The castor plant (*Ricinus communis* L.) is a perennial of indeterminate growth habit that is believed to have originated in Abyssinia. Castor is now distributed throughout the tropics and subtropics, and is well adapted to the temperate regions of the world. Major producers and exporters of castor oil are Brazil and India. The United States is the largest importer and user, with over 55 million kg of oil imported annually. During the 1960's, up to 30,000 ha of castor were grown in the United States, but its production diminished to zero in the early 1970's. Castor oil is a versatile chemurgic raw product, and is used in hundreds of industrial applications. It is the chief raw material for production of sebacic acid, which is used in producing synthetic fibers and resins. The paint and varnish industry is a large user of dehydrated castor oil. Other users include manufacturers of plastics, artificial leather, brake fluid, soap, perfume, cosmetics, textiles, and lubricants (Zimmerman, 1958). Seed of open-pollinated cultivars and hybrids developed in the United States contain 48 to 50% oil on a dry weight basis.

I. PARENTAL MATERIAL

*Ricinus* is considered to be a monotypic genus and belongs to the Euphorbiaceae or Spurge family. *Ricinus communis* L. encompasses the many polymorphic types known in the world. Several of these were designated early as subspecies, but they are cross-compatible and are not true subspecies as usually defined in other plants.

The USDA National Seed Storage Laboratory, Fort Collins, Colo., maintains over 900 accessions of castor in the United States. The USDA Southern Regional Plant Introduction Station, Experiment, Ga., has over 270 accessions in a collection. Important centers are also in Campinas, Brazil, and Hyderabad, India. In the Northern Caucasus region of USSR,
the Kuban Experiment Station of the All-Union Institute of Plant Industry (VIR) has an extensive collection, as does the All-Union Research Institute of Oil Crops (VNIIMK) in Krasnodar. Israel, Yugoslavia, Hungary, and several other countries also have centers that maintain limited germplasm collections.

II. PLANT CULTURE

A. Field

Castor plants are adapted to a wide range of well-drained soils free of compacted or impervious layers. Sandy loams and loams usually produce optimum yields. Castor is not suited to saline soils, those subject to erosion, or those with low fertility. A moderate level of nitrogen is recommended for nursery plantings. Excessive nutrients and moisture can lead to a highly vegetative plant which is low in seed production. Standing water can cause the death of plants from insufficient oxygen in the root zone. Thirty-eight to 50 cm of rainfall are required during the growing season for satisfactory plant growth and seed production. In arid lands, 60 to 100 cm of irrigation water may be needed for best yields.

To allow normal branching, plants should be spaced 50 cm or more apart in the row when rows are 1 m apart. Plants can also be established in hills in a grid system using various spacings.

Most castor selections bloom satisfactorily under the photoperiod available during the summer growing season in the United States. However, duration of photoperiod and light level may influence formation of flower primordia in certain genotypes (Scully and Domingo, 1947). Light level and quality are usually adequate for field culture of castor. Temperatures in excess of 37°C can cause abortion of seed in certain environments, and unusually low temperatures contribute to poor seed set.

Excessive relative humidity (60 to 70% and above) and frequent rain showers encourage a complex of fungus diseases on the developing capsules, their pedicels, and, in some cases, the raceme axis. Damage may vary from a slight reduction in seed weight to complete destruction of the raceme.

Castor plants do well in winter nurseries, such as in southern Florida, and can withstand light frosts without appreciable damage.

B. Growth Chamber and Greenhouse

Plants can be grown satisfactorily under greenhouse conditions in soil benches, large crocks, pots, and buckets, if a suitable soil mix and adequate bottom drainage is provided. A 2:1:1 mixture of soil, sand, and peat moss over a 3- to 5-cm layer of gravel has been used with good results. Plants can also be grown in ground beds. Starting seedlings in peat cups and transplanting to the ground bed lessens the chance of skips in the greenhouse planting. Spacings should be similar to those in field nursery plantings.
The need for additional nitrogen fertilizer can usually be determined by appearance of the plant, and small amounts should be added periodically as needed. Plants should only be watered enough to promote vigorous growth since excess moisture can lead to excessively high relative humidity and encourage diseases.

Lights may be used over castor plants when overcast winter conditions prevent the reception of normal sunlight, or when day length is shorter than desired. Plants are tolerant of varying photoperiods, and light level and quality are not critical.

Growth chambers can be used, but plants should be grown in small containers to limit their size. Shiffriss (1964) found a continuous light level of 15 klux, a constant temperature of 21 to 23 C, and relative humidity of 40 to 50% to be favorable for growth, flowering, and seed production. In both greenhouse and growth chambers, frequent observations for pests should be made. White flies [Trialeurodes vaporariorum (Westwood)] and two-spotted spider mites (Tetranychus urticae Koch) are often found on castor plants grown in greenhouses and growth chambers. Inadequate control measures can lead to leaf drop, reduced plant growth, and possible loss of plants.

III. FLORAL CHARACTERISTICS

Inflorescences of castor are borne terminally on the main and lateral branches. The main stem ends in a raceme, usually the largest on the plant, which is designated the first or primary raceme (Fig. 1). After the first raceme appears, two or three branches arise at the nodes immediately below it. Each of these branches terminates in a raceme after four or more nodes have formed. These racemes are commonly called the second set or secondary racemes. Branches arise from the nodes just beneath secondary racemes, ultimately terminating in a third set or tertiary racemes. This sequence of development continues as long as the plant remains alive and healthy and has a proper environment for growth, thus producing the indeterminate growth habit of the species. The sequential development of racemes along any one axis makes it possible for a plant to have racemes in all stages of development from the bud stage to complete maturity.

The racemes of castor are usually monoecious, with the pistillate flowers on the upper 30 to 50% and staminate flowers on the lower part of the inflorescence. Raceme size, number of flowers, and proportion of male to female flowers vary greatly. Both male and female flowers are apetalous, each being enclosed in a fused perianth, and are borne on pedicels of varying lengths. The bud of the male flower is flattened conically, and the five segments of the perianth surround a cluster of numerous stamens bearing branched filaments. The male flowers are yellow at anthesis, and become pale yellow with time. The female flowers are conical and more pointed than the male flowers. The perianth encloses a pistil with a three-carpellate ovary and sessile stigmas. Usually each of the three carpels has a single ovule, and each ovule produces one seed. The three stigmas of each ovary are reddish or green, branched near the apex, and have a papillate surface.
Plants with two, four, or more locules per capsule have been observed, in contrast to the normal three. Hermaphrodite flowers are also found occasionally.

Under field conditions, the fine, light-weight castor pollen is carried to the stigmas mainly by wind, although bees and other pollinating insects are usually found in flowering racemes of castor, and may carry pollen from one plant to another. The anthers of the male flowers burst explosively upon drying, which tends to scatter the pollen grains. Due to a lack of any barriers such as self-sterility within the plant, selfing also occurs under natural conditions, and the tendency is most pronounced in the central racemes. Natural outcrossing of dwarf-internode castor can be in the range of 70 to 90% for the Texas High Plains (Brigham, 1967).

Pollen is normally shed from 2 to 3 hours after sunrise until late afternoon, but usually peaks near mid-morning. Meinders and Jones (1950) observed nearly all pollen was shed between 0730 and 1130 hours in June at Stillwater, Okla. Cool weather can delay the shedding of pollen until late morning.

Fig. 1—Diagram of mature castor plant showing sequential raceme development.
The staminate flowers on the lowest portion of the raceme axis reach maturity first, and anthesis usually occurs a short time before the earliest pistillate flowers open on the upper portion of the axis. This timing provides an ample source of pollen for the first pistillate flowers that open and become receptive. Pistillate flowers may bloom over a 21-day period, and staminate over a 35-day period (Pustovoit et al., 1967). The staminate flowers dry within a few days after anthesis and usually drop off of the raceme axis. The stigma is fully receptive a few hours after the flower opens, but is often difficult to pollinate immediately after the flower opens. The branches of the stigma cease to grow shortly after fertilization takes place. If pollen is not available or if it is excluded from the stigmas by artificial means, such as covering with a paper bag, the stigmas continue to elongate, reaching 10 to 20 mm in length in some cases. Depending upon climatic conditions, stigmas may be receptive up to 7 days during favorable weather.

The length of time between pollination and fertilization is not documented, but should be several hours to a day, depending upon length of the stigma and temperature during pollen tube growth.

IV. ARTIFICIAL HYBRIDIZATION OR SELF-POLLINATION

A. Equipment

An apron with several pockets is commonly used to carry equipment for crossing and selfing castor. The equipment consists of paper bags, a plier-type stapler with chisel-point staples, marking pencil, forceps, camel-hair artist's brush, field books, and record books. Usually a plastic bottle of denatured ethanol is used for removal of pollen from forceps or camel-hair artist's brush and fingers when changing male parents. Bags for covering racemes are usually prepared beforehand and by cutting a V-shaped portion from the open end of the bag with large shears or a paper trimmer. Kraft paper, sorghum-pollinating bags are preferred for general use, but kraft grocery bags can be used under arid conditions where waterproof glue to hold the bag together is not a requirement. Parchment paper bags with waterproof glue have also been used with good results.

B. Preparation of the Female

Racemes of monoecious plants should be selected immediately before pistillate flowers open. Primary racemes are preferred because they are larger and produce more seed than secondary racemes. Staminate flowers, opened or unopened, are removed from the lower portion of the raceme axis with the fingers or forceps. If staminate flowers have already opened and anthesis has occurred, the perianth of the pistillate flowers should be inspected closely to be sure they are free of stray pollen grains. Care must be taken to remove any staminate flowers and hermaphroditic flowers which may be interspersed among the pistillate flowers. Removal of staminate
flowers and covering with a paper bag may be done at any time of day, but small racemes are more turgid and tend to break off more easily in the mornings; therefore, afternoons are favored for emasculating and bagging racemes.

The main stem is usually sufficiently strong to support a paper bag covering the primary raceme. The small vegetative bud or buds at the base of the raceme, plus one or two adjacent leaf petioles, should be removed to insure a firm attachment of the bag when covering secondary racemes (Fig. 2). The bag is placed carefully over the raceme, the notch in one side is placed against the next available leaf petiole, and the ends of the bag are

Fig. 2—Bagging operation. A, secondary raceme properly prepared for bagging; B, bag is placed over raceme until notch is against petiole; C, tails of bag are folded snugly against stem and stapled; D, plier-type stapler and properly installed bag.
brought together and folded snugly against the stem. A staple is placed through the four layers of paper. Care must be taken to position the staple as close as possible to the stem so that a slight pull on the bottom of the bag does not allow the bag to slip toward the raceme. If the bag slips, it should be repositioned and restapled. The bags are normally stored flat and must be opened and fully expanded before they are placed over a raceme, otherwise the flowers tend to be compressed and misshapen. Paper clips have been used to secure bags in areas where wind is not a factor, but a chisel-pointed staple applied with a plier-type stapler is more satisfactory in most areas. When bagging pistillate racemes, a careful check should be made for any interspersed staminate or hermaphroditic flowers.

At the time of bagging, the date and time can be marked on the bag with a waterproof marker. Small, white parchment bags are often used temporarily to cover the raceme after emasculating, as the raceme axis is quite short. Because larger parchment or kraft bags are used for selfing or following pollination of racemes, one can visually pick out the small bags, indicating that pollen is yet to be applied.

C. Pollination

Depending upon weather conditions, many of the pistillate flowers will normally be open and receptive 5 to 7 days after bagging. The proper interval can easily be ascertained by removing a bag from an emasculated raceme and inspecting it for receptive pistillate flowers. If staminate flowers are used for direct application to the stigmas, pollination can be carried out at any time of day when pollen is shedding freely from the anthers, but should be accomplished when wind movement is at a minimum.

The staminate flowers are usually collected in the morning shortly before or after anthesis and stored in a small paper bag, plastic petri dish, or other container that will not crush or compress the flower. To obtain bulk pollen, the bag containing staminate flowers collected earlier is shaken vigorously after the anthers have dehisced to encourage additional pollen shed. The pollen is shaken to one corner of the bag and the corner is torn off to gain ready access to the pollen.

Pollen will remain viable several days after the flower is picked, and will still be usable the second or third week if stored under room conditions (Pustovit, 1967). Packets of pollen have been sent through the U.S. mail with good success when 2 to 3 days delivery time was possible. Pollen can also be frozen or freeze-dried successfully and will remain viable up to 1 year (Haarling et al., 1969).

Before application of pollen, the raceme on which the female flower is located should be carefully checked and any interspersed staminate or hermaphroditic flowers removed.

When the stigmas are well exposed, the pistillate flowers can easily be pollinated by dusting pollen on the stigmatic branches. This can be done by holding the dehisced staminate flower with forceps and lightly touching it to the stigmas. One staminate flower can be used to pollinate several pistillate flowers, but should be discarded when pollen is sparsely evident upon
touching to the thumbnail. When pollen has been collected in bulk from staminate flowers, a camel-hair artist’s brush may be used to apply the pollen. Fingers, forceps, and brushes should be cleaned with alcohol when changing from one male parent to another.

The raceme is covered with a bag immediately after pollen is applied and the source of pollen and date of pollination is recorded on the bag. If all pistillate flowers are not receptive at first pollination, a second pollination can be made after a few days.

Unless exceptionally hot or wet weather follows pollination, seed set should be nearly 100%. From the pollination of 40 pistillate flowers, 120 seeds are possible, since three seeds are normally produced in each capsule.

In routine selfing, monoecious racemes are selected and prepared as above, except the staminate flowers are not removed. The date of bagging is usually marked on the bag. The initials or identifying mark of the person applying the bag may be added to facilitate a check on proper preparation of the plant and fastening of the bag by individuals working in the nursery. It is helpful to face the bags in one direction as much as possible (usually facing plant no. 1) so workers performing follow-up operations can proceed along the row in one direction and see the date the bags were placed on the racemes. Depending upon weather conditions, many of the pistillate flowers usually will be open and receptive 5 to 7 days after bagging, and the bags should be agitated for best pollination and seed set. This is customarily done by holding opposite edges of the bag about halfway from the top, and making several short, quick pumping motions, similar to pumping a bellows. This causes the pollen to move upward in a cloud, where it falls on receptive stigmas. Care must be taken not to loosen or tear the bag and bags should be dry; therefore, this operation is often carried out the latter part of the day. Pumping of bags should be continued until all pistillate flowers have opened and all stigmas have received pollen. This may require several trips over to the nursery at 4 to 5-day intervals after bagging commences. Workers should be alert for loosened, torn, or split bags; vegetative shoots or leaves growing in the bag with the raceme; and racemes which have elongated until the apex of the raceme is touching the bottom of the bag. If left unattended, the apexes of extremely long racemes of certain genotypes may force their way through the bag, exposing receptive stigmas to foreign pollen, and resulting in seeds of unknown male parentage.

When capsules have all set seed, the selfing bags may be removed to allow drying, and to avoid growth of fungi on capsules and their pedicels. The paper bag is removed, folded in half lengthwise, folded around the base of the raceme, and stapled. If the bag is not torn, it can be used to harvest the capsules from the raceme. The bag is slipped over the raceme that bears the dry capsules, gripped near the base of the raceme, and pulled upward, stripping the capsules into the bag, which is then folded and stapled shut. Row and selection number plus other information should be recorded on the bag.

D. Factors Affecting Efficiency

Breeding nurseries are usually planted in a series of short rows with parental lines to be frequently used in crossing grouped together. If large amounts of hybrid seed from a cross are required, the male and female parents are often planted adjacent to each other to facilitate hybridization. If
sufficient land is available, the two parental lines can be planted in isolation and plants of the female line can be emasculated or rogued before natural pollination. Spatial requirement for isolation will vary with wind movement, but should be at least 800 m and not downwind from other castor plantings.

Because of the indeterminate nature of the castor plant and the progressive flowering of numerous racemes, it is usually not necessary to alter flowering dates unless the plants are extremely late flowering, are planted extremely late, or are grown in a short growing season. When one parent is much earlier than the other, racemes in the bud stage can be removed to delay onset of flowering.

Genetic markers for identifying hybrid seed are not easily interpreted, and are usually not relied upon in a breeding program. The markers most used for identifying hybrid plants are red or mahogany stems dominant to green stem color; waxy bloom dominant to absence of bloom; and spined dominant to spineless capsules. The gene for dwarf-internal node is also recessive, and plants with this characteristic can easily be differentiated from normal-internal node plants that may be involved in crosses.

**V. NATURAL HYBRIDIZATION**

Use of hybrid seed of castor has been feasible since the development of suitable female lines beginning in the 1950's. True male sterility has not been found in castor, but the absence of staminate flowers causes racemes to be completely pistillate. A simply inherited recessive gene, now designated \( sf \), for absence of staminate flowers (Katayama, 1948; Claassen and Hoffman, 1950) permitted production of the first commercial \( F_1 \) hybrid by roguing the normal monoecious plants from the backcross \( F_1 \) line to obtain a population of 100% pistillate plants in the female rows of hybrid seed fields. This procedure required several trips over the field, and was laborious and expensive. Identification of a type of femaleness that is genetically unstable and may undergo sex reversal (Shifriss, 1960; Brigham, 1961) was next reported. Before this system was utilized in hybrid production, a unique sexual mechanism combining the gene for pistillate flowers and environmentally sensitive genes for interspersed staminate flowers was developed by Zimmerman and Smith (1966). This led to the release of a female line, designated \( CNES-1 \), which was widely used in the production of commercial \( F_1 \) hybrids (Fig. 3). This line is normally pistillate under moderate temperatures, but produces interspersed staminate flowers under high temperatures. In crossing fields, usually only one or two roguing of the female line are necessary to insure that all flowering plants are pistillate, and to remove off-type plants that appear.

In practice, female lines are obtained by selecting all-female plants in backcross populations, growing the progenies under a warmer and longer than usual growing season, roguing before flowering plants that are monoecious, and harvesting bulked seed from both those plants that remain pistillate and those that produce pollen from interspersed staminate flowers. Under proper environmental conditions, this bulked seed will produce plants in seed rows that are 100% pistillate on the first and second sets of racemes. Constant selection pressure must be maintained in the foundation seed fields to prevent excessive expression of the genes for interspersed
staminate flowers which can result in selfing of the female parent.

A genetic type with a fused perianth of the male flowers has been reported (Subramanian and Sivasubramanian, 1975). This anomaly prevents normal pollen shedding, and may find use later in developing female lines for use in commercial hybrid seed production.

The layout of isolated crossing blocks or fields is similar to that used for other wind-pollinated crops. Usually two rows of male parent are planted for every 10 to 12 female rows. Plantings should be oriented so that prevailing winds blow across the rows for best pollen distribution. The male parent should be earlier flowering than the female to avoid the necessity of planting at different times. The male and female parents should be rogued for off-type plants just prior to blooming and the female parent should be rogued for any pollen-shedding plants at the early bloom stage of the primary raceme. Isolation distance should be at least 800 m and not downwind from other castor plantings. All wild castor plants growing along roadsides or in fence rows within 800 to 1,000 m of the isolated planting should be removed.

VI. SEED DEVELOPMENT, HARVEST, AND STORAGE

After pollination, capsules on the racemes begin to expand if fertilization has occurred and normal seed development is in progress. When the seeds have matured, capsules begin to dry, and the three locules separate or

Fig. 3—Flowering racemes of CNES-1 (female parent), Lynn (male parent), and a near-mature raceme of the F₁ hybrid used for commercial castor seed production.
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partially separate at the sutures (Fig. 4). Capsules are then removed from the plant either by placing a paper bag over the raceme and stripping the capsules from the raceme axis, or hand stripping with the use of leather gloves or a special stripping cup (Weiss, 1971).

Dry capsules may be stored for long periods prior to hulling the seed from the capsules. Small hullers used in breeding programs in the United States usually are equipped with rubber-covered vertical discs approximately 30 cm in diameter (Schoenleber and Taylor, 1954). One disc is stationary, while the other is rotated by an electric motor, which also powers a cleaning fan to separate hulls from seed. The distance between the face of the discs is adjustable, permitting efficient hulling without excessive cracking of the seed coat. Small, hand-powered hullers are described by Weiss (1971). Although the seeds are large, the seed coat is fragile and easily broken if mechanical pressure is applied.

Seed can be stored in paper envelopes, paper bags, or cloth bags after harvest. Preferably, storage should be in a refrigerated seed storage facility,

Fig. 4—Capsules and seed. A, mature dry capsules; B, segments (carpels) of a capsule that contain the seed; C, clean seed; D, hulls removed from seed.
but germination remains fairly high for several years when seed are stored at room temperature. If individual packets or bags can be stored in tight-fitting metal or wood storage containers, paradichlorobenzene crystals or nuggets can be added to repel insects.

VII. TECHNIQUES FOR SPECIAL SITUATIONS

Spraying of castor seedlings in the two to four-leaf stage with gibberel-lin A₁ has been reported to increase the female tendency on the primary, secondary, and tertiary racemes (Shiffriss, 1961). In contrast, male tendency has been induced by use of ethyl hydrogen-1-propyl-phosphonate (Philopos and Narayanaswamy, 1976). Embryo culture and grafting have generally not been used in castor research programs.

Because castor is a true perennial, it is possible to transplant the mature plants near the end of the growing season. The main stem is usually cut 12 to 20 cm above the ground line, and side branches are pruned to within 10 to 12 cm of the main stem. The root system is dug sufficiently deep and pruned to fit inside a large container (nominal capacity of 20 to 25 liters), or is transplanted to a sufficiently large hole dug in soil. Roots can be kept moist by immediately wrapping them in wet cloth after digging. New shoots arise from dormant buds at the nodes of the main stem and the side branches. Care should be taken in cutting the main stem and branches to prevent splitting or crushing the stem. A single blow with a sharp machete has been used successfully for the above-ground pruning operation.

In areas where winter temperatures are subfreezing for only a short time, castor plants can be pruned and covered with soil in the fall of the year, and uncovered in spring after danger of frost is past. The main stem is carefully cut 10 to 14 cm above the ground line, and side branches are removed before covering the stem with soil. After uncovering in spring, buds emerge from the nodes of the main stem, and new branches with racemes follow. Some plants do not survive due to root rot, rodent damage, etc., but over 50% recovery has been reported (Brigham, 1961).

REFERENCES


