Breeding Biennial Crops

I. L. Goldman
University of Wisconsin, Madison, Wisconsin, U.S.A.

INTRODUCTION

Biennial plants require two seasons of growth to complete their life cycle. The breeding of biennial crops typically involves crop or propagule production during the first season of growth, followed by a vernalization period in controlled environment and a subsequent flowering and hybridization period in either controlled environment or the open field. Thus, breeders of biennial crops have at least two opportunities to evaluate the quality of the crop: at the end of the first season's growth and after the vernalization period. In this way, biennial crop breeding allows breeders to evaluate crop quality and productivity in the field and to further refine their selections after evaluating storage traits during the vernalization phase. Biennial crop breeding may be compressed into an annual cycle if controlled environments are used; however, in many cases two full seasons are required for a single breeding cycle, making it a more time-consuming process than the breeding of annual crops.

BREEDING METHODS FOR BIENNIALS

Perhaps the most important innovation for breeding biennial crops was the introduction of controlled environments. The use of greenhouses and growth chambers, beginning in the early part of the 20th century, allowed plant breeders to compress the two-season life cycle of a biennial plant into a calendar year. This, in turn, greatly facilitated breeding procedures and allowed for greater gains from selection as well as enhanced precision in hybridization. One of the first uses of this procedure was in the cabbage breeding program of J.C. Walker at the University of Wisconsin. Dr. Walker made use of greenhouses during the winter months to allow for the flowering and hybridization of cabbage plants during the development of yellows-resistant cabbage.[1] The use of greenhouses for breeding allowed Walker to reduce the amount of time it took to develop improved cabbage germplasm by one-half. Furthermore, the use of a controlled environment such as a greenhouse allowed for precise pollen control and improved seed set, which are crucial to the success of any breeding program.

Breeding programs for biennial crops, such as those for vegetable crops, use the first season of growth to produce the crop or propagule. In this discussion, propagule is synonymous with crop because the crop itself is later used as the propagule for seed production. For example, in the case of a crop such as carrot, the crop and the propagule are one and the same. In temperate regions, crop production may take place during the spring and summer months, so that by the end of summer or the beginning of autumn the crop is harvested and ready to be vernalized. Vernalization then takes place under controlled environment for a specified period, often coinciding with autumn. Following a suitable period of vernalization, plant propagules are brought into growth chambers or greenhouses where they are placed under long days and allowed to flower. Hybridization and seed production take place during this period, usually coinciding with winter and early spring. Thus, by the end of the pollination and seed production season, the biennial life cycle has been compressed into a single calendar year for the purpose of efficiency.

This scheme requires a vernalization chamber or access to a climate in which propagules can successfully overwinter outside, as well as access to greenhouses or growth chambers for reproduction. Therefore, while it is very efficient from a calendar point of view, the scheme requires large inputs of energy and resources in order to accomplish the compression of the life cycle. This program has been highly successful with many biennial crops, although not all biennial crops can be bred in such a way. Onion (*Allium cepa*), for example, requires a long vegetative period and long vernalization period, which typically do not allow its life cycle to be compressed into a single calendar year. In such cases, the vernalized propagules are held in cold storage for a longer period of time, perhaps as long as five months, during which time it is possible that they will have become de-vernalized. These propagules are planted as quickly as possible in the spring, where elongation of the flower stalk and flowering commences immediately.

Unlike the breeding of annual crops, the breeding of biennial crops allows for at least two primary opportunities to evaluate crop performance and quality. This is true whether the biennial cycle is compressed into a

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calendar year or whether two full seasons are used to complete the life cycle. The reason for these two opportunities is that the propagules harvested for vernalization must be handled at first to prepare them for vernalization and then again after vernalization and prior to planting for reproductive purposes. For example, the breeding of table beet follows an annual cycle with two opportunities for selection.[2] Seed is sown in May in the field. After approximately 70–90 days, plants are harvested and roots are separated from leaves with a scissors. Roots are selected, washed, trimmed, and placed in paper bags containing wood shavings. These paper bags are placed in plastic bags that are then sealed. The microclimate inside the paper bag where the propagules are placed is humid enough to prevent desiccation but dry enough to reduce damage caused by plant pathogens. Following a period of vernalization that typically lasts 10–12 weeks, roots are removed from the vernalization chamber and reselected.

Performance in storage is as crucial a trait for a biennial crop as yield performance during the first season of growth. The reason for this is that the biennial crop must be vernalized for an extended period of time, and therefore traits associated with high quality during this period are of great value in a crop cultivar. In addition, breeders of biennial crops realize that many of these same traits are those preferred by consumers for these same crops sold out of storage. For example, carrot germplasm that has been selected for superior traits during vernalization (retention of color and flavor, resistance to storage pathogens, inhibition of sprouting) will be more valuable in a breeding program as well as in a supermarket. Thus, selection for traits associated with quality factors during vernalization will serve the dual purpose of being valuable at a commercial level once a cultivar is produced.

In this way, biennial crops are often selected twice: once in the field following the harvest of the first season's growth and again following the vernalization period. Both of these opportunities for selection allow the breeder a chance to improve the crop for characteristics such as field performance and storability, which are both of great value in determining the success of a cultivar.

Following this second selection, propagules may be planted under controlled environment conditions, such as a greenhouse, where they will bolt and begin to flower. Typically, greenhouse conditions for hybridization and seed production are under long days, which will promote flowering in biennial plants.

Breeders of biennial crops have made use of genes that alter crop life cycles and thereby enhance the efficiency of breeding. One such example is the use of the *B* allele, which conditions an annual habit in *Beta vulgaris*. Plants carrying *bb* are biennial; however, a single *B* allele will result in an annual growth habit. W.H. Gabelman obtained the *B* allele conditioning annual flowering habit from sugar beet breeding material from Dr. V.F. Savitsky.[2,3] In general, the *B* allele allows for efficient development of sterile inbreds since spring-sown plants carrying *Bb* flower in the midwestern United States by mid-August. A cross of the constitution $Bb \times bb$ will give rise to 50% annual (*Bb*) progeny, which, because they are flowering, can be classified for sterility and other floral traits in the field. These annual sterile plants can then be decapitated, vernalized, and reflowered in winter in the greenhouse nursery, ensuring continuous inbreeding of the sterile line with its maintainer line.[2]

When biennial plants carrying sterile cytoplasm are desired, such as during the latter stages of an inbred development program, the remaining 50% of the segregating progeny from the above-described cross that were not flowering can be chosen for appropriate test crosses or commercial use.[3] These are of the desired genotype *bb*. In practice, use of the *B* allele in table beet breeding allows for greater flexibility and precision in inbred development because one can choose annual or biennial (or both) plants in the field and more accurately choose and plan the crosses to be made during winter months.

CONCLUSION

Biennial crop breeding, like much of modern scientific plant breeding in the United States during the 20th century, has followed a path toward the inbred-hybrid method. The inbred-hybrid method of breeding, which was developed in maize during the early decades of the 20th century, set the pattern for breeding techniques in many crops.[4] The inbred-hybrid method allowed for the development of F_1 hybrids, which offered superiority in terms of early season vigor, productivity, and uniformity. Procedures similar to those used in annual crops have been used to apply the inbred-hybrid method to the breeding of biennial crops. The primary difference found in biennial crops bred using this method is the increased AQ2 length of time required for each cycle of breeding, although as discussed above this can be greatly shortened with controlled environment nurseries.

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REFERENCES

1. Walker, J.C. *Plant Pathology*; McGraw-Hill: New York, 1950; 699 pp.
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3. Bosemark, N.O. Genetics and Breeding. In *The Sugar Beet Crop: Science into Practice*; Cooke, D.A., Scott, R.K., Eds.; Chapman and Hall: London, 1993; 67–119.