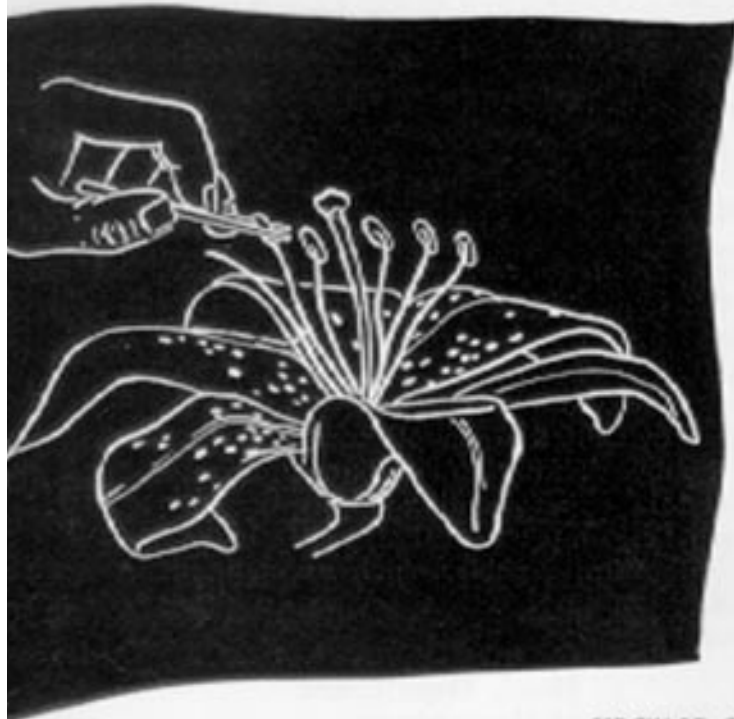


FRENCH
Plant Breeding
Diversity
The importance of genetic diversity in plant breeding is often overlooked. It is the raw material from which new varieties are developed. Without it, the process of plant breeding would be impossible. This is why plant breeders often look to wild relatives of their crops for new sources of genetic variation. The process of plant breeding is a complex one, involving the selection of parent plants, the crossing of these parents, and the selection of the best offspring. It is a process that requires patience and a deep understanding of the genetics of the plants being bred.



Plant Breeding as a Hobby



CIRCULAR 817

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
COLLEGE OF AGRICULTURE COOPERATIVE EXTENSION SERVICE

PLANT BREEDING AS A HOBBY

Breeding plants to create new varieties and improve upon old ones is a hobby that nearly everyone can engage in. The crossing techniques are easy to learn and you can experiment with many kinds of plants. Generally, amateur plant breeders work with traits that are fairly easy to change—for example, flower color, fruit shape, or plant size. Nevertheless, although your experiment may be simple, it is possible for you to produce unusual or beautiful plants.

In order to breed plants successfully it is important to understand the principles of plant reproduction. The purpose of this circular is to explain these principles and to describe some of the simple techniques that you can use to produce new varieties or strains of plants.

Plant Selection

Plant characteristics can be changed after many generations by a process of selection. There are two types of selection—natural and artificial.

Natural selection is the process that occurs in nature whereby strong and well-adapted plants survive while weak and poorly adapted plants eventually die out. This process has taken place since the beginning of life on earth and it is still occurring in nature.

Artificial selection is the process that humans use to obtain more desirable types of plants. Thousands of years ago people learned that saving seed from the kind of plant they wanted to continue growing would increase the chances of getting a plant similar to the original. But our ancestors didn't know what their chances of success were nor did they understand the processes by which traits were changed or maintained. It wasn't until the eighteenth and nineteenth centuries that humans began to understand the laws of heredity and the processes of plant reproduction. Even today these fundamentals aren't completely understood. But enough is known so that we can select plants for breeding with considerably more assurance of success than our primitive ancestors did.

Fundamentals of Plant Reproduction

Kinds of reproduction

Plants reproduce in two ways—asexually and sexually.

Asexual, or vegetative, reproduction occurs without the fusion of germ (reproductive) cells. In garden plants, asexual reproduction occurs when a part of the plant is separated from the parent plant and develops into a complete plant, as when strawberries produce runners which take root and form new strawberry plants. Asexual reproduction can be brought about artificially by means of leaf cuttings, stem cuttings, root cuttings, etc. Plants that originate from asexual reproduction are usually identical to the parent plant.

Sexual reproduction involves the union of a male and a female germ cell. From this union a seed—and ultimately a new plant—is produced. Sexual reproduction is the most common type of reproduction for garden plants. The plants originating from sexual reproduction are often quite different from their parents and from each other. Because of this possibility for variation, sexual reproduction of plants is the method used by plant breeders in developing new strains and varieties.

Parts of the flower

Sexual reproduction of plants is carried on in the flower. The reproductive organs of the flower are the stamen and pistil (Fig. 1). A part of the stamen called the anther produces pollen grains, which contain male germ cells. At the base of the pistil is the ovary; it produces ovules, which contain the female germ cells. When the ovules are fertilized by the male germ cells, they develop into seeds in the ovary.

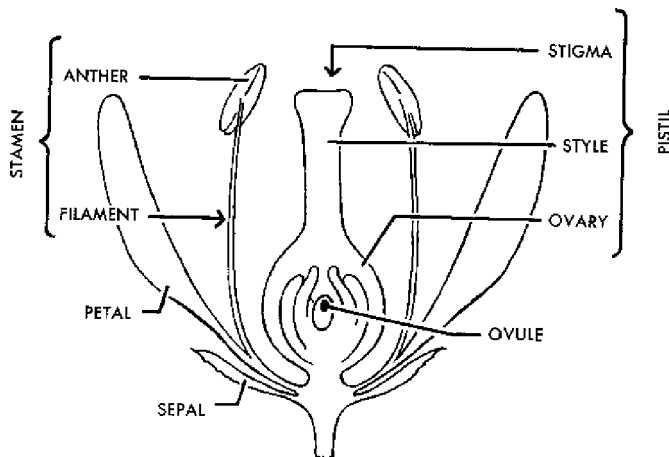
The petals, which add greatly to the beauty of flowers, serve such useful functions as aiding in pollination and protecting the sex organs from physical damage. The sepals, which often are green, cuplike structures, support the petals and protect the floral parts.

The flower parts vary greatly in size, shape, color, and number, but generally it is easy to distinguish the pistil from the stamens. You can identify the stamens by the yellow powder (pollen) on their tips and the pistil by a bulge (the ovary) at its base. On an unusual flower, however, it might require careful study to tell them apart.

Types of flowers

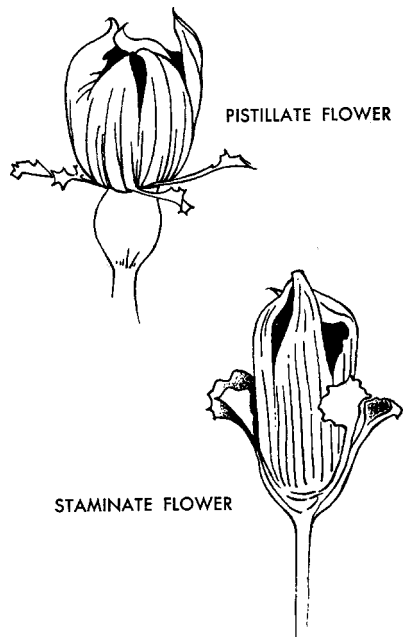
Usually a plant's reproductive organs are arranged in one of three ways—as a perfect flower, as an imperfect flower, or as a composite flower.

A **perfect flower** contains both stamens and a pistil (Fig. 1) It is the most common type of flower. Some common perfect flowers are those of tomatoes, morning-glories, snapdragons, petunias, lilies, and irises.



Parts of a flower. The flower shown here is a perfect flower; that is, it has male and female reproductive organs. The stamen is the male organ and the pistil is the female organ. (Fig.1)

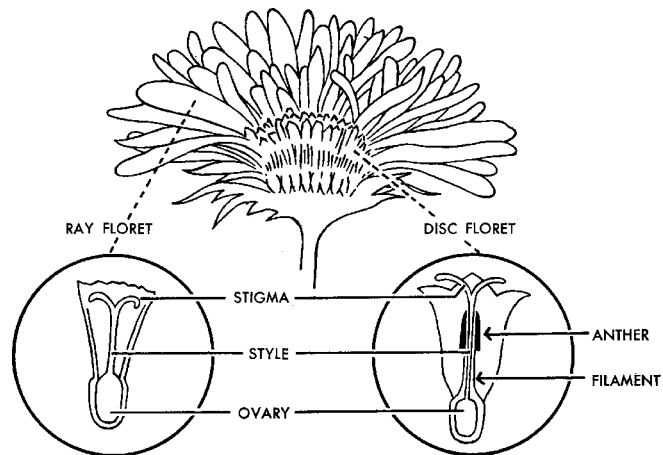
An imperfect flower (Fig. 2) contains only one type of sex organ. Those containing the pistil are called pistillate flowers; those containing stamens are called staminate flowers. Both pistillate and staminate flowers may grow on the same plant, or the staminate flower may be on one plant and the pistillate flower on another. Examples of plants with pistillate and staminate flowers on the same plant are squash, corn, clematis, bittersweet, and begonias. Plants with staminate and pistillate flowers on different plants include asparagus, spinach, willow, and cottonwood.



The flowers of squash are imperfect, each flower having only one type of sex organ. (Fig. 2)

A **composite flower** (Fig. 3) is actually a cluster of small flowers, called florets, joined together in what is called a flower head. The florets often resemble petals. Some florets have both stamens and pistils; they are called disc florets. Some have only pistils; they are called ray florets. A composite flower can be made up of only disc florets or of a combination of disc and ray florets. Typical composite flowers are zinnias, chrysanthemums, asters, and marigolds.

Cross section of a chrysanthemum. Composite flowers, such as chrysanthemums, are made up of clusters of florets. Some composite flowers have both ray and disc florets while some have only ray florets. (Fig. 3)



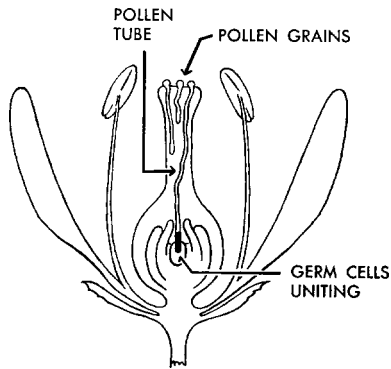
Pollination and Fertilization

Pollination is the transfer of pollen from an anther to a stigma. When the anther is mature it splits open and discharges the pollen. The pollen is then carried to the stigma by various natural means, the most common being wind and insects. In plant breeding, pollination is carefully controlled by humans.

There are two kinds of pollen transfer—cross-pollination and self-pollination. In cross-pollination the pollen is transferred from the anther of a flower of one plant to the stigma of a flower of another plant. In self-pollination the pollen is transferred from the anther to the stigma of the same flower or to another flower of the same plant.

Fertilization is the uniting of two germ cells. After the pollen has come to rest on the stigma, under favorable conditions the pollen develops a tube which grows downward through the style and into the ovule (Fig. 4). It is in the ovule that the male and female germ cells unite. Once fertilization has occurred development of the ovule begins. The result is a seed.

The parent flower that furnishes the pollen is called the pollen parent; the one that bears the seed is called the seed parent.



Fertilization takes place when the male and female cells unite in the ovule.
(Fig. 4)

Heredity

Plants inherit characteristics from their parents in the same way that animals do. The laws of heredity explain why different traits are inherited by offspring of the same parents. Moreover, these laws make it possible to predict the number of offspring that will inherit a certain trait. A knowledge of the laws of heredity is essential for effective plant breeding.

Genes. All cells contain genes, which are the units that determine the traits of a plant or animal. Except for the germ cells, each cell in a plant contains two genes for each trait—for example, for the trait of color a plant could have one gene for yellow and one for red. The germ cells have only one gene for each trait. Of the thousands of germ cells that a plant produces, about half have one of the genes for each trait and about half have the other gene.

When the male and female germ cells unite in the ovule each contributes one gene for each trait so that the new seed then has two genes for each trait. The various combinations of the many genes inherited from the pollen parent and from the seed parent determine the traits of the offspring and of future generations.

You can't tell by looking at a plant exactly what genes it contains. For example, a plant may have one gene for red and one for yellow, but only a red color may show in its flower; by looking at the plant you have no way of knowing about the gene for yellow. Nevertheless, the gene for yellow is present in the plant's cells and some of the plant's offspring will inherit this gene, which they in turn will pass on to their offspring. If the plant and its offspring are self-pollinated, in the first or second generations following, depending on how the genes interact, some of the offspring will produce yellow flowers. By observing the occurrence in the offspring of different colors (or other traits that you are interested in) you can find out what genes the parent plants have and how they interact. With this knowledge, your plant-breeding job will be greatly simplified.

If a plant that is self-pollinated produces offspring identical to itself, then it is said to breed true. If the first-generation offspring are not all identical to the parent plant, then it is said that segregation has occurred.

		Seed parent	
		R	R
Pollen parent	r	Rr	Rr
	r	Rr	Rr

Each square represents one seed of the F_1 generation. Each seed inherits a gene for red (R) from one parent and a gene for yellow (r) from the other.
(Fig. 5)

How genes interact. In the following discussion, we will assume that we have crossed two true-breeding plants, one having two genes for red-colored flowers and the other having two genes for yellow-colored flowers. The offspring of this cross are called the first filial or F_1 generation. Figure 5 illustrates the ways in which the genes of the pollen parent can combine with those of the seed parent. Each square represents one seed. In the diagram the letter R represents the gene for red color and the letter r represents the gene for yellow color. As shown in Fig. 5, each F_1 plant will inherit a gene for red from one parent and a gene for yellow from the other parent.

When the F_1 plants are self-pollinated, or “selfed,” their genes can combine in four different ways. Figure 6 illustrates the four possible combinations. The offspring resulting from the self-pollination of the F_1 generation are called the second filial or F_2 generation.

		Seed parent	
		R	r
Pollen parent	R	RR	Rr
	r	Rr	rr

When the F_1 plant is selfed segregation occurs, and the F_2 generation inherits traits in a 1:2:1 ratio (1 RR, 2Rr, 1rr).
(Fig. 6)

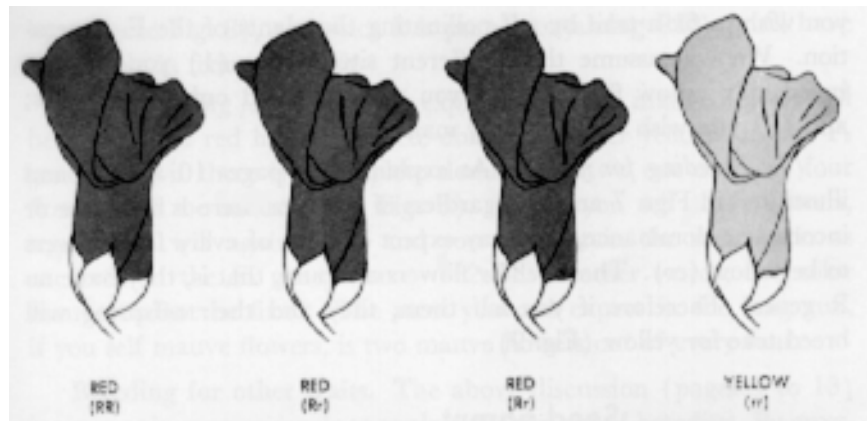
As shown in Fig. 6, out of every four seeds that are produced we may expect one seed that will have two genes for red (RR), two seeds that will have one gene for red and one gene for yellow (Rr), and one seed that will have two genes for yellow (rr). (This ratio, like all ratios concerning probability, is based on large numbers. If there are only a small number of seeds, the ratio may vary somewhat from the one given above. However, for large numbers of seeds, the above ratio will hold true.)

If a seed contains two genes for the same color, it is said to be pure for that trait and the resulting flower will show that color. For example, in Fig. 6 the seeds containing two genes for the color red (RR) will result in red flowers and the seeds containing two genes for yellow (rr) will result in yellow flowers. The seeds containing genes for both colors (Rr) may result either in flowers that are red or in flowers that are mauve (a shade halfway between red and yellow), depending on whether the gene for red has complete or incomplete dominance.

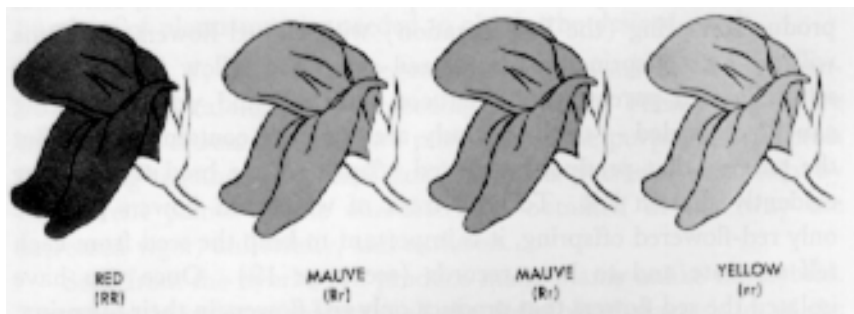
Complete dominance. Some genes are dominant and some are recessive. Whenever a dominant and a recessive gene for a particular trait occur in the same plant, the dominant gene will cause its character to show up in the plant to the exclusion of the recessive trait.

In Figs. 5 and 6, let us assume that red (R) is dominant and yellow (r) is recessive. Whenever an R occurs, even if an r also occurs, we can expect the flower to be red. In Fig. 5 (F₁ generation) all the seeds have an R gene; thus all the flowers will be red. In Fig. 6 (F₂ generation) R occurs in three of the squares; these three seeds will result in red flowers. The dominant gene R does not appear in the lower right square; therefore the recessive trait yellow will show in the flowers of this plant. Thus, for a large number of plants in the F₂ generation, where red has complete dominance over yellow the color ratio will be 3:1, that is, three red to one yellow (Fig. 7).

If red has complete dominance over yellow, then the seeds represented in Fig. 6 will develop flowers having a color ratio of 3:1—out of every four flowers, three will be red and one will be yellow.
(Fig. 7)



Incomplete dominance. Sometimes neither gene is dominant or recessive and when they occur in the same plant, they form an intermediate characteristic. If we assume incomplete dominance in Figs. 5 and 6, then wherever Rr occurs we can expect the flower to be mauve. An examination of Figs. 5 and 6 shows that in the F₁ generation all the flowers will be mauve while in the F₂ generation we may expect one red (RR), two mauve (Rr), and one yellow (rr) flower out of every four—a 1:2:1 ratio (Fig. 8).



If red has incomplete dominance over yellow, then the seeds represented in Fig. 6 will develop flowers having a color ratio of 1:2:1—out of every four flowers, one will be red, two will be mauve, and one will be yellow.
(Fig. 8)

Fixing a trait. Cross-pollination is usually necessary to develop new varieties. Once the trait that is desired is fixed, that is, the plant, when self-pollinated, breeds true for the trait, then all you have to do to continue obtaining that trait is to self the plant and its offspring. Sometimes a trait cannot be fixed and many plants may have to be grown in order to produce a few showing the desired trait.

Continuing to use Fig. 6 as an example, let us now assume that you wish to fix a trait by self-pollinating the plants of the F_2 generation. We will assume three different situations: (1) you wish to breed only yellow flowers; (2) you wish to breed only red flowers; and (3) you wish to breed only mauve flowers.

(1) *Breeding for yellow.* As explained above and illustrated in Figs. 7 and 8, regardless of whether there is complete or incomplete dominance, you may expect one out of every four flowers to be yellow (rr). These yellow flowers are pure, that is, they have no R genes. Therefore if you self them, they and their offspring will breed true for yellow (Fig. 9).

		Seed parent	
		r	r
Pollen parent	r	rr	rr
	r	rr	rr

When a purebred plant is self-pollinated, it breeds true; that is, the offspring are all identical to the parent and to each other. (Fig. 9)

(2) *Breeding for red.* If red is the *dominant* gene, the F_2 generation will produce three red flowers out of four, some of the red flowers containing Rr and some containing RR (see Fig. 7). The problem, then, is to isolate the ones containing RR , since they are the ones that will breed true. If you self all the plants with red flowers, some will produce offspring (the F_3 generation) with all red flowers and some will produce offspring with some red and some yellow flowers. The self-pollinated parents that produced both red and yellow offspring can be discarded—they obviously are the ones containing Rr . But the parents that produced only red offspring have bred true—they evidently contain RR . To keep track of which red flowers produce only red-flowered offspring, it is important to keep the seed from each self separate and to keep records. Once you have isolated the red flowers that produce only red flowers in their offspring, then all you need to do to continue obtaining red flowers is to continue selfing the parents or the offspring.

If red has incomplete dominance, only one out of four flowers will be red (see Fig. 8), and since it is pure (containing RR) you'll have no trouble in fixing the trait.

(3) *Breeding for mauve.* As explained earlier, mauve flowers will be obtained if red has incomplete dominance over yellow. In the F_2 generation, if there is incomplete dominance, two out of every four flowers will be mauve (see Fig. 8). When you self these flowers, segregation will again occur and you will obtain the same ratio as occurred in the F_2 generation—1:2:1. In other words, the color mauve cannot be fixed. The most you can expect in the long run, if you self mauve flowers, is two mauve flowers out of every four.

Breeding for other traits. The above discussion is given only as an example to explain the process of heredity. By crossing and selfing plants and observing the ratios of the traits that you are interested in, you can soon find out whether you are dealing with complete or incomplete dominance. (A 3:1 ratio in the F_2 generation usually indicates complete dominance; a 1:2:1 ratio, incomplete dominance.) You will then be able to tell whether or not it is possible to fix a trait.

You may wish to breed for more than one trait. Some traits that are often relatively easy to change are: yield, flower color, plant size, leaf size, fruit shape, and fruit size. With two genes for each trait in each parent, you will have to grow many offspring before one will appear with all the desired traits. Even if you are interested in replacing only one trait with a more desirable one, you may have to grow many plants in order to obtain one that shows the desired trait without showing any changes in other traits. Some characteristics, such as yield and fruit size, are governed by many genes, and vast numbers of plants may be needed to obtain the desired result.

Hybrids. F_1 hybrids of vegetables and flowers are often mentioned in seed catalogues and breeding programs. These varieties are the result of crosses between two pure lines. The purpose of the cross is to bring together in a plant desirable traits possessed separately by the parent plants. Some characteristics obtained in this way are increased vigor, uniformity, and earliness.

Seed from the hybrid will produce many plants unlike the hybrid. Therefore, in order to maintain all the desirable characteristics of the hybrid, the original parents are crossed each year. It is seldom worthwhile to save seed from the hybrid for commercial production, although it can be used in a breeding program.

General Breeding Techniques

Equipment

The equipment required for plant breeding is relatively inexpensive and easy to use. Here are some items that you may find useful:

- Magnifying glass (10 or 15 power)
- Tweezers
- Small sharp-pointed scissors
- Camel-hair brush
- Small containers or vials
- Alcohol
- Rubber bands or soft wire
- Paper or cellophane bags
- Paper clips
- Tags
- Notebook

When to breed

Prepollination steps generally should begin just before the flower opens. If you wait until after it opens, it may be pollinated by natural means, which would make the flower useless for experimentation. Since most plants bloom over a period of time, even if some of the flowers on a plant have bloomed before you have prepared them for breeding, there will probably be others that haven't opened yet and that you can still experiment with.

Extremely high temperatures or moist conditions are harmful to pollen. For best results you should pollinate plants on dry days during the cool hours of the morning or as soon as the anthers have split open.

Selecting the parents

Some plants have natural barriers to cross- or self-pollination. It is advisable to check for this before you begin breeding, for although you frequently can overcome these barriers, some plants cannot be artificially pollinated. An example of a barrier that can be overcome is the natural cross-pollination prohibitor of snapdragons; snapdragon flowers are constructed so as to prevent entry of wind-borne pollen from other flowers. It is possible, however, to open the flower by hand. An example of a barrier that cannot be overcome is the self-pollination prohibitor of some orchids; the stigmas of certain orchids produce a substance which kills the pollen of flowers of the same plant. The mechanism that performs this cannot be removed without destroying the pistil.

The plants you select for breeding should be sturdy and healthy. It is usually easier to tell which ones are healthy after a few flowers on the plant have bloomed.

In choosing a pollen parent, select one that has a heavy yellow powder on the anther. This powder is the pollen. If you brush your fingernail against the anther, a trace of pollen should adhere to your nail. A fresh flower is more likely to have healthier pollen than one that has started to wilt or dry out.

In choosing a seed parent, examine the stigma. It should have either a glistening substance on it that is sticky to the touch or a “hairy” surface. It is this substance or surface that retains the pollen, thus making fertilization possible.

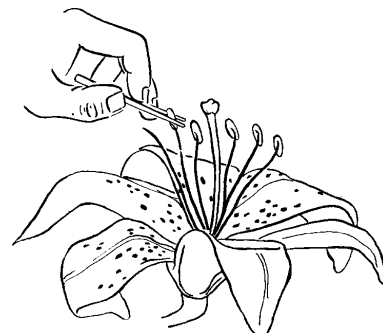
Once you have selected the pollen and seed parents, you are ready to begin pollination.

Prepollination steps

The first step is to mark those flowers that are to serve as pollen parents and those that are to serve as seed parents. This can be done with colored thread, one color for the male and another color for the female. Or you can use paper labels, covered with varnish to protect them from the weather. Some plant breeders use bands designed for marking chickens.

Your next step is to protect the plant from unwanted pollen. If the plant is to be cross-pollinated, the stamens will have to be removed to prevent the possibility of selfing. The removal of the stamen is called emasculation. It should be performed before the anthers split open to release pollen. This may require opening the flower by hand before it is ready to bloom. Emasculation can be accomplished by: (1) pinching off the stamens or anthers with tweezers (Fig. 10), or (2) snipping off the stamens or anthers with sharp-pointed scissors, or (3) removing the petals to which the stamens are sometimes attached. A magnifying glass will be particularly useful in emasculation.

*Emasculation is necessary to prevent self-pollination.
Remove all anthers or stamens.
(Fig. 10)*

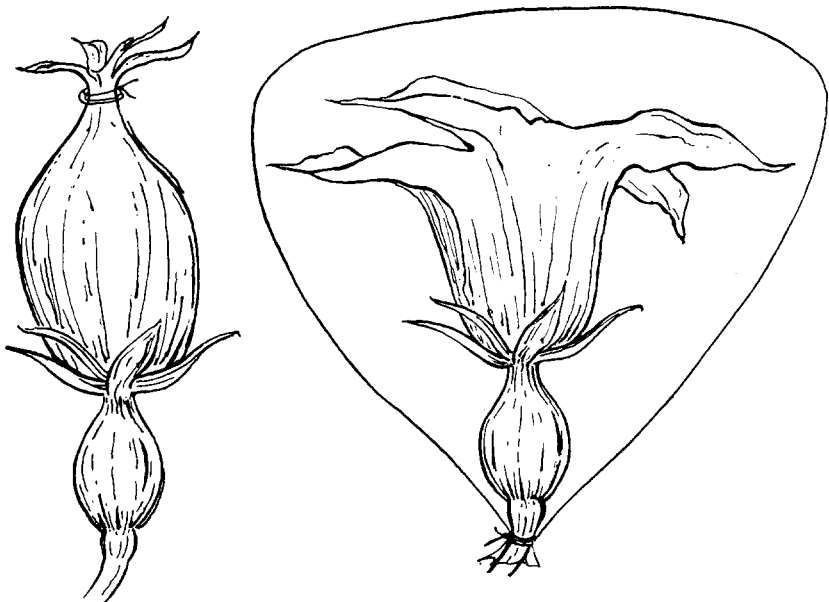


Both the seed and pollen parents should be protected from contamination by foreign pollen. This can be done by one of the following methods:

Closing the flower. In many flowers, such as morning-glories, petunias, and lilies, the petals can be closed around the floral organs with a piece of soft wire, string, or rubber band (Fig. 11) Care should be taken not to tear the petals.

Covering the flower. Some flowers, such as composite flowers, cannot be closed. To protect them from unwanted pollen, you can cover the flower with a paper bag. Or, if you wish to observe the flower at all times, you can cover it with a cellophane bag. The bag should be held securely in place with a paper clip or string (Fig. 11).

To protect the flower from unwanted pollen, close it with a string or soft wire (left) or cover it with a bag (right). A cellophane or plastic bag will permit you to observe the flower at all times. (Fig. 11)



Flowers that are to be self-pollinated should likewise be protected from foreign pollen by either closing or covering the flower.

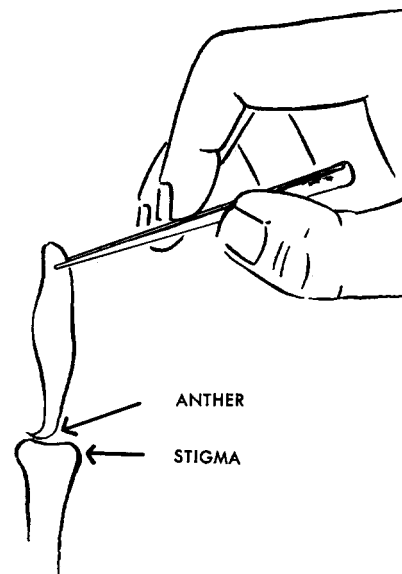
If the plant is grown indoors there is little likelihood of contamination by foreign pollen and you do not have to cover or close the flower. However, indoor as well as outdoor plants require emasculation to avoid self-pollination.

Pollination steps

Crossing. There are several methods that can be used for crosspollinating flowers. Here are four of the most common methods:

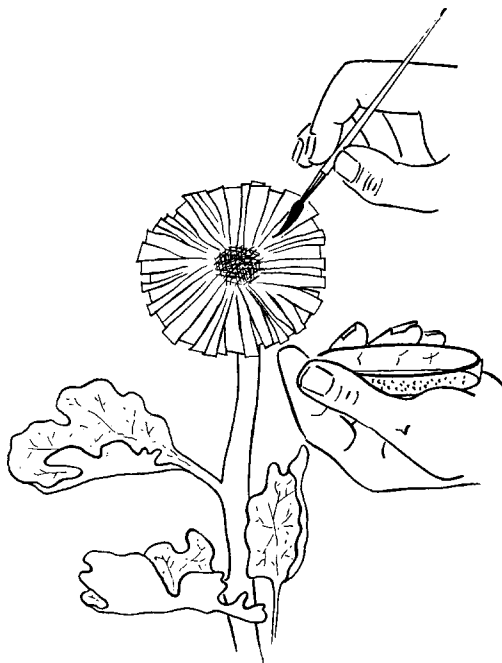
(1) Remove the stamens from the pollen parent with tweezers. Place the stamens in a small container. Remove the protector from the seed parent. Holding a stamen with the tweezers, gently brush the anther across the stigma (Fig. 12). Replace the protector.

One way to cross-pollinate is to remove the stamens from the pollen parent and then, holding a stamen with tweezers, brush the anther across the stigma of the seed parent. (Fig. 12)



(2) Cut the flower that is serving as the pollen parent. Remove the protector from the seed parent. With tweezers remove a stamen from the pollen parent and brush an anther gently across the stigma of the seed parent. Replace the protector.

(3) With a camel-hair brush, transfer the pollen from the anthers of the pollen parent into a small container. Remove the protector from the seed parent and brush the pollen across the stigma (Fig. 13). Replace the protector.



If the stamens are too small or too difficult to grasp, you can cross-pollinate by transferring the pollen from the anthers with a brush into a container and then brushing the pollen onto the stigma. (Fig. 13)

(4) Shake the bagged pollen parent so that the pollen is collected in the bag that is covering it for protection. Remove the bag from the pollen parent, being careful not to spill the pollen. Remove the protector from the seed parent and place the bag containing the pollen over the seed parent and shake the bag so that pollen falls on the stigmatic surfaces. This is usually done on corn.

Each time you use different pollen, be sure to first wash with alcohol the camel-hair brush, tweezers, and any other item which might have touched some pollen. This step is very important to prevent pollination of the seed parent with unwanted pollen that has adhered to the equipment. After you wash the instruments be sure that they are dry before using them again.

Selfing. Procedures for self-pollinating flowers will depend on the type of flower. For perfect flowers, your job is done once you have closed or covered the flower, although you can sometimes help the pollen land on the stigma by shaking the flower once a day for several days after the pollen develops.

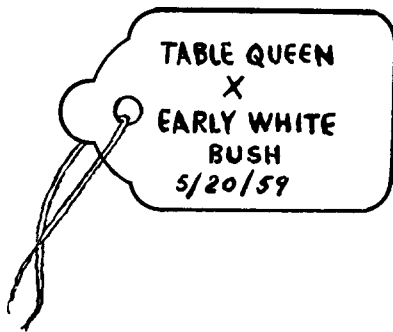
Only those composite flowers containing both disc and ray florets can be self-pollinated. Since they have both pistils and stamens, they can be selfed in the same way as perfect flowers.

With imperfect flowers, you will be able to self only those flowers that are on the same plant. In selfing imperfect flowers, the pollen from the staminate flower must be transferred to the stigma of the pistillate flower on the same plant. To do this you can use any of the methods given above for cross-pollination.

Postpollination steps

Immediately after pollination, close or cover the flower again. The next step is to label the seed parent. The standard method of labeling is as follows:

1. Write on the label in the following order: (a) the number that you have assigned or the variety name of the seed parent; (b) the letter X; (c) the number or variety name of the pollen parent; and (d) the date the cross was made (Fig. 14).



Each pollinated flower should bear a label containing the name of the seed parent, the letter X (to signify a cross), the name of the pollen parent, and the date of the cross. (Fig. 14)

2. Attach the label to the stem just below the flower that has been pollinated.

Once the seed parent is labeled, your next step is to record the cross or self in a notebook. Keeping complete and accurate records of your breeding operations is very important. The information that you record should contain all essential facts regarding the cross or self so that you can refer to it at a later time and even do the job again from the beginning if necessary.

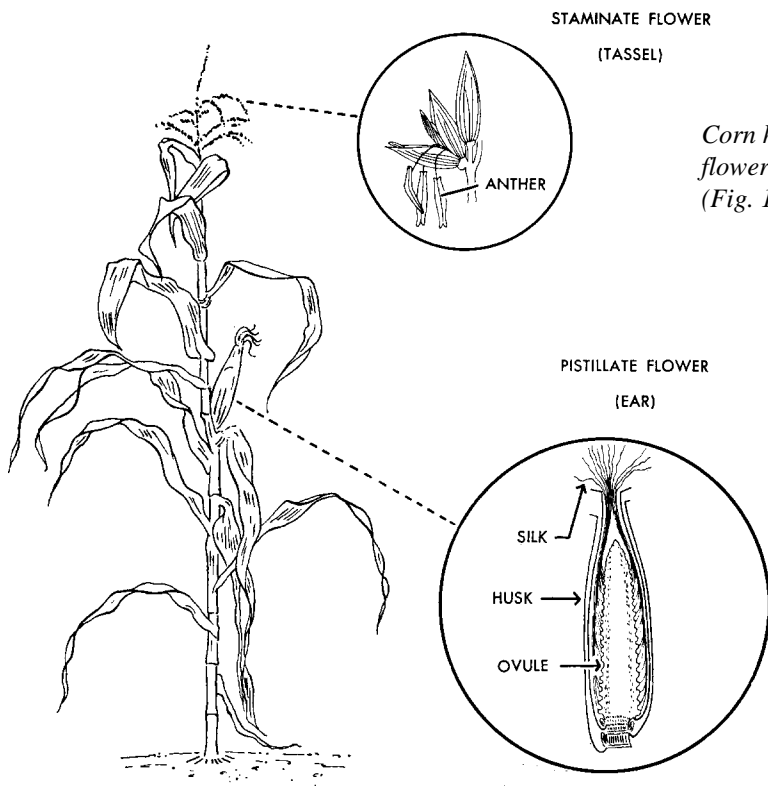
A separate form or page should be used for each cross or self that you make. An easy way to keep track of the offspring is to assign consecutive numbers to each generation resulting from each cross or self.

Breeding Experiments for You to Try

The following crops have been selected to serve as examples of the various types of flowers encountered in plant breeding—perfect, imperfect, and composite. The techniques suggested here, with slight modifications, can be used for crossing other plants having similar flowering systems.

Corn

Corn is a good plant for the amateur plant breeder to experiment with because it is easy to work with and often shows visible changes in the kernels of the F_1 generation. Some of the varieties that you can work with are yellow field corn, white field corn, sweet corn, popcorn, calico corn, and strawberry corn.



Corn has an imperfect flower. The staminate flower is the tassel and the pistillate is the ear. (Fig. 15)

Corn has an imperfect flower, with both staminate and pistillate flowers on the same plant (Fig. 15). The staminate flower is the tassel; the pistillate flower is the ear. The silk, which has a hairy surface throughout most of its length that is receptive to pollen, is the corn's stigma.

Procedure:

1. Decide on the varieties of corn that you wish to cross and plant the seeds in your experimental area. You can work with as many varieties as you wish, but if this is your first experiment it will be best to limit yourself to three or four. Corn tassels lose their pollen in a relatively short time, so in order to have the pollen of the different varieties ready at about the same time, plant a few seeds of each variety weekly over a period of weeks. Mark the rows for future reference.

2. As soon as the plants develop ear shoots and before the silks emerge, cover the shoots with a loosely fitted bag secured at the bottom with a paper clip or string. A clear plastic or glassine bag will allow you to watch the silks develop. Cover several ear shoots, for the more that are pollinated the greater your chances of getting desired results.
3. Keep a close watch on the ears. When the silks are visible the ear is ready for pollination. The appropriate tassel should then be bagged for use the next morning. The bag should be secured tightly at the base of the tassel to keep the pollen from falling out and to keep it from becoming contaminated with other pollen.
4. The following morning shake the bagged tassel vigorously to loosen the pollen. Remove the bag from the tassel, bending the tassel downward to prevent pollen from spilling out (Fig. 16).



*When collecting corn pollen, bend the tassel downward to prevent the pollen from spilling out of the bag.
(Fig. 16)*

5. Remove the bag covering the silk. Place the bag from the tassel over the ear, being careful not to spill any pollen. Secure the bag to the stalk below the ear and shake (Fig. 17).

*Place the bag containing pollen on the ear of the corn, secure the bag to the stalk below the ear, and label the pollinated ear.
(Fig. 17)*



6. Label each of the ears that have been pollinated with the name or number of the plants that are serving as seed and pollen parents and enter the cross in your record book.

7. Leave the bagged ear on the plant until the leaves dry. After the pollinated ear has dried, record any changes that may have occurred in the kernels. Then harvest the kernels and save them for future planting.

Squash

The flowers of squash are large and easy to work with. The flowers are imperfect, with both the male and female flowers on the same plant. The pistillate flower is enlarged at the base while the staminate flower is borne on a long stem (see Fig. 2).

Although some varieties of squash are cross-sterile, that is, they cannot be crossed, many others can be crossed. It is also possible to cross some varieties of pumpkin and squash.

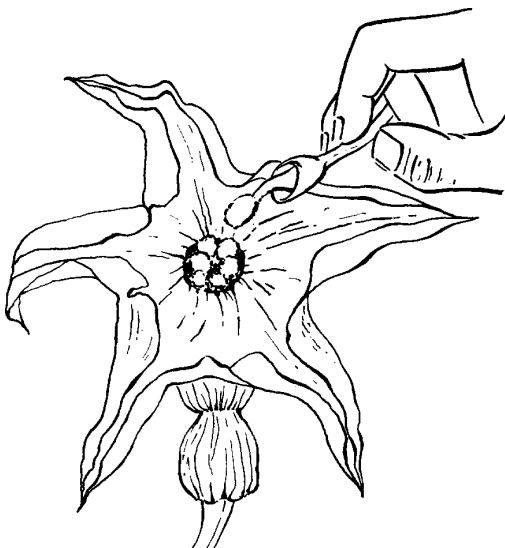
Remember that if you are crossing pure varieties, segregation won't occur until the F_2 generation; that is, the various colors and shapes that the offspring have inherited will not all show up until the offspring are self-pollinated and the seeds that they produce bear fruit.

Procedure:

1. Plant the different varieties of squash. Label the rows so that you will know which plants are to be seed parents and which are to be pollen parents. You won't have any difficulty in having the male and female parents ready for pollination at the same time, for squash produces flowers over a relatively long period.

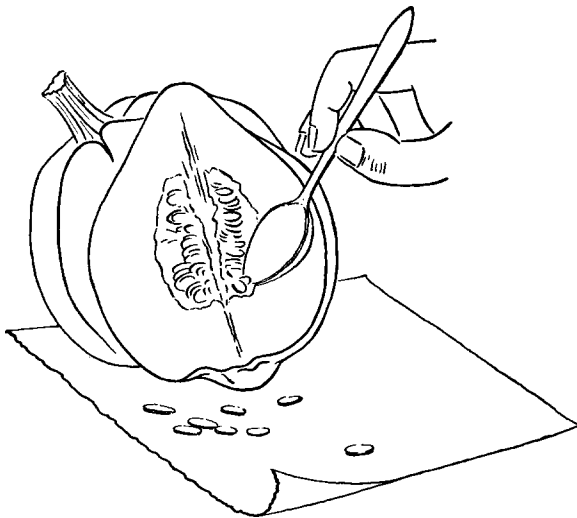
2. The evening before the flowers open, place a bag over them or close the flowers with rubber bands or string (see Fig. 11). It is easy to tell in the evening which flowers will open the following morning. The flowers will be slightly open, revealing the inner color, which is brighter than the color on the outside of the petals. Both pistillate and staminate flowers should be protected, to prevent bees from entering.

3. Early in the morning on the day that the flowers open, remove the stamens from the staminate flower and gently rub the anthers across the stigma of the pistillate flower. (Fig. 18.)



To pollinate squash, gently rub the anther across the stigma of the pistillate flower. (Fig. 18)

4. Replace the bag on the pistillate flower.
5. Label the pollinated pistillate flower and, enter the cross in your record book.
6. You can remove the protective covering when the petals have dried on the pistillate flower or when the ovary bulges through the bag.
7. Harvest the seeds when the fruit is mature (Fig. 19). Maturity is usually reached about 45 days after pollination. Save the seeds until the next year, when you will (1) plant them, (2) self-pollinate the resulting flowers, and (3) again harvest the seeds. The year after that, when you plant the seeds resulting from the self-pollination of the F generation, segregation will probably occur.



*Harvest the squash seeds and save them for planting next year.
(Fig. 19)*

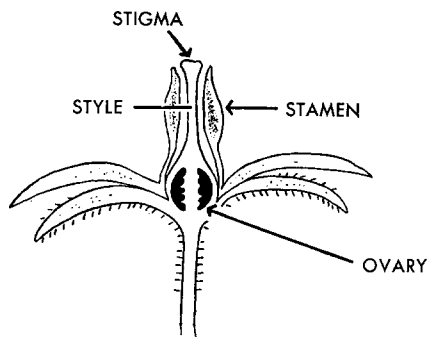
Tomatoes

The tomato has a perfect flower, with male and female organs both within the same blossom (Fig. 20). The sex organs are easy to tell apart and therefore it is relatively easy to cross tomatoes.

For this experiment, choose tomatoes with two different fruit colors, such as red and yellow. If the tomatoes are pure, variations in color will show up in the F₂ generation. Along with color variations, there will probably be changes in fruit shape and other plant characteristics.

Procedure:

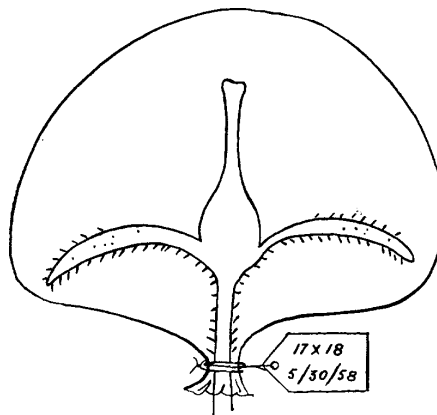
1. Plant the seed or young plants and label the rows so that you will know which will bear red fruit and which will bear yellow fruit. The tomato produces flowers for several weeks, so there will be no difficulty in having pollen and seed parents ready at the same time.
2. As soon as the flowers that will serve as seed parents begin to open, the plant should be emasculated. The stamens are fused to the petals, so all you need to do to emasculate the plant is to pull out the petals.



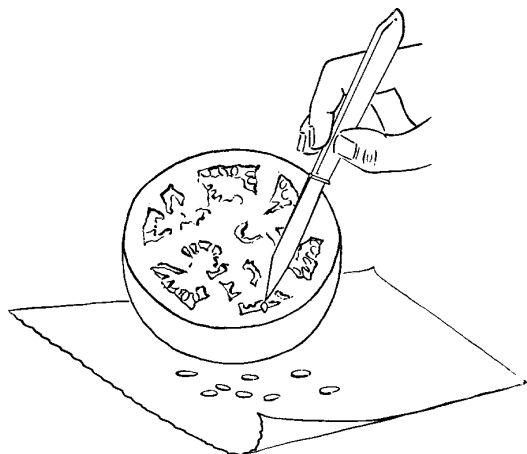
*The reproductive parts of the tomato.
(Fig. 20)*

3. After you remove the stamens from the seed parents, cover the flowers securely.
4. The pollen parents that you wish to use should be in the same stage of opening as the seed parents. Cover the pollen parents at the same time that you cover the seed parents.
5. As soon as the pollen-parent flower is completely open, remove one of its stamens with scissors or tweezers. Remove the bag from the seed parent and gently brush the anther across the stigma.
6. Replace the bag that was removed from the seed-parent flower.
7. Label the flower that was pollinated (Fig. 21) and enter the cross in your record book.

*A tomato flower that has been
emasculated, pollinated, and labeled.
(Fig. 21)*



8. After a week remove the bag from the seed parent and leave it off.
9. When the fruit is ripe, harvest and store the seeds for future planting and self-pollination (Fig. 22).



*Harvest the tomato seeds and save them
for planting next year.
(Fig. 22)*

Chrysanthemums

Chrysanthemums are composite flowers. If they are not available for crossing, you can use any other composite flower, such as zinnias or asters. Composite flowers are more difficult to cross than complete or incomplete flowers. If you are crossing plants for the first time, it would probably be best if you gained experience by first crossing a simpler flower, such as squash, iris, or lily, before trying to cross composite flowers.

Procedure:

1. Plant the seeds or young plants. Mums, zinnias, and asters bloom over a relatively long period, so there will be no difficulty in having pollen and seed parents ready at the same time.
2. Immediately after the seed-parent flowers open and before the pollen is mature, remove the disc florets with tweezers. As shown in Fig. 3, the disc florets are in the center of the flower. They are easy to identify because they are often yellow in color and they have both pistils and stamens, whereas the ray florets, which surround the disc florets, have only pistils. Remove some of the ray florets near the center of the flower just to be sure that you haven't missed any of the disc florets. If any disc florets are left on the flower, the flower is likely to be self-pollinated (Fig. 23).



*When emasculating chrysanthemums, make sure that you remove all of the disc florets.
(Fig. 23)*

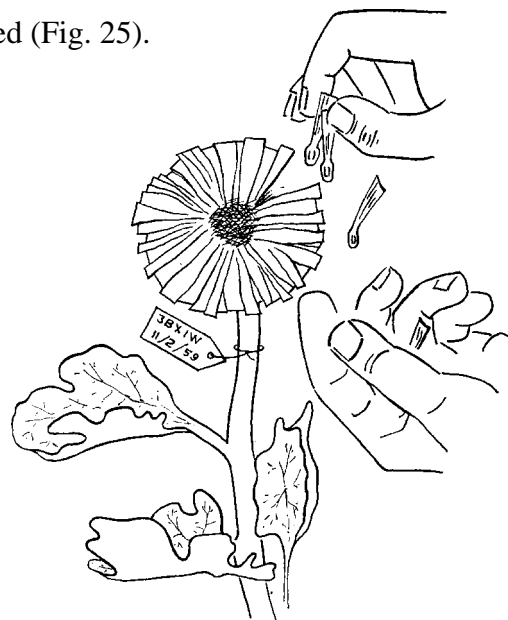
3. After removing the disc florets, cover the seed-parent flowers with bags.
4. As soon as the flowers of the pollen parents open, cover them with bags.
5. Pollination will be more effective if you trim the ray florets on the seed parents to just above the stigmas. This step can be done at any time after the disc florets are removed and before pollination takes place (Fig. 24).



*Trim the ray florets for more effective pollination.
(Fig. 24)*

6. The flower is ready for pollination about four or five days after it opens. Shortly before you pollinate the flower, dip a camel-hair brush in alcohol and allow it to dry.
7. Remove a flower from the pollen parent. With the camel-hair brush, gently brush the disc florets of the pollen-parent flower. The pollen should adhere to the brush. Then gently brush the trimmed ray florets of the seed-parent flower (see Fig. 13). Each time you change pollen parents dip the brush in alcohol and let it dry.
8. Replace the protective bags on the seed and pollen parents.
9. Label the pollinated flower and enter the cross in your record book.
10. Three or four days later, repeat step 7. Be sure to use the same pollen parent that you used the first time. Replace the bag on the seed parent.
11. Remove the bag from the seed parent about a week after the final pollination.
12. After the seed head has dried, harvest and store the seed (Fig. 25).

*Each mature ray floret will have a seed. Harvest these seeds and plant them next year.
(Fig. 25)*



Helpful Books

For further information on plant breeding the following books may prove helpful:

Practical Plant Breeding, W. J. C. Lawrence, George Allen and Unwin Ltd., London, 1951.

1937 Yearbook of Agriculture, U. S. Department of Agriculture.

Simple, Practical Hybridising for Beginners, D. Gourlay Thomas, John Gifford, Ltd., London, 1957.

Plant Breeding for Everyone, John Y. Beaty, Charles T. Branford Co., Boston, 1954.

The Genetics of Garden Plants, M. B. Crane and W. J. C. Lawrence, Macmillan Co., London, 1952.

Handbook on Breeding Ornamental Plants, Brooklyn Botanic Garden, Brooklyn, N. Y., 1959.

Plant Breeding and Cytogenetics, Fred C. Elliott, McGraw-Hill Book Co., New York, 1958.

Methods of Plant Breeding, H. K. Hayes, F. R. Immer, and D. C. Smith, McGraw-Hill Book Company, New York, 1955.

General Genetics, Adrian M. Srb and Ray D. Owen, W. H. Freeman and Co., San Francisco, 1952.

Vegetable and Flower Seed Production, Leslie R. Hawthorn and Leonard H. Pollard, The Blakiston Co., New York, 1954.

Vegetable Growing, James S. Shoemaker, John Wiley and Sons, New York, 1947. (Chapter 1 contains information on harvesting seeds.)

Explanation of Terms

Anther: The part of the stamen that develops and bears pollen.

Composite flower: A cluster of small flowers joined together in a flower head, having either pistils only or both pistils and stamens.

Cross-pollination: Transfer of pollen from the anther of a flower to the stigma of a flower of another plant.

Disc floret: small flower in a composite flower, having stamens and a pistil. Emasculation: Removal of stamens or anthers to prevent selfpollination.

F₁, F₂, etc.: Designation of generations of plants. F₁ is the first filial generation, F₂ the second, etc.

Gene: The unit that carries hereditary traits.

Germ cell: The reproductive cell which, when united with a germ cell of the opposite sex, develops into a new individual.

Imperfect flower: A flower having stamens or pistil, but not both.

Ovary: The enlarged base of the pistil in which the seed develops.

Perfect flower: A flower having both stamens and a pistil.

Pistil: The female reproductive organ, which produces female germ cells and bears the seed. Usually a pistil has an ovary, a style, and a stigma.

Ray floret: A small flower in a composite flower, having a pistil but no stamens.

Self-pollination: Transfer of pollen from the anther of a flower to the stigma of the same flower or of another flower on the same plant.

Stamen: The male reproductive organ, which produces male germ cells, carried in pollen grains.

Usually a stamen has a filament and an anther.

Stigma: The surface of the pistil on which pollen grains are deposited in the process of pollination.

Style: The usually elongated portion of the pistil connecting the stigma and ovary.

This circular was prepared by J. D. BUTLER, Assistant Professor of Horticulture, and N. F. OEBKER, formerly Associate Professor of Horticulture. The authors express appreciation to the following persons for their help in preparing this circular: D. F. DAYTON, Professor of Plant Breeding; G. M. FOSLER, Instructor in Floriculture; and R. W. HEPLER, formerly Research Associate in Horticulture.

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