Seed Production and Saving for Small-Scale Producers

A Short Course given January 25, 2007 at the Southern SAWG 16th Annual Conference in Louisville, KY. This course was offered by the Southern Sustainable Agriculture Working Group in partnership with the USDA Risk Management Agency (*www.rma.usda.gov*).

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Proceedings

These notes provide information, discussions, and questions and answers from the course that are additional to the printed materials provided to participants (enterprise manuals, presentations, and other resources).

DISCUSSION:

● Introduction—What Course Participants Want to Learn

Of the eight participants in the course, only one expressed interest in producing seed for sale on a small scale; others want to produce, save and select seed for their own use and seed swapping. Other interests included:

- Saving seeds from ornamental flowers
- Seed selection and saving in Florida, where heirloom vegetables are hard to grow
- Save seed to enhance farm diversity
- Preserve traditional tribal foods—food sovereignty
- Want to save all of own seed to minimize inputs on subsistence farm
- Develop program to save all of own seed for horticulture project in Alabama
- Securing germplasm in the public domain; *One Seed at a Time* seed bank project

● Notes

1) The material presented in this course was designed for organic growers, and does not include recommendations for synthetic pesticides, fungicides, seed treatments or fertilizers.
2) The following notes are not in exact chronological order, but are organized by topic, with material from the lecture and the hands-on demonstrations integrated, especially for seed processing and cleaning topics.

● Basic Plant Genetics as Related to Seed Saving and Variety Selection

Open-pollinated and *F1-hybrid* Crop Varieties, and Creating New Varieties

When Cricket went over the basics of open pollinated (OP) *vs* F1 hybrid varieties, and why the F2 generation of a hybrid does not "breed true," the group wanted to learn more about breeding or selecting a new OP variety from a hybrid. The F2 shows a wide diversity of plant types, some looking like one or the other parent or the F1, and everything between. By selecting plants with

the desired traits and planting seeds from those plants, the F3 is a bit less random. Selecting thus over seven generations results in a new OP variety that breeds fairly true, though some additional stabilization and selection may be desired.
The normal practice of classical crop breeding to develop new varieties looks very much like this: Two parent OP varieties with desired traits are crossed to create an F1 hybrid. Since these plants are fairly uniform, they offer little opportunity for selection, and are simply grown (often in a greenhouse or other controlled environment) and harvested to obtain the F2 seed. Public breeders at Cornell and some other universities make the initial cross of breeding lines, grow out the F1 generation in the greenhouse over winter, and offer the F2 seed to interested growers.

In the F2 generation, genetic traits segregate randomly at each of thousands of gene loci, resulting in a great deal of variation and an opportunity to begin intensive selection for desired traits. Careful selection over seven generations can result in a new variety. The same "pool" of F2 seeds can lead to more than one variety, if selection is done in very different environments and/or with different selection criteria.

Another source of new crop varieties is the *sport*, an off-type with one or more interesting traits that spontaneously arises within an existing variety. A third parent can be crossed in at the F1 or F2 generation in order to incorporate additional desired traits, though the process is more complicated and requires a couple more generations to develop and stabilize the new variety.

In the Northeast, the Restore Our Seed project has crossed the Brandywine tomato with the Rose de Brun variety, and is sending F2 seeds out to different growers to select new varieties on their farms. The Organic Seed Partnership at Cornell University is likewise looking for farmers to work with some of the breeding lines they have developed.

NOTE: in the seed business, hybrid varieties are almost always labeled as such (*F1* or *hybrid*) in the seed catalogue and/or on the seed packet itself.

Homozygous versus *Heterozygous*

A plant has several dozen pairs of chromosomes, with 1,000 or more gene *loci* (sites at which individual genes occur) per chromosome pair. One copy of each gene occurs on each chromosome in the pair. Most genes can occur as any of two or more different *alleles,* which confer different traits (e.g. red, yellow or blue flower color, short or tall plant, or susceptible or resistant to a particular pathogen). In an OP variety, most of the plant's gene loci are *homozygous*, meaning that the two copies of a gene are represented by the same allele. A small minority of loci is *heterozygous,* or represented by different alleles on the two chromosomes of a pair. In an F1 hybrid, derived from two different parent lines, many more gene loci are heterozygous. When these heterozygous genes *segregate* in the F2 generation, the gene expresses in three different ways (AA, Aa/aA, and aa). When this effect is multiplied by thousands of genes in a plant's genome, the tremendous random variability observed in an F2 planting results. When a new OP variety has been selected from this F2 mix, the number of heterozygous genes is greatly reduced, but it is important to retain some heterozygous genes to maintain genetic diversity and resilience within the variety.

Often the heterozygous condition confers greater vigor for the trait regulated by that gene. This hybrid vigor is called *heterosis* and is the main reason for agriculture's interest in F1 hybrids.

One student asked whether there is a trade-off between the larger size associated with the hybrid, and greater sustainability associated with the smaller, homozygous breed. For example, the Pineywoods cattle breed is a smaller animal, and may have less environmental impact. OP crop varieties tend to be less hard on soil and thus more sustainable, and they often have more flavor. However, a balance between homozygous and heterozygous genes is critical, especially in regions with heavy disease pressure where greater vigor may enhance disease tolerance. Heterozygous genes also provide genetic diversity for ongoing selection and adaptation to varying local conditions. Traditional *land races* are maintained through selection processes that balance homozygous stability and heterozygous diversity. For example, Aztec farmers saved corn seed at their own farmsites each year, and every third year they went to regional gatherings at which everyone mixed their saved seed together, and then divided it up to take back home.

Another reason for maintaining some genetic diversity within an OP variety is that some genes carry weaknesses that, if expressed, can reduce vigor, yield, flavor or nutritional value. Weak traits are most likely to express when the gene locus is homozygous for that trait. When excessive inbreeding reduces the genetic diversity within a plant species or cultivar, it may undergo *inbreeding depression,* a loss of vigor and other desirable traits as a result of more gene loci becoming homozygous for weak traits. Too little diversity (too narrow a genetic base) can also cause *genetic bottlenecking,* which is less severe, but can still reduce seed production or quality. Different crops and varieties have different degrees of susceptibility to inbreeding depression or bottlenecking. This susceptibility is also known as the variety's *genetic load.*

While it is important to understand these general principles of plant genetics, it is not necessary to characterize individual genes on the crop variety's genome in order to breed successfully. Genetic testing can be done on the seed itself or on foliage or other plant tissue, but it is costly and time consuming. Genetic testing is sometimes needed to verify that seed have not become contaminated with genetically engineered (GMO) crop varieties.

● **Flower Structure and Degree of Outcrossing in Different Crop Families**

<u>Pollination basics</u>

Pollen grains germinate only when they land on a receptive stigma (top of pistil, the female part of the flower), and receive the right chemical stimulus. The pollen tube grows down through the pistil, much like a germinating seed's root grows down into the soil. When it arrives at the ovary, the male gamete within the pollen tube fertilizes one ovule (female gamete), which then develops into a seed. Each ovule is fertilized by a different pollen grain. In some plant families, the ovary develops into a fruit (e.g. nightshades, cucurbits) or a pod (e.g. brassicas, legumes).

Multiple seeds within a fruit or pod all come from the same *mother* plant, but can have different *fathers* or pollen sources. Flowers can have both stamens (male) and pistil (female) (perfect flower—the most common), or can have the stamens and pistils in separate flowers on the same plant (imperfect flower, monoecious), or male and female flowers on separate plants (imperfect flower, dioecious). Some plants are primarily self-pollinated (pollen from same flower or same plant fertilizes most or all the ovules), while others are cross-pollinated by wind and/or insects. Some of the latter are *self-incompatible*, so that a pollen grain will *not* fertilize ovules on its own plant. The course manual lists vegetables and other crops that are primarily self-pollinated, and those that are primarily cross-pollinated.

The course materials list important crop species as self- or cross-pollinated. Two corrections were noted: lettuce is self-pollinated, and carrot is cross-pollinated.

Cucurbitaceae—squash, melon, watermelon, cucumber, pumpkin, gourd

Cucurbits have imperfect flowers, with male and female usually on the same plant. A few varieties have male and female plants, and a planting must include some male plants for fruit and seed production. Both male and female flowers have nectaries that attract pollinating insects. Squash blossoms produce enough nectar to taste sweet to the human tongue, and are harvested as a gourmet food. Male flowers have more nectar, but female flowers have the tiny "baby squash" —so both are highly valued in the gourmet food trade.

Fertilized ovules stimulate the growth of the cucumber fruit. Incomplete pollination causes cucumber fruits to grow unevenly or curl around as they develop. Research has shown that it takes about 28 visits by an effective pollinating insect to completely fertilize the 500 or so ovules in a female cucumber flower, and thus ensure a straight, full-sized fruit. Squash flowers are larger with fewer ovules, and may not require as many visits. However, it is essential to provide or encourage pollinators in production of all cucurbit crops.

The vegetables we call *squash,* including pumpkins (= orange, round squash), come from four species of *Cucurbita,* which rarely cross with one another. Thus it is much more important to isolate varieties *within* each species than to separate the different species. *C. pepo* includes most summer squash, delicata, acorn squash and small to medium sized pumpkins. *C. maxima* include many of the largest winter squash and pumpkins, and also buttercup. *C. moschata* includes butternut, cheese pumpkin and Tennessee vining pumpkin. Winter squash in this species often have the best flavor. *C. mixta* includes the cushaw.

Brassicaceae—cabbage, cauliflower, broccoli, kale, collard, mustards, Oriental greens, arugula, turnip, radish, etc.

This family has small, perfect flowers that produce small amounts of nectar. They are mostly wind pollinated, though some insect pollination also occurs. Brassica plants are *self-incompatible*, so that a pollen grain that falls on the stigma of its own flower, or on a flower that is a very close genetic "match" will not germinate or fertilize the ovule. Pollen germination is regulated by a set of about 20 alleles (versions) of incompatibility genes that occur at four gene loci. When the alleles at all four loci in the pollen grain match those in the stigma, the match is incompatible, and the pollen does not germinate. The fewer loci that have a genetic match, the more likely that the pollen will germinate and fertilize an ovule to form a seed. The self-incompatibility genes help maintain sufficient diversity throughout the plant's genome to keep the genetic load down. In breeding brassica varieties, it is essential to maintain some genetic diversity within a brassica variety, including about three to four different self-incompatibility genes, so that effective cross-pollination can occur.

Leguminosae—bean, pea, clovers
Beans, peas and other legumes (clovers, alfalfa, vetches, soybean, etc.) have perfect flowers that are mostly self-pollinated. Pollination can sometime even occur before the flower opens. However, some outcrossing via insect pollination occurs, perhaps 5 percent to 20 percent, which may help maintain vigor and limit inbreeding. Bees occasionally chew through the sides of bean flowers to get at their nectar, thus effecting cross-pollination.

For beans and other "self-pollinated" crops, Cricket recommended encouraging pollinators to promote crossing and thus maintain genetic diversity within the variety. To maintain seed purity in seed production, he also recommended treating beans and peas as cross-pollinated plants in terms of isolation distances.

*Solanaceae (*nightshade family)—tomato, pepper, eggplant, potato, tomatillo
Nightshade family crops have perfect flowers that can be either self-pollinated or insect pollinated. In hot peppers, eggplant and older heirloom and OP tomato varieties, the stigma often sits slightly *above* the anthers in the flower, which results in a greater likelihood of cross-pollination by insects. The flowers of sweet pepper, new tomato breeds and modern F1 tomato varieties have their stigmas *recessed,* or slightly below the tops of the anthers, which promotes self-pollination over crossing by insects. In general, the more "wild" a variety is, the more its flower structure favors cross-pollination by insects. Cricket speculated that tomato and pepper varieties that have been bred under "industrial agriculture" production systems with intensive pesticide usage (thus very few insects present) have evolved for more effective self-pollination, as manifest by the recessed stigma.

Poaceae (grass family)—small grains, forage grasses, corn
The cereal grains and other grasses are either self- or wind-pollinated. Some are self-incompatible. Most have perfect flowers, and corn is unusual in that the male (tassel) and female (ear/silk) are separate.

In wild grasses, the *rachis* (main stalk of the seed head) breaks into small pieces at maturity, causing the seed head to shatter, rendering collection of the grain impractical. Domesticated grains have been bred for a rachis that does not break, so that seed heads can be harvested and threshed to obtain grain.

● Seed Production Basics—Population Size, Isolation Distances, and Important Nutrients in Seed Production

Population size
Cricket gave some guidelines for population sizes—the number of plants of a particular variety from which to collect seed—to maintain sufficient genetic diversity and thus seed quality and overall vigor and quality of the variety. In general, self-compatible and self-pollinated crop varieties require a lower population than cross-pollinated or self-incompatible varieties, with wind-pollinated crops needing even larger populations. For large plants, such as tomato or squash, a somewhat smaller population may suffice, whereas smaller vegetables such as lettuce or carrot may need a larger population.

Corn has a particularly high genetic load, and the seed grower should start with a population of at least 2,000 plants for a single variety to maintain superior seed quality for commercial production. Brassica crops require about 500 plants, beans about 60, and vegetables in the nightshade and cucurbit families, about 45. These populations allow for *roguing* and *selection,* to eliminate weak and off-type plants, leaving a sufficient number of high quality plants to maintain the genetic base. Somewhat smaller initial populations can give adequate seed quality for home-garden seed saving purposes.

<u>Isolation to Maintain Varietal Purity</u>

The course manual includes a detailed chapter on isolation distances required for different crops to prevent crossing between two varieties. For commercial seed production, minimum distances vary from 75 feet to 150 feet for highly self-pollinated crops (lettuce, modern tomato varieties) up to 0.5 mile or more for wind- or insect-pollinated crops (cucurbits, corn). As noted earlier for nightshade crops, isolation distances can vary among varieties of a given crop, depending on flower structure or other characteristics. Cricket discussed several additional measures for variety isolation, including barriers, caging and separation in time, which can allow seed production in situations where the long distances are not practical.

Alternate-day caging allows seed production from two varieties of a crop in relatively close proximity. A screen or row cover cage excludes insects; thus in order to effect pollination of an insect-pollinated crop variety, either each planting must be uncaged on alternate days, or suitable pollinator insects must be introduced within the cage. To switch cages between two varieties, work while insects are least active, and cage the exposed variety *first,* then uncage the variety that had been caged the previous day. Wind-pollinated crops can be caged with row cover, and they also need alternate day caging to allow adequate cross-pollination. For self-pollinated crops, shake individual plants to ensure adequate pollination.

Isolation in time entails scheduling planting so that pollination of two varieties occurs at least three weeks apart. Take into account the days-to-maturity for each variety. For corn, note that “days to maturity” for sweet corn (milk stage) is generally 25-30 days less than the “days to maturity” for flour corn or field corn. Thus a 75-day sweet corn variety and a 100-105-day field corn variety planted on the same date will shed pollen at about the same time.

Physical barriers such as woodlands, tree lines, hills, ridges, tall crops of an unrelated species, or even large buildings can reduce crossing by wind or insects, and can somewhat reduce the minimum isolation distances. A row of pines with dense foliage to the ground or a multilayer tree planting will provide a better barrier than a line of tall trees from which lower branches have been shed or pruned. An alternate pollen source—a strip or bed of sunflowers, borage, bee balm or other nectar-rich species—located in the “flyway” between two varieties of an insect pollinated crop can help prevent unwanted outcrossing and reduce isolation distances for insect-pollinated plants by 10 percent.

A strong prevailing wind, such as often occurs in a mountain valley, can increase the isolation distance, at least for the downwind planting. When scheduling plantings for isolation in time, plant the later variety upwind of the earlier variety

Another strategy for maximizing both seed purity and desirable crossing *within* a variety is to plant the seed crop in a square patch rather than in a long, narrow row or bed. For example, a grower wanting to produce tomato seed from a starting population of 100 plants can set them out in a 10 by 10 array, rather than a long single or double row. This arrangement exposes interior plants to cross-pollination from eight neighbors (compared to just two in a single row), and shields them from foreign pollen. If the grower suspects that isolation from other tomato varieties was not quite sufficient, he or she can discard the outer perimeter of plants and still harvest pure seed from the 64 interior plants.

Critical nutrients for seed crop production

The manual includes a graph showing the effects of soil pH on availability of each of the essential plant nutrient elements. The wider the bar for a given nutrient at a certain point on the pH scale, the more available that nutrient becomes at that pH. Soil pH of 6.5 to 7.0 (very slightly acid to neutral) makes phosphorus (P) most available, and is thus optimal for seed crop production. The micronutrients zinc (Zn), boron (B) and iron (Fe) are also important for high quality seed. Alkaline soil conditions (pH 7.5 or higher) make these nutrients less available, and therefore should be avoided or remedied.

- **Coping with Genetically Engineered (GMO) Seeds—Biological Issues**

GMO crop varieties are notorious outcrossers, and often outcross more strongly than conventional varieties of the same species. Genetic engineering produces unexpected and unpredictable results. For example, researchers planted a test variety of mustard equidistant between a conventional variety and a GMO variety of the same species. The GMO variety crossed into the test variety at *24 times* the rate observed for the conventional variety. In a similar but accidental "experiment," the Roundup Ready trait from GMO canola has entered wild mustard, rendering this weed herbicide resistant and causing a real problem for growers of Roundup Ready soybeans. In Percy Schmeiser's words, "There isn't a field in Canada now without some Roundup Ready wild mustard." What goes around comes around.

With many farmers raising GMO corn and Monsanto now in possession of thousands of Seminis vegetable varieties, isolation distances for seed production in insect- and wind-pollinated crops now need to take the GMO factor into account. For corn, isolation distances between a seed crop and a GMO crop should be more than one-half mile.

In addition to compromising varietal purity, the presence of GMO traits in a seed crop can raise legal issues (see next section) as well as costing the grower his or her market for the seed. Several students asked how one can verify that a seed crop is GMO-free. Answer: there are now a few laboratories that can test a seed lot for GMO contamination. A large sample of seed is needed to get a good test. Blue River Hybrids, a producer and vendor of organic corn and soybean seeds, has increased isolation distances, avoids planting seed crops anywhere near a GMO crop, and utilizes seed testing services to verify their seed as GMO-free.

Cricket advises seed growers to get to know their neighbors, find out what they are planting, and determine whether any of their crops are GMO.

● **GMO Seeds, F1 Hybrids and Seed Patenting—Legal Issues**

Once we had discussed the bio-hazards of GMO contamination in seed crop production, the disturbing topic of seed patenting inevitably came up. Biotech corporations routinely patent their GMO varieties, and are now patenting an increasing number of conventional F1 and OP varieties as well.

The old system of Plant Variety Protection (PVP) was quiet fair. A PVP holder (usually the breeder who did the work of developing a new variety) has the right to restrict the *production for sale* of her/his PVP variety for a period of seven years. The PVP does not prohibit growers from saving their own seed, selling the crop as food or fiber, or even using the PVP variety as germplasm in breeding new varieties.

Enter the Utility Patent, originally intended for better mousetraps and other nonliving inventions. In 1980, the U.S. Supreme Court approved the patenting of living organisms and/or individual genes. Any variety or genetic trait can now be patented, *unless the variety is seed-banked, maintained and documented as a public domain variety or genetic trait, with documentation dated* ***before*** *the patent application was filed.* Keeping a crop variety public and unpatentable entails preserving and periodically growing-out and reproducing the seed, with thorough documentation and dating. Unlike the PVP, the utility patent can remain in force for long periods of time. It used to be 17 or 25 years, but recent court decisions have allowed holders of some patents to renew them for up to 100 years.

The so-called Enole bean—actually a traditional Mexican land race yellow bean—is an example of the abuses that can arise from utility patents on crop varieties. A manager of a seed company went to Mexico, noticed the people growing and consuming the yellow beans, and brought a sample back to Colorado to grow it out. He then applied for and received a patent on this bean variety, and told the Mexican farmers that they could no longer save seed from their crop. When the case came to court, the judge ruled that the farmers had no record, preserved samples or documentation to establish their traditional yellow bean as public domain germplasm, and awarded the case to the patent holder.

Several organizations have responded with concerted efforts to bank and document valuable crop germplasm within the public domain. About 30 years ago, Kent Whealy and co-founders of the Seed Savers' Exchange in Decorah, Iowa first learned about the legal issues developing around crop germplasm, and have since been working with local and regional seed banks across the U.S. to preserve, maintain and document public varieties. In early 2005, the Save Our Seed project launched a new seed bank for the Southeastern United States, called One Seed at a Time. Cricket and his wife Courtney Guido are managing this project. For more information, visit *www.savingourseed.org*.

With regard to F1 hybrids, a new legal concept is now being discussed within the seed industry: "essentially derived." If this legal concept is accepted, then any new OP varieties derived from an F1 hybrid, or even from a cross between an F1 and another line, may be considered "essentially derived" from that hybrid. Depending on what legal precedents are set, the process of "dehybridizing" an F1 to develop a new OP line with similar traits, or otherwise using F1 hybrid germplasm, could become an "intellectual infringement." At this point, it is not known whether the "essentially derived" concept would apply to non-patented hybrids.

- **Variety Trials—What is the Best Seed for My Farm?**

Variety trials were discussed briefly. Cricket emphasized that the grower is the best judge of what varieties will work best for her/his farm. It depends on soil type and conditions, local climate, and cropping system including such details as cropping schedules and whether and how heavily the crop is mulched.

In designing a field trial of several varieties, several factors need to be considered, including variability of soil within the field, year-to-year weather variations, and genetic variation within varieties. A single field, especially on sloping or rolling land, can contain two or more soil types, and can vary from sandy to clayey, and from wet to well-drained. For this reason, it is better to evaluate varieties in two or more replicates or *blocks*, rather than planting one patch of variety A next to one patch of variety B. Even in a very small-scale trial, it is better to plant two separate rows of five plants each for each variety, rather than one row of ten plants. A two-block trial might look like:

A (5 plants) C (5 plants) B (5 plants) C (5 plants) B (5 plants) A (5 plants)

A good design for testing four or five varieties is the *Latin square,* in which the field is divided into a 4 by 4 or a 5 by 5 array of plots, with each variety appearing once in each row and once in each column. The trial should be surrounded by a perimeter planting of edge rows that will not be evaluated, to eliminate "edge effects." To avoid bias in evaluation, Cricket recommended a system in which the grower does not know which variety is which, but simply knows them as A, B, C, D and E.

- **Roguing and Selection—Maintaining and Improving the Variety**

The seed grower needs to take steps to *maintain*, and if possible *improve*, the genetic and physiological quality of the seed for the variety being grown. In producing seed of a variety that has already been developed to a desired level of quality and purity, the grower must harvest seed only from those plants that will maintain quality and desired traits. More intensive and targeted selection is required to improve a variety; to adapt a variety to one's own region, soil or climate; to stabilize a variety that shows a lot of off-types; or to breed a new variety from the F2 generation of a cross of two varieties.

This work is accomplished in two phases. *Roguing* is the removal of weak, diseased or off-type plants *before* flowering and pollination take place. *Selection* is harvesting seeds only from the "best" plants—which might include the most vigorous, least diseased, or those with desired color, flavor, size or shape.

If seed is saved from all plants within a variety planting, seed quality will deteriorate. Selecting the best half or two-thirds might maintain the variety, whereas collecting seeds from only the best 5 percent to 7 percent of a *large* population can dramatically improve a variety or shift specific traits in a desired direction. Selecting this severely from a *small* population may cut the genetic base too narrow and lead to genetic bottlenecking. Keeping a higher percentage may also be advisable for an insect-pollinated crop if the pollinator populations are not high.

Cricket recommended planning to produce enough seed for the next three years—this way one doesn't have to save seed from every variety every year, and the work load is more manageable.

Although environmental factors contribute to variation in plant size (e.g., a clump of rich compost), selecting from the most vigorous plants generally enhances the variety. Never use surplus produce from the farmers' market or CSA to save seed, and always rogue and select to some degree to maintain quality. Also avoid eating/selling the best tomato, squash, cut flowers, etc.—save them for seed.

Selection criteria for each variety should be determined before planting the seed crop. Resistance or tolerance to locally prevalent diseases and pests is important, as are yield, overall stress tolerance, and adaptation to organic production systems. However, Cricket reminded us to select also for *flavor*. Tasting food from the same plant that is to produce seed can be tricky, and he had some suggestions. Winter squash can be cut open, the seeds set aside, the fruit cooked and tasted, and the seeds from those with the best flavor are then saved. Sweet corn can be peeled back a little to take a bite (sacrifices 10 percent to 15 percent of the seed). A small slice can be cut off the side of a beet or other root vegetable for tasting.

In selecting for disease resistance, the difference between *vertical resistance* (immunity based on a single gene, often defeated by mutation of the pathogen) and *horizontal resistance* (reduced susceptibility based on many genes, not easily defeated by pathogen mutation) is critical. A single, disease-free plant in a diseased field is probably exhibiting vertical resistance, while several plants that show mild symptoms and continue to produce while the rest of the field dies down are likely exhibiting horizontal resistance. A tomato or other fruiting plant that continues to set and ripen fruit after other plants have ceased doing so because of disease, is worth selecting. Brett Grohsgal, a grower and breeder in Maryland, has successfully bred for horizontal resistance to Septoria leaf spot in cherry tomatoes. (Note that if the late-fruiting plant also *began* production much later than the rest of the field, one could be selecting for lateness as well.)

Both vertical and horizontal resistance traits can be useful. It may be quite difficult to select simultaneously for horizontal and vertical resistance, since the disease won't express at all in the presence of the vertical resistance gene. However, Jeff McCormack (formerly with Southern Exposure Seed Exchange, now managing Garden Seed Medicinals) has discussed the possibility of back-crossing a vertical resistance trait into an already horizontally resistant variety.

Several course participants asked how to identify or develop new tomato varieties with increased tolerance for prevalent diseases in hot, humid, disease-prone climates such as central Florida or the southern Piedmont region. Cricket recommended that each grower start with OP varieties or strains that seem to show greater disease tolerance in his or her area, and make crosses. For central Florida, he also suggested obtaining varieties from tropical regions like Puerto Rico or the Virgin Islands, and/or breeding lines from the Universities of Florida and Hawaii. Even F1 hybrids can be good sources of germplasm (however, note possible legal issues regarding the use of F1 hybrids mentioned earlier). The USDA Germplasm Collection is also a good resource. The collection includes some 40,000 tomato varieties and breeding lines, and the database can be searched by specific desired characteristics to identify strains suitable for one's particular location, climate, disease complex, etc.

Frank Morton of Wild Garden Seeds, a breeder in the Northwest who has developed "great varieties of salad greens," was acknowledged as the source of the new strategy of selecting for vigorous emergence by saving the first-emerging healthy seedling out of five to ten per pot.

Beets, chard, carrots, lettuce, onions, some other root crops and many brassica varieties are *biennial*, and need a cold period to induce bolting, flowering and seed production. Careful management is required to provide sufficient chilling yet protect the crop from winterkill. For greens and root crops, it is important to select *against* early bolting, and to collect seeds from plants that are both vigorous and relatively slow to begin flowering.

Cricket cautioned against "selecting for good soil." Plants growing in the poorer part of a field or farm may provide valuable material, if one selects from the plants doing the best in that spot. This can be especially helpful for other farmers in the region who might not have as good a soil as the seed producer.

● **Managing Diseases Pests and Weeds in Seed Crops**

Diseases, pests and weeds raise two major concerns in crop seed production. First, they can adversely affect the quantity and/or quality of seed produced. Often, the *economic threshold* for a pest or disease is much lower in seed production than it is in growing produce or grain as food. Since the plant must remain healthy and productive until the seed is fully mature, it must be protected from diseases, pest damage and weed competition throughout its life cycle. Thus weeding efforts and effective pest/disease control must be sustained longer than for market vegetable production. Lettuce, for example, is harvested for market at a young vegetative stage, 40-60 days after sowing, while it may take four or five months to form mature dry seed. Thus weeds or fungal diseases that have only a minor impact on lettuce *greens* production could devastate lettuce *seed* production. Similarly, it might be possible to produce a satisfactory crop of *fresh snap beans* in the presence of moderate Mexican bean beetle pressure, but the same pest population might later explode and severely curtail production of *mature dry seeds* for snap bean varieties.

Second, some crop diseases are often *seed-borne*, which means that the seed harvested can carry the pathogen into the next crop wherever and whenever it is planted. This is one of the biggest challenges in seed production.

Fortunately, many of the seed-borne pathogens can be eliminated by means of a simple hot water seed treatment that is entirely nontoxic and is allowed under the National Organic Program. Seeds are immersed in hot water at a specific temperature (usually about 120°F) for a specific period of time. Detailed instructions for hot water treatment of different seeds are given in the course manual. Hot water is most effective against pathogens on or near the seed coat surface, and may not work for certain viruses or for other pathogens that have lodged deeply within the seed tissues.

NOTE: hot water seed treatment shortens seed longevity, as it essentially initiates the germination process. Hot water treated seed are no longer of salable quality, and should be planted within a few months after treatment. The procedure is most useful after screening a variety or varieties for disease tolerance. The selected seeds, which likely carry some pathogen inoculum, are hot water treated and planted in a disease-free field to grow clean, commercial quality seed. Hot water treatment is also useful on the farm for removing any seed-borne pathogens just before planting.

Diseases may be caused by viruses, fungi or bacteria. The way to tell these apart (usually) is that "fungi are fuzzy, bacteria are slimy, and viruses are patterned." The mosaics and other patterns caused by viruses result from virus-induced differences in plant cell and tissue growth. Viruses are often seed-borne, and are generally the most difficult to manage in seed production.

The course manual includes considerable information on the major diseases affecting seed production in several vegetable crops. Additional information shared in the discussion is summarized below.

Diseases and Pests of Beans

Anthracnose can be seed-borne, infecting either the seed coat or the interior of the developing seed. Sometimes it is invisible, though more commonly it can be seen on the seed surface as brown spots. If it has not penetrated into the seed, anthracnose can be eliminated by a hot water seed treatment.

One student asked about a batch of home-produced soybean seeds, about 10 percent of which had discolored spots, but seemed to germinate OK—were they diseased? Probably some microorganisms grew on the seeds, but if the seedlings were healthy, there was not a significant disease problem.

Mexican bean beetle must be controlled rigorously to ensure that the bean crop retains sufficient functional leaf area to support full development of the bean seeds. Timely releases of *Pediobius* ("pedio") wasp are strongly recommended for bean seed production. Dr. Richard McDonald's website (www.drmcbug.com) includes a listing of sources for pedio wasp, and guidelines for most effective timing and quantities of releases. The first release should take place when the first generation of small bean beetle larvae appears. The yellow bean beetle eggs look somewhat like lady beetle eggs (they are in the same family of insects). However, the beneficial ladybeetles tend to lay fairly neat rows of a dozen or so eggs, while Mexican bean beetles lay densely packed, round or irregular-shaped clusters of several dozen eggs.

If one farmer in a neighborhood has purchased and released pedio wasp, neighboring farmers can sometimes obtain this beneficial by harvesting "mummies" from the first farm. Bean beetle larvae (normally yellow) that have turned a dark reddish brown and become immobile are parasitized "mummies" and contain several pedio wasps that will soon hatch out and parasitize additional larvae. Pedio wasp normally does not overwinter in Virginia, though Jeff McCormack has reported at least one instance of pedio overwintering in the state (global warming?). Pedio is likely to overwinter successfully in Florida.

Diseases and Pests of Cucurbit crops

Butternut squash and other varieties of *Cucirbita moschata* often show the best disease and pest resistance.

Hot water treatment often works well on many of the seed-borne diseases of this plant family, especially Anthracnose. Precise directions are given in the course manual.

A serious seed-borne disease of watermelon, called Bacterial Fruit Blotch, made seed companies very shy of carrying watermelon seeds at all for a while. The disease is hard to detect by looking at the seed, and it requires seven years without cucurbits and four years without nightshades to eliminate it from the soil. Fortunately, a good test for this pathogen is now available, and seed companies are now carrying watermelon seed that has passed the test.

Among the viral diseases of cucurbits, the cucumber mosaic virus (CMV) affects a wide range of other crops as well, especially pepper. Fortunately, it can usually be eliminated by hot water seed treatment.

Pest nematodes elicited some discussion, as they can be a real problem in some Southern soils. Some varieties of marigold can suppress pest nematodes, and some varieties have been bred for stronger nematicidal properties. Cowpea and sorghum-sudangrass can also suppress pest nematodes. Research by several soil scientists indicates that pest nematodes (that feed on plant roots) can be suppressed or supplanted by high populations of harmless nematodes (that feed on soil bacteria and fungi) associated with good organic soil management and high overall biological activity. Some legumes (e.g. crimson clover) can host pest nematodes, though other research suggests that legumes inoculated with the proper strains of symbiotic *Rhizobium* bacteria carry fewer nematodes than uninoculated legumes.

Cucumber beetles, the notorious vector for bacterial wilt in cucumber, can also impact seed production directly. When the beetles feed on the plant without transmitting disease, the plant can still mature its fruit but seed quality may be lowered.

Squash vine borer is another major pest. The solid-stemmed *C. moschata* squashes are fairly resistant, especially the “Seminole” pumpkin. Cricket and one course participant have observed that mixing two handfuls of hardwood ashes into each hill at planting, followed by another handful sprinkled around the plants when they are eight inches tall, can reduce squash vine borer damage.

Diseases and Pests of Tomatoes

Of the several common tomato diseases, fusarium wilt is usually not seed-borne, anthracnose is possibly seed-borne, while early blight and bacterial canker definitely are. Proper seed fermentation and handling can usually eliminate early blight. The fermentation period is usually less than 96 hours, but a longer fermentation at lower temperature can help prevent bacterial canker.

Tomato hornworm is only occasionally a major problem, as natural enemies usually keep this spectacular caterpillar pest under control.

Diseases and Pests of Brassica Crops
In addition to alternaria leaf spot and black rot, downy mildew is potentially seed-borne.

As with many insect pests of seed crops, the action threshold for Harlequin Bug is lower for a seed crop than in vegetable production. This insect attacks the siliques (seed pods), sucking out juices, resulting in low seed quality and germination. Cricket recommended integrating chickens into the crop rotation. The pest overwinters on brassica crops or residues—so the grower can enclose chickens with overwintered brassica crops. The pest's eggs hatch about ten days after they are laid. When eggs are first spotted, put the chickens in for twelve days, take them off for a week, then back on for two days to catch any "escapes." This can reduce harlequin bug below the action threshold for up to two years. However, if neighbors grow brassicas without adequate harlequin bug control, this can spell trouble.

Caterpillar pests—imported cabbageworm, diamondback moth and cabbage looper—can compromise seed production when they attack young plants, but have less impact when they feed on mature plants. They do not spread diseases.

Diseases of Peppers
Peppers have relatively few insect problems. Grasshoppers may nibble on the plants but have little impact on seed production. Caterpillar pests, including corn earworm and tomato fruitworm, occasionally bore into pepper fruit and can thus damage seeds.

Southern blight *(Sclerotium rolfsii)* is a severe fungal disease that can be a major problem in pepper, and it affects many other vegetables, including beans. Cricket mentioned a "lettuce leaf drop" caused by this organism that can fell entire lettuce plants during seed stalk formation. (Note: in 2006 field trials at Virginia Tech, a "lettuce drop" disease was attributed by Virginia Tech's plant disease clinic to a different pathogen, *Sclerotinia sclerotiorum*.)

Seed-borne diseases and methods of control include:
- bacterial leaf spot, controlled by crop rotation;
- Cercospora leaf spot, controlled by hot water seed treatment;
- anthracnose, controlled by sanitation, fermentation and avoiding diseased fruit when harvesting for seed. Good biological control of aphids helps limit the spread of tobacco and cucumber mosaic viruses.

● Seed Storage and Seed Longevity

The storage life of seeds is critically determined by the seeds' moisture level. The USDA Federal Seed Act of 1976 sets maximum moisture contents at which different crop seeds intended for sale may be stored in sealed containers. These values mostly range from 5 percent to 7 percent, which are the moisture levels at which seeds keep longest. If seed moisture is in this range, the best method of storage is in sealed glass jars or metal cans in a freezer (0°-10°F). However, if seed moisture levels are too high, freezing can kill the seed; such seed should be refrigerated at slightly above the freezing point.

A jar of refrigerated or frozen seed should be allowed to warm to room temperature before the jar is opened; otherwise moisture may condense within the jar and reduce seed longevity. A quart jar should be allowed to warm for 24 hours, and a larger jar for even longer.

Silica gel dessicant can remove excess moisture from seeds, and is allowed by the National Organic Standards, but the indicator dye in most silica gel is not. Rice is also a fairly good desiccant for seed storage.

Seed *viability* is the ability to germinate; seed *vigor* is the strength of the germinating seedling, as assessed by how quickly the radicle (initial root) emerges, how quickly the seedling emerges from the soil, and height and thickness of the seedling stalk. As seeds age, vigor declines before viability does. If seeds show a decrease in vigor, use them this year, not next, when viability may also be lost.

Courtney Guido (540.894.8865) conducts seed germination tests using professional standard procedures, at a fee of $5 per sample. Proceeds from these tests go to the One Seed at a Time project.

- **Seed Harvest, Processing, and Cleaning**

The first rule is to label each seed batch carefully at every stage of the process to minimize the possibility of mislabeling a variety, losing the identity of a seed lot, or commingling two varieties. With full and accurate documentation, if one seed saver ceases to do this work for any reason, another seed saver can maintain and carry on the seed variety or varieties. In processing, following a seed batch of one crop (e.g. tomato) with a batch of another crop (e.g. pepper) can make it easier to detect and remedy any commingling, than if two tomato batches are run through in succession.

<u>Flower seeds</u>
The seed development and dry-down stages are critical. Some flowers form cup-like seed structures that face up and can hold moisture, which may lead to a Rhizoctonia fungal infection and loss of seed quality. Lettuce has a similar problem. Such seeds must be protected from rain—either with a shelter to exclude rain from the crop, and/or by cutting seed stalks and bringing them indoors. This should be done as soon as the flower seeds "look like the seeds that were planted." Seed stalks can be spread out on a blanket, sheet, or floating row cover (all of which drain well), but not on a tarp, on which moisture can condense and pool.

A few flowers, such as four o'clock, tend to "throw" their seeds as they mature. The grower may need to collect seeds by "teasing" flower heads and collecting seeds that fall out.

For zinnias, Cricket suggested collecting flowers that have dried up, drying them another week inside, and then threshing them during low-humidity weather. Flower heads can be broken up by hand and screened. Heads that don't break apart easily are immature, and can be discarded. (This is true of many kinds of flower heads).

Wet-process seeds—tomato, pepper, squash

The wet fermentation for tomato seeds (at 70°-75°F for 36 to 96 hours with periodic stirring) is described in some detail in the course manual. A Victorio strainer ($50) is excellent for separating seeds (to ferment, dry and collect) from pulp (to process into sauce or salsa). For demonstration purposes, Cricket had purchased some commercial tomatoes (off-season—i.e. January) and tried to ferment their seeds in his cool apartment. The results were instructive. There wasn't much fermentation happening in the jar, which illustrated two important points: underripe fruit and cool temperatures (60°F or lower) are both unfavorable to seed fermentation.

One function of fermentation is to break down the gelatinous material surrounding fresh tomato seed, which contains germination inhibitors. Fermenting seeds should be stirred every eight hours. Inadequate stirring leads to formation of white bacterial foam that can be somewhat detrimental to seed quality. The rinsing process at the end of the ferment not only removes dirt and residues, but also facilitates separation of good seed from poor seed. The former sink, and the latter float and can be poured off.

After fermentation, tomato seeds can be dried in small polyester row cover bags hung on the face of a box fan, or spread out on stainless steel window screen set in a wooden frame, or in other ways.

Cricket emphasized that seeds should be cleaned as soon as they are dry (true of all crops). The longer seeds remain in contact with the chaff, the greater the risk of seed-borne diseases. The basic method of cleaning seed is to run them through two screens—one with openings just larger than the sound seeds, and one with openings just smaller than the seeds. Seed savers typically purchase or collect a large number of screens with a wide range of sizes of openings, to facilitate cleaning of all seed types. Even different varieties of tomato seed may need different screen sizes.

Another challenge with tomato is that the seeds tend to stick together in clumps of ten to fifteen as they dry, and need to be separated by rubbing them through a screen just slightly larger than the single seeds. In larger scale tomato seed production, the dried seeds are placed with ball bearings in a tumble dryer (no heat). This process does damage a few seeds, but it also removes the fine hairs that make the seeds stick together. The hairs can also wick moisture to the seed; thus removing them extends the seeds' shelf life.

Pepper seeds can be processed by a dry method, but the beneficial fungi present in a fermentation process can reduce seed-borne disease, and the rinsing stage allows for separation of good (heavy) from poor (light, floating) seed.

Small batches of squash or cucumber seed can be washed and drained in a colander.

One participant asked whether the seeds of each crop have characteristic fungi that ferment those seeds. Although plant root–soil organism relationships are known to be quite species-specific, it is not known whether this occurs in seed ferments, or whether it is more a question of "whatever is in the air."

Dry Process Seeds—brassicas and beans

Many brassica varieties are biennial, and require a cold period to induce flowering. Cabbages can be protected over winter with hay mulch. In the spring, remove the hay and cut an X in the top of the head to facilitate emergence of the flower stalk. Iceberg lettuce may need the same treatment.

Timing harvest of brassica seeds can be tricky, especially at a larger scale in which the seed will be combined. If the crop is cut too soon, many seeds will be immature; if it is cut too late, many of the siliques will split open and throw their seed (shattering). Best time to harvest is to wait until no green pods are left, then harvest without further delay.

At a smaller, less mechanized scale, whole seed stalks are cut when the pods are mature and dry, cured out of the rain for a week or two and threshed by any of several methods. These include walking or driving on the seed heads, or using a plot thresher (used in agricultural field research, and rather expensive) or a converted leaf shredder or wood chipper.

High quality brassica seeds are nearly spherical, while lower quality seeds have a "divot" in one side. They can be separated by rolling them down a plywood ramp equipped with runners. The good seeds roll to the bottom much faster than the poor seeds. In commercial seed production, the seeds are rolled down a spiral device. The round seeds roll fastest and eventually fly out the side of the spiral, to be collected separately from the chaff and weak seeds that slide to the bottom of the spiral.

In our humid climates, beans need to be picked when the pods are yellow and leathery to minimize the risk of fungal growth on the seeds. Beans can be threaded together and hung on a string to dry, or placed on a screen in a plywood box with a fan to draw air across them. Cricket showed us a design in which the screen is about a foot above the bottom of the box, and a small fan near the bottom draws air *down* through a single layer of beans spread on the screen.

Thoroughly dry bean pods can be threshed by placing them in a plastic feed sack and hitting them with a 1½ inch heater hose or similar flail.

More on winnowing and cleaning seeds

Seeds can be winnowed (separated from chaff) with a hair dryer on a no-heat setting. Cricket demonstrated a homemade hand-cranked winnower, which works for a wide variety of seed. He first demonstrated with zinnia seed (very light), and noted that the same device can be used for the much heavier seeds of beans or corn, in batches up to 10-15 pounds. Seeds are added to the chute slowly and evenly, and the hand crank is turned at a rate that blows out chaff and poor seed, and allows good seed to fall to the bottom chamber. The rate of cranking needs to be calibrated according to the seed being winnowed. It is easier for two people to do this precisely—one focused on pouring evenly, the other on cranking evenly. The best place to do this is indoors, on a garage floor where good seed can be retrieved if too-fast cranking blows it out the top.

The course manual includes plans for making this winnowing machine. A carpenter or handy person can easily construct one from this plan. Felipe noted that it could be a good project for community garden programs.

- **Producing Seed as an Income Source; Contract Opportunities**

How much seed crop (planted area, and amount of seed) would one have to grow in order to make a reasonable return by selling it to a seed company? It depends on seed quality, contract with seed vendor, and what crops and varieties are desired. Good organic lettuce seed can fetch up to $1,000 per pound; however, competition from California (where dry climates facilitate lettuce production) can be intense. One quarter-acre of squash can make a good seed crop. Even starting with 60 squash plants, assuming one selects the best 30, can yield 8 pounds of seed worth $50 per pound.

Cricket noted that Ira Wallace and Courtney Guido at the Southern Exposure Seed Exchange table in the trade show area were seeking contracts with growers to produce certified organic or ecologically grown seed. For more information on Southern Exposure visit www.southernexposure.com, or call 540.894.9481. Fedco Seeds (www.fedcoseeds.com), High Mowing Seeds (www.highmowingseeds.com), and Seeds of Change (www.seedsofchange.com) also contract directly with growers for organic seed production.

The Organic Seed Partnership (www.organicseedpartnership.org), coordinated through Cornell University, with additional "hubs" at several locations across the United States, including West Virginia and Mississippi (Alcorn University) also had a table at the Southern SAWG Conference trade show. OSP is seeking to conduct variety trials of promising vegetable varieties and breeding lines for organic production in different climates and soils throughout the South and other regions of the U.S. For more information, contact Matt Falise of the Department of Plant Breeding and Genetics at Cornell University, e-mail mf93@cornell.edu.

- **Concluding Remark**

"Anyone who can grow a good crop and can recognize the best plants is intellectually equipped to save seed."