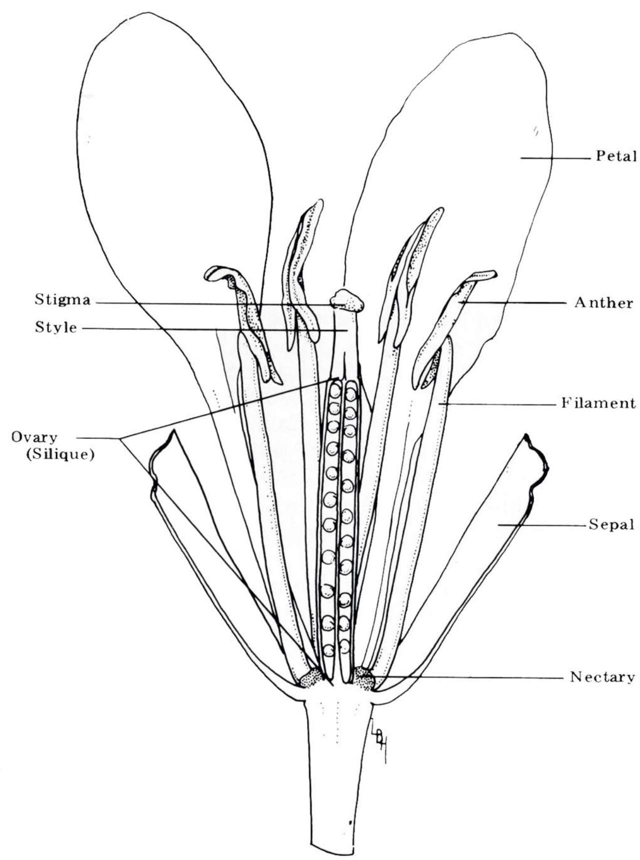
BRASSICA SEED PRODUCTION

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



For updates visit www.savingourseeds.org
For comments or suggestions contact: jeff@gardenmedicinals.com

For distribution information please contact:

Cricket Rakita
Carolina Farm Stewardship Association
www.carolinafarmstewards.org
www.savingourseed.org
P.O. Box 448, Pittsboro, NC 27312
(919) 542-2402

or

Jeff McCormack
Garden Medicinals and Culinaries
www.gardenmedicinals.com
www.savingourseeds.org
P.O. Box 320, Earlysville, VA 22936
(434) 964-9113

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

TABLE OF CONTENTS

Botanical classification 3
Climate and soil requirements 3
Plant characteristics 4
Isolation distances 7
Minimum population size 9
Techniques for avoiding inbreeding depression 10
Seed production methods 10
Cabbage 10
- Cauliflower and heading broccoli 14
- Sprouting broccoli 16
- Collards and kale 18
- Brussels sprouts and kohlrabi 19

Insect and disease management 19
Insect pests 20
Diseases 21
Selected bibliography and literature cited 23
Credits 23
Distribution and licensing information 24

SCOPE OF THIS MANUAL

The scope of this manual is devoted mainly to the major cole crops: broccoli, cabbage, and cauliflower, and the minor cole crops: Brussels sprouts, kale, and collards. Normally these are all biennials, growing vegetatively the first year and flowering the next.

BRASSICA SEED PRODUCTION

BOTANICAL CLASSIFICATION

Botanical classification of commonly cultivated species of *Brassica*):
Family: Brassicaceae (mustard family), formerly called the Cruciferae

Common name	Scientific name	Horticultural Group
Broccoli	*Brassica oleraceae*	Botrytis
Broccoli (sprouting type)	*Brassica oleraceae*	Italica
Brussels sprouts	*Brassica oleraceae*	Gemmifera
Cabbage	*Brassica oleraceae*	Capitata
Cauliflower	*Brassica oleraceae*	Botrytis
Chinese kale	*Brassica oleraceae*	Alboglabra
Collards	*Brassica oleraceae*	Acephala
Kale	*Brassica oleraceae*	Acephala
Kohlrabi	*Brassica oleraceae*	Gongylodes
Mustard greens	*Brassica juncea*	
Broccoli raab	*Brassica rapa*	Ruvo
Pak-choi	*Brassica rapa*	Chinensis
Pe-tsai	*Brassica rapa*	Pekinensis
Spinach mustard	*Brassica rapa*	Perviridis
Turnip	*Brassica rapa*	Rapifera
Rutabaga	*Brassica napus*	Napobrassica
Radish	*Raphanus sativus*	
Sea kale	*Crambe maritima*	
Siberian kale	*Brassica napus*	Pabularia
Horseradish	*Amoracia rusticana*	
Cress, upland	*Barbarea verna*	
Cress, garden	*Lepidium sativum*	
Cress, watercress	*Nasturtium officinale*	

More members of this plant family are grown as vegetables than any other botanical family. Though there is quite a bit of variability in the vegetative appearance at the mature, edible stage, the young seedlings are very difficult to tell apart. Brassicaceae are easily recognized by the cross-shaped, yellow flowers that give the family their former name, the Cruciferae (often used interchangeably with Brassicaceae). The leaves of some members of this family also have a cross-like (cruciform) shape at the distal end of the leaf.

CLIMATE AND SOIL REQUIREMENTS

The ancestors of cabbage and its relatives are native to the coastal regions of southern Europe, from Greece to Denmark, especially along the eastern Mediterranean Sea. The cultivated brassicas were brought to North America in the 16th and 17th centuries and were commonly cultivated by the colonists by the 1700's.

Because of their Mediterranean origin, brassicas are best grown in cool climates with relatively high humidity. The optimum temperature for growth is between 50 and 77ºF (10 and 25ºC). Temperatures above 80ºF (27ºC) slow or arrest growth. Ideal growing regions are coastal areas where the climate is cool with moderate to heavy rainfall during the vegetative stage of growth followed by a non-rainy period during the period of seed harvest.

Of the brassicas, cabbage is the most commonly cultivated, ranking fourth in total vegetable production in the United States. The most well known regions for cabbage production for market are upstate New York, Wisconsin, and Ohio where cole crops are started under glass and set out in the field during the summer. Georgia, Florida, and Texas are the primary cabbage production areas for market during the winter months. Plants are seeded in late summer or early fall and then grown and matured over the winter. As the temperatures rise in the spring, the plants flower and go to seed.

The primary region of cabbage seed production is in the Skagit Valley of the Puget Sound in Washington State. This region has the most favorable climate, excellent soil, and an abundance of bees and syrphid flies for efficient pollination.

Seed production in the Mid-Atlantic and South:

The Mid-Atlantic and South can't match Skagit Valley, but brassica seed can be produced successfully in many of parts of this region. Two areas offer the best possibilities, the coastal regions for crops seeded in late summer and early fall, and the mountain regions for heat-sensitive brassicas seeded in late winter or early spring.

In the coastal regions, the winter temperature is mild enough to allow brassicas to grow slowly or to winter over in the field without added protection from subfreezing temperatures. In the warmer coastal areas crops must have at least four to six weeks exposure to cool temperatures to induce flowering. This is discussed in more detail in the section on vernalization and flowering. The Virginia Truck Experimental Station (VATES) has traditionally bred and produced a lot of brassica seed in coastal Virginia. Many of the cultivars bred at the station are still available today.

The mountain regions offer a cooler climate in the summer for vegetative growth of heat-intolerant brassicas, but for seed production, the over-wintered plants need to be protected from sub-freezing temperatures. Much of the Blue Ridge Mountains and southern Appalachians offer good growing areas, especially the higher mountain valleys. Some parts of these ranges are cool and with ample rainfall and some of the higher valleys offer good growing conditions for brassicas. When plants reach maturity in the fall, they must be harvested with roots intact and stored in outdoor pits or a root cellar, until plants can be transplanted out in late winter or early spring. Some brassicas can be left to over-winter in the field provided they are heavily mulched.

Brassicas are hardy to light freezes. Many members of this family are able to tolerate winter temperatures as low as 15ºF (-9ºC) for several days especially if hardened off. A few varieties are able to tolerate brief exposure to cold temperatures as low as 5ºF (-15ºC). (Brett Grohsgal has bred a number of brassica cultivars, including Chinese greens and collards, which he claims can take -10ºF (-23ºC) temperatures with thirty mile per hour winds for prolonged periods.) At least two varieties of collards are able to withstand a temperature of 0ºF (-18ºC) for a brief time. There are large variety differences in cold susceptibility. Cold tolerance is measured not so much on the lowest temperature exposure, but the longest sustained low temperature exposure. Other factors have a bearing on cold tolerance, for example, wind, age of the plant, and amount of nitrogen in the soil, especially as the plants are becoming established. Too much nitrogen in the soil can lead to softening of plant tissues and increased susceptibility to freezing and tissue damage.

Members of the Brassicaceae are shallow-rooted and do best in well-drained, fertile soils rich in organic matter. Early season varieties require higher fertility levels than do late-season varieties. The presence of rich organic matter is especially important, not only for maintaining high fertility, but also for proper soil aeration and water-holding capacity. Brassicas do not tolerate waterlogged soil, drought, or poor soil. A steady supply of moisture is necessary through the growing season; otherwise supplemental irrigation may be necessary.

PLANT CHARACTERISTICS

General:

Cole crops are succulent, large-leaved, generally low-growing plants that reach a height of one or two feet before flowering. Upon flowering they reach a height of two to seven feet. Most are biennial, though most cauliflowers and some broccolis are annual.

Roots:

The roots of cole crops tend to be fibrous, finely branched, and widely spread. The main taproot and laterals typically penetrate the soil at an oblique angle, forming a cone-like mass that is mostly in the upper foot of soil with the narrower (apex) part of the cone reaching a depth of two or more feet depending on the type and tilth of the soil. A well-grown cabbage growing in good soil may have a root spread of three feet. A cabbage that has been uprooted in the fall and transplanted in the spring will develop a very dense root mass. Because brassicas are heavy feeders, they should be well supplied with nutrients and water during the growing season to help assimilate those nutrients.

Vernalization and flowering:

Length of photoperiod has no significant effect on induction of flowering, but most brassicas require a period of cold exposure before flowering can occur. This cold requirement is called vernalization. Typically, biennial brassicas must be over-wintered for vernalization to occur. Vernalization of the seed, seedling, or young plant is not sufficient to cause flowering because there must be sufficient nutrient reserves to support flowering. When the plant is in the seedling stage it is still physiologically juvenile and not sensitive to low temperature exposure, but as the seedling increases in size, it becomes more sensitive to vernalization. In cabbage, the stem of the seedling has to be at least ¼" (5 mm) or larger before flowering can be induced. Vernalization requires exposure to a temperature of 39 to 50ºF (4 to 10ºC) for at least four to six weeks, depending on the duration of the exposure and the absolute temperature. The most effective temperature is 45ºF (5ºC). It is only the meristem (terminal growing point or bud) that is physiologically sensitive. During cold exposure, cellular processes are set in action that convert vegetative meristem to reproductive meristem. The longer the plant is vernalized, the sooner the plant will bolt when temperatures rise. Longer vernalization also produces more flowers, which can result in greater seed yield per plant. If the temperature does not fall below 59ºF (15ºC) plants will usually remain vegetative. For cabbage, formation of a head is not necessary for vernalization.

Flowers:

Brassica flowers are borne in racemes (rows of simple flowers arranged on an elongated axis) that grow from the main stem and lateral branches. The flowers have four bright-yellow petals (½ to 1" long) that are broad on the distal end, and appear in the form of a cross, hence the former family name Cruciferae (cross bearing). There are six stamens, all of which face the style, but two of the stamens are usually shorter and lean away from the style: the other four stamens are longer than the style. The single pistil contains a two-chambered ovary that contains many ovules. The pistil develops into a long, slender silique (pod) which projects upward at an angle.

Pollination and pollinators:

Cole crops require cross-pollination and are highly attractive to bees. The open architecture of the flower allows access to many kinds of insects. The principal and most efficient pollinator is the honeybee: it typically pollinates 85 to 100% of the flowers in large commercial plantings. In smaller plantings, especially those plantings of small-scale seed growers, wild bees and flies (blowflies in particular) are important pollinators. In fact, breeders occasionally use blowflies inside pollination cages to cross-pollinate plants when only a few plants are involved.

Because cole crops grow best in cooler areas, the plants may bloom at low temperatures, often below 55ºF (13ºC) which is the minimum temperature for honeybee flight. Several species of wild bees, if abundant enough, can pollinate cole crops at low temperatures. In fact, wild bees can be more efficient than honeybees as pollinators of cabbage, even above the minimum temperature for honeybee flight. Their role is especially relevant in light of the fact that in recent years honeybee populations have been decimated by the accidental introduction of parasitic mites.

To attract wild bees to small-scale seed production plots, it is important to grow seed plants within a biologically diverse community. Such a community should include both annual and perennial flowers that serve as alternate pollen and nectar sources throughout the year when the cole crops are not available as a food supply. The only sustainable ways to maintain a population of wild bees is to use organic growing methods, plant perennial flowers that offer alternate pollen sources, and to model the seed-growing environment (as far as practical) to mimic natural communities. Although any form of agriculture is inherently unnatural, the more biodiversity in the seed growing area, the more successfully plants will be pollinated. In my experience, one of the most challenging aspects of producing cole crops for seed is ensuring adequate pollination, especially at low temperatures. Adequate pollination is not only important for overall seed yield, but also is important in producing larger, more vigorous seed.

The flowers of cole crops open during the early hours of daylight. A few hours later, the anthers dehisce exposing their pollen. Because of this time differential, cross-pollination is obligatory. Though pollen is not available to pollinators in early morning, they are drawn to the nectar. Most varieties have two nectaries located between the ovary and the bases of the two short stamens. During the three days that a flower is open, the nectaries produce about one-third of a cubic centimeter of nectar. The stigma of the flower is receptive for about five days prior to anthesis (pollen release) and up to four days after anthesis. Because the stigma is receptive before the flower opens it is possible to artificially cross-pollinate the flowers by opening the flower bud and applying pollen. This technique is called bud-pollination and is used by breeders to produce hybrid seed. Though too labor intensive to use on a wholesale scale, bud pollination is a useful method for small-scale seed growers who want to work on variety improvement. Another method of producing hybrid seed is the use of male-sterile breeding lines.

Fertilization and incompatibility:

Most varieties of cole crops are self-sterile. Cross-pollination between flowers on the same plant does not result in pollination because of one or more biological incompatibility mechanisms. Most brassica species are predominately self-incompatible, but it is a matter of degree, and the incompatibility varies with the species, the variety, the age of the plant, and age of the flower. One mechanism of incompatibility is poor germination of the pollen on the stigma of the same flower (Nieuwhof, 1969). Another possible mechanism is slow growth rate of the pollen tube in selfed plants relative to pollen originating from other plants. Regardless of the mechanism, incompatibility is most strongly expressed in freshly opened flowers, thus reinforcing the reproductive strategy of outcrossing. When self-pollination does occur, it tends to be late in the life span of the flower (as well as the life span of the plant). There may be times however, when pollinators are scarce, and as a fail-safe mechanism, selfing is allowed by the normal developmental process. This helps to ensure the perpetuation of the species when pollinators are scarce. On the other hand, results of self-pollination tend to be characterized by inbreeding depression, lower seed set, and decreased yield in the subsequent generation.

Some cole crops, notably certain varieties of cauliflower and broccoli (*Brassica oleracea*), and turnip (*Brassica rapa*) may set seed by selfing to a significant degree. Although these species are both self- and cross-pollinated, cross-fertilization is favored, resulting in better seed set and more vigor.

In summary, even though self-fertilization can occur in certain brassicas (as part of a fail-safe evolutionary strategy for survival) the best quality seed, the highest yields, and the most vigorous plants are the result of outcrossing. Without significant outcrossing, brassicas are subject to inbreeding depression and poor vigor. For this reason, the seed grower must design planting arrangements using minimum population sizes that foster a maximum of outcrossing. These issues are discussed later in more detail.

Fruit (pod) or silique:

Brassica flowers produce a silique, commonly called a pod. Siliques range from 1 to 4 inches in length depending on the species. A silique differs from a true pod in that unlike a pod, the silique has a thin membranous partition or septum dividing the fruit lengthwise. As the fruit dehisces (opens and unfolds) the placenta (membranous partition) is exposed. As the placenta dries, 10 to 30 seeds are released.

Seed:

Seeds of the cole crops are small (approximately 1/16 inch in diameter). Seeds of the different cultivated species are indistinguishable from each other, except for Chinese cabbage and turnip which have smaller seeds. When first harvested, the seeds are light brown in color, but as they age, they gradually change to darker shades of brown, and in some cases to a dark bluish brown. Seed yield varies according to species, variety, growing conditions, and pollination efficiency. In cabbage, the typical seed yield is 12 to 20 seeds per pod. A large, well grown, efficiently pollinated cabbage will yield up to one half-pound of seed per plant. This figure should not be used for planning purposes because pollination and growing conditions are rarely optimum. When estimating yield under normal conditions with average pollination and seed set, a more conservative yield of one-quarter pound of seed per plant is a more realistic estimate. The average number of seeds per ounce for cabbage, cauliflower, collard, kale, kohlrabi, Brussels sprouts, Chinese cabbage, and collard ranges between 7,000 and 9,000. Mustard and turnip average 15,000 seeds per ounce, and radish 2,500 seeds per ounce.

Seed germination:

The statistics on seed germination in relation to temperature are given in the table below:

Type of crop	**Minimum (ºF)**	**Optimum Range (ºF)**	**Optimum (ºF)**	**Maximum (ºF)**
Cabbage	40	45 to 95	85	100
Cauliflower	40	45 to 85	80	100
Radish	40	45 to 90	85	95
Turnip	40	60 to 105	85	105

Note: The optimum temperature for germination is higher than the optimum temperature for crop growth. These data on soil-temperature conditions for vegetable seed germination were compiled by J.F. Harrington, Dept. of Vegetable Crops, University of California, Davis.

ISOLATION DISTANCES

Complexities within the brassicas that affect isolation distance determinations

Determination of minimum isolation distances in the production of cole crops is complicated by the fact that not only will members of the same type of crop cross with each other, but also two different crops (such as cabbage and cauliflower) will cross with each other if they belong to different subspecies or horticultural groups (in this example, *Brassica oleracea captata* x *Brassica oleracea botrytis*). An additional layer of confusion arises with *Brassica rapa* due to the fact that some members of the *B. rapa* subspecies may have more than one common name. These issues make seed production in cole crops much more complicated than other seed crops. Pollinators of the cultivated brassicas do not make botanical distinctions between the types of flowers they visit. Therefore, for determining isolation distances, it is essential that the seed grower make the necessary botanical distinctions, because the pollinators will not.

Adding to this complexity is the fact that certain cole crops (for example, *Brassica rapa*) are still in taxonomic flux due to differing interpretations by taxonomists. The Chinese (Asiatic) cabbages and mustards are illustrative of this point. For example, most taxonomists place Chinese cabbages and mustards into one of three groups:

- Pekinensis Group (Chinese cabbage, celery cabbage, and pe-tsai)
- Chinensis Group (non-heading Chinese mustard, celery mustard, and pak-choi)
- Perviridis Group (spinanch mustard)

The uncertain taxonomic relationships of *Brassica rapa* remain to be sorted out by molecular geneticists. For the seed grower, regardless of the taxonomic classification of the subspecies, it is important to know that all of these will cross with each other (and with turnip and broccoli raab) because all these subspecies belong to *Brassica rapa*.

Another confusing group is kale. By reference to the botanical classification table on page 3, it can be noted that kale (*Brassica oleacea)* will cross with other members of the same species, such as cabbage, broccoli, cauliflower, collards, kohlrabi, and Brussels sprouts. However, several kales (for example, Hanover Salad and Siberian Kale) are *Brassica napus* which will cross with rutabaga, but not sea kale (*Crambe maritime*) or Chinese kale (*Brassica oleracea*).

Other factors to consider in determining isolation distances are environmental conditions, planting time, and earliness to flower. Previously it was mentioned that short-season broccolis planted in early spring might flower and produce seed by late summer. Also Chinese cabbage and

Chinese mustard which are normally biennials, when planted early in the season and subjected to hot temperatures, may flower and produce seed in one season.

Finally, throughout the southeast, there are strong stands of wild mustards and turnips that can cross with domesticated varieties. Care must be taken to cut back, grazed down, or dig up any such plants near seed plots before flowering.

Given the various complexities of this group, the take home message for the seed grower is that, if you have any uncertainty about the proper species classification, the easiest solution is to grow only one cole crop for seed during the growing season.

Recommended isolation distances for brassica seed production

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." This manual covers case studies of certain crops, issues related to large-scale versus small-scale production. It also gives guidelines for adjusting and interpreting isolation distance recommendations within the context of the grower's environment, especially conditions related to organic agriculture.

Therefore, the discussion here is limited to the recommended isolation distances for cole crops. In the Isolation Distances manual, the isolation distance recommendations for different crops are based on the intended use of the seed: the purity of seed required is related to the intended use. 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 cole crops based on intended use of the seed:

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

Note: When brassica 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 need to be increased, as discussed in the "Isolation Distances" manual.

Evidence of crossing:

Studies of the amount of crossing in large commercial plantings of brassica seed crops varies from one-fourth mile to two miles depending on the purity required. For example in one study, 0.6% crossing was reported between two brassica varieties planted approximately one mile apart (Haig, 1956). This amount of contamination is not significant for production of a commercial crop, but it is important for a producer of pure seed. Most cross-pollination of brassica crops occurs within 300 feet (Gill and Vear, 1958).

Cross-pollination: an example of the effect of doubling the isolation distance:

Because each doubling of the isolation distance decreases the amount of cross-pollination by a factor of four, increasing the isolation distance from 300 feet to 1200 feet (nearly a quarter of a mile), causes the likelihood of cross-pollination to decrease by a factor of 12. Now suppose, for the sake of illustration, that 10% crossing occurs at 300 feet — at 1200 feet, the amount of crossing would drop to 0.83%. This distance is 120 feet shy of one-fourth mile (or 1320 feet) which is the minimum recommended isolation distance given in the chart above — but, this does not include the effect of barrier crops which reduces the crossing even further.

Suppose the isolation distance is increased from 300 feet (where 10% crossing occurs) to one-half mile, the amount of crossing then decreases by a factor of at least 20 (equivalent to five doublings of the isolation distance). In this hypothetical example, the amount of cross-pollination drops then to 0.5%. This percentage is similar to the 0.6% figure cited (Haig, 1956) for two varieties in large commercial plantings separated by one mile. Note that in mathematical terms, the amount of crossing follows a geometric curve, and theoretically never approaches zero at large distances (see Figure 1), but as seed growers, we are interested in the biological significance. In point of fact, most pollinators do not fly more than ¼th mile, and the amount of cross-pollination does approach zero within ½ to 1-mile distance.

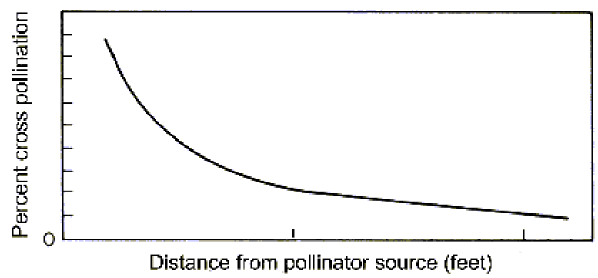


Figure 1. General relationship between cross-pollination and distance from pollinator source.

MINIMUM POPULATION SIZE

Brassicas are outbreeding plants and are therefore subject to inbreeding depression, unless the population grown for seed is of such a size to allow for a healthy amount of outcrossing. All interbreeding populations contain a pool of genetic variability. Each gene that controls a certain characteristic may exist in more than one form of the gene. These different forms of a gene are called alleles. Some alleles are dominant, and others are recessive (meaning that they are over-ridden or masked by the dominant genes). When a population size is small, more recessive genes may be expressed than would normally be expressed in a large population. Some of these recessive genes, when not masked by dominant alleles may have undesirable qualities such as low vigor, undesirable growth habit, poor insect and disease resistance, poor flowering, low yield, or off-type foliage. For this reason, a population size has to be large enough to express the full range of variability and genetic resources. Another reason for the need of a large breeding population is that some individuals may be genetically incompatible in terms of their breeding relationships.

The job of the seed grower is to keep the population size large enough while narrowly selecting for desirable traits. The trade off is that the more you select the variety, the more you narrow the genetic base. For most outbreeding plants such as brassicas, it is important to save seed from a minimum of 60 to 75 plants, and in most cases at least 125 to 150 plants.

If the variety has been badly mismanaged when you first acquire it, you should start with about 500 plants. Of those, cull out approximately half the population by selecting out those that have low vigor, undesirable growth habit, and reproductive maladies such as poor flowering and poor seed set. The second year your selection criteria can be more narrowly focused on flavor and tenderness, and in the case of root brassicas, keeping quality in storage, and root shape and quality. Another focus is selecting for insect and disease resistance.

If the variety has been very well managed and you want to select intensively for one or two traits, the minimum population should be at least 40 plants. Usually this small population size is used only when developing a sub-line selection for breeding purposes or to be used with other sub-lines for multi-line selection.

TECHNIQUES FOR AVOIDING INBREEDING DEPRESSION

There are two basic methods for avoiding inbreeding depression. The first method has already been described, that is preserving genetic diversity by means of a large population size. The second method is to grow the plants utilizing a planting arrangement that encourages cross-pollination, rather than self-pollination.

Large commercial plantings of brassica seed crops are done in large plots, but small-scale growers are more likely to plant in long single or double rows. When planting brassicas (or other outbreeders) for seed production, the plantings should be done in blocks rather than rows. The reason may not be obvious at first, but it becomes more apparent when considering the behavior of pollinators. In a long row, a bee will spend more time visiting nearest neighbors in a row, perhaps even re-visiting the same plant, or the bee may then fly off to visit flowers on an unrelated plant. This behavior of the pollinator foraging within a linear-geometric context can result in patches of inbreeding depression within the row. Though the seed from the row will likely be pooled, "patches of inbreeding" persist within the pool (in a statistical sense) and there will be less heterogeneity in the pool as a whole. On the other hand, if the seed crop is planted within a block, bees will visit a larger part of the neighborhood because the "nearest neighbor effect" is larger in a block. In other words, each plant in a block will be surrounded on all four sides and all four corners (which is eight nearest neighbors). In contrast, a plant in a row has only two nearest neighbors. Thus block plantings can theoretically result in four times as much cross-pollination. The four-fold increase in cross-pollination in blocks versus rows is a hypothetical figure because it doesn't factor in other variables. Nevertheless it serves to illustrate the importance of using block rather than row plantings for maximizing cross-pollination.

Suppose you plant your collards in a long single row resulting in some inbreeding depression, can you regain some of the heterogeneity? The answer is yes. You need only to plant the next generation of plants in a block, preferably using a larger number of plants. If instead, you plant the next generation in a long row, the amount of inbreeding will be increased, especially if it is a small population of plants.

What if you don't have enough space to grow out the minimum number of plants required to prevent inbreeding depression? The answer to this is to trade time for space, by pooling the grow-outs from several years. The first year you grow as many plants as you can and save the seed. The next year, use only the seed from the original seed lot to grow out another seed crop. The seed lots from both years are then pooled. As long as you have ample stock of your original seed you can do this for a number of years.

SEED PRODUCTION METHODS

Cabbage (*Brassica oleracea*)

Culture:

Cabbage is a biennial, and therefore during the first year of growth, it is grown for seed in the same manner that it is for eating, market, or processing. Early-season cabbages take two months to develop heads whereas late-season cabbages can take four months. When grown for seed, the planting time must be adjusted to allow the proper conditions for wintering over. If planted too early in the season, the heads may split. If planted too late in the season, the heads may be immature. The heads should be fully mature before the onset of winter, so that the plants can be dug and stored in a cellar, or protected in some other way. Winter storage is necessary in some parts of the Mid-Atlantic where temperatures drop below 20^{o}F (-10^{o}C). In USDA zones 8 and 9, mature heads will over-winter without protection and may continue growing during a mild winter. Such areas include the coastal area of Virginia, and coastal and inland regions of the Carolinas, and southern states such as Georgia, Alabama, Missouri, and Louisiana.

Propagation by seed:

Seeds are sown ¼" deep in cell packs or pots, two or three seeds per pot. After seedlings emerge the most vigorous seedlings are selected and the remaining seedling or seedlings are cut off at the soil line. Seeds are started four to six weeks before transplanting. The temperature range for seed germination is 45 to 95ºF (7 to 35ºC) and the optimum temperature is 85ºF (29ºC).

Rouging:

Rouging is done throughout the growing cycle with particular attention to low-vigor plants. Off-types can be spotted on the basis of leaf shape and color, but some off-types may not be spotted until the outer leaves are stripped off prior to storage.

Winter protection and storage:

Late season varieties are the best for winter storage. Early season varieties have more succulent tissue and are more susceptible to freezing injury. Most cabbage varieties, if sufficiently acclimated to cold will tolerate 20ºF (-7ºC). Rapid freezing and thawing are apt to cause more damage than gradual acclimation, due to the formation of ice crystals which compromise membrane integrity. In cabbage, there are large variety differences in freezing susceptibility, for example, red cabbage is significantly less cold tolerant than white Savoy cabbage. It is the pith of the stem that is most sensitive to freezing injury. The plant may survive, but if the pith freezes it will become spongy and then hollow as it dries. For this reason, if the cabbage is not dug up for winter storage in a cellar, the soil should be mounded up high enough to protect the pith by covering the stem. In colder regions, the heads may be protected by adding 12 to 16 inches of straw over the heads. If rodents are a problem, large wide boards may be placed in inverted V-shape over the heads with wire mesh added to the ends of the boards. This then is covered with straw. It is better to hill up soil around cabbage than to dig them and put them in trenches. If the subsoil is not well drained, water may pool in the bottom of the trench encouraging disease. The partially exposed tops of hilled cabbage can withstand temperatures of 5 to 10ºF (-15 to –12ºC). If the plants are exposed to colder temperatures, they should be mulched with straw until it is safe to uncover the heads.

Storage of cabbage involves substantial risk, so it is important to have the proper conditions. Cabbages dug for winter storage in root cellars should have firm, solid heads. Loose-wrapped heads will not keep well. When digging plants, trim the root system to about 12" long and trim off the loose outer leaves. The entire plant is then placed on slatted shelves or wire mesh leaving several inches between plants to allow for good air circulation and ease of inspection. Other methods of storing cabbage include covering the roots with damp sawdust and wrapping the heads in several layers of newspaper. Cabbages can also be layered in a thick bedding of straw. Unlike root crops, cabbage plants cannot be stored in bins or piles because they release a lot of water during storage, especially in the fall and spring when root cellar temperatures are higher. One other method of storing cabbages is to tie them upside down from rafters. Regardless of the storage method, the storage temperature and humidity are important for good results. Keep them cool, between 32 to 40ºF (0 to 4ºC) at high relative humidity, at least 80%, and preferably 90%. The low temperature discourages disease while keeping the cabbage dormant. Though high humidity favors disease, it reduces dehydration. The two major storage diseases of cabbage are gray leaf mold (*Botrytis*) and leaf spot (*Alternaria*). The storage life of cabbages is three to six weeks for short-season types and four to six months for large slow-growing types. In the Mid-Atlantic region the storage period may average two to three months.

For organic growers, some important points regarding the storage procedure are: (1) carefully inspect cabbages for disease prior to storage, (2) avoid nicking or bruising the heads while handling, (3) inspect the stored crop on a regular schedule, removing any plants that show signs of storage disease before it can spread, (4) use disease-resistant varieties, (5) grow varieties that store well, and (6) keep soil nitrogen levels from being excessively high, otherwise growth of soft tissue will be encouraged, which in turn can lead to freezing damage and disease.

Replanting:

Plants that have been stored in a cellar are set out in the spring as soon as the soil can be worked. Cabbage can withstand moderate subfreezing temperatures, but as a precaution against extreme cold weather, the plants can be set low in the soil so that the head is either on the soil or slightly above.

This helps protect the sensitive stem from freezing. Plants are spaced 24 to 36" apart in rows 3 to 5 feet apart. The spacing between rows is based on plant size and whether the rows will be mulched or cultivated. Early planting and mulching helps ensure adequate moisture in the soil. As temperatures become more moderate and weeds begin to emerge, it is advisable to apply mulch to retain soil moisture. Because cabbage is very responsive to nitrogen, a straw mulch containing manure will provide a stimulus for early and rapid growth. Within a week or two of planting, two cuts are made at right angles across the top of each head, no more than 2" deep. This allows the growing point of the seed stalk to emerge through the head. The cuts should not be so deep that they injure the growing point, but if not cut deep enough it may be necessary to make repeated cuts so that the seed stalk can grow, emerge, and develop normally.

Staking:

Staking the flower stalks makes it easier to handle the seed crop when it matures. There is no significant difference in seed yield between plants that are staked and un-staked when the seed is mechanically harvested. In small-scale operations, staking does make it easier to move along closely spaced rows, especially if mechanical cultivation (rototilling) is necessary to control weed growth on un-mulched soil. Staking also makes it easier to hand harvest the seeds because less bending and movement is involved in grasping the branches of seed. Staking is done by driving 5-foot stakes into the ground at intervals of about 10 feet. Two lines of heavy twine are strung between the stakes, each line woven to one side or the other of the flower stalk, much in the same way the Florida weave system is used to support tomato vines. A thunderstorm with heavy winds can apply a lot of force on the seed stalks causing them to bend one way or the other, so it may be necessary to run twine at more than one height to fully support the stalks. Staking should be done not long after the flowers begin to set seed because as the pods fill out, the stalks start bending in various directions, sometimes nearly to the ground.

Harvesting:

One of the problems with harvesting brassica seed is that the pods do not ripen all at once, but rather in the same sequence of flower opening. This means that as pods yellow, dry and mature to a light brown color, the oldest pods will dehisce first and scatter the seeds. If only harvesting a small amount of seed (less than a pound) it is sufficient to visit the crop every day or two and rub the mature dry seedpods between the hands over a large plastic basin, or a wheelbarrow. Though this method may give slightly higher germination seed, it is too time consuming for the small benefit involved. A better method for dealing with larger quantities is to walk down the rows with a corn knife, machete, or long-handled pruning shears and cut off the maturing seed stalks. This is done when the basal pods on the seed stalks have matured to a yellow-brown color and some of the other pods are yellow-brown. The stalks can be harvested even earlier provided the basal pods are yellow and their seeds are brown. The seed itself, when mature, should not split or crush when rubbed between the hands. When stalks are harvested by this method, pod color on the seed stalks ranges from yellow-green to yellow to light brown. The yellowish pods will have quite a bit of moisture because the seeds are still maturing. The harvested stalks are then brought under cover and placed on plastic tarps to cure and dry. During the curing process, immature seeds continue to grow and develop until they become fully mature and dry. When arranging the stalks for drying, the stalks should not be piled too deeply, otherwise mold may develop. In the Mid-Atlantic and South where high humidity is a problem, it is wise to allow ample air circulation around the stalks, or to use a fan to help circulate the air. The process of curing and drying may take anywhere from 10 to 14 days or longer depending on weather conditions. Some growers recommend pulling the whole plant when the seed stalks are ready to harvest. Although this method may give slightly better seed germination, the advantage is minimal. The disadvantages are that this takes much more space, increases the likelihood of mold, and risks contamination of the seed with bits of soil and small seed-sized stones.

Threshing and winnowing:

The method employed for threshing brassica seed stalks depends on the scale of the operation.

- **Small-scale threshing** is done by hand and is suitable for small seed lots. If seed stalks have been gathered and piled on tarps, some seeds will release during the drying process. The seed stalks are gathered and twisted or wrung back and forth in gloved hands causing the seeds to be released into a wheelbarrow or over a tarp. Another method involves walking back and forth with a twisting motion over the seed stalks which are spread out on a plastic tarp or a concrete or wooden floor. Though some sources mention jogging or stomping on the seed pods to thresh the seeds it should be borne in mind that seeds can be damaged by overly vigorous threshing. Such damage may not always be visible to the eye but will become manifest when germination tests are conducted. It is better to wear soft-soled shoes and to walk firmly over the seedpods with a twisting motion of the feet. The object is not to apply brute force or a heavy grinding, but rather to apply a light, shearing action to force the seedpods open. Another possibility that I would like to explore is running the seed stalks through the wringers of an old wringer washing machine. The rollers of such machines are spring mounted so that the rollers recede in response to the amount of pressure on the rollers. By varying the tension on the rollers it might be possible to adapt the wringers for threshing.

- **Large-scale threshing** methods are employed when producing more than 75 to 100 lbs. of brassica seed. Most threshing machines are too expensive to warrant their purchase by small-scale growers; however they are appropriate when used by a cooperative. Most threshing machines are called combines which consist of a feeding section and a threshing section. The feeding section typically consists of a reel, divider, cutter bar, and feed mechanism. The threshing section consists of rubber-coated rollers through which the milled stalks are fed. (or in another variation, the stalks are fed between rubber-coated cylinders that rub against concave fixed bars). The old literature on threshing suggests feeding the butt end of the stalks into the thresher first. By feeding the thickest part of the stalks first, one can tell the maximum load on the rollers and thus avoid overfeeding. The feeding should be done at a continuous steady rate, close to the maximum capacity of the thresher. The general rule in setting the clearance of the rollers is that the distance between the rollers or cylinder and concave bar be at least 1-½ times the diameter of the seed. The cylinder speed of the combine should be less than 700 rpm in order to minimize the splitting of dried seed.

Seed cleaning:

Fortunately the round, fairly uniform shape of brassica seed makes them easy to clean. The first step is to remove large stems and other debris by pouring the rough chaff and seed through a large mesh screen such as ¼" hardware cloth. The next step is to clean the seed with two seed-cleaning screens.

There are two basic types of screens used for cleaning round seed: (1) a round-hole top screen, and (2) a slotted bottom screen. In the case of brassicas, a 1/8" round-hole screen works well as the top screen. This allows the seed to pass through while screening out the chaff and larger debris. The bottom screen is used to catch the seed, while allowing the fine chaff and dirt to pass through. The bottom screen can either be a slotted screen or fine wire mesh. The size isn't critical; it need only retain the brassica seed while allowing the chaff to pass through. After screening, brassica seed needs to be blown free of fine chaff. If an air separator or seed blower isn't available, a stainless steel bowl and a hair dryer are sufficient for cleaning small lots of seed. For cleaning larger quantities, the seed can be poured in front of a box fan. The seed will be caught by a large container or tarp below the fan, and the chaff will be blown beyond the container or tarp. Cabbage seed may be sized into several sizes for precision planting.

One method of separating high-quality brassica seed from poor-quality brassica seed and small chaff is to use a slant-board. Poor-quality brassica seed is often not round and will not roll all the way down a board inclined at a shallow angle. To build a slant-board, fasten small strips of wood along the long edge of a 4 x 8-foot sheet of plywood. Raise the 4-foot edge 18" off the ground and then evenly disperse ¼ lb of seed along the top edge. Gently tap the bottom side of the plywood until the roundest seeds make it to the bottom. Discard everything remaining on the slant board.

The basic procedures for threshing and winnowing seeds are covered in the companion manual in this series titled: "Seed Processing and Storage."

Additional information on seed threshing and cleaning may be found at www.savingourseeds.org, and www.agronomy.ucdavis.edu/LTRAS/itech/ .

Seed storage:

Cabbage seed will remain viable for about five years when properly stored at low humidity (less than 50%). The seed moisture content should not exceed 6% during storage. For detailed information on this topic, see the companion manual titled: "Seed Processing and Storage."

Cauliflower and Heading Broccoli (*Brassica oleracea* var. *botrytis*)

Climate and soil requirements:

Cauliflower and heading broccoli are predominately biennial crops that do best in cool, humid climates. The techniques for growing seed are similar to those for cabbage, but the planting time and growing temperature are more exacting. For this reason, successful production of seed is more difficult, though this is offset by a higher return received for the seed crop. Cauliflower and broccoli are more sensitive to heat and freezing injury. For cauliflower, sowing dates must be adjusted so that both young plants (at the first stage of development), and older plants (during the stage of curd initiation) are exposed to cool temperatures. Exposure to high temperatures during these critical periods may have an adverse effect on development and seed production. The optimum temperature for growth of young cauliflower seedlings is 74ºF (23ºC), and for more mature plants is 64 to 68ºF (17 to 20ºC). Temperatures above 84ºF (29ºC) will slow vegetative growth and delay curd initiation, and if the curd has already formed, the bracts on the flower stalks may grow and protrude through the head.

Like cabbage, cauliflower can withstand frosts and sub-freezing temperatures provided the curd is protected by tying up the wrapper leaves over the curd. Cauliflower, depending on the variety, can survive to 18ºF (-7ºC) provided that the plant has been slowly acclimated and hardened to endure sub-freezing temperatures. Tying up the leaves or handling the plant during sub-freezing temperatures is not recommended because tissue damage may result. Like cauliflower, the pith of the stem is most sensitive to freezing injury, as well as young succulent growth.

Annual forms of cauliflower are not as temperature sensitive as biennial types. Seed can be produced during a single, sufficiently long season, though if the season is not long enough, the plants may need to be transplanted into a greenhouse. Annual forms do not require vernalization nor is there a minimum size requirement for curd development. When annual varieties are grown at a temperature above 68ºF (20ºC) the heads will be of low quality. Annual varieties of cauliflower developed in tropical regions such as India will form heads at moderately high temperatures.

Heading broccoli is less demanding than cauliflower. Unlike cauliflower, it is less sensitive to warmer conditions and more tolerant of lower soil moisture. Like cauliflower it needs favorable growth conditions for the formation of high quality heads.

Primary seed production regions:

Cauliflower is a specialty, high value crop because of its growing requirements. In the United States the primary areas of seed production include the middle coastal areas of California, the Puget Sound in the state of Washington, and historically Long Island, New York.

Seed production in the Mid-Atlantic and South:

Cauliflower and heading broccoli are best grown for seed in mild winter climates. This is primarily cool coastal areas where the winter is mild enough to cold enough to allow for vernalization, but not so cold that the plants are subject to freezing. Like cabbage, heading broccoli and cauliflower can be dug for winter storage in late fall/early winter but the plants remain in good condition for only six weeks at best. This requirement defines those locations where seed growing can be successful.

Culture:

Many cultivars of cauliflower and heading broccoli are biennial, and therefore during the first year of growth, they are grown for seed in the same manner as for eating, market, or processing. Depending on the variety, plants are spaced 2-½ feet to 3 feet apart in rows 4 feet apart. A constant supply of water is required to grow these crops well. The soil should neither be waterlogged, nor allowed to dry out. Organic growers are advised to use surface irrigation (drip hoses) rather than sprinkling which favors disease. If overhead sprinkling is used, it should be done in the morning so that the leaves dry off during the day.

Propagation by cuttings:

The cultivated brassicas can be successfully propagated by cuttings. In Japan, seed producers have used cuttings of broccoli to produce seed. The technique involves sowing the seed in the spring and harvesting the head two months before a killing frost. The plant is then cut to form a stump 4 to 6" tall. After the side shoots grow to a length of 4", the shoots are treated with a rooting hormone and planted in heated soil in nursery beds. The rooted cuttings are planted in the spring, and because they are vernalized they produce seed. This production method using synthetic growth regulators is not appropriate for organic growers, but the technique raises some interesting possibilities. Non-synthetic growth regulators are allowed for organic production. One natural source of rooting hormone is from "willow water." Willow water is made by placing cuttings of the willow tree or pussy willow (*Salix* spp.) in a container of water for several days. The water is then collected (and frozen for later use). The collected water contains a high concentration of auxin, a natural growth regulator called indole acetic acid (IAA) which stimulates root formation. When rooting a cutting, the basal end of the cutting is cut ¼" below the lowest node, and then placed in a natural substrate. This technique might be employed successfully by rooting cuttings in a cool greenhouse where the nighttime temperatures are kept below 50ºF (10ºC). Though I am not certain whether the technique would work it might a technique worth investigating.

Developmental phases and abnormalities:

Cauliflower and heading broccoli thrive best when growth is slow, steady and consistent without environmental extremes or stresses. Cauliflower is especially sensitive to stress during the transition period between the three major stages of development: the vegetative stage, curd formation stage, and maturation of the head. The most common stress-related problems are buttoning, no heads formation, leafy curds, and riciness.

- **Buttoning** is characterized by the formation of small tiny curds when the shoot is very small. The phenomenon is not well understood, but appears to be caused by moisture stress (too much or too little), transplanting of root-bound plants or old plants, transplant shock, mineral nutrient stress (primarily low nitrogen), and excessive low temperature during a change in developmental phase. In other words, buttoning is a stress-related phenomenon, often with multiple causes that may act singly or together. Heading broccoli is also subject to buttoning, though to a smaller degree. If buttoning occurs, it is most likely to occur shortly after transplanting. It can be prevented by making sure that the transplants are young and actively growing with no checks in growth prior to transplanting. Once the transplants are established in the field, environmental stresses are much less likely to cause buttoning. Buttoning is more a problem with early varieties which can be induced to develop curds at an earlier developmental stage. The basic precautions to avoid buttoning are:
    - Don't expose transplants to freezing temperatures.
    - Keep the air temperature above 70ºF (21ºC) and soil temperature above 60ºF (16ºC) during the seedling stage.
    - Transplant 4 to 5 week old plants. Don't transplant large, old, or root-bound plants.
    - Minimize or avoid transplant shock.
    - Keep an eye on the weather forecast and avoid transplanting when temperatures are below 50ºF (10ºC) for more than four days.
    - Maintain conditions for good steady growth, notably proper water and nutrient levels.

- **No head formation** is the result of high temperatures keeping the plants in the vegetative phase until temperatures fall low enough for curd formation to take place.

- **Leafy curds** are the result of improper nitrogen balance or large swings in day or night temperatures.

- **Riciness** is a condition characterized by a rough or granular appearance of the curd. This can be caused by low temperatures or improper (often excessive) nitrogen availability after transplanting. This is less of a problem for organic growers who rely on available soil nitrogen rather than amendments after transplanting.

- **Blindness** is a condition characterized by collapse of the growing point that results in coarse leaves, no main curd, and small curds that develop from axillary shoots. Blindness can occur when seedling are exposed to freezing temperatures.

- **Nutrient deficiencies:** There are two nutrient deficiencies that affect cauliflower in particular:
    - **Boron deficiency:** This occurs when the soil pH is high, or soil boron levels are low. Boron availability to plants declines markedly above soil pH 7.0. At pH 7.5, the availability of boron decreases by half, and at pH 8.0 the availability decreases to one-fourth. Symptoms of boron deficiency include collapsed internal pith resulting in hollow stems, chlorotic leaf margins in older cauliflower plants, and elongated, dark green brittle leaves in young plants. Boron deficiency can be prevented by lowering the pH by addition of organic soil amendments such as composted pine needles, or oak leaves, or other acidic composted plant material. If soil levels of boron are low, organic growers may increase boron levels by application of certain non-synthetic or synthetic soluble boron products (e.g. borax at 20 to 30 lbs. per acre), but growers must first document the deficiency by testing. Foliar application of boron may be helpful. Consult your organic certifier before applying regulated boron products.
    - **Molybdenum deficiency:** In severe cases, this causes a condition also known as "whiptail," which is due to the failure of the leaf lamina to develop properly along the midrib of the leaves. Plants with whiptail will be stunted and either won't produce a curd or the curd will be leafy and poor quality. In milder cases of molybdenum deficiency, the leaves become narrower with ruffled, irregular margins. Young seedlings have cupped leaves with chlorosis around the leaf margins. Molybdenum is fully available at soil pH 7.0 and above, but availability declines with increasing acidity. In pH 6.0 soil, molybdenum availability is only half that compared to neutral soil. Adjustment of soil pH is the best prevention; otherwise consult your organic certifier.

Rouging:

Rouging is done throughout the growing cycle with particular attention to low-vigor plants. Off-types can be spotted on the basis of head characters such as size, depth, uniformity, color, and compactness. Other undesirable characteristics include loose curds, leafy curds, and non-uniformity. Because cauliflower is an expensive crop to produce, it pays to rogue carefully.

Flowering:

The heads of cauliflower contain a number of non-functional flowers, which is one reason why the seed yield is lower than cabbage. On the other hand, purple cauliflower has fully functional flowers. The flowering stalk of cauliflower and heading broccoli is much shorter and more compact than that of cabbage, usually not more than 24 to 30" tall, compared to cabbage which is typically 48" tall. In addition, the flowering occurs within a period of 10 to 14 days which is a much shorter flowering period than cabbage.

Harvesting, threshing and cleaning:

Cauliflower and heading broccoli are processed the same way as cabbage. Cauliflower seed crops tend to mature later than most cole crops. Seed yields average 150 to 200 (up to 350) pounds per acre (approximately 4 pounds/1000 square feet) compared to cabbage which averages 400 to 800 pounds per acre (9 to 18 pounds/1000 square feet).

Sprouting Broccoli (*Brassica oleracea* var. *italica*)

General:

The term sprouting broccoli refers to plants that produce small heads of immature flower buds. Sprouting broccoli does not produce a central head. White sprouting broccoli is actually a type of cauliflower.

Climate and soil requirements:

Sprouting broccoli is easier to grow than cauliflower. It is adapted to warmer and less humid climates, planting times are more flexible, and is not as demanding in its requirements. Though more tolerant of warmer climates, best growth of broccoli occurs during the cooler months of spring and autumn. The optimum temperature range for growth is 59 F to 68ºF (15 to 20ºC). The maximum temperature for production is 77ºF (25ºC). Temperatures above 82ºF (28ºC) will delay initiation of heading and flowering, and if bud clusters (small heads) have formed the flower stalks will lengthen, the bud clusters will become looser and will wilt rapidly after harvest. Soil should be kept moist, otherwise drought will result in the production of smaller heads and more fiber in the stalks. Once plants approach maturity plants should receive 1 to 1½" of water a week. The sensitivity of broccoli to freezing injury depends on the developmental stage. A light frost is of little consequence, but the floral buds and pith within the stalks are sensitive to sub-freezing temperatures. Freezing injury will be manifested as water-soaked tissue followed by rotting of affected tissue.

Plant characteristics:

Sprouting broccoli typically has a small central head and numerous side heads, which develop over a period of weeks. Plants are usually about 24" tall, but when the heads of broccoli mature beyond eating or market stage the small heads expand and the flowering stalks expand to form an inflorescence similar to that of cabbage.

Culture:

Broccoli, like cabbage requires fertile soil and grows best when well irrigated. Like other cole crops, the soil should be high in organic matter to increase drainage and water-holding capacity. When planted for home or market, broccoli is spaced 16 to 24" in the row and 18 to 36" between rows, but when grown for seed the rows are spaced 30 to 40" apart. In the South, broccoli is often direct seeded but in the Mid-Atlantic plants are started as transplants after the danger of subfreezing temperature has passed. Spring-planted broccoli matures a seed crop in the fall, and fall-planted broccoli which has been over-wintered matures seed the following summer. One of the factors that differentiates broccoli cultivars is temperature tolerance. Early varieties that mature in 55 to 80 days tolerate higher temperatures, whereas later varieties that mature in 80 to 105 days are more suited for fall production. Soil fertility should be managed to encourage moderately rapid growth. Growth that is too rapid can produce hollow stems. Growth that is too slow due to limited nutrition will result in a low seed yield. Broccoli is similar to cauliflower in being sensitive to boron deficiency.

Fertilization and incompatibility:

Like other cole crops, broccoli is not normally self-fertile, so consideration should be given to factors that avoid inbreeding depression as discussed previously.

Rouging:

Aside from rouging out low vigor plants, emphasis should be placed on removing off-types. Though foliage characteristics should be noted when rouging, the characteristics of the head are the most important. Desirable characteristics include compact heads with buds of similar type and color and heads that lack leaves. It is important to know the variety when rouging. For example, some varieties are known for their dark green or blue green color in contrast to the medium or lighter green color of other varieties. Other variety specific qualities include bud side and size of number of side shoots.

Harvesting and threshing:

Broccoli seed is harvested, cured and threshed in the same manner as cabbage, and because it is usually grown in a warmer and drier climate than cabbage, the seed cures more rapidly.

Collards and Kale (*Brassica oleracea* var. *acephala*)

Climate and soil requirements:

Both collards and kale are biennials that produce seed the second year. Kale and collards are considered the more "primitive" of the cole crops in that they more closely resemble wild cabbage. They were grown by the ancient Greeks, and later introduced into Britain and France by the Romans and Celts. Their climate and soil requirements are similar to cabbage, but they are hardier than cabbage, tolerating both low and high temperatures better. Collards, in general, are hardier than kale. For seed production, winter temperatures should be below 50ºF (15ºC) for at least six weeks for vernalization to occur. Most adult plants can withstand winter temperatures down to 14ºF (10ºC) provided the growing location is well drained. Several varieties can survive down to 5ºF (-15ºC) (As noted earlier, Brett Grohsgal has bred varieties that can tolerate lower temperatures). Collards can be grown where it is too hot to grow cabbage.

Seed production in the Mid-Atlantic and South:

For seed production in the Mid-Atlantic region using the seed-to-seed method, cold-hardy varieties may be left in the field to over-winter in USDA zones 7b and higher, otherwise zones 8b through 10 for sensitive varieties. Some varieties bred by Brett Grohsgal are winter-hardy to zone 6a. though still unprotected In areas where winter lows are too low to leave the unprotected plants in the field, the plants are started in late July, and are grown to only moderate size in the fall (approximately 8 to 12"), and then transplanted in late fall to pots to be brought into the greenhouse. The plants are then set out in the early spring. Another alternative is to thoroughly mulch the plants in the late fall, carefully protecting the central stem and growing tip, during the coldest part of the winter. One other technique that may be used is to construct an inexpensive hoop house in the field. This can be done by cutting 100-foot rolls of flexible 1" (outside diameter) water supply pipe into 5 to 7 foot hoops (depending on height of plants to be protected). The ends of the pipes are inserted over 8 to 12" pieces of rebar, rigid plastic pipe, or galvanized metal conduit that is ¾" or less (outside diameter). The hoop house frame is then covered with 6-mil polyethylene. Boards may be used to hold down the edges of the plastic, but a strong gust of wind may pull the plastic from beneath the boards. For that reason, u-shaped soil clips are a better solution. These are normally used to secure floating row cover. Hoops should be spaced no more than 18 to 24" apart, otherwise a heavy wet snow load may bend or collapse the hoops. Venting the hoop house is important on warm winter days, otherwise inside temperature and humidity may rise high enough to damage the plants or affect their cold hardiness.

Plant characteristics:

Collards and kale are considered minor brassica crops because there are fewer varieties and the total amount of acreage devoted to seed production is much lower than for cabbage, cauliflower, and broccoli. Kale resembles wild cabbage more than most cultivated brassicas. Kale has an open type of growth with typically curly leaves and no head. Varieties of kale vary considerably in growth habit, plant size, and leaf color, texture, and thickness. Collards are much less variable. Whereas most varieties of kale are shorter with a thinner stalk, collards have a thick central stem that terminates in a loose, cabbage-like foliage. Some varieties are non-heading, whereas others form a loose head or cluster of leaves at the top of a long stalk.

Flowering and pollination:

Pollination and incompatibility relationships of collards and kale are similar to cabbage. Likewise, a vernalization period is required in order for flowers to be produced. In some locations in the deep South (for example, southern Louisiana), collards may not act like a true biennial. There, collards can be planted any month of the year and will produce seed stalks by early March. The temperature and light conditions will cause two-month old plants to flower at the same time as nine-month old plants, but of course the older plants will produce much higher seed yields.

Rouging:

Rouging for trueness to type is especially important with the minor crops because seed companies tend not to invest much in their development and maintenance. When rouging collards and kale special attention is given to the edible part, sweetness, tenderness, and texture. Other qualities include cold hardiness, insect resistance, and disease resistance.

Harvesting and threshing:

Collards and kale are handled similarly to cabbage. Seed yields are lower than cabbage, ranging from 300 to 600 pounds per acre (7 to 14 pounds/1000 square feet).

Brussels sprouts (*B. oleracea* var. gemmifera) and Kohlrabi (*B. oleracea* var. gongylodes)

General:

Both Brussels sprouts and kohlrabi are minor crops of relatively recent origin. Brussels sprouts dates from the late 1500's in the region of Brussels and Belgium. The ancestor of Brussels sprouts is thought to have been a type of Savoy cabbage in which the terminal growing point was routinely removed, resulting in the formation of axillary buds similar to Brussels sprouts. Normally, Brussels sprouts grow 3 feet tall with a rosette of leaves at the top with compact miniature "heads" which are large axillary buds that develop along the stalk. Dwarf varieties have shortened internodes. The sprouts at the top tend to be smaller than those at the base because of apical dominance, hormonal suppression of growth of the upper buds.

Kohlrabi was also developed in the late 1500's in northern Europe and became popular in Germany where it acquired the German name kohlrabi, which means turnip. Botanically it is not a turnip, but rather a variant of cabbage with a swollen stem. The stem does not elongate and the leaves are arranged in spiral fashion.

These crops are handled essentially the same as other biennial cole crops using the seed-to-seed method and allowed to winter over.

In terms of heat tolerance, kohlrabi and Brussels sprouts are more tolerant than cabbage, but less tolerant than kale and collards. Regarding kohlrabi, early varieties subjected to cold temperatures below 50ºF (10ºC) for one week or more after germination are susceptible to early bolting. Slow bolting varieties require a longer exposure to vernalization temperatures (below 50ºF (10ºC)), and there is no correlation between earliness and cold temperature exposure. Kohlrabi and Brussels sprouts may be over-wintered in the field where temperatures permit, otherwise they may be dug in late fall and stored in a cellar at 32 to 40ºF (0 to 4ºC) and high humidity.

Rouging:

Proper rouging is important for the minor cole crops because they may have not been as well maintained or selected. Both should be rouged at the time of prime market maturity. Kohlrabi should be selected for uniform size, shape, and color. Brussels sprouts should be rouged for large compact buds that are firm and uniform.

Harvesting and threshing:

The seeds of kohlrabi and Brussels sprouts are harvested and threshed in the same manner as other cole crops. Seed yields from kohlrabi average 800 to 1,300 pounds per acre (18 to 30 pounds/1000 square feet). Seed yields from Brussels sprouts average 300 to 600 pounds per acre (7 to 14 pounds/1000 square feet).

INSECT AND DISEASE MANAGEMENT

As a preface to the sections on insect pests and diseases, it should be noted that the control treatments recommended are for organic growers. Regulations regarding approved methods may change from time to time and approval of certain methods of control may depend on the certifying agency. Check with your organic certifier before using pest and disease control treatments. There is no substitute for prevention via good crop management. This includes: (1): proper attention to crop nutrition and growth conditions, (2) crop rotation, (3) sanitation, (4) maintenance of biodiversity to encourage beneficial organisms (4) scouting to detect problems at an early stage to allow time for intervention, management and control, and (5) use of spot treatments instead of broadcast treatments where appropriate. In the material below, mention is made of varieties that have resistance to certain diseases or insects. Bear in mind that resistance is often not complete, may be subject to change, and may depend on environmental conditions.

INSECT PESTS

There are a number of insects that feed on cole crops. Pests include cabbage aphids, flea beetles, beet armyworm, cutworms, and cabbage maggots. The major insect pests for cole crops grown in the Mid-Atlantic and South are described below.

- **Cabbage looper (*Trichoplusia ni*):** The adult is rarely seen because it is a night-flying moth. It has mottled gray-brown wings with a sock-shaped silvery spot in the center of each forewing. The caterpillar stage is found predominately on the underside of the leaf, along leaf margins, but may be found anywhere on the plant feeding between the leaf veins. Because cabbage loopers have no middle legs, they loop their bodies as they crawl. When disturbed, larvae may drop to the base of the plant. Mature caterpillars are 1½" long with two thin white stripes down the back and two wider pale white stripes along the sides. The ridged, round white eggs are laid singly on the underside of outer leaves.

- **Diamondback moth (*Plutella xylostella*):** The moth is small and narrow with folded wings. The female is gray-brown but the male has three yellow diamond-shaped spots where the wings meet. The yellow-white, football-shaped eggs are laid singly or in small groups on the underside of the lower leaves. The larvae are small, not much more than ¼" long when mature. Yellow-green in color, they have a "forked tail" and black head. When disturbed they often drop or hang from the plant by a thin silk thread. They prefer to feed on new growth and the buds of young plants. It is important to scout the plants when they are young, especially because feeding may cause malformations.

- **Imported cabbage worm *(Pieris rapae*):** The adult is a butterfly with white wings and black spots on the forewing. When the flying adults are seen, it is time to start scouting for damage. The female chooses seemingly random places to lay an egg, one at a time anywhere on a single plant and similarly on a number of plants. The eggs have distinct ridges and are white when laid but turn a dusky yellow when they mature. The mature larvae are 1¼" in length and are identified by the light yellow stripe down the middle of the back. Frequently they are found feeding next to the midrib or veins on the underside of the leaf. The caterpillars pupate on the underside of the leaves. Damage can be extensive on young plants.

- **Cross-striped cabbageworm (*Evergestis rimosalis*):** The yellow-brown moth has zigzag markings on the wing. It lays light yellow, scale-like eggs in masses of 20 to 30 on the underside of leaves. This late season caterpillar is bluish-gray with numerous tiny black stripes running transversely across the back. On each side of the body is a black and yellow stripe. Mature caterpillars are ¾" long. Because the eggs are laid in clusters, scattered individual plants may be infested severely. Larvae prefer young terminal growth, often riddling it with holes. When the larvae are ready to pupate they drop to the soil and form a cocoon just under the soil surface.

- **Corn earworm or cabbage headworm (Heliocoverpa zea):** This is a late season pest often encouraged by the presence of a corn crop.

- **Harlequin bug (*Murgantia histrionica*):** The harlequin bug is a major pest of cole crops in the Mid-Atlantic and South. It can devastate most cole crops if not controlled. Easy to identify, it is shiny, red, orange, and black, shield-shaped bug, about ¼" to ½" long. It may produce three or four generations per year, but in the South it may breed year-round. The distinctive white and black barrel-shaped eggs are laid in double rows on the underside of leaves.

Control measures for caterpillar pests:

Fortunately, control of caterpillar pests is not difficult. The most important measure is thorough scouting on a regular basis. Also, a growing environment that encourages biodiversity is important for supporting predatory and parasitic wasps (such as *Cotesia* and *Diadegma*) that prey on caterpillars. Other than creating a conducive environment for natural control, organic growers can easily and effectively use *Bacillus thuringiensis* (also called "*B.t.*") provided that the formulation used does not contain prohibited materials. *Trichogramma* wasps, which parasitize moth eggs, can also be purchased**.** Yet another part of the strategy involves use of resistant varieties. Varieties with reported resistance to caterpillars include the following:

- **Broccoli:** 'Atlantic'
- **Cabbage**: 'Mammoth Red Rock', 'Chieftain Savoy', and 'Perfection Drumhead Savoy'
- **Cauliflower:** 'Snowball A' (some resistance)
- **Collards:** 'Cascade Glaze' and 'McCormack's Green Glaze'
- **Kale:** 'Vates' and varieties with the green glaze leaf (in development)
- **Mustard:** 'Southern Giant Curled'

Control measures for harlequin bugs:

In small plantings consisting of a few plants, they may be controlled by hand picking. The best prevention is early scouting and use of insect-resistant varieties. Several varieties of collards and kale are quite resistant due to the glaze leaf characteristic. Breeding programs should focus on incorporating the glaze leaf characteristic into other brassicas. Natural pyrethrum or other approved botanicals may be used provided documentation of lack of alternatives is provided. Varieties with reported natural resistance include:

- **Broccoli:** 'Atlantic'
- **Cabbage:** Copenhagen Market', 'Early Jersey Wakefield', 'Perfection Drumhead Savoy', and 'Stein's Flat Dutch'
- **Cauliflower:** 'Early Snowball Y' and 'Early Snowball X'
- **Collards:** 'Cascade Glaze' and 'McCormack's Glaze'
- **Kale:** Varieties with the green glaze leaf (in development)
- **Mustard:** 'Old Fashion' (some resistance)

DISEASES

Any disease that affects cabbage can also affect other brassicas to a greater or lesser degree. Prevention plays a key role in controlling diseases, and the most basic steps involve proper management of insect pests, good soil nutrition and growth management, composting crop residues, removal, destruction of diseased material through burial, and crop rotation. It is important that cole crops not be grown in soil that has grown any member of the cabbage family for two to three years previously. The major diseases that can affect seed growers in the Mid-Atlantic and South are discussed here.

- **Alternaria leaf spot (*Alternaria brassicae and A. brassicicola*):** This fungus disease is common to all brassicas. Also called black leaf spot, symptoms appear chiefly as small, concentric spots with brown-black rings on the lower leaves. Spots may grow to nearly ½" size during favorable weather. The fungus over-winters in seed and plant residues.

- **Yellows (*Fusarium oxysporum* f. sp. *conglutinans*):** Also called "cabbage yellows" because it is most severe on cabbage, the causative organism is a soil fungus. It can persist in the soil for many years and is favored by high soil temperatures. Symptoms first appear as a yellowing of lower leaves, followed by progressive wilting and loss of lower leaves one by one, and finally plant death. One diagnostic feature is the presence of black vascular tissue.

- **Black rot (*Xanthomonas campestris* pv. *campestris*):** Black rot is a bacterial disease carried on the seed and on crop residues. On older plants, symptoms appear initially as v-shaped yellow areas along the outer leaf edges. As the disease progresses it moves from the leaf margins to the base of the plant, the yellow areas turning brown and the veins turning black. Plants are stunted, lower leaves drop, and the diseased areas are invaded by soft rot. Young seedlings show a different pattern — they yellow and die.

- **Bacterial soft rot (*Erwinia* and *Pseudomonas* species):** Bacterial soft rot is caused by several species of bacteria, most commonly *Erwinia carotovora*. The bacteria colonize plants as a consequence of wounding during cultivation, or from damage caused by insects or other diseases. Symptoms initially appear as water soaked areas that turn soft, decay, liquefy, and emit a distinctive foul odor. Hot wet weather promotes disease development. Burying crop residues and rotating with a grain crop will reduce bacterial populations.

- **Downy mildew *(Peronospora parasitica)*:** Downy mildew is caused by a fungus that is promoted by cool, wet weather in the spring and fall. Symptoms first appear as small irregular yellow leaf spots on the upper leaf surface. A gray mold develops on the underside of the leaves. During wet weather, the mold appears downy white. The vascular tissue may be invaded and discolored, setting the stage for invasion by bacterial soft rot. The disease can cause large losses in seedbeds.

- **White rot (*Sclerotinia sclerotiorum*):** White rot (also called white mold or white blight) is a soil-borne fungal disease. Symptoms first appear as water-soaked spots that enlarge into long, irregular-shaped areas covered by white-cottony mold. The disease is typically first seen on the stalk, base of petioles, or leaves closest to the ground. The lesions may girdle the stalk, causing it to break. A diagnostic sign is the presence of elliptical black sclerotia (fungus spore-bearing structures) which vary from 1/8" to ½" in length.

- **Black leg (Leptosphaeria maculans):** Black leg is a fungal dry rot. Symptoms first appear as black round spots. As the disease progresses, the spots enlarge becoming grayish-tan in color punctuated with small black pycnidia (tiny black spore cases) which are diagnostic of the disease. The stem may become constricted at the soil line.

- **Wire stem (Rhizoctonia solani):** This is the fungus that commonly causes damping off of seedlings and causes dry rot of the stem just below the soil line. It is common in most soils, and is encouraged by damp conditions with poor air circulation.

- **Club root (*Plasmodiophora brassicae*):** Caused by a fungus, club root causes leaf wilting and yellowing, especially during especially during hot, sunny days. The diagnostic symptom is the formation of spindle-like galls on roots. Germination of the spores of this soil-borne disease is favored by a soil pH of 7.2 or less. Spores may persist in the soil for at least seven years, and infected soil may be essentially unusable for brassica crops. Control can be achieved by keeping the soil slightly alkaline.

Control measures for diseases:

Many disease problems (especially soil-borne diseases) can be prevented or managed by use of disease-free seed and disease-free transplants, rotation of brassica crops with non-brassica crops for a minimum of two to three years, burying or destroying infected crop residues, controlling insects that damage plants, removing wild brassicas that serve as disease hosts, sanitation of tools and equipment that have come into contact with diseased plants, and use of tolerant or resistant varieties. Interestingly, there is a loose association between insect resistance and disease resistance in some (but not all) varieties. This is no accident. The correlation is based on the fact that plants injured by insects have opened the doors to opportunistic colonization by disease organisms. Also, certain insect-resistant varieties are resistant by means of antibiosis, the production of phytochemicals that in addition to having biological affects against insects may have biological effects on certain disease organisms.

Seed-borne diseases:

Organic growers can control seed-borne diseases by using hot water treatment of seed. A full discussion of this technique is covered in the companion volume in this series: "Seed Processing and Storage." Other organic seed treatments are available at www.growseed.org/seedtreatments.html.

SELECTED BIBLIOGRAPHY AND LITERATURE CITED

Ashworth, Suzanne 1972. Seed to Seed: Seed Saving and Growing Techniques for Vegetable Gardeners. Seed Savers Exchange, Decorah, IA.

Briggs, F.N. and P.F. Knowles. 1977. Introduction to Plant Breeding. University of California, Reinhold Publishing Corporation, NY.

Deppe, Carol 2000. Breed Your Own Vegetable Varieties. Chelsea Green Publishing, White River Junction, VT.

Free, John B. 1970. Insect Pollination of Crops. Academic Press, NY.

Haig, J.C. 1956. Plant breeding report. National Vegetable Research Station Report. 4: 10-13.

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

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

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

McGregor, S. E. 1976. Insect Pollination of Cultivated Crop Plants. Agricultural Handbook No. 496, U.S. Department of Agriculture. Washington, DC.

Schery, Robert W. 1972. Plants for Man. (2nd ed.). Prentice-Hall, Englewood Cliffs, NJ.

Yepson Jr., Roger B (ed.). 1976. Organic Plant Protection. Rodale Press, Emmaus, PA.

WORLD WIDE WEB RESOURCES

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

Mississippi State University: Commercial Production of Cabbage
http://msucares.com/pubs/infosheets/is1513.html

Ohio State University: Vegetable Seed Production – "Dry" Seeds
http://www.ag.ohio-state-edu/~seedsci/vsp02.html

Michigan State University: Vegetable Production and Management
http://www.rec.udel.edu/veggie/kee/colecrops.htm

CREDITS

Front matter illustration is from McGregor, 1976 (page 166).