Sunflower

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The cultivated sunflower \textit{Helianthus annuus} var. \textit{macrocarpa} (DC.) Ck11.] is one of the four most important annual crops in the world grown for edible oil. There is archaeological evidence that the present sunflower with a single head was grown in the prehistoric North American Indian culture and may have been domesticated before the introduction of corn \textit{(Zea mays L.)}. The Indians used the crop as a source of food. Early Spanish explorers introduced the plant to Europe where it was largely used as an ornamental.

Extensive use of sunflower as a source of edible oil began in 1830 after the crop reached Russia. The sunflower has become the main source of edible oil in the USSR, other eastern European countries, and Argentina. The crop was re-introduced to North America from Europe in the late 19th century with initial interest being its use as silage. Commercial extraction of oil began in 1946 in Manitoba when Canada promoted it as an oilseed crop. Some of the crop grown in North America is for confectionery and birdfeed purposes.

In the last 10 to 15 years, production increased greatly in some other countries, including the United States where plantings in 1977 were approximately 1,000,000 ha. Much of the stimulus in the United States has been due to the importation of Russian germplasm with oil content consistently above 40\%, and the discovery of a cytoplasmic male sterile and fertility restorer system which is used to produce hybrid seed. The introduction of hybrid seed has improved the yield and uniformity of the crop, as well as disease resistance.
I. PARENTAL MATERIAL

The genus *Helianthus* comprises over 100 species but about 50 species found in North America have been studied in more detail. Considerable differences of opinion exist as to the classification and grouping of the *Helianthus* species. Heiser (1965) pointed out three distinct groups in the genus: (1) North American annuals and tap-rooted perennials; (2) North American herbaceous perennials, mostly rhizomatous; and (3) South American, more or less shrubby perennials. More recently, Heiser et al. (1969) delineated the second group into western perennials or Ciliaries and eastern perennials or Divaricati.

Not all possible hybrid combinations have been made among the species in the genus. Most of the species in the first group can be crossed with *H. annuus*, a member of the same group, but the seed set is usually low. The percentage seed set and germination may depend on the species used as female.

*H. annuus* itself is a highly variable species. Wild *H. annuus* is abundant, particularly in north central U.S. It crosses readily with the cultivated *H. annuus* and creates a problem of contamination for hybrid seed producers. Wild *H. annuus* is usually taller than the cultivated sunflower with profuse branching. It has been a source of genes for fertility restoration, and for rust and Verticillium resistance. The haploid chromosome number of *Helianthus* species is 17 or multiples of it. Both the cultivated and wild *H. annuus* are diploids with chromosome number (n) of 17.

A widely exploited cross has been *H. annuus* with *H. tuberosus* L. (Jerusalem artichoke). The latter is a hexaploid, perennial species which is grown occasionally for its tubers. The initial cross can be achieved easily and sometimes occurs naturally, but backcrosses using *H. annuus* as the recurrent parent are more difficult to obtain. Pustovoit and Pustovoit (1972) reported successful backcrosses by exposing the F₁ hybrids to thermal shock during meiosis.

*H. petiolaris* Nutt., an annual, diploid species, has been crossed by *H. annuus* (LeClercq, 1969). Progeny of the cross revealed a cytoplasmic male sterility system which is presently exploited on a commercial scale to produce sunflower hybrids. *H. petiolaris* closely resembles wild *H. annuus*, but can be distinguished by a white deposit on its face. Mature heads of *H. petiolaris* which have dispersed their seed have lighter colored chaff than those of *H. annuus*.

Other annuals species that cross readily with cultivated *H. annuus* are *H. argophyllus* and *H. paradoxus*. These species are being investigated by American breeders as a possible source of insect resistance (Fick et al., 1976). Two diploid species occurring frequently in the North American plains, *H. maximiliana* Schrad. and *H. giganteus* L., have been crossed to cultivated *H. annuus* by using wild *H. annuus* as a bridge (Whelan, 1976). Other species reported by Soviet breeders that can be crossed with cultivated *H. annuus* include *H. grosseserratus*, *H. rigidus*, *H. decapetalus* and *H. hirsutus* (Table 1).
The largest collection of Helianthus species in North America is being maintained by the United States Department of Agriculture at Bushland, Tex. Smaller collections are kept by Government Research Stations at Fargo, North Dakota and Morden, Manitoba. The USDA world sunflower collection consisting of about 500 entries, mostly cultivated types, from over 30 countries is maintained at the North Central Regional Plant Introduction Station at Ames, Iowa. In Europe, large collections of wild and cultivated Helianthus cultivars are maintained at the Station d’Amélioration des Plantes, Clermont-Ferrand, France, at the Research Institute for Cereals and Industrial Crops in Fundulea, Romania, the N.I. Vavilov All-Union Research Institute of Plant Industry (VIR) at Leningrad, USSR, and by the All-Union Scientific Research Institute of Oil-Bearing Crops (VNIIMK) at Krasnodar, USSR.

II. PLANT CULTURE

A. Field

Sunflower will grow in a wide range of soils, but prefer those that warm up quickly, such as well-drained sandy soils. Sunflower can tolerate drought better than many annual crops because they are more efficient in extracting soil moisture. Photosynthesis has been found to continue in sunflower at high levels of moisture stress (Boyer, 1970). Soil moisture is most critical at flowering time for proper seed development. Soil fertility requirements are similar to those for most other crops with the best growth being obtained where levels of N are adequate (Zubriski and Zimmerman, 1974). Sunflowers are adapted to high light level, and some studies in France have shown that sunflowers grown in shade produce low seed yields. Commercially, sunflowers may be planted at populations of between 4 to 7 plants per m² without significantly affecting the yield. It may be desirable to have a lower plant density in breeding nurseries.

Many sunflower lines and cultivars are short-day plants, although some of the more popular lines are not sensitive to photoperiod. Breeders have observed that the shorter photoperiod in Florida and Hawaii hastens the initiation of flower primordia of some genotypes, while others are not affected. Seed yield often is reduced under these growing conditions.
Sunflower requires warm temperatures for fertilization and seed development. Cool temperatures can delay or prevent the pollination and fertilization processes by affecting the activity of pollinators and the metabolism of the plant. Temperatures in excess of 30°C also may prevent normal pollination and fertilization. This particularly applies to plants with erect heads where the upper part of the head is exposed to direct sunlight which can raise the temperatures of the pollen and stigma to injurious levels. Smith (1978), for example, has noted pale pollen following periods of high temperature and bright light in California. Even though fertilization does not occur, the ovary wall will usually develop almost normally to produce empty hulls.

Many companies and public agencies have breeding programs in Hawaii, Florida, or South America where seed is increased and crosses are made in the winter. Seed set usually is lower in winter nurseries, but the crop matures and can be harvested considerably earlier than in the temperate zones.

B. Growth Chamber and Greenhouse

Sunflower can be grown successfully to maturity in the greenhouse or growth chamber. The plants may be grown in 15 or 20 cm pots provided soil that drains easily is used. Because sunflower is a large user of water, daily watering is necessary. Nutrients should be supplied frequently either in soluble form with water or in the slow release form.

An important requirement in the greenhouse is sufficient light. Low light level, particularly in the blue and ultra-violet spectra, produces tall plants with weak stems that break easily. Plants produced in the greenhouse generally have smaller heads, smaller seed, and lower seed yields than those grown under normal field conditions. The senior author and other breeders have found that greenhouse-produced seed tends to be more dormant and requires a longer rest period than field-produced seed.

Sunflower may be dwarfed to facilitate crossing and moving in the greenhouse. A reduction in height of up to 40% has been obtained with (2-chloroethyl) trimethylamination chloride (CCC) and succinic acid, 2,2-dimethylhydrazide (SADH) (Dorrell, 1973).

III. FLORAL CHARACTERISTICS

Sunflower is a highly cross-pollinated plant. The individual disc flowers are effectively protandrous and the positioning of the stigma above the anthers makes self-pollination difficult. A genetically controlled system of self-incompatibility in certain lines prevents the pollen from penetrating the styles and carrying out fertilization (Putt, 1941; Schuster, 1961).

Sunflower is pollinated mostly by insects. Bees are frequent visitors to flowers on warm, sunny days. Little pollination is accomplished by wind (Putt, 1940). Sunflower pollen is rather heavy and sticky and most of it drops on the leaves or on the ground in clumps of five or more grains.
The head of the sunflower (*Helianthus annuus* L.) is a compound inflorescence composed of many individual flowers in a large disc subtended by large ray flowers (Fig. 1). The ray flowers are normally asexual, but some may produce pollen. The disc flowers are perfect with petals and five anthers that are united in separate tubes. The disc flowers are arranged in concentric circles radiating from the center of the head. The ray flowers open first and flowering then proceeds from the periphery to the center of the head at the rate of one to four rows per day.

The development of individual disc flowers has been described by Plotnikov (1940) and Putt (1940). Early in the morning the staminal filaments rapidly elongate and exert the anther tube from the corolla (Fig. 2A). This occurs about 0700 hours on warm, sunny days, but later on cool, wet days. Immediately after this stage is reached, the anther locules dehisce, releasing their pollen inside the anther tube (Fig. 2B). An elongation of the lower portion of the style follows, which forces the two-lobed pubescent stigma up the anther tube (Fig. 2C). During its upward movement the stigma pushes the dehisced pollen through the upper end of the anther tube. The stigma is not receptive at this stage because the two lobes are held together covering the inner receptive surface. At the same time, the staminal filaments lose turgidity and the anther tube begins to recede into the corolla. The next day, the stigma lobes are fully emerged and have separated to expose the receptive surfaces to pollination (Fig. 2D). Pollination and fertilization soon occur, after which the stigma withers and recedes. By the morning of the second day, after the flower opens, both the anther and the stigma have receded almost completely into the corolla (Fig. 2E).
IV. ARTIFICIAL HYBRIDIZATION AND SELF-POLLINATION

A. Equipment

Emasculation of the female parent can be performed with forceps. Workers have individual preferences for the type of forceps. Some prefer a fine, sharp-pointed surgical type; others use a somewhat larger, coarser type with points about 3 mm wide.

Putt (1941) has described a knife for removing unwanted flowers that is made by splitting a pair of cover slip forceps and mounting each portion in a small wooden handle. The tip is sharpened to obtain a knife with a small blade set at an angle to the handle (Fig. 3). A disinfectant, such as ethanol, is used for sterilizing the forceps between emasculations to prevent unwanted cross-pollination.

B. Preparation of the Female

The ray flowers and bracts usually are removed before emasculation to make the flowers on the disc more accessible and to eliminate a large surface area on which pollen could lodge. Unless a large quantity of seed is desired, it is prudent to emasculate only those flowers which open on a single day and remove all the others. This precaution reduces the hazards of uncon-
trolled cross-pollination, as well as self-pollination. The flowers opening prior to the day of emasculation can be removed from their ovaries by a simple sideways pulling motion with the thumb and forefinger.

In the field, emasculation should be carried out very early in the morning. On sunny, warm days this would be prior to 0700 hours, but may be later on cool, cloudy days and in the greenhouse in winter. The ideal time to emasculate is in the period when the anther tube is extended sufficiently to be grasped with the forceps but the pollen has not yet dehisced. In practice, however, because of the short duration of this period, the anther tube often is removed after dehiscence (Fig. 2B and 4A), but before the stigma has grown far enough into it to be injured or for the stigmatic lobes to separate when the tube is removed. Free pollen on the outside of the stigma lobes must be blown off.

Undeveloped central florets are removed, usually by cutting them off with a knife at a point just above the ovaries (Fig. 4B and C). A few flowers closely adjacent to those emasculated cannot be cut off with a knife without danger of damaging the emasculated flowers. These can be removed with forceps.
The stigma normally remains receptive for 3 to 5 days, although its viability can be preserved up to 17 days under field conditions (Plotnikov, 1940). Stigmas of flowers which are not fertilized continue growth for several days to form a coil which will allow the stigmatic surface to contact pollen adhering to the outer surface of the stigma lobes (Fig. 2D).

Emasculated flowers may be protected from being pollinated with unwanted pollen by covering the head with paper, cotton, or perforated plastic bags.

Emascation is not necessary in some cases. Heads of male sterile or highly self-incompatible plants, for example, can be pollinated directly provided they have been protected to prevent undesirable outcrossing.

C. Pollination

Self-pollination is achieved by placing a bag over the head before anthesis or anther dehiscence. The amount of seed set depends on the degree of self-compatibility of the lines and type of bag used. Cloth bags have been found to be the most efficient among several kinds tested for effecting self-fertilization of sunflower (Kalton, 1951; Putt, 1940). Seed set was increased considerably when heads were manipulated by brushing with cotton batting (Putt, 1940).

Pollen for crossing is collected by placing bags over the heads of the male parents a day or two before flowering begins (Fig. 5). Paper bags are most convenient and adequate pollen will be found in the bags 1 or 2 days after flowering commences. It is best to use the pollen shortly after collection. According to Arnoldova (1926), pollen can be stored for a year, but other workers have found that viability is lost within a month whether the pollen is stored at room temperatures or is refrigerated (Plotnikov, 1940; Putt, 1941).

Pollen should be applied when the stigmatic lobes have separated and have exposed their receptive surfaces (Fig. 4C). Receptive stigmas are brushed with a pollen laden cotton wad or camel’s hair brush usually a day after emasculation. Some breeders prefer the cotton wad because pollen adheres to it better and it can be discarded after one pollination, thus reducing the hazard of contamination and removing the need to sterilize with ethanol.

Fig. 4—Stages in the emasculation of a sunflower head. A. Before emasculation. B. Several rings emasculated with part of the outside rings removed. C. A head 1 day after emasculation showing the stigma lobes ready for pollination with ray and central florets removed.
Pollination in field nurseries can be effected simply by rubbing heads from the two parents against each other. If one of the heads is emasculated or male sterile, the cross is one-way. Because of the high degree of self-incompatibility in the sunflower, rubbing unemasculated heads of two normal lines will result in reciprocal crosses.

The pollinated head is maintained in isolation by rebagging. The bags also serve as a protection against birds. Identity of the cross may be lettered on the bag or indicated on a tag attached to the plant, depending on the preference of the breeder and the procedures used from harvest to storage of seed.

Fertilization of the flowers is indicated by withering and receding of the stigmas. This condition may be observed the morning after pollination. The success rate of pollination should be almost 100%. Lower seed sets usually result from non-viable pollen or stigmas.

Fig. 5—Sunflower head just before anthesis.
D. Factors Affecting Efficiency

The most common field plan to facilitate crossing places the female and male parents of planned hybrids adjacent to each other to facilitate the transfer of pollen. This may require planting by hand rather than using the spacings and seed arrangements feasible with a commercial planter. Plant population normally is not critical in field nurseries and the population often is lower than that used commercially. A lower population results in larger seeds and easier maneuverability among plants.

The cultivated sunflower normally has only one head per plant which requires the plants to bloom at the same time for cross-pollination to take place. Inbred lines with a branching character are available which have numerous heads which enables the plant to produce pollen over a longer period than the single-head type. The branching trait is conditioned by recessive genes in all commercial lines used for hybrid seed production, thus branching does not appear in commercial hybrids (Fick and Zimmer, 1974). The branching character evident in wild *Helianthus* species generally is controlled by dominant genes.

Branching can be induced in normal sunflower plants with a single head by removing the apical floral bud to stimulate the formation of new floral buds in the leaf axils. The time of flowering has been hastened in *H. tuberosus* by shortening the photoperiod (Shchibrya, 1938). We have observed more vigorous initial growth and earlier flowering in *H. annuus* following application of high phosphate fertilizer.

Hybrid sunflower seed cannot be distinguished from self-pollinated seed on the female parent because the hull characteristics are controlled by the female genotype.

Self-pollination and fertilization might inadvertently occur in making controlled crosses because it is difficult to achieve absoluteemasculature. This problem is more common when self-compatible lines are used as the female parent. Hence, some method of distinguishing hybrids from maternal plants is desirable. Usually hybrid plants are more vigorous than either of the parents and this vigor may be observed at the seedling stage. Other characters controlled by dominant genes that may aid in differentiating hybrids from the female parent include anthocyanin pigment in the stalks, leaves, corolla and anthers; yellow coloration and ligulate shape of petals; and some types of branching.

V. NATURAL HYBRIDIZATION

Natural hybridization in sunflower is made possible by using male sterility and self-incompatibility systems. Both systems have been exploited in commercial production of hybrids.

The first hybrids used for commercial planting were developed in Canada using a type of self-incompatibility system or conversely a feature of high cross compatibility (Unrau and White, 1944). The female parent was not highly self-compatible or was a sparse pollen producer. It was inter-
planted with an abundant pollen producer, and a proportion of its seed was from hybridization. The proportion of fertilization occurring as a result of cross-pollination depended on the ratio of male to female plants, degree of isolation, and weather conditions which would favor insect activity. In commercial practice the percentage of hybrid seeds averaged only from 39 to 45%, with some samples being as low as 19% (Pett, 1962). The full potential of heterosis was not realized and other means of exploiting it were sought.

Both genetic and cytoplasmic male sterility occur in the sunflower. Genetic male sterility is found frequently in nature and has been used for commercial hybrid seed production in Romania. This type of sterility is controlled by any one of at least five recessive genes \( ms_1, ms_2, \ldots ms_n \). Only \( ms \), has been exploited commercially because it is linked closely with the locus for a dominant gene controlling anthocyanin production (Vranceanu and Stoenescu, 1970). In the coupling phase, this linkage permits the producer to remove purple seedlings which will produce male-fertile heads. The male-sterile plants will lack the purple color characteristic of anthocyanin. This system theoretically should result in 100% hybridization, but the purple color is not always expressed and some male-fertile plants will escape removal.

More recently, LeClercq (1969) discovered cytoplasmic male sterility (CMS) which is used extensively now for hybrid seed production. Shortly after its discovery, fertility restoring genes were discovered (Anonymous, 1970). In hybrid seed production, rows of the CMS line are interplanted with rows of a fertility restorer line in ratios from 2:1 to 6:1. If the time from planting to flowering differs for the parents, they must be planted at different dates to foster coincidence of bloom. Other practices to overcome this difference include planting the earlier blooming parent deeper to delay emergence and blooming or using a fertilizer practice which will hasten bloom of the later parent.

**VI. SEED DEVELOPMENT, HARVEST, AND STORAGE**

Seed set can be detected by the plumpness of the seed and the uniform dense color of the pigmented layer when it is a character of the female parent. These characteristics are usually visible at about 20 days after fertilization. Sunflower heads should not be harvested before the onset of yellow color in the head and browning of the bracts. This stage usually occurs at about 45 days after fertilization. The junior author has observed that plantings in greenhouses can be hastened to maturity by ceasing to apply water 20 days after blooming terminates. If not completely dry when harvested, the heads can be dried in an oven at about 40 C for several days.

Individual heads can be threshed easily, without hazard of mixing, with a circular, wooden disc mounted on a stand above a chute (Fig. 6). Several wires are mounted, equally spaced across the face of the disc. The disc is rotated by a motor and the rubbing action of the wires dislodges the seed when the sunflower head is pushed against the disc. If only a few heads are involved in a program other simple devices can be used in removing seed
from the head. Basically these can be any rough surface against which the heads can be rubbed, such as pieces of coarse screen, wood with staples or nails protruding 3 to 5 mm above the surface, or wood wrapped with coarse wire at 10 to 15 mm intervals. After cleaning, the seed should be kept in cool storage free of insects and mice.

VII. TECHNIQUES FOR SPECIAL SITUATIONS

A technique often used to obtain male-sterile plants is the application of gibberellic acid at the bud stage (Anaschenko, 1967; Seetharam and Kusumakumari, 1975). Gibberellic acid, in a 50 to 100 ppm solution, is applied shortly after floral bud initiation. Seetharam and Kusumakumari (1975) emphasized the importance of this stage to obtain maximum male sterility.

Dormancy is a problem often encountered in efforts to germinate sunflower seeds shortly after harvesting. Udayakumar and Krishnasastri (1974) reported that much higher germination was obtained in 20-day devel-
oping, dehusked seeds than in the 30- and 40-day-old seeds. The same workers were able to obtain better germination in dehusked seeds with applications of different growth regulators. Most effective was ethrel at 25 ppm concentration.

REFERENCES


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