bug control in organic production begins before the first seed is planted. The squash bug is the most serious pest of squash, and although it prefers squash, it will feed on cucumber, melon, and watermelon. Both the adult and the nymphs damage the plants by sucking plant juices and injecting a toxin that causes plants to wilt, blacken and die. The wilting is referred to as "Anasa wilt." Squash bugs also transmit bacterial wilt, which is differentiated from "Anasa wilt" in that the crop recovers if squash bugs are removed. Considerable reductions in yield can occur in the presence of significant numbers of squash bugs, and in fact some plants may produce no fruit at all. (Adam, 2004)

The adult squash bug (Figure 17) is a member of the true bug family of insects. It is a hard bodied, shield-shaped bug, approximately 5/8" long, with dark brown or mottled wing covers. When disturbed or crushed it emits a disagreeable odor. The eggs are found mostly on the underside of squash leaves and are typically arranged in clusters. Freshly lain eggs are yellow-orange turning to a shiny dull bronze color (Figure 18) before they hatch. Nymphs (Figure 19) appear substantially different from the adult. As the nymphs mature and go through molting they become gray with dark legs. They range in size from 0.1 to 0.4." Usually there is only one generation per year but in the South there are two generations per year.

Figure 17. Adult squash bug.
Photo by Scott Bauer USDA.

Figure 18. Recently hatched squash bug eggs: note the openings on the egg cases and feeding damage from nymphs.
Photo by Jeff McCormack.

Figure 19. Squash bug nymph.
Photo by Jeff McCormack.

Cucurbita moschata is resistant to squash bugs, and resistance is found is some cultivars of *C. argyrosperma*. (Robinson and Decker-Walters, 1999). Among the *C. pepo* cultivars, there is a preference for straightneck and crookneck varieties. I have used 'Black Beauty' zucchini very successfully as a trap crop. Given that organic control of squash bugs can be labor intensive, it would be interesting to try grafting plants of a susceptible variety onto a resistant variety as a way of preventing squash bug damage. From a cost-benefit perspective, this might be less labor intensive and less costly than using some other control measures.

The insect preventative measures described in the introduction of this section are important. Unfortunately crop rotation often may not significantly reduce populations when the adults migrate from nearby gardens or fields. I don't recommend mulching the soil around squash with leaf mulch or straw because such coarse mulch provides hiding places for the adults when the plants are disturbed. Instead, only fine-textured mulch such as well-rotted sawdust is recommended. For small plantings, it is easy to trap adults by laying down boards alongside the plants. The adults congregate under the boards where they are easily collected and removed. Adults also tend to congregate at the base of the plants and this behavior can be used to advantage when using approved insecticides, but the adults are not easy to kill and of the various botanical insecticides, only sabadilla seems to be effective. The nymphs are more easily controlled. Early scouting of insect outbreaks is critically important when managing pest infestations. Whereas in real estate, the buzzwords are "location, location, location'" the equivalent in pest management is "scouting, scouting, scouting."

There are biological controls for the squash bug, such as the tachinid fly parasitoid, *Trichopoda pennipes*. It lays its eggs on adults and large nymphs, but the parasitized squash bugs continue to feed and lay eggs for a while before succumbing. Though parasitism levels may reach as high as 80%, it is not sufficient without adjunct control measures. Regarding pesticides (botanical or otherwise). to effectively control pest populations, a kill level of 95 to 98% may be necessary to knock down the pest population sufficiently. This level of knockdown can be difficult to achieve in practice when using botanical pesticides: more than one application may be necessary. The message here is that no one strategy is totally effective, but when biological control is instituted within the context of other measures it is possible to achieve the desired level of control.

Adams (2004) reported on a research project that was conducted by Kathleen Delate at Iowa State University. Three methods of control were compared: (1) application of kaolin clay (Surround™) applied bi-weekly from seedling emergence up until a month from harvest, (2) interplanting buckwheat with squash to provide a food source for the tachinid fly parasite of the squash bug, and (3) use of floating row cover from seed emergence to the onset of flowering. After three years, the study concluded that use of row covers is the most effective method.

Pickleworm (*Diaphania nitidalis*) and Melonworm (*D. hyalinata*):

The caterpillars of these two night-flying moths feed on fruits of cucumber, melon, and squash. Eggs are deposited singly or in groups on the underside of leaves, stems, and fruits where the caterpillars feed. They burrow into developing buds and fruits, often introducing secondary fruit rots. Caterpillars also feed on foliage and grow to about 7/8" long and pupate by spinning silk on the underside of leaves causing the leaves to curl and die. Pickleworms are yellowish-white and melonworms are greenish yellow. Whereas the melonworm attacks both the foliage and the fruits, the pickleworm feeds primarily on the fruit. Largely a problem in the Southeast they produce one to four generations a year.

In addition to the usual preventative measures, early planting and use of protective row covers is very helpful for minimizing damage. Early applications of *Bacillus thuringiensis* help control caterpillars before they are shielded by protective foliage. In the Deep South wild cucurbits may serve as hosts for pickleworms and melonworms.

Resistant varieties of cucumber and melon have glabrous (smooth) foliage that is associated with an allele that prevents formation of trichomes on foliage. Because the trichomes serve as a stimulus for oviposition, the moths lay fewer eggs on glabrous plants. *Cucurbita moschata* varieties have generally more resistance than *C. pepo* varieties (Robinson and Decker-Walters, 1999).

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INTERNET RESOURCES

Due to the dynamic and ever changing nature of resources available on the World Wide Web, Internet resources cited or resourced 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.

- **Melon classification:**
  - http://www.scindex.org/Melon.html
- **Cucumber:**
  - http://cuke.hort.ncsu.edu/cucurbit/cuke/cukemain.html
  - http://oregonstate.edu/Dept/NWREC/cucumber.html
- **Squash:**
  - http://www.cals.ncsu.edu/sustainable/peet/profiles/c16squas.html
  - http://oregonstate.edu/Dept/NWREC/squash.html
- **Luffa gourd:**
  - http://cuke.hort.ncsu.edu/cucurbit/luffa/luffamain.html
- **Melons**:
  - http://cuke.hort.ncsu.edu/cucurbit/melon/melonmain.html
  - http://oregonstate.edu/Dept/NWREC/melon.html
- **Watermelon:**
  - http://cuke.hort.ncsu.edu/cucurbit/wmelon/wmhndbk/wmcontents.html
  - http://oregonstate.edu/dept/hort/233/watermelon.htm
- **ATTRA National Sustainable Agriculture Information Service:**
  - http://attra.ncat.org/

- **Organic Crops Workbook: A Guide to Sustainable and Allowed Practices**
  - http://attra.ncat.org/attra-pub/summaries/cropsworkbook.html

- **Farmscaping to Enhance Biological Control**
  - http://attra.ncat.org/attra-pub/PDF/farmscaping.pdf
  - http://www.drmcbug.com/

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