Forage Legumes

C. E. Townsend

USDA-SEA and Colorado State University
Fort Collins

This chapter emphasizes those species of forage legumes other than alfalfa, Medicago sativa L., and the clovers, Trifolium spp., that have an economic or potential economic importance in North America and Europe. Information is considerable for some species, but essentially nonexistent for others. The principal species are identified by both their common and Latin names in Table 1. In general, these species are used for hay or pasture, but some of the winter annuals are used as cover crops.

I. PARENTAL MATERIAL

New cultivars of birdsfoot trefoil (Lotus corniculatus L.) have been developed in Canada and the United States with germplasm available within the species (Seaney and Henson, 1970), but interspecific hybridization offers a means of improving certain traits. With the most successful method, the chromosome number of the diploids (Wernsman et al., 1965) or interspecific diploid hybrids (Somaroo and Grant, 1972) is doubled with colchicine, and the resulting tetraploids are crossed directly to tetraploid (2n = 24) L. corniculatus. A less successful approach is to cross the diploids directly with L. corniculatus. This procedure requires backcrossing the triploid progenies, which are usually sterile, to the tetraploid parent.

Somaroo and Grant (1971) intercrossed seven diploid species closely related to L. corniculatus: L. alpinus (DC.) Schleich. ex. Ramond, L. japonicus (Regel) Larsen, L. filicaulis Dur., L. schoelleri Schweinf., L. krylovii Schischk. and Serg., L. tenuis Waldst. et Kit. ex Willd., and L. corniculatus var. minor Baker. In some crosses, interspecific hybrids were grown directly from seeds; in certain crosses, embryo culture was necessary to produce the hybrids; and in other crosses, hybrids could not be produced even with embryo culture. They noted that crosses were easier to make if the self-compatible species were the female parent.
Table 1—Information concerning the breeding and improvement for 10 species of forage legumes.

<table>
<thead>
<tr>
<th>Species and common name</th>
<th>Growth form and type of inflorescence</th>
<th>Probable origin</th>
<th>Chromosome no. (2n)</th>
<th>Type of inheritance</th>
<th>No. of ovules per ovary</th>
<th>Time from pollination to mature seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astragalus cicer L. Cicer milkvetch</td>
<td>Perennial (rhizomatous); Raceme</td>
<td>East-central Europe</td>
<td>64</td>
<td>Unknown</td>
<td>12</td>
<td>28 to 35 days</td>
</tr>
<tr>
<td>Coronilla varia L. Crownvetch</td>
<td>Perennial (creeping-rooted); Umbel</td>
<td>Central Europe</td>
<td>24</td>
<td>Tetrasomic (Berchtold et al., 1973)</td>
<td>9 to 15</td>
<td>Townsend, unreported</td>
</tr>
<tr>
<td>Lespedeza cuneata (Dumont) G. Don Sericea lespezea</td>
<td>Perennial; Compound raceme—1 to 4 flowers, Cleistogamous flowers not in a raceme</td>
<td>N. E. Asia (Henson, 1957)</td>
<td>20</td>
<td>Disomic (Hanson and Cope, 1955)</td>
<td>1</td>
<td>46 to 59 days</td>
</tr>
<tr>
<td>Lespedeza stipulacea Maxim. Korean lespezea</td>
<td>Annual; Flowers borne in leaf axils at the tips of stems</td>
<td>N. E. Asia (Henson, 1957)</td>
<td>20</td>
<td>Disomic (Ofutt, 1976)</td>
<td>1</td>
<td>28 to 42 days</td>
</tr>
<tr>
<td>Lotus corniculatus L. Birdfoot trefoil</td>
<td>Perennial; Umbel</td>
<td>Mediterranean Basin</td>
<td>24</td>
<td>Tetrasomic (Dawson, 1941)</td>
<td>45</td>
<td>28 to 42 days</td>
</tr>
<tr>
<td>Lupinus albus L. White lupine</td>
<td>Annual; Upright raceme</td>
<td>Mediterranean Basin</td>
<td>50</td>
<td>Functional diploid (Lamberts, 1955)</td>
<td>20 to 70</td>
<td>(Seaney and Henson, 1970)</td>
</tr>
<tr>
<td>Lupinus angustifolius L. Blue lupine</td>
<td>Annual; Upright raceme</td>
<td>Mediterranean Basin</td>
<td>40</td>
<td>Functional diploid (Lamberts, 1955)</td>
<td>6</td>
<td>(Jaranowski, 1962a)</td>
</tr>
<tr>
<td>Lupinus latens L. Yellow lupine</td>
<td>Annual; Upright raceme</td>
<td>Mediterranean Basin</td>
<td>52</td>
<td>Functional diploid (Lamberts, 1955)</td>
<td>5.5</td>
<td>25 days (Jaranowski, 1962a)</td>
</tr>
<tr>
<td>Onobrychis vicifolia Scop. Sainfoin</td>
<td>Perennial; Raceme</td>
<td>Cultivated for several centuries in the USSR and Europe</td>
<td>28</td>
<td>Tetrasomic (Chapman and Yuan, 1968)</td>
<td>1.5</td>
<td>25 days (Jaranowski, 1962a)</td>
</tr>
<tr>
<td>Vicia sativa L. Common vetch</td>
<td>Annual; Raceme</td>
<td>Mediterranean Basin</td>
<td>12</td>
<td>Disomic (Donnelly, 1958)</td>
<td>6</td>
<td>42 to 49 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Hollings and Stace, 1974)</td>
<td>(Darlington and Wylie, 1956)</td>
<td>Probable autotetraploid</td>
<td></td>
<td>(Ditterline, 1977)</td>
</tr>
</tbody>
</table>


Amphidiploids produced by doubling the chromosome number of interspecific diploid hybrids were crossed to *L. corniculatus* (Somaroo and Grant, 1972). The crosses were successful when *L. corniculatus* was the male parent, but difficult in the reciprocal crosses. Embryo culture was not used. Because the genetics of diploids is less complicated than that of tetraploids, they suggested that certain desirable traits be improved at the diploid level and then transferred to *L. corniculatus* by way of amphidiploidy.

Attempts to hybridize *Lespedeza* species have met with varying success. Hanson and Cope (1955) cross-pollinated 13 annual and perennial species with emphasis on combinations involving serenic lespedeza (*Lespedeza cuneata* [Dumont] G. Don), Korean lespedeza (*L. stipulacea* Maxim), and common or striate lespedeza (*L. striata* [Thunb.] H. & A.). The annual species have lower tannin content than the perennials. All successful crosses, however, involved perennial species of Asiatic origin, as follows: *L. cuneata × L. latissima* Nakai, *L. latissima × L. cuneata*, *L. cuneata × L. inschanica* (Maxim.) Schind., *L. hedysaroides* (Pall.) Ricker × *L. cuneata*, *L. hedysaroides × L. inschanica*. Crosses involving diploid and tetraploid forms of *L. cuneata*, *L. stipulacea*, and *L. striata* have been unsuccessful (Brinkley et al., 1959). Ovules of the most promising *L. stipulacea × L. cuneata* cross began to collapse about 6 days after pollination; the collapse was attributed to endosperm failure. Cope (1957) discussed breeding-related research for the *Lespedeza* species.

Offutt (1962) increased the variability of several characters in *L. stipulacea* by gamma-ray and thermal-neutron irradiations and considered irradiation a useful tool for plant improvement. Donnelly (1971) found many mutants in a mutation breeding program with *L. cuneata* and developed a cultivar from one of the mutants.

The isolating barriers between *Lupinus* species within the Old World and New World groups are different (Jaranowski, 1962a). Hybridization occurs between American species, but not between the Old World species which are the ancestral forms of the cultivated species white lupine (*Lupinus albus* L.), blue lupine (*L. angustifolius* L.), and yellow lupine (*L. luteus* L.). Jaranowski (1962b) made all possible reciprocal crosses between these three species, except for the cross *L. angustifolius × L. albus*. Fertilization occurred in all crosses, but the embryos aborted because of endosperm failure. In certain crosses, embryo abortion was delayed somewhat, and embryo culture was suggested as a possible means of overcoming the sterility barrier. From 5,730 crosses of *Lupinus* species in 81 combinations, Kazimierski (1961) reported the following successful crosses: *L. albus × L. jugoslavicus* Kazim. & Now., *L. albus × L. termis* Forsk., *L. angustifolius × L. linifolius* Roth, and *L. arboreus* Sims × *L. hartwegii* Lindl. Many other interspecific hybridization studies have been made, but they are beyond the scope of this review.

Lamberts (1955) discussed the lack of genetic variability in lupine breeding programs and stated that collections should be made in their center of origin. Forbes et al. (1975) located disease resistance in natural populations of *L. angustifolius* in the western Mediterranean region. Gustafsson and Gadd (1965) suggested that genetic variability might be increased through induced mutations.
Although various *Vicia* species possess certain desirable characters, genetic barriers prevent or hinder their transfer to the more commonly grown forms. To elucidate the problem, Donnelly and Clark (1962) made intraspecific pollinations between strains of common vetch (*Vicia sativa* L.), *V. villosa* Roth, and *V. dasycarpa* Ten. and interspecific pollinations between 30 species pairs for 12 species of *Vicia*: *angustifolia* L., *articulata* Hornem., *atropurpurea*, *dasyarpa*, *ervilia* (L.) Willd., *galeata* Boiss., *grandiflora* W. Koch., *lutea* L., *pannonica* Crantz, *sativa*, *serratifolia* Jacq., and *villosa*. The *V. angustifolia* parent (2n = 10) was later reclassified as *V. cordata* Wulf. (Donnelly and Hoveland, 1966). Normal pods and seeds were produced from cross-pollinations within *V. sativa* and *V. dasycarpa*. However, crosses between certain strains of *V. villosa* produced only shrivelled seed. *Vicia villosa* apparently had more genetic diversity than did the other two species. The only successful interspecific crosses were *V. villosa* × *V. dasycarpa* and *V. sativa* × *V. cordata*. All F₁ seedlings from the first cross were chlorophyll-deficient. Considerable variability existed among the F₁ plants from the latter cross and more F₁ plants resembled the parental types for vigor than would have been expected if random chromosome segregation and recombination had occurred.

Germplasm possessing several desirable traits has been developed from advanced generations of the *V. sativa* × *V. cordata* hybrid, and three cultivars have been released (Donnelly, 1977). In addition, *V. sativa* and *V. serratifolia* have been successfully crossed and a cultivar has been released from an advanced generation of the hybrid (Donnelly, 1977). Leeuwirk and Elliott (1965) overcame the sterility barriers between *V. sativa* and *V. angustifolia* at the diploid (2n = 12) level by doubling the chromosome number of each species with colchicine and crossing at the tetraploid level.

Interspecific hybridization has not played a role in breeding sainfoin (*Onobyrichis victifolia* Scop.), crownvetch (*Coronilla varia* L.), or cicer milkvetch (*Astragalus cicer* L.). Several *Onobyrichis* species have the same chromosome number as O. *victifolia* (Chapman and Yuan, 1968), but interspecific hybridization studies have not been reported. *Coronilla varia* L. has been crossed with *C. globosa* Lam., *C. glauca* L., and *C. viminialis* Salisb., but the crosses were not successful (Risius, 1977). The prospects of hybridizing *A. cicer* with other related species are not promising because of its high ploidy level.

II. PLANT CULTURE

A. Field

The species determines the type of breeding nursery. The nurseries for the self-pollinated, annual species are typical of those used to develop pure-line cultivars. Plants may be spaced in rows or may be bulk-sown. The breeding nurseries for *Lespedeza cuneata* are similar to those of the self-pollinated species. For perennial, cross-pollinated species the desired parental plants or clones are vegetatively propagated and the resulting propagules are placed in crossing blocks. The methods of vegetative propagation for the different species are as follows: *Lotus corniculatus*, by root or stem cuttings (Seaney and Henson, 1970); *O. victifolia*, by bud cuttings (Ditterline, 1977); *C. varia*, by root or stem cuttings (Cope, 1977); and *A.
cicer, by rhizomes. Although L. cuneata can be vegetatively propagated, the availability of self-pollinated seed negates the need for this practice (Donnelly, 1977). Occasionally, the superior plants in breeding nurseries of perennial species are permitted to flower and set seed while the unselected plants are cut before flowering.

Spacing distance between propagules is determined by whether the species spread by rhizomes or other vegetative means, by expected life of crossing block, and by the type of cultivation equipment. The propagules of rhizomatous and other spreading species should be placed on relatively wide spacings, such as 1.2-m centers, with closer spacings for nonspreading species. The number of clones in a crossing block is variable and may range from 4 to more than 50. The number of replications for each clone is usually three or more with one or more propagules per replication. The randomized complete block is a common nursery design.

Seed usually is produced during the year of establishment, but some clones of certain species, such as A. cicer, flower sparsely the first year, and 2 years may be required to produce enough seed for progeny testing. Seed identity is maintained on a maternal plant basis. To overcome some of the nonrandom pollination that occurs with early and late flowering clones, seed should be harvested from the latest as well as the earliest appearing inflorescences on all clones.

B. Growth Chamber and Greenhouse

Several species within this group have flowering requirements that are quite different from those of the more commonly grown forage legumes. The Lespedeza species are unique in this respect. Temperature influences the proportion of chasmogamous and cleistogamous flowers in L. stipulacea under a 12-hour photoperiod (Hanson, 1943). Chasmogamous flowers predominate at 27 °C and above, whereas cleistogamous flowers are the most common at 21 °C. Seed set in the chasmogamous flowers is higher in the summer under field conditions than during the winter in the greenhouse. Cleistogamous flowers are highly fertile under both conditions.

Photoperiod influences both the initiation of flowering and flower type in L. stipulacea, L. striata (Nakata, 1952), and L. cuneata (Bates, 1955). In general, all species remain vegetative at photoperiods of 14 hours or longer and only cleistogamous flowers form at photoperiods of 10 to 12 hours. For L. stipulacea, only chasmogamous flowers develop at photoperiods of 12.5 to 13.5 hours (Nakata, 1952). Strains of L. cuneata differ in the proportion of flower types produced, but chasmogamous flowers are most frequent under a 13-hour day (Bates, 1955). Plant height and day length also interact to influence the type of flower produced. Vegetative growth ceases when flowering begins.

Initiation of flowering in Coronilla varia depends on both photoperiod and temperature (McKee et al., 1972). The species flowers profusely with photoperiods of 15.5 hours or longer with the proper thermo-induction treatment. Exposure to minimum temperatures of 4 to 10 °C for various periods of time is enough to induce flowering in most plants. Plant age and genotype influence flowering response.

Flowering in A. cicer is enhanced by pretreating the plants at −2 to +5 °C and by growing them at 27 °C day/21 °C night temperatures under a 15-hour photoperiod (Townsend and McGinnies, 1973). A practical method
for flower induction is to leave the plants in the field until mid-December, then place them in a greenhouse or growth chamber under a 16-hour or longer photoperiod at temperatures of about 27°C day/21°C night. It is very important to have an adequate light level, such as that provided at a photosynthetic photon flux density of 450 to 500 μE m⁻² sec⁻¹.

The flowering requirements for the lupine species are not fully understood. Species of Mediterranean origin are long day and respond to vernalization, but temperature appears to play a more dominant role than photoperiod (Gladstones, 1970; Rahman and Gladstones, 1972). The flowering response of *Lupinus albus* to photoperiod, however, is less pronounced than that of *L. angustifolius* or *L. luteus*. Gladstones and Hill (1969) found single dominant genes in *L. angustifolius* and *L. cosentinii* Guss. that removed most of the vernalization requirements.

The flowering requirements for *Lotus corniculatus*, a long-day species, are similar to those of the more commonly grown legumes, such as *M. sativa* L. and *Trifolium* species (McKee, 1963). *Onobrychis vicifolia* is a long-day plant (Ditterline, 1977) and *V. sativa* is a short-day plant (Donnelly, 1977), but their flowering requirements have not been resolved.

### III. FLORAL CHARACTERISTICS

The flower structure of the species discussed in this chapter is typical of other legumes (Chapter 2). The flower types and pollinating systems of *lespedeza* present unusual challenges to the plant breeder. The cleistogamous flowers produce only self-pollinated seed, whereas the chasmogamous flowers produce both self- and cross-pollinated seed in various proportions. Cross-pollination in *Lespedeza cuneata* ranged from 16 to 43% because of a large environmental effect (Cope, 1966).

Meiosis and microgametogenesis appear to be the same for both flower types in *L. stipulacea*, but anthesis and pollen dehiscence occur only in the chasmogamous flowers (Hanson, 1953a). At high temperatures, anthesis generally occurs between 0700 and 1000 hours, but the flowers close before night and generally remain closed. Fertilization takes place 24 to 48 hours after pollination. The stigma appears to be receptive to pollination 1 to 2 days before anthesis. Some pollen grains in cleistogamous flowers may germinate within the anther sacs and their tubes penetrate the anther wall, enter the adjacent stigma, and effect fertilization. The cleistogamous flowers have reduced corolla, stamens, and pistil (Hanson, 1943).

In the cross-pollinated *Lotus corniculatus*, anthers dehisce before the flower is completely open, but the stigmatic membrane must be broken before the pollen will germinate (Tome and Johnson, 1945). Materials released by the ruptured membrane appear to enhance pollen germination. Only about 40% of the ovules develop into mature seed following cross-pollination (Wojciechowska, 1963). The reduced seed set may be due to uneven maturation of ovules within an ovary and to the exhaustion of the supply of stigmatic fluid (Bubar, 1958). The stigmatic fluid dries up within 24 hours and repeated pollinations are ineffective.

Cross-pollination in *O. vicifolia* exceeded 90% under field conditions, but ranged from 8 to 28% for two-clone combinations under isolation with honeybees (*Apis mellifera* L.) as pollinators (Knipe and Carleton, 1972).
Under greenhouse conditions with honeybees as pollinators, *C. varia* averaged 94% cross-pollination (Risius, 1977). *Astragalus cicer* is predominantly cross-pollinated, but no information is available on its percentage of cross-pollination because marker genes have not been discovered. *Vicia sativa* and related species are highly self-pollinated (Donnelly, 1958; Mlyniec, 1962).

Lupines are predominantly self-pollinating with varying amounts of natural cross-pollination. They do not require bee visitation for pollination, but such visitations generally improve seed set. Flowers of *Lupinus angustifolius* are not particularly attractive to pollinating insects, because they do not produce nectar. Natural cross-pollination in *L. angustifolius* ranged from 0 to 12%, depending on genotype, location, year, and honeybee population (Forbes et al., 1971). When grown in alternate rows with other cultivars of the same species, Barbacki and Kapsa (1960) reported no natural cross-pollination for *L. angustifolius*, 4% for *L. albus*, and 10% for *L. luteus*.

**IV. ARTIFICIAL HYBRIDIZATION AND SELF-POLLINATION**

**A. Equipment**

The equipment for artificial hybridization is simple and consists of items such as forceps, scissors, toothpicks, and marking tags. The most expensive piece of equipment is the vacuum pump for the suction emasculation technique.

**B. Preparation of the Female**

Flowers on inflorescences of most species mature from the base to the top; consequently, withered, fully open, and immature flowers may be found on the same inflorescence. Temperature influences the rate of flower development and the length of time the flower remains receptive. In general, flowers remain receptive for 1 or 2 days after maturity.

In any emasculation procedure, the number of newly opened florets on an inflorescence must be reduced to a manageable level, usually 15 to 20. Suction emasculation and alcohol emasculation can be used for both cross- and self-pollinated species (Chapter 6). Seaney (1962) emasculated *Lotus corniculatus* by removing the stamens and fused keel petals with forceps while leaving the standard and two wing petals intact. Knipe (1972) described two methods to emasculate flowers of *O. vicifolia*. The first method consists of removing the standard petal with forceps and forcing the keel away so that the stamens and pistil are exposed. The flowers are immersed in a solution of 47.5% ethyl alcohol for 5 sec and rinsed in water. In the second method, pressure is applied to the base of the keel which causes the staminal column to protrude. The stamens are then rubbed between the thumb and forefinger. Both methods are effective, but the latter is much faster. A common procedure for emasculating the self-pollinated species is to remove the anthers with forceps before pollen shedding (Donnelly and Clark, 1962). Emasculation may not be necessary for either self or cross-pollinated species if 1) genetic markers such as seedling pigmentation or
flower color are available or 2) if the female parent is highly self-incompatible.

C. Pollination

Pollinations usually are made within a few minutes or 1 or 2 hours after emasculation; however, *Lotus corniculatus* and *Lupinus* species may be pollinated 2 to 4 days after emasculation (Seaney, 1962; Jaranowski, 1962a). For most species, emasculation and pollination can be made during any time of the day, but the best seed set in *O. viciifolia* follows late afternoon or evening pollinations (Knipe, 1972). In most self and cross-pollinated species, fertilization occurs within 24 to 48 hours after pollination.

Bud pollination is used frequently to cross self-pollinated species (Donnelly and Clark, 1962) and to cross the chasmogamous flowers of *Lespedeza* species. In *L. stipulacea*, Hanson (1953b) recommended that the flower bud be opened by applying gentle pressure with the thumb and forefinger to the ventral and dorsal sides. Sometimes a sharp probe must be used to separate the keel petals. Anthers of the male parent are held by forceps and brushed against the stigma. Self-pollinated species may be bud pollinated in a similar manner. Bud pollinations are successful because the stigma is receptive 1 or 2 days before pollen shedding.

Self-pollination can be accomplished in most cross-pollinated species by rolling the florets between the thumb and fingers, by tripping florets with a plain toothpick or with a toothpick that has a piece of emery cloth or sandpaper glued to one end, or by tripping florets with a folded piece of firm paper, such as heavy brown wrapping paper that has been trimmed to a point on one end. Cross-pollination with or without emasculation can be accomplished with either the toothpick or folded-paper method. Cross-pollinations in *O. viciifolia* are made by collecting pollen on a fingernail and rubbing it against the stigma of an emasculated flower (Knipe, 1972). When the operator’s fingers come in direct contact with pollen, they must be washed with alcohol or with soap and water and dried before the next pollination.

Flowers that have been recently emasculated or pollinated do not need to be protected in a greenhouse. In the field, however, small muslin bags or some protective device must be placed over the inflorescence to exclude pollinating insects. Pollinated inflorescences are usually identified with small (1.5 × 2.5 cm) marking tags. Information, such as parents of the cross and date of pollination, is recorded on the tag. Expected seed set following hand pollination is determined primarily by the number of ovules per ovary. For those species with a single ovule per ovary, it may be difficult to get enough seed for subsequent progeny evaluation.

Little information is available on the storage of pollen. Because all parental plants did not flower at the same time, Grant et al. (1962) stored pollen of *Lotus corniculatus* under refrigeration in small gelatin capsules contained in stoppered shell vials. Pollen of *V. sativa* remained viable for 21 days when stored under low temperature and humidity (Milczak, 1971).
D. Factors Affecting Efficiency

Some clones of perennial species may flower less profusely than others or may be exceptionally slow to flower after they are brought from the field to the greenhouse or growth chamber. For clones that flower less profusely than desired, more propagules must be started. To synchronize flowering, the late-flowering clones may be started earlier than the other clones in the greenhouse or growth chamber.

Simply inherited traits are more common in diploid and functional diploid species than in polyploids. They are easier to use in the diploid than in polyploid species because of the more complex inheritance in the latter. Genetic information is more voluminous on the *Lupinus* species than for any other group in this chapter. Gladstones (1970) lists a number of traits on which genetic information is available; many of these, including flower color, plant color, and seed color, are useful as genetic markers. In *Lespedeza* species, flower color (Hanson, 1953c; Offutt, 1976), tannin content (Cope, 1966), and seed color (Bates and Henson, 1955) serve as genetic markers. Flower color or plant pigmentation traits are available as genetic markers in *V. sativa* (Donnelly, 1958; Clark and Donnelly, 1964), *V. villosa* (Clark and Donnelly, 1964), *V. grandiflora* (Clark and Donnelly, 1964), and *O. vicifolia* (Knipe and Carleton, 1972). The exposed stigma trait may also be used in *O. vicifolia* (Knipe, 1972). In *L. corniculatus*, a flower color trait (Hart and Wilsie, 1959) and cyanogenesis (Dawson, 1941) can serve as markers. Grant et al. (1962) noted that certain characters are dominant in F₁ hybrids of diploid species closely related to *Lotus corniculatus*. Of these characters, red stem coloration, striping on the flower bud, reddish-brown keel tip color, pod and seed stippling, and positive reaction for the presence of hydrocyanic acid in the leaves might be used as markers. A white-flowered trait is available as a marker in *C. varia* (Riusi, 1977). Genetic markers have not been reported for *A. cicer*.

V. NATURAL HYBRIDIZATION

Cross-pollinated species are well-adapted to natural hybridization because insect pollinators are required for these crops (McGregor, 1976). In these species, the flower must be tripped before pollination can occur, and under natural conditions the insect pollinator does the tripping. Self-pollinated species are not suitable for natural hybridization because tripping is not required for pollination, however, insect pollination may improve the seed set on some species. Honeybees and bumblebees (*Bombus* species and *Pyrobombus* species) are common pollinators, and certain wild bees may be important pollinators under some conditions. If the population of natural pollinators is low, hives of honeybees should be placed near the crossing block. Commercial beekeepers should be contacted for sources of pollinators. There is little or no information on the distances required for proper
isolation of a field planting from others of the same species. Most researchers, however, use the isolation requirements for alfalfa as a guide (Chapter 9).

Conditions favorable for natural hybridization can be provided in greenhouses and in field cages. Desired plants and a hive of honeybees can be placed in a greenhouse that is screened against foreign pollinating insects. When placed in the greenhouse, the pollinators must be free of pollen from the species to be pollinated or contamination will occur. Cages of various sizes, shapes, and construction material may be placed around one or more plants in the greenhouse or field before floret opening (Kazmierski, 1961). The construction material (wire screen, plastic screen, or gauze) must provide for sufficient light to enter the cage and for adequate ventilation. Most cages have supporting structures, but Carleton et al. (1970) described a polyethylene, non-rigid, pneumatic isolation chamber for controlled matings. The cages confine or exclude pollinating insects according to the nature of the study.

Self-incompatibility is an excellent means of enforced outcrossing. The cross-pollinated species are predominantly self-incompatible (gametophytic type), but a few plants in most species set relatively large amounts of seed when self-pollinated (Thompson, 1938; Seaney, 1964; Risius, 1968; Townsend, 1971; Scheetz et al., 1972). Inheritance of self-incompatibility is complex in these species. Most breeders tend to select parents with high levels of self-incompatibility to reduce the potential for inbreeding depression that accompanies self-pollination.

To measure maximum cross-pollination among the chasmogamous flowers of *L. cuneata*, Cope (1966) established high and low-tannin plants alternately on about 1-m centers so that either a low or a high-tannin plant had a plant of the opposite type on all four sides. To increase the amount of cross-pollination he suggested that selection be practiced for a high ratio of chasmogamous to cleistogamous flowers (self-pollinated). He also proposed a minimum percentage of chasmogamous seed for breeder and foundation seed. The latter would be accomplished mechanically, because chasmogamous seed is larger than cleistogamous.

VI. SEED DEVELOPMENT, HARVEST, AND STORAGE

Pod development usually indicates seed formation except in interspecific crosses. Number of seed per pod and length of time from pollination to mature seed varies with species and environmental conditions. Mature seed of the *Lespedeza* species and *O. vicifolia* remains in the pod after threshing. Seed resulting from hand pollination is harvested and threshed by hand. When large volumes of seed are involved, some type of small thresher (Harmond and Rampton, 1956) is used. An excellent hulling machine (W. A. Rice Seed Co., Jerseyville, IL 62052) consists of two rubber rollers that revolve in the opposite direction at different speeds. It is especially good for processing some *Astragalus* species with very tough seed pods. The South Dakota seed blower (E. L. Erickson Products, Brookings, SD 57006) is an excellent machine for the final phase of cleaning small seed lots. Seed identity for self-pollinated species is maintained on the basis of
individual crosses, while that for the cross-pollinated species may be maintained in the same manner or on the basis of the maternal parent when produced under polycross or open-pollination conditions.

Hard-seed coats are common for *Lotus corniculatus*, *C. varia*, *A. cicer*, *L. cuneata*, and some strains of *Lupinus* species. Hard-seeded *Vicia* lines, a desirable character for reseeding purposes, have been developed by interspecific hybridization (Donnelly and Hoveland, 1966). Seeds with hard coats are impermeable to water and will not germinate unless scarified or treated with sulfuric acid to permit imbibition of water (Brant et al., 1971). Most mechanical scarifiers process only small quantities of seed. A versatile scarifier has been developed that scarifies a few seeds or several kilograms equally well and is especially suitable for scarifying seeds with exceptionally hard seed coats, such as those of *A. cicer*. (This machine originally was designed by Dr. H. J. Gorz, University of Nebraska, Lincoln, NE 68503, and has been modified by the Giddings Machine Co., Fort Collins, CO 80524.) Seed longevity is favored by storage at low relative humidity and low temperature. Because the hard seed coat also favors longevity, seed intended for storage should not be scarified.

ACKNOWLEDGMENT

The author extends his appreciation to the following people for reviews of this chapter: R. W. Cleveland, C. S. Cooper, W. A. Cope, R. L. Ditterline, E. D. Donnelly, W. F. Keim, and M. L. Risius.

REFERENCES


FORAGE LEGUMES


