



**Development, Maintenance,
and Seed Multiplication of Open-Pollinated
Maize Varieties**

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Preface

The availability of higher yielding maize materials in the developing world has grown dramatically over the past decade. With this research progress, the need for more effective seed production systems has become increasingly crucial to the efforts of national research programs to transfer improved maize technology to farmers. In many countries, considerable investments are still needed to create the necessary infrastructure to produce and deliver quality commercial seed to farmers in a timely fashion. Adequate procedures will also have to be instituted to maintain quality and efficiency standards in the seed production process. Although adequate documentation exists for the production of hybrids, little information has been published on proper procedures for the development and maintenance of open-pollinated maize varieties. Hence, this bulletin on guidelines for the development, maintenance and seed production of open-pollinated maize varieties.

Over the past three years, several CIMMYT staff have presented papers at conferences and symposia on the subject of production and maintenance of open-pollinated maize varieties. This bulletin is a synthesis of these various efforts, and special recognition is given to Drs. Alejandro Ortega, Surinder Vasal, and Shivaji Pandey for their contributions in the development of this bulletin.

In the sections describing variety development, specific numbers are given for quantities of progeny to be grown and selection intensity to be exercised. Similarly, specific variability standards have been given for various classes of seed. These numbers are to be used only as guidelines, however, and not as sacred and inviolable tenets of maize variety breeding. The variability found within a variety, the resources available for seed production, and the quantity of seed required may alter the number of progeny grown and the selection intensity utilized. Variations, no doubt, will also exist from country to country in breeding methodology and in the form that national seed programs will take. However, the efficient development and distribution of improved varieties to farmers must remain central to the agricultural development efforts of all nations. It is our hope that the pages following will make a contribution to the achievement of this vitally important goal.

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Introduction

A cross-pollinated crop like maize offers unique opportunities for developing and releasing various types of cultivars, whether hybrids or open-pollinated varieties. The former have dominated the developed world; the latter are commonly grown in the developing countries. The procedures involved in the production of hybrid seed and maintenance of parental lines are well documented. However, an adequate documentation on the development, maintenance, and multiplication of improved open-pollinated varieties is lacking. In this paper, various aspects of maintenance and seed production of open-pollinated varieties are presented. The procedures outlined herein are appropriate for the maintenance of open-pollinated varieties, regardless of the method used for population improvement and varietal development.

Appropriateness of open-pollinated maize varieties

Millions of hectares of land in the developing world are devoted to open-pollinated varieties annually, because such varieties are seen to be well suited to those vast regions wherein traditional agricultural practices are still the rule. Improved open-pollinated varieties have several salient features which contribute to their appropriateness in several parts of the world:

- The maintenance and seed production of an improved open-pollinated variety is relatively simple. The planned seed production targets can be easily and rapidly achieved in open-pollinated varieties.

- New and better varieties extracted from an on-going population improvement program can replace the old ones when desired, either as new varieties or as improved versions of existing varieties. Similarly, switch-overs from one variety to another can be achieved rapidly, for example, when a disease-susceptible variety needs to be replaced with a resistant one.
- Seed production costs are relatively low, and seed quantities of open-pollinated varieties can be built up rapidly; commercial grain production is only two generations away from the breeder's seed.
- Open-pollinated varieties have a distinct advantage where seed distribution is difficult and costly. The seed of open-pollinated varieties can move from farmer to farmer and be saved by the farmer from year to year; both of these factors have a multiplicative effect in area coverage.
- Exchange of germplasm among national programs is easier with open-pollinated varieties than with some closed pedigree maize materials that involve proprietary rights.

Changes in the concept of open-pollinated varieties

Since maize is an open-pollinated crop, most of its land races exhibit high genetic variability. Genetically diverse maize types have been crossed to produce maize populations (composites, germplasm complexes, and advanced generations of varietal crosses) which are then improved and often released for cultivation. In most cases, the bulk from the latest cycle of improvement is released as a

variety. Unfortunately, many of the released materials have been too variable in agronomic attributes and have lacked phenotypic appeal. This situation was largely a result of the somewhat looser definition of "variety" which prevailed in the past.

More recently, however, a "variety" has come to be redefined as a superior fraction of an improved population that is different, relatively uniform, and stable. Such a variety is different because it possesses traits that distinguish it from other known varieties and define its identity. It has reduced variation for significant agronomic traits and is relatively stable, in terms of the expression of many of these traits over time in its area of adaptation. The variety should not exhibit variation beyond the acceptable standards fixed for different characteristics. A variety constituted by recombining 8-10 selected families from a family structured population can be sufficiently uniform in its appearance, if care is exercised to select families that are similar in maturity, plant height, ear height and other characteristics. The phenotypic uniformity of the variety implies less rigorous roguing operations in subsequent phases of seed multiplication as well as better acceptance by the farmers.

In summary, then, "variety" should be an assemblage of relatively uniform phenotypes representing the superior fraction of a population in a given improvement cycle. Selection of superior families for constituting a variety is necessary even in populations that have been subjected to several cycles of improvement.

Variety Development, Evaluation, and Characterization



Before describing procedures for seed maintenance and production it is appropriate to briefly review the procedures for development of a variety and its evaluation and characterization.

Variety development procedures

A variety can be developed in several ways, depending upon the on-going population improvement program. As many different population improvement schemes are used in maize, the genetic components entering into the formation of a variety differ in their family structure, genetic complexity, and degree of inbreeding. Variety development from some of the most commonly used population improvement schemes is described below (see Fig. 1):

- If a half-sib scheme is employed, a variety can be developed by recombining 6-8 half-sib families. The superior half-sib families can be identified by replicated multilocation progeny trials. Remnant seed of these families is used in the recombination process. The families can be recombined in a diallel crossing system or by bulk sibbing. It is critical at this stage to rogue out off-type plants and even eliminate complete families and their crosses if a mistake was made in their selection. Uniformity in plant type, flowering, and kernel texture and color are very important in the ensuing stages of seed multiplication.
- In full-sib family selection, about 8-10 superior families can be identified on the basis of replicated multilocation progeny tests. Using the remnant seed, the breeder can recombine these families as described above.

- In an S_1 or S_2 selection scheme, the S_1 or S_2 lines can be selected through multilocation replicated progeny trials. Using remnant seed, the breeder can recombine the superior 8-10 lines by making all possible crosses among them.
- In recurrent selection for general combining ability and reciprocal recurrent selection, remnant S_1 seed from the selected 8-10 lines is used in the recombination process, and the same procedure should be used for variety formation as outlined for S_1 or S_2 selection schemes.

It is recommended that the F_1 seed be advanced to F_2 to provide adequate seed quantities for varietal evaluation and to reduce any heterotic effects in the variety. Any of the following procedures can be used for preparing the F_1 sample for advancing to F_2 , depending on the facilities and precision required (see Fig 1).

- Assuming that 10 families were used to form the variety, there would be 45 possible crosses. A roughly equal number of selected ears from each possible cross can be shelled, keeping each cross bulk separate. Then a specified seed number or an approximate seed quantity using a volumetric measure can be taken from each cross and mixed to make the F_1 bulk, for planting and advancing to F_2 . Alternatively each of the 45 possible cross bulks can be planted separately. If a family has been wrongly selected, the crosses involving this family can be rejected. Any refinement of selection practiced at this stage will prove useful in the subsequent stages of seed multiplication.

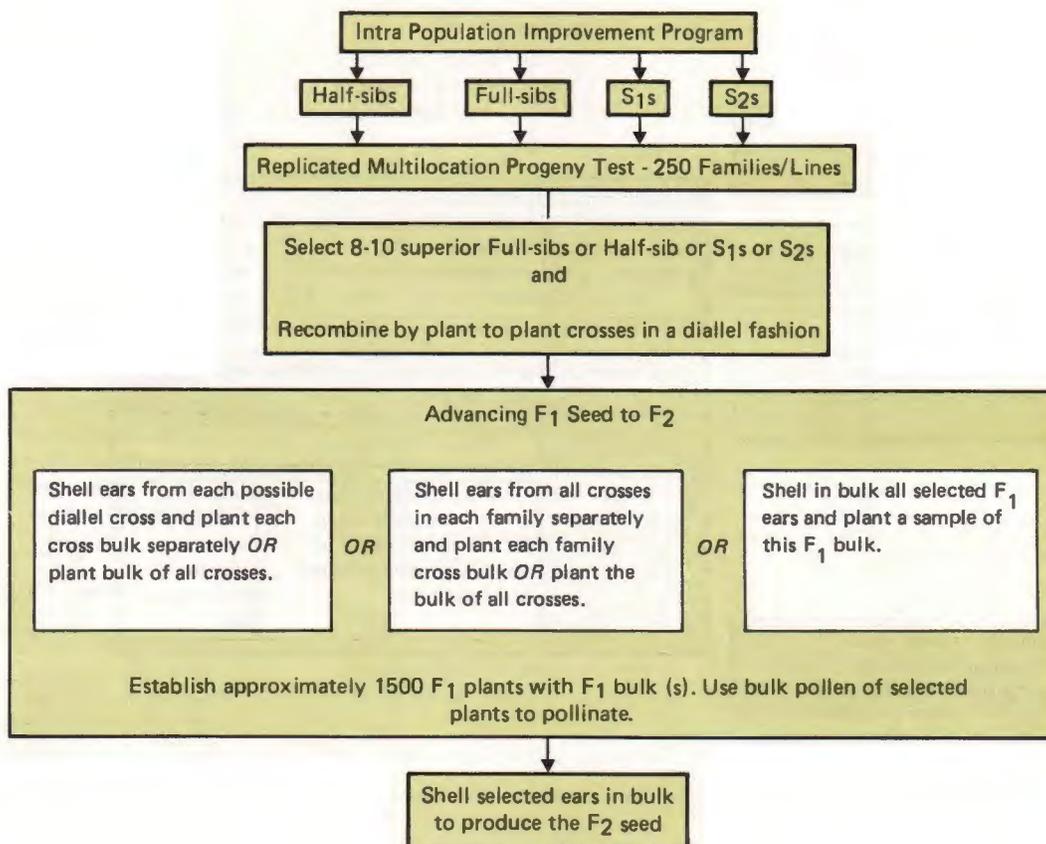
- In another alternative a roughly equal number of selected ears from each family that is crossed with all other families can be shelled and bulked. Thus, if 10 families were involved there would be only 10 family-cross bulks. A pre-calculated quantity can be taken from each family bulk to make the balanced F₁ bulk for planting to obtain the F₂ seed. These family bulks can also be planted individually. If any family bulk is exhibiting undesirable attributes, it can be eliminated from the recombination process. This will not, however, completely preclude the participation of a

poor family in the recombination process as it has already contributed as a pollen source to other bulk families.

- In a still simpler procedure all the selected ears from all family crosses are bulked, taking precaution that roughly equal numbers of ears are taken from each family. This bulk is shelled and thoroughly mixed to produce the F₁ bulk. A sample of the bulk is planted to get the F₂ seed.

Whichever procedure is used, it is suggested that, as a precaution, at least two sets should be prepared in case one is lost through accident. The quantity of F₁ seed should be such that enough F₂ seed is produced for variety evaluation and future multiplication of the variety finally selected for farmers' use. No matter which of the above alternatives is chosen, the F₁ seed should be advanced to F₂ through controlled pollination. For example, plant approximately 1,500 F₁s; rogue out all undesirable plants; select and tag desirable plants; use bulk pollen only from the selected plants for pollination; shell selected ears in bulk to produce the F₂ seed.

Figure 1. Variety Formation and Obtaining F₂ Seed from Different Intrapopulation Selection Schemes



Evaluation and variety release systems

Evaluation and variety release systems vary with national programs. In most developing countries the prevailing conditions at the experiment station and in the farmers' fields are so different that any assessment of variety performance without conducting off-station trials may be unreliable. The evaluation system employed should facilitate identification of superior varieties as rapidly as possible and involve simultaneous tests on several sites at experimental stations as well as in farmers' fields, along with

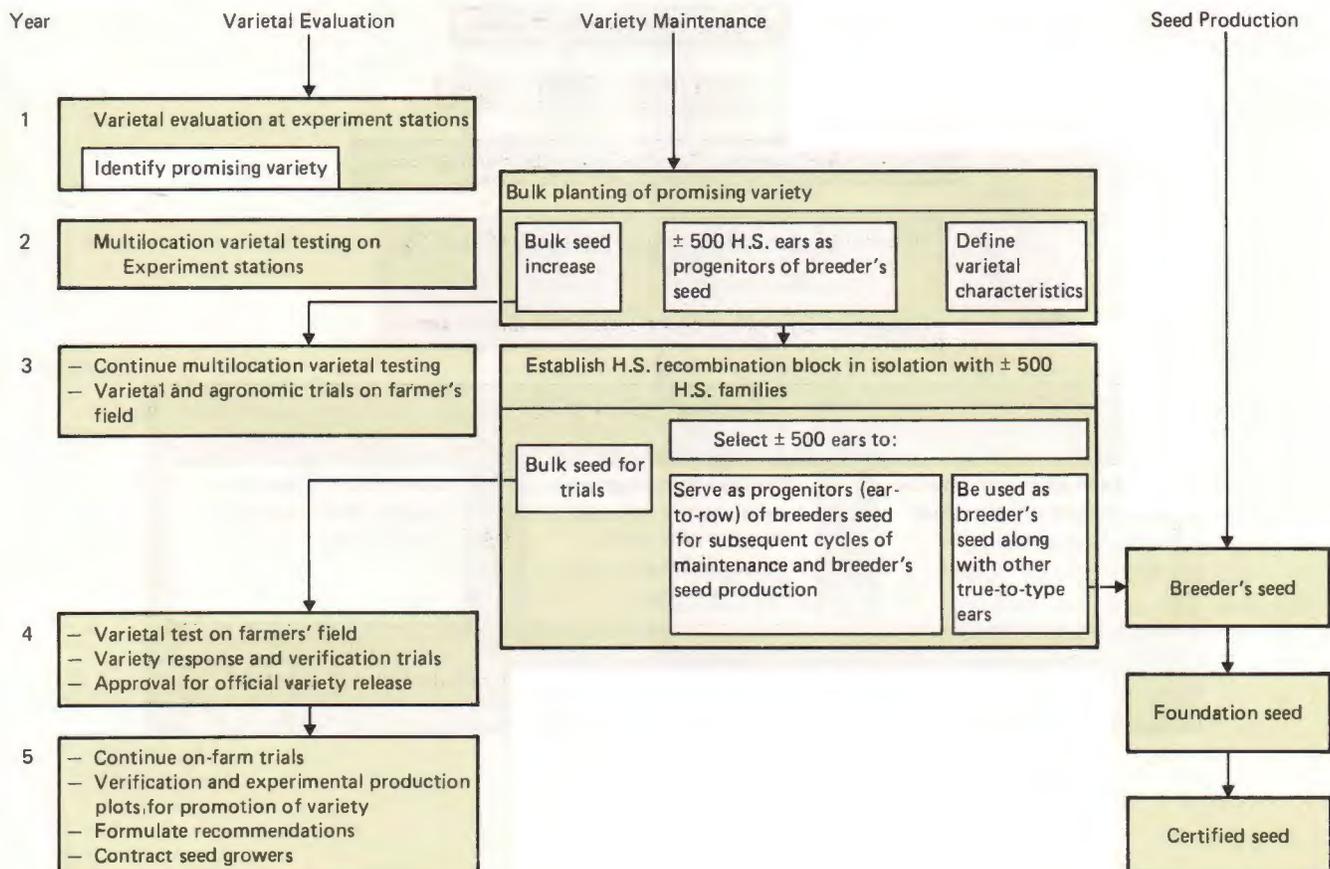
appropriate checks (see Fig. 2). The multilocation test data can be used as a substitute for testing the same variety over years. Simple agronomic off-station trials can form the basis for agronomic recommendations to be used with a particular variety. Variety release, and seed certification policies and regulations, should be such that they facilitate the delivery of superior materials to the farmers.

Characterizing an open-pollinated variety

Once a variety has reached the release stage it should be described for salient attributes in the area of its adaptation. An important attribute of

any good variety is its uniformity. However, an open-pollinated maize variety will seldom be as uniform as a single cross hybrid. Even though the elite fraction of the population is recombined to produce a variety, it is recognized that the variety will show some variation for several important agronomic attributes. The morphological traits and variations expected within a variety should be adequately described as a guide for its maintenance and for seed certification. The certification standards set for varieties should not be too stringent. They should be realistic and appropriate for the conditions prevailing in a given country.

Figure 2. Sequence of Events in Varietal Evaluation, Variety Maintenance and Seed Production Program



Characters such as adaptation, plant height, ear height, maturity, grain color, grain texture, cob color, plant architecture, and tolerance of or resistance to pests and pathogens should be considered in varietal descriptions.

Each variety would also possess some distinct genetic feature(s) which can be used to distinguish it from other varieties. Attributes such as plant color, tassel color, tassel size and configuration, seed shape, leaf orientation, stem pigmentation, ear shape, silk color, midrib color,

among other traits, can be considered in characterizing a variety. It would be easier to find distinguishing features between varieties derived from different populations than between those derived from the same population. A list of traits that can be used in describing a variety is given in Table 1. In case of quantitative characters used as variety descriptors, expected standard deviation from mean should be given

to indicate the acceptable variation within the variety. For qualitative characters the expected variants may be given in percentages, (e.g., cob colour-white, other colours- pink not exceeding 10 percent.)

It should be understood that the quantitative descriptors will be of value in the maintenance of variety and production of breeder seed. In subsequent stages of seed multiplication and for certification standards mostly qualitative characters should be used as guidelines.

A variety should show little change in its phenotypic attributes when reproduced for maintenance and/or seed increase from one cycle to another. This stability is highly desired by farmers because only a stable variety will perform in accordance with expectations from year to year.

Table 1. Characteristics that May be Considered in Description of a Variety

Plant parts	Characteristics	
	Qualitative	Quantitative
Stem	Color	Height No. of nodes No. of tillers
Leaves	Color of leaves Color of central vein Color of leaf sheath Pubescence of sheath	Total no. of leaves No. leaves above ear Leaf angle Width ear leaf Length ear leaf
Tassel	Color of glumes Color of anthers Compact or open	Length of peduncle Length of central axis No. of branches Days 50% plants with pollen
Ear	Color of stigmas Color of dry husks Husk pubescence Husk texture Ear shape Kernel row arrangement Cob color	No. per plant Insertion angle Length of ear peduncle No. of kernel rows Length Diameter Weight Shelling percentage Cob diameter
Seed	Color of pericarp Color of aleurone Color of endosperm Texture (dent, flint, etc.	Length Width Weight 1000 seeds Thickness of seed

Maintenance and Seed Production



The maintenance and seed production of open-pollinated varieties of maize can be easily managed through three stages of seed multiplication namely breeder's seed, foundation seed, and certified seed. The need for registered seed seems less obvious and this subject has been omitted from discussion. The breeder seed field should show the minimum variation; the certified seed field will have more variation; and foundation seed field will be intermediate between the two. The certification standards should be fixed carefully for various stages of seed multiplication to provide quality control but not hamper seed production and distribution.

Breeder's seed

The responsibility for maintaining the purity of breeder's seed, as long as the variety is in production, should rest with the breeder. When a released variety is replaced by a superior one, seed maintenance of the old variety can be discontinued. The quantity of breeder's seed produced can be regulated by increasing row number or row length in the breeder's seed maintenance plot. However, in order to maintain the highest level of purity, the breeder's seed plot should be small and manageable.

Any of the procedures described in Figure 3 may be used in the maintenance and production of breeder's seed.

Bulk pollination:

Grow the F₂ bulk seed to obtain approximately 8,000 plants. Select about 3,000 plants that fit the phenotypic description of the variety.

Bulk the pollen of the selected plants to pollinate these plants. At harvest select approximately 500 ears from the selected plants that have ear and kernel characteristics of the variety. These ears are referred to as the progenitors of the breeder's seed. A bulk of equal quantity of seed from each of these ears is called breeder's seed. Both the number of ears selected as progenitors and the quantity of seed sampled from them can be manipulated to obtain the required amount of breeder's seed for foundation seed production. If the demand for breeder's seed cannot be met by sampling the ears selected as progenitors, seed can also be saved from other true-to-type ears produced on selected plants but not used as progenitors of breeder's seed.

Isolated mass selection plot:

Plant F₂ bulk seed in isolation to obtain about 8,000 plants. The entire field can be stratified in grids. At flowering, detassel plants which do not fit the description of the variety. Before harvest, tag acceptable plants in each grid. At harvest, select ears from each grid with acceptable kernel color and texture. A total of 500 ears selected in this manner should constitute progenitors of the next generation of breeder's seed. A sample of seed bulked from these ears and/or seed from additional true-to-type ears from selected plants would provide breeder's seed.

Isolated bulk planting converted into half-sib crossing block:

Establish approximately 12,000 plants in rows and in isolation with F₂ bulk seed. At about the time of flowering, the rows are arbitrarily designated as males and females alternating in the ratio of 1 male row to 2-3 female rows. All the plants in the female rows are detasseled. Undesirable and off-type plants (as many as 20-40 percent) can be detasseled in the male rows depending upon the ratio of females to male. In this manner a better control can be exercised on the pollen source in the male rows used as pollinators.

If detasseling is done carefully the female rows produce more seed of better quality.

The male rows provide a good indication of environmental variation in the field. This facilitates selection in the female rows of those plants which conform to the varietal description.

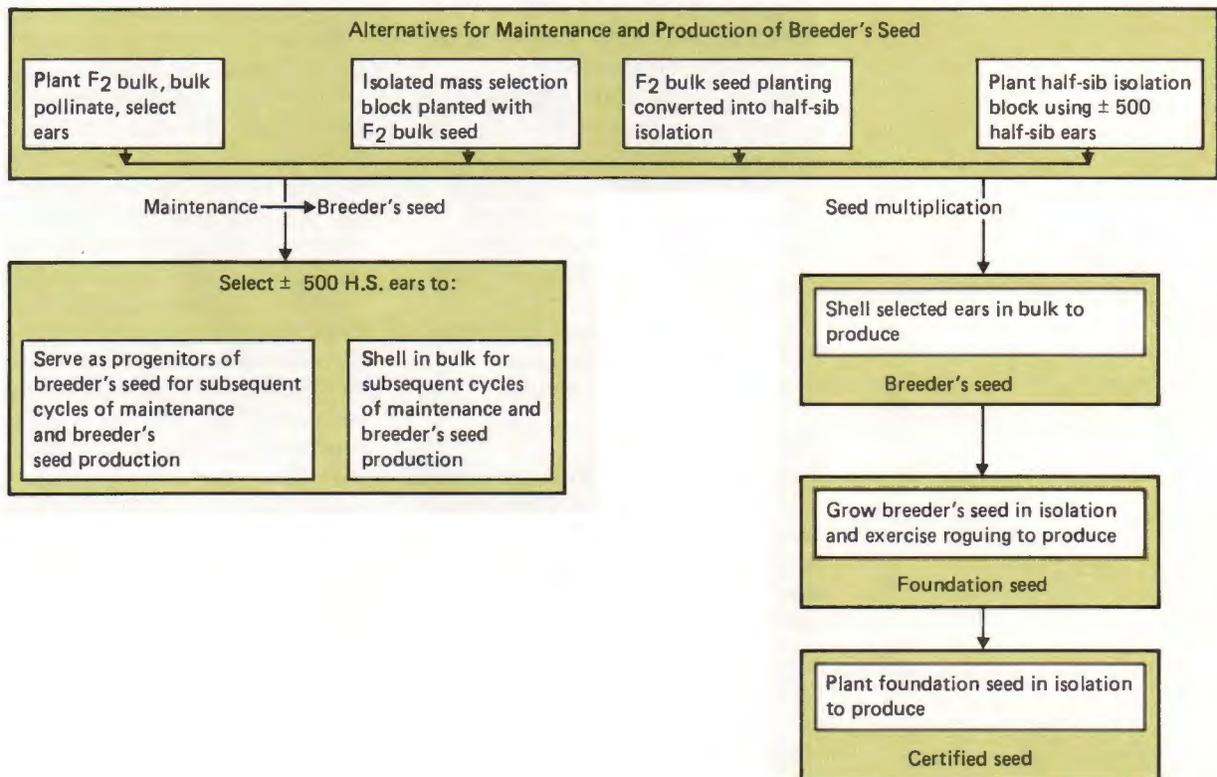
Prior to harvest, treat each female row of 16 plants as a grid. Mark two to three plants that meet the varietal description, and select one or two ears from each grid. About 500 ears can be selected in this manner as progenitors for the next generation

of breeder's seed. A bulk sample of seed from these ears and/or seed from additional true-to-type ears from selected plants would provide breeder's seed.

Isolated half-sib ear-to-row crossing block:

This is a simple and effective system for maintaining a variety and producing breeder seed. It requires isolation and can be initiated with the F₂ ears shelled individually from the plot when F₁ seed was advanced to F₂ or the individual ears saved as progenitors of the breeders seed through any of the methods discussed above. It involves the following steps (see Figure 3):

Figure 3. Maintenance and Seed Production of an Open-Pollinated Maize Variety





(1) The selected half-sib ears (\pm 500) are shelled individually. The following season these are planted as individual female entries in a half-sib crossing block. The male rows are planted with a balanced bulk made up by compositing an equal quantity of seed from each half-sib ear. A planting system of 2 females: 1 male or 3 females: 1 male or 4 females: 2 males, or 6 females: 2 males may be used. At flowering, the female rows are detasseled, as are 20-40 percent of the plants in the male rows which may be off-type or not true-to-type.

(2) Prior to harvesting, approximately 50 percent of the female rows, which conform to the description of the variety, are selected. The male rows serve as checks to select the female rows. From each of the selected female rows, 2-4 ears are taken to obtain approximately 500 ears as progenitors of the breeder's seed for future increase and maintenance. If the requirement for the breeder's seed is small, it will be preferable to take a bulk sample from these 500 ears to provide breeder's seed for the foundation seed multiplication. Additional true-to-type ears from the selected plants, in the selected families, may be saved as breeder's seed if a larger quantity of seed is required.

Foundation seed

The first increase of breeder's seed is usually referred to as foundation seed. The responsibility for producing foundation seed often rests with a seed production agency, with assistance from breeder(s)

responsible for maintaining the purity of the variety. The foundation seed should be produced through open-pollination in well-isolated plots away from any source of pollen contamination. All off-type and diseased plants must be rogued before pollination. As many as 10-15 percent of the plants may have to be rogued out. A second generation of foundation seed can be produced from the first generation foundation seed when large quantities of foundation seed are to be produced. In foundation seed plots maintenance of genetic identity and the purity of the variety should be emphasized and these plots should be monitored closely by persons responsible for the production of foundation seed under technical guidance from the breeders.

Certified seed

Certified seed is the last stage in the seed multiplication process and is generally produced from foundation seed. It should be grown in isolated plots. Again, off-type and diseased plants should be rogued before pollination though the percentage of roguing will be less than in the foundation seed plots. The certified seed should be produced by selected seed growers or at seed farms, and its production should be coordinated and supervised by public or private seed enterprises responsible for seed multiplication and distribution. The seed specialists and seed certification agency should assist the growers in production of good quality certified seed. It is suggested that a slightly lower than optimum plant density be used for production, as this ensures better quality seed. The certified seed should be properly processed and treated with insecticides and fungicides before it is sold to farmers.

Isolation standards for seed production

To maintain genetic purity and avoid varietal deterioration, seed multiplication fields should be adequately isolated. More stringent isolation is required for production of breeder's and foundation seed than for that of certified seed. Isolations can be arranged by distance or by dates of sowing. In isolations by distance, 300 meters are considered adequate for breeder's seed and foundation seed, and 200 meters for certified seed. A greater distance is desirable if possible.

In isolation by time of sowing the two seed fields can be planted side by side at an appropriate time interval. Stigma emergence and pollen shed in the first planted

isolation should be over by the time the tassels in the second isolation start emerging. A combination of both dates of sowing and distance can also be used in planning isolations. When several isolations need to be arranged in the same field, the information on number of days to pollen shed is valuable in planning such isolations. A time isolation can easily be inserted between two distant isolations with an appropriate interval so that their flowering does not coincide. The field experience, differential maturities, known trend of prevailing

winds at flowering, and natural or artificial barriers should be considered in determining safe distances for isolation.

Standards for maintaining varietal uniformity

As it goes through different stages of seed multiplication a variety is likely to become more and more variable. It is therefore imperative that some parameters be established as guidelines for different stages of seed multiplication. Although various criteria can be used, it is suggested that the maintenance of a variety at the breeder's seed level should be such that the selected families fall within the limits of $\bar{x} \pm 0.7s$ (standard deviation). In foundation seed plots, plants which fall outside the limit of $\bar{x} \pm 1.55s$, should be rouged out. In certified seed, some rouging should be made, if possible, of those plants which fall outside the limit of $\bar{x} \pm 1.96s$.



Other considerations in planning seed production



In addition to the proper procedures for maintenance and seed production of open-pollinated varieties, various other aspects of seed production must be planned adequately if good quality seed is to reach the farmer in adequate quantities and in a timely fashion. These include maintenance of reserve stocks, localizing of seed multiplication fields, and guidelines to determine how much seed of a given variety to produce.

Reserve stocks

The need for saving and storing enough reserve seed is well recognized for any seed production program, to guard against losses resulting from crop failures. The reserve stocks help to ensure continuity of a seed program. Enough seed from the progenitors of breeder's seed should therefore be maintained to last for at least two generations and stored under cold storage conditions.

Similarly, reserves of breeder's seed and foundation seed should also be adequate for at least two generations. For certified seed, any surpluses can be stored for up to a year, under proper conditions.

Localizing seed multiplication fields

Rapid shifts in the genetic make-up and hence phenotypic characteristics of maize varieties may occur if they are multiplied in areas outside their adaptation. For maintenance of breeder's seed and for the production of foundation and certified seed it is therefore important that the chosen

environments permit reproduction of all plants. To achieve this goal, breeder's seed and foundation seed plots of open-pollinated varieties should be located in the area of adaptation of the variety. The restriction is less important for certified seed, if its production is only two generations away from the breeder's seed. The maintenance and seed production of different seed categories in their area of adaptation, and under proper management, also helps to achieve greater quantities of high quality seed.

Guidelines for determining seed quantities

To avoid shortages or unwanted surpluses, it is important to plan ahead for adequate seed production. One should know in advance the requirements of different seed categories, and thus the following factors should be considered:

- Area to be covered by a released variety, based on its adaptation;
- Seed replacement interval—one, two, or three years;
- Mode of production of certified seed—seed generations needed to produce certified seed.

- Potential requirements for certified seed which in turn determine the requirements for foundation and breeder's seed;
- Land requirements for the production of different categories of seed;
- Ratio of male to female rows in a half-sib system for breeder's seed production;
- Percentage of roguing in different seed categories; and,
- Seeding rate (lower than that used in commercial grain production) for production of breeder's, foundation, and certified seed.

Table 2 illustrates the seed requirements of various categories and area for seed production to produce sufficient certified seed to plant 200,000 hectares. If a seed rate of 20 kg per hectare is used, one needs 4,000 tons of certified seed. The production of this quantity requires 1,333 hectares to be planted with 20 tons of foundation seed using a seeding rate of 15 kg/ha. This foundation seed can be produced in an area of 20 hectares, using only 300 kg of breeder's seed. The figures allow for retaining half the foundation seed as reserve stock. This example shows the rapidity with which certified seed can be produced and made available: farmers are never more than two generations away from the breeder's seed.

Table 2. Area, Seed Required and Production in Tons of Different Seed Classes to Cover 200,000 Hectares under Commercial Production

Seed category	Expected yield ton/ha	Areas in hectares	Seed rate kg/ha	Seed required in tons
Commercial	--	200,000	20	4,000
Certified	3	1,333	15	20*
Foundation	2	20	15	0.30
Breeder	-	0.4	--	--

* Plus 20 tons reserve stock

Conclusion

This paper has dealt briefly with the large topic of maize variety development, maintenance, and seed multiplication. CIMMYT's intent has been to convey only the essential information on this topic and to make the information conveyed as readily usable as possible.

The issue of open-pollinated versus hybrid seed development has not been discussed. Each type of cultivar has obvious advantages and drawbacks, depending on the research and production circumstances found in different maize-growing regions. CIMMYT believes that open-pollinated varieties, properly developed, have an important role to play in many developing countries at present. With proper varietal development procedures, and an effective seed multiplication program, open-pollinated varieties stand to make substantial contributions to raising maize productivity in much of the tropics and subtropics in the coming decades.



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