Barley

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Barley (Hordeum vulgare L.) is an important feed and food grain grown in temperate parts of the world. It grows well where the ripening season is cool, rainfall moderate, and soil medium-well to well-drained. World production has increased by 60% during the past 15 years. Major producing countries are the USSR, China, Canada, France, United Kingdom, and United States. The most important uses are animal feed, malt for beverage and food products, and human food. Spring barley is predominantly grown, with winter types being grown in regions with mild winters.

I. PARENTAL MATERIAL

Hordeum species are classified into four sections—BULBOHORDEUM, CEREALIA, HORDEASTRUM, and STENOSTACHYS (Price, 1968). Grain-producing forms are in the section CEREALIA. The basic chromosome number is seven with species in CEREALIA being diploid, and those in other sections being either diploid, tetraploid, or hexaploid. Included within CEREALIA are three cultivated species (H. vulgare L., H. distichum L., and H. irregulare E. Aberg and Wiebe) and two wild species (H. spontaneum C. Koch and H. agriocrithon E. Aberg). Rajhathy et al. (1963) consider all species within CEREALIA to be H. vulgare since there is almost complete fertility in crosses among them.

While gene exchange among species within CEREALIA is achieved easily, exchange between this section and other Hordeum species and other genera has rarely been reported. Natural hybrids are not known and, although artificial hybrids have been made with species from other sections, their sterility restricts transfer of genes into species of CEREALIA.

A few successful crosses between barley and other genera have been reported. Among these are H. vulgare × Secale cereale L. (Thompson and

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Johnston, 1945) and *H. vulgare × Triticum aestivum* L. em. Thell. (Thomas et al., 1977). These intergeneric crosses are sterile and can be maintained only as vegetative clones. The cross with *T. aestivum* was achieved by using barley as the female parent, which is contrary to general expectations.

One of the largest barley collections in the world, consisting of more than 20,000 cultivars, lines, introductions, and wild species, is maintained by the USDA. Germplasm samples and information on entries are available from Curator, Small Grains Collection, Bldg. 046, Beltsville Agricultural Research Center, Beltsville, MD 20705.

II. PLANT CULTURE

Hybridization is facilitated by having vigorous, healthy plants. Soil fertility, moisture, temperature, and lighting are important considerations for production of plants, regardless of whether grown in the field or under artificial conditions. Each location for growing plants has advantages and disadvantages. The choice will be determined by facilities available, population size, crossing techniques to be used, and other considerations.

A. Field

Space limitations are rare and cost of producing plants is less in field nurseries than in greenhouses or growth chambers. Field-grown plants generally tiller well, are hardy, and shed abundant pollen. However, weather conditions in the field can be quite adverse at flowering, making plants difficult to hybridize.

Requirements for growing plants in the field are similar to those for the commercial crop or for breeding and yield nurseries. Best soils are well-drained loams and clay loams with a pH of at least 6.0. Where lime is needed, it should be applied before or at the time of seedbed preparation. Complete fertilizers, depending on soil test results, should be applied before or at planting. Nitrogen applications must be adequate for good growth, but excess quantities cause lodging. With fall-sown barley, part of the nitrogen should be applied at planting and an additional amount applied as top-dressing in early spring. Where supplemental moisture is available, adequate amounts should be supplied to keep plants growing vigorously, especially up to and through flowering.

Low temperatures and short days favor vegetative growth, tillering, and the development of good root systems, while higher temperatures and longer days stimulate seed production. Under field conditions, little can be done to modify photoperiod, temperature, and relative humidity; however, one can plant at an appropriate time to obtain flowering under the most favorable conditions. If working entirely with spring types, planting should be done early in the spring in order that plants will tiller and produce good root systems under short, cool days and will flower before weather gets too hot. With winter types, one should plant early in the fall in order that plants
may become well established and tillered prior to cold weather. When working with both spring and winter types, selecting an appropriate planting time becomes difficult. Spring types likely will winterkill if fall planted. If all are spring planted, planting must be sufficiently early to provide adequate cold for vernalizing winter types. Even if winter types are vernalized, they likely will flower later than spring types. One could plant winter types in the fall and spring types in the spring, but spring types usually will flower later than winter types. Problems of this sort favor use of greenhouses or growth chambers to grow plants for hybridizing.

Plants or rows in the field should be arranged so they are accessible for emasculating and pollinating. The design in the nursery will depend on whether one is working with individual plants or rows and the number of crosses to be made. Breeders sometimes use plants from yield or breeding nurseries for crossing purposes. If special plantings are made, plants are spaced 10 to 20 cm apart in short rows or they are solid-planted in short rows with 0.6 to 1 m between rows and rows arranged in tiers with alleyways 0.6 to 1 m wide. This arrangement allows easy access to all rows.

**B. Growth Chamber and Greenhouse**

Advantages of growing plants in greenhouses or growth chambers rather than in the field include better control of temperature, lighting, water, and relative humidity; less chance of outcrossing and of infection by seed-borne diseases; more opportunity to manipulate flowering to match maturities; more planning of work for several days ahead since weather generally is not a factor; and better scheduling of crossing when it does not conflict with field work. In addition, plants generally contact fewer diseases, pots can be moved and adjusted for effective emasculation and pollination of plants, and seed quality is good. Disadvantages include space limitations, usually a smaller number of tillers per plant, large capital investment, and high cost of energy for lighting, heating, and cooling.

Plants can be grown in pots of various sizes, but a 15-cm-diam clay pot works well. Smaller pots limit tillering, require more frequent watering, and do not provide an adequate base for support of tall plants. Larger pots require more bench space and growing medium, and are difficult to move when needed to facilitate emasculation and pollination. One plant per pot is usually adequate, with two to four being the limit, depending on pot size. Gravel or sand benches are more satisfactory than solid tables because roots grow through holes in pot bottoms into sand and fine gravel, which hold moisture and allow less frequent watering.

Several media are satisfactory for growing plants, and most soil mixes should be acceptable if they have adequate fertility. Because barley grows best in a medium having a pH of 6.0 to 6.5 it may be necessary to add limestone. Even though starting with adequate fertility, it is often necessary to add a water-soluble fertilizer once or twice during the growing period. Plants should have adequate moisture, but the growing medium should not be kept wet continually.
One should attempt to simulate in growth chambers or greenhouses conditions which favor good growth in the field. This means providing cool, short days until the plants have tillered well and then lengthening days and increasing temperatures to initiate flowering. Reid (1977) suggested planting in the greenhouse in late November and maintaining a temperature of 13 °C during the day and 7 °C at night. If these conditions are maintained for 6 to 7 weeks, both winter and spring types will tiller well and most winter types will be vernalized. At the end of this period, supplemental light should be provided for 2 to 3 hours in the middle of the night and the temperature should be increased. Interrupting the dark period is better than lengthening natural daylight hours and requires a briefer period of supplemental light. A clear, 100-W incandescent bulb placed every 2 m² of bench space is adequate to provide the needed far-red spectrum. Day temperature should be increased to 16 °C and night temperature to 10 °C. Three to 4 weeks later, day and night temperatures should be increased another 3 °C, while maintaining the same light schedule. This temperature and light schedule should be maintained until plants mature. Under these conditions, spring types head in early March and winter types from late March through April. When using growth chambers where temperature and light can be fully controlled, date of planting is not critical. In regions where temperatures are cool during early fall, plantings in the greenhouse may be made earlier than November.

Every effort should be made to grow plants under conditions which delay flowering until the spike is well developed, because such spikes are much easier to work with, set a higher percentage of seed, and produce larger seed than poorly developed ones. This primarily is a matter of keeping temperatures and day lengths within the ranges suggested above. Temperatures above 21 °C often cause pollination to occur while the spike is deep within the boot. Flower development and pollen shedding are reduced during periods of cool, cloudy weather. This can be partially overcome in the greenhouse by keeping lights on during such periods.

Greenhouse or growth chamber plants require some type of support when tillers start elongating. Plants generally are attached to bamboo stakes or metal rods by means of string, wire, or plastic ties. Sometimes plants are surrounded by a frame covered with wire mesh. Adequately supported plants should require no additional support when glassine bags are placed on them at the time of emasculation.

III. FLORAL CHARACTERISTICS

Barley has an incomplete flower because it lacks sepals and petals. Florets are perfect, with stamens and pistil being enclosed within the same floral structures. The inflorescence is a spike with alternating rachis nodes on each side and with three spikelets at each node. Each spikelet normally consists of a pair of narrow glumes and one floret. The central floret is largest, with laterals ranging from fully fertile to vestigial in different species and cultivars. In six-rowed cultivars, lateral florets are largely fertile, while in two-rowed types they are largely sterile. The outer lemma and inner palea (closest to the rachis) of each floret enclose the stamens and
pistil. When awns are present, they are an extension of the lemma. The pistil consists of a two-lobed ovule and a two-branched feathery stigma. Featherness tends to be reduced in smooth-awned types. There are three stamens, each composed of a two-lobed (four locules) anther and a slender filament which originates at the base of the ovule. Filaments are capable of extensive elongation at flowering and often push anthers outside their enclosures. Two anthers are located toward the palea and the third is toward the lemma. At the base of the ovule toward the lemma are two lodicules which swell and force the lemma and palea apart, exposing the stigma, if pollination does not occur at normal flowering time (Pope, 1944).

Barley is normally self-pollinated, with anthers often dehiscing before spikes emerge from the leaf sheaths (boots) and usually without flowers opening (Pope, 1944). The degree of spike emergence prior to anthesis varies widely with environment and cultivar. Hot weather prior to flowering favors early anthesis (Harlan et al., 1943). Six-rowed types tend to emerge farther before anthesis than two-rowed types. Under field conditions, pollination often is practically complete before anvil tips appear, especially in two-rowed types. In the greenhouse, flowering can be delayed until spikes are almost out of the boot if temperatures prior to flowering are kept below 21°C. Under high temperatures or toward the end of the flowering season, spikes flower while deep in the boot and peduncle and floral parts are extremely tender and fragile.

The first florets to mature on a spike are in the central row in the mid to upper part of the spike. This is a good position to check for stage of maturity. Florets mature in both directions from this section, with tip and base florets maturing up to 2 days later. Lateral florets mature later than central ones, but in the same order.

Anthony and Harlan (1920) studied the period of stigma receptivity and pollen viability under field conditions. They emasculated at a stage when pollination might naturally have occurred the following day. Seed set was 100% when pollination occurred 2 days following emasculation and decreased to 0% at 6 days. In their opinion, hybridization failures were more often due to faulty pollen than to any lack of stigma receptivity. They tested pollen viability from anthers in various stages of development by pollinating flowers emasculated 48 hours earlier. The period of pollen viability was short. There was no seed set from immature pollen, 30% when pollen was from anthers 2 to 3 hours away from normal dehiscence, 60% from dehiscing anthers, 40% from anthers which had dehisced 2 to 3 hours earlier, and less than 1% when pollen was from anthers that dehisced 24 hours earlier. Mature pollen grains exposed to free air were shrunken but still germinable after 2 min of exposure. After 10 min, the pollen lost its germinative properties completely. Pollen could be kept for several days by picking spikes just before pollen matured and putting them in an ice-box. When pollen was needed, they placed stems in water in a warm room and the spikes completed development. Reid (1977) held immature spikes in a refrigerator with stems in water to delay flowering.

Pope (1939) studied viability of pollen and ovules of barley following storage at three temperatures: 2.2, 4.4, and 10°C. The storage chamber was dark and maintained at 82% relative humidity. Culms of barley with some
spikes emasculated and others not emasculated were cut from plants above the third node below the spike. Their cut ends were placed in vessels of water and they were placed in cold storage within 3 days after emasculation. The extreme limit of storage found for the production of seed from stored, emasculated spikes pollinated with fresh pollen was 42 days at 2.2 C, 29 days at 4.4 C, and 14 days at 10 C. Seeds produced on these spikes germinated, but were reduced in size and sometimes required special treatment, such as germinating on filter paper and transferring to soil. The extreme limits of pollen storage were 26 days at 2.2 C, 19 days at 4.4 C, and less than 14 days at 10 C. Viable pollen was scarce at all temperatures after 1 week. Cold storage of both pollen and emasculated spikes gives a degree of flexibility in matching parents for making crosses.

Harlan et al. (1943) studied effects of temperature on seed set in barley crosses under field conditions at Aberdeen, Idaho. They found that temperatures prevailing 5 days preceding emasculation had a decided effect on seed set. With temperatures in the 15 to 21 C range, pollination up to 4 or 5 days following emasculation gave excellent seed set. At 32 to 38 C, the flowers were ready to pollinate 1 day after emasculation and seed set was reduced with subsequent pollinations. They attributed their failures in hybridization to periods of hot weather during which spikes aborted after emasculation and when it was practically impossible to use certain cultivars because pollen ripened when peduncles and glumes were very immature. Anthony and Harlan (1920) observed little development of anthers in the field during periods of cold, wet weather. Anthers rupture as they lose moisture and as the temperature rises; therefore, the most active period of pollen shedding usually is mid-morning.

Pope (1937) found that pollen germinated in the greenhouse within 5 min after reaching the stigma. Male gametes entered the pollen tube within 10 min, reached the level of the micropyle in 40 min, and within 45 min the two male gametes had entered the embryo sac.

IV. ARTIFICIAL HYBRIDIZATION OR SELF-POLLINATION

A. Equipment

Equipment for emasculating and pollinating barley consists of dissecting forceps, dissecting scissors, tags for recording parents and dates, glassine bags for covering spikes, paper clips for closing glassine bags, and pencils. The scissors should have fine points, a screw joint, and measure about 115 mm in length. Forceps should have fine or medium-fine points with guidepins and a length of 115 mm. They should have a delicate spring to prevent tiring of the fingers while working. The points of the forceps may need modifying to suit one’s needs. I grind the points to make them thin and square-edged, and medium-fine rather than fine. Thin, square edges provide a cutting tool for removing spike tips and accessory florets; medium-fine points are less likely to rupture anthers while emasculating. It is convenient to have the forceps and scissors strung around the neck.
Tags used in identifying parents and dates should be sufficiently large to record necessary information, but not large enough to cause bending of the peduncle. A size of 45 by 28 mm with string attached is quite appropriate. Bags for covering heads generally are made from glassine paper, about 38 mm wide by 153 mm long. Dialysis tubing also can be used for covering and can be obtained with a diameter of 25 mm and in rolls of various lengths. Pieces have to be cut to desired lengths and one end stapled or taped. Pope (1944) suggested that, if glassine bags are not available, spikes may be wrapped in ordinary tissue paper or toweling and tied with string.

A stool of comfortable height with storage compartment for equipment and supplies is necessary for field crossing because most of the work will be done in a sitting position. In the greenhouse, one may work standing or sitting and may adjust the height of plants by placing them on inverted pots, benches, or other items of varying heights.

B. Preparation of the Female

Biffen (1907) and Pope (1944) described in detail the mechanics of emasculating and pollinating barley. In general, a spike ready for emasculation will have anthers that are plump and light green to yellowish in color. The spike usually will be in the boot, but will have enlarged until the edges of the flag-leaf sheath have separated to partially expose it. Awns may have emerged 30 to 50 mm depending on the awn length characteristics of the cultivar. A check of central florets in the middle of the spike should suffice to indicate appropriate development. A spike generally premature for emasculating is shown in Fig. 1A, and Fig. 1B shows one that generally would be at the appropriate stage.

Emasculations may be made at any time of day; however, many prefer to emasculate during afternoons because mornings generally are better for pollinating. When emasculating during mornings, one frequently encounters pollen shed and has to remove florets in advanced stages of development or discard entire spikes.

The flag-leaf sheath (boot) is opened either by forcing the leaf edges apart with both thumbs or by splitting the sheath lengthwise with the point of the forceps (Fig. 2A). A gentle rotation and forcing apart of the sheath exposes the spike. The sheath and its attached flag leaf are cut off at the level of the first node of the rachis (Fig. 1C). If cut lower, the weak peduncle may not support the weight of the spike. Lateral florets and all undeveloped florets at the tip and base of the spike are removed using either the forceps (Fig. 1D and 2B) or by grasping the awns between the forefinger and thumb and pulling gently out and downward. Lateral florets of tworowed barley sometimes bear viable pollen and should be removed from the spike.

From six to eight florets on each side of the rachis are sufficient for a simple cross. When many seeds are desired, the lateral florets also may be emasculated. The most common practice followed for anther removal is to clip the lemma and palea at a level just above the anthers with scissors as described by Biffen (1907) (Fig. 1E and 2C). Proper height for cutting can be
determined by holding the spike to light and seeing the position of anthers. Pope (1944) suggests a slanting cut with the lower end toward the operator. The cut generally is initiated near the middle of the lemma and palea at an angle of 30 to 45° from horizontal. The three anthers are removed with forceps (Fig. 2D). If florets are not well developed, two anthers may be hidden in the edge folds of the lemma and palea. In addition to facilitating anther removal, clipping also causes flowers to open widely in a day or two, exposing stigmas for pollination (Fig. 1F). To assure that anthers are removed from all florets, it is best to start with the top floret on one side of the rachis, remove all anthers as you go down the spike, then move to the top floret on the other side and proceed likewise.

Wells and Caffey (1956) described scissor emasculation of wheat and barley. Clipping florets just below anther tips several days before normal dehiscence proved to be an effective and efficient emasculation procedure. The green anther bases were not removed. Clipping in this manner severely pruned the stigma, but had little effect on seed set. Because of smallness of the barley anther, considerable care was necessary to assure that all anthers were cut, especially in the lateral florets where anther tips were at a lower level than in central ones. They postulated that failure of the lower anther portion to form viable pollen after removal of the top portion was probably due to desiccation and death of immature pollen grains. Wells (1962) later

Fig. 1—Barley spikes at various stages of emasculation and pollination. A, Premature for emasculation; B, approximate stage for emasculating as shown by separation of flag-leaf sheath edges and emergence of awns; C, spike unwrapped from flag-leaf sheath with sheath cut off at spike base; D, with lateral florets removed, leaving two central rows; E, clipped florets with anthers removed; F, 2 days after emasculation; G, extrusion of anthers from florets which have been clipped prior to use of spike in pollination; H, a spike 4 days after pollination.
reported on more extensive studies with this technique and indicated a range of 0.7 to 3% self-pollination from scissor emasculation. The use of marker genes to identify hybrid plants would be helpful when using this technique.

Following emasculation, spikes should be covered immediately with glassine bags, sections of dialysis tubing, or tissue paper to prevent out-crossing. If the covering is heavy, it should be attached to a stake to prevent breaking of the peduncle. In the field, coverings should be attached securely at the base of the spike with a paper clip to prevent blowing off. A tag should be hung on the culm showing the plant number or parentage and date emasculated.

C. Pollination

Emasculated flowers generally are ready to pollinate 2 days following emasculation, but may be ready after 1 day during periods of high temperatures. Spikes ready for pollination will have the lemmas and paleas separated and the feathery stigma branches exposed. Pope (1944) suggested that closed flowers found between widely opened ones should be removed prior to pollination because selfing probably has occurred.

From early to mid-morning is the most effective period for collecting pollen and pollinating. Some pollen generally may be found throughout the day, becoming quite scarce past mid-afternoon, especially during periods of high temperature. The stigma appears receptive at all times of day if pollen is available.

Fig. 2—Steps in emasculating and pollinating barley. A, unwrapping spike from flag-leaf sheath; B, removal of lateral florets; C, clipping across lemma and palea of florets prior to removal of anthers; D, position of fingers while holding spike and forceps during anther removal; E and F, position of female and male spikes in the hand when pollinating by swirl method.
Pollen collecting and pollinating generally are done concurrently rather than having periods of time devoted to each. A spike with suitable pollen is one near emergence from the flag leaf sheath and in which anthesis normally would occur that day. It would be slightly more advanced than the stage described for emasculation. Anthers ready to dehisce will be plump and yellow.

Various methods are used for collecting and applying pollen, depending on individual preference, amount of pollen available, and number of florets to be pollinated. A slow, but reliable, method is collecting individual anthers from spikes cut from plants of the male parent. Florets in the proper stage, usually main florets and some laterals, are cut just above the anther tips. In a matter of minutes, anthers ready to dehisce are pushed out of the flower by elongating filaments (Fig. 1G). These anthers may be used directly or stored in the palm of the hand, on the wrist at the base of the thumb, or in a suitable clothing fold or small container. After removing the cover from an emasculated spike, single anthers are broken against the lemma and palea edges of each floret, allowing pollen to fall on the stigma. A single good anther may be used to pollinate several florets if pollen is abundant.

Pope (1944) described a more rapid method of pollinating which consists of shaking a spike that has dehisced anthers inside a paper cone which encloses the emasculated spike. Clipping the florets of the male parent facilitates pollen shed. Several female spikes may be pollinated with one good spike of the male parent by enclosing them within the same cone. As new male parents are used, fresh cones are required because pollen may stick to the inside surface of the cone. Wells (1962) described a technique for cone pollinating that was similar to Pope’s (1944). He made cones from medium-sized milk shake cups by removing the bottoms, cutting a vertical strip to reduce the diameter, and restapling to form cones approximately 6.5 cm in diameter at the top and 4 cm at the bottom.

Reid (1977) suggested using one hand to form an enclosure around the emasculated spike, and then twirling the clipped pollen parent spike around the emasculated spike by rolling the peduncle between the thumb and index finger of the other hand as the two spikes are encased loosely (Fig. 2E, F). Hands should be washed when pollen parents are changed.

Anther extrusion and dehiscence can be hastened by placing clipped male spikes in the sun. In the greenhouse, Reid (1977) places the clipped spike on white paper about 15 to 20 cm below the bulb in a crook-necked lamp. Heat, not light, seems to be responsible for speeding anther extrusion and dehiscence.

Rosenquest (1927) described a pollination technique designated as the approach method. On spikes used as female parents, all outer glumes, lemmas, and stamens were removed. A male spike near maturity was selected and the outer glumes and lemmas were removed. The two spikes were then fastened together with clips, the male spike against and slightly above the female. Both spikes were covered with a paper bag which was shaken three to four times on succeeding days. This system was adapted for field use by placing the male culm in a bottle of water.
Spikes of female parents must be covered following pollination, generally with the same material used to protect them following emasculation, to prevent outcrossing. Wells (1962) studied the effect of several types of coverings on seed set and seed size. When using kraft paper, wax paper, and glassine paper, there was no difference in percentage seed set. However, kernels covered with kraft paper were 23.8% heavier than those produced under the other coverings.

Following pollination, the male parent and date of pollination are added to the tag attached at emasculation time. The tag may then be folded, clipped to the glassine bag, or cut with scissors to indicate that pollination has been completed.

Success in hybridizing will vary with individuals, general vigor of plants, and prevailing climatic conditions. Inexperienced persons often have little success because they mutilate emasculated florets or choose poor pollen sources. An experienced worker expects better than 90% seed set if adequate pollen is available and climatic conditions are favorable.

D. Factors Affecting Efficiency

Several simple techniques may be used to synchronize flowering of parents, a necessity for efficient hybridization. Parents may be planted at two or more dates. Variations in temperature, day length, or both may be used to alter flowering if two or more rooms are available in greenhouses or growth chambers. Flowering is accelerated by growing plants under high temperatures and long days and is delayed with low temperatures and short days. Johnson and Taylor (1958) found temperature effects on heading to be almost negligible at 13-hour photoperiods, but increased temperatures greatly accelerated development with 17-hour photoperiods.

When a cultivar heads too early, the flowering culms may be removed, causing secondary tillers to develop. Early removal of primary culms stimulates development of secondary tillers better than if removed at an advanced stage of development. Spikes of secondary tillers may be small, but generally will be adequate for use as female or male parents. Cold storage of excised culms as suggested by Pope (1939) is useful when flowering of parents is not simultaneous.

The inheritance of numerous traits in barley has been thoroughly studied (Smith, 1951; Nilan, 1964). Many are conditioned by single dominant genes which can be used as marker genes to verify hybridization among F1 plants.

V. NATURAL HYBRIDIZATION

The extent of natural crossing generally is less than 0.2% (Stevenson, 1928; Robertson and Deming, 1931). Cultivar and seasonal differences exist, with cultivars being a greater source of variation than seasons. Six-rowed types tend to have more natural crossing than two-rowed types, and natural crossing tends to be higher in awnless, awnleted, and naked types.
It is possible to increase natural hybridization through the use of genetic male-steriles. Suneson (1940) was the first to report a genetic male-sterile, conditioned by a single recessive gene. This trait made it possible to produce hybrid seeds on a scale heretofore impossible in barley. Ways in which male sterility can be used in barley improvement were suggested by Suneson (1945) and Suneson and Wiebe (1962). Because male sterile plants fail to produce seed unless fertilized by foreign pollen, its use provided new possibilities for genetic recombination on a continuing basis in populations with this trait, especially when seed is saved only from male sterile plants. Through the use of male sterility, a large number of composite cross populations have been produced and made available to barley breeders throughout the world (Wesenberg and Craddock, 1975). The availability of male sterility has greatly expanded possibilities for recombination and recurrent selection.

When using conventional breeding procedures, and particularly in backcrossing, male sterility can be used effectively to eliminate emasculation. This trait has been backcrossed into a large number of spring and winter cultivars (Hocket et al., 1968). When using male sterility, female spikes should be prepared for pollination by clipping florets and bagging prior to stigma receptivity. Pollination is done in the same ways as previously described for emasculated spikes.

VI. SEED DEVELOPMENT, HARVEST, AND STORAGE

Within 2 to 4 days after pollination, one can tell if fertilization has occurred (Fig. 1H). Kernels reach maximum length in 7 days and mature in approximately 26 days (Harlan, 1920). Seed development in the greenhouse may be enhanced if glassine bags are removed from spikes about 4 days after pollination. If this is done, florets that have not set seed should be removed to eliminate possible outcrossing. Spikes may be harvested and placed in coin envelopes when peduncles turn yellow or seeds at the tip are mature, which usually is approximately 30 days after pollination.

Following harvest, seeds should be kept in a dry place at temperatures below 38 C until fully dried. Threshing generally is by hand to avoid seed damage and loss. Dried seeds may be stored for short periods at room temperature, but should be stored in a freezer or refrigerated seed-storage room for long periods.

Freshly harvested seeds of some cultivars exhibit dormancy. Brown et al. (1948) found that most cultivars germinated at 10 C, whereas a considerable number were dormant at 30 C. Removal of seed coats over embryos gave prompt germination even in the most dormant cultivars. An association of dormancy with winter growth was noted. Reid (1977) suggested avoiding dormancy by harvesting 10 to 14 days after pollination and planting directly. Seedlings from seed harvested this early tend to be weak until fully established.
VII. TECHNIQUES FOR SPECIAL SITUATIONS

Pope (1935, 1942) produced barley seeds with detached spikes. Culms harvested prior to flowering or following emasculation, placed in water, and subsequently pollinated produced seeds which were slightly more than one-third as heavy as normal kernels produced under similar conditions. These small kernels required special handling, such as germinating on blotteres, to produce viable plants. This technique could be used to bring excised culms from one location for pollination at another, to hold spikes under refrigeration until a pollen source is ready, to save a pollinated spike which may have broken from the plant, or to bring a large number of spikes together for pollination by the approach method.

REFERENCES


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