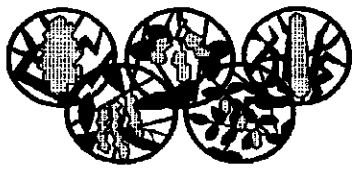
Management Procedures

for

Pearl Millet Breeding

Compiled by

T. Nagur and D.L. Oswalt



Skill Development Series no. 8

ICRISAT

Human Resource Development Program

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India

1992

Publications in this Skill Development Series (SDS) are issued semiformally for limited distribution to program participants, colleagues, and collaborators. Copies may be requested by the SDS number. Constructive criticism from readers is welcomed by: Program Leader, Human Resource Development Program, ICRISAT.

Acknowledgments

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We gratefully acknowledge the contributions made by scientists and Information Services staff. Thanks to Mr S.V. Prasad Rao, Mrs Jagatha Seetharaman, and Mr P. Chenchaiah for computerizing this manuscript.

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Introduction

Pearl millet (*Pennisetum glaucum*) is one of the cereals being improved at ICRISAT. The improvement in skill development involves collection and conservation of genetic material, evaluation of high-yielding genotypes with good quality grain and resistance to abiotic and biotic stresses, and developing agronomic practices to increase its grain yield. Individualized skill development programs are provided to improve field and laboratory techniques.

MP 1. Pollination

Pollen Collection

Pollen can be collected from pearl millet by:

a) shaking the bagged earhead
b) clipping the nonbagged earhead which shows anther emergence.

Note: Pollen from the nonbagged earhead is likely to be lost or contaminated.

Pollination

The earheads of the female and male (synchronized for flowering) are bagged before the stylar emergence. An earhead of the female parent with emerged stigma is identified. A bagged male-parent earhead, that is shedding pollen is shaken. The bag with pollen is removed and folded in the middle. The earhead of the male parent is rebagged to obtain selfed seed. The bag on the female-parent earhead is removed, quickly covered with the pollen bag and shaken. When the female parent is tall, the plant is bent and the earhead is brought near to a horizontal position and covered with the pollen bag and shaken. The open end is folded and stapled close enough to the peduncle so that the bag is not blown off, but which is loose enough to allow for elongation of the earhead without pushing through the top.

The details of the cross, the date, and person's name are printed on the bag using a waterproof marker. When earheads of the male parents are limited, a single earhead is clipped and used for several pollinations. The bag of the female parent is cut along the top and the clipped earhead is introduced into the bag and rotated around the earhead gently brushing the stigmas. Then the bag on the female is folded down and stapled. All details of the cross are printed on the bag. When the female and male parents are in proximity, are of same height, and are synchronous in flowering, the earheads of both parents are placed under one bag for pollination. This method works well between male-sterile and fertile (maintainer/restorer) lines. The details of the cross are printed on the bag used for the combined-bagging (Burton 1980).

MP 2. Male-sterile Maintenance ('A' Line)

Origin of a Male-sterile Line

Male sterility is an interaction of male-sterility inducing cytoplasm and a pair of recessive genes for male sterility. The first pearl millet cytoplasmic-genetic male-sterile (CMS) line was developed from a cross between 556 and Tift 23 (Burton 1958). The F_1 of the cross 556 × Tift 23 was male-fertile, but the F_2 gave three fertile plants to one male-sterile plant. The progeny of the backcross of male-steriles with Tift 23 were completely male-sterile. The interaction of the sterility inducing cytoplasm of 556 with the pair of recessive genes of Tift 23 resulted in the male sterility. The sixth backcrossed progeny of male steriles with the recurrent parent Tift 23 were not only male-sterile but similar to Tift 23 for other characters. The Tift 23 male-sterile line is Tift 23A and the maintainer for Tift 23 was named Tift 23B (Fig. 1).

Maintenance of the male-sterile line

The male-sterile line ('A' line) cannot set seed by itself. It must be crossed with the maintainer line ('B' line) for its maintenance (Fig. 2). For this purpose the 'A' line and its 'B' line are sown side by side in the nursery. The partially extended earheads of A and B line plants, without stylar emergence, are bagged. The openend of the bag is folded and stapled close to the peduncle so that it does not blow off. Space is left in the bag above the panicle to accommodate the growing panicle. Pearl millet is protogynous since the stigmas emerge 2–3 days before the anthers. The anthers of the 'A' line are pale, small, shrivelled, and do not shed pollen when the earhead is tapped. The 'B'-line anthers are yellow, large, plump, and shed pollen when the earhead is tapped. The 'A' lines usually have a few mutant plants that shed pollen. They must be removed and not used for crossing. One should wait until the anthers emerge on the heads of the 'A' line, make sure the anthers are sterile, and only then cross them with the 'B' line.

Pollination

First, the pollen is collected from the 'B' line by bending the plant and shaking pollen into the bag. The bag is taken off, pollen gathered at the bottom of the bag and then folded in the middle. This 'B' line head is immediately rebagged to obtain selfed seed. The bag on the nonpollen-shedding earhead in the 'A' line is removed and the 'B' line pollen-containing bag is rapidly inverted and placed over the 'A' line earhead and shaken. The openend of the bag is folded and stapled close to the peduncle. The details of the cross (Tift A × Tift B), date, and person's name are printed on the bag with a waterproof marker. Insecticide treated bags are used to protect the seed from insects and birds. The 'A' and 'B' lines are harvested at physiological maturity first the 'B' lines, and then the 'A' lines. They should be dried in the sun or with a hot-air blower at not more than 40°C until the seed moisture content is below 12%. The 'A' and 'B' lines are separately threshed, processed, mixed with a fungicide (captan or thiram) and stored in plastic containers.

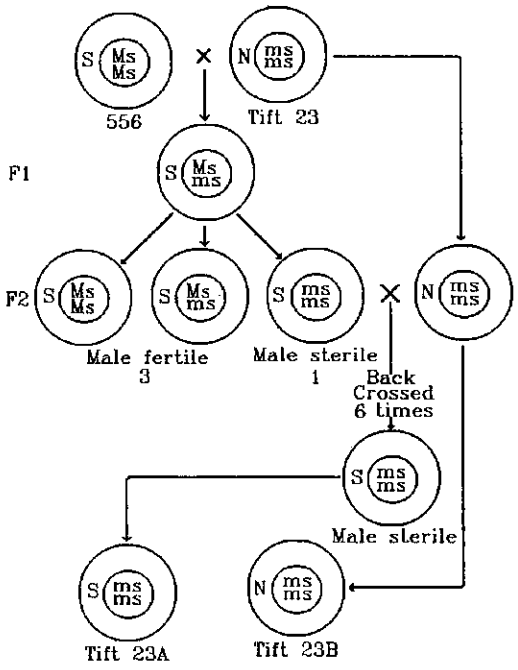

Figure 1. Development of a cytoplasmic genetic male-sterile.

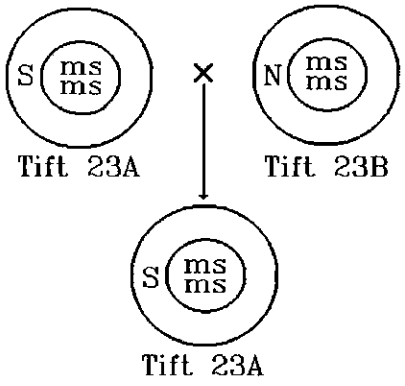

Figure 2. Maintenance of a male-sterile line.

MP 3. Male-sterile Seed Production ('A' Line)

The 'A' line seed is produced on a large scale by sowing 'A' and 'B' lines in isolation. To avoid contamination by pollen, no other millet should be allowed to grow within 400 m of seed-production plots.

A level field with irrigation facilities is selected. The usual N-P-K fertilizer is applied. The 'A' and 'B' lines are sown perpendicular to the wind direction expected at flowering. The 'A' and 'B' lines flower at the same time since they are near isogeneic thus staggering sowing dates is not normally required to ensure nicking.

Four rows of the 'A' line are sown for two rows of 'B' line. This ratio can be adjusted for a specific location to achieve satisfactory pollination and seed-setting in the 'A' line. Four rows of the 'B' line are sown on all sides of the 'A' line production plot to ensure an adequate supply of pollen for the 'A' line plants (Fig. 3).

The 'A' and 'B' lines look similar throughout their growth except for pollen-shedding. The 'B' line has normal anthers and sheds pollen, while the 'A' line has shrivelled anthers and does not shed pollen. To distinguish one from the other, marker plants of a different crop are sown at the beginning of each set of 'B' line rows. For example in front of the millet 'B' line a hill of maize or sunflower may be sown to identify the 'B' line rows. Plant protection measures are identified to control the pests and diseases.

Roguing is done in the 'A' and 'B' lines throughout the vegetative stages. The 'A' line usually produces a few pollen-shedding mutants. The pollen shedders in the 'A' line must be identified and immediately removed just as the anthers emerge. The final roguing in the 'B' line rows is done before their anther emergence. It is useless to rogue the 'B' lines after flowering since by that time any alien plant in the 'B' line would have already contaminated the 'A' line plants.

When the 'A' and 'B' lines attain physiological maturity, the 'B' line heads are harvested first to prevent contamination. The 'A' and 'B' line heads are separately dried, threshed, and processed. The seed can be treated with a fungicide (captan or thiram) and stored in plastic containers or cloth bags.

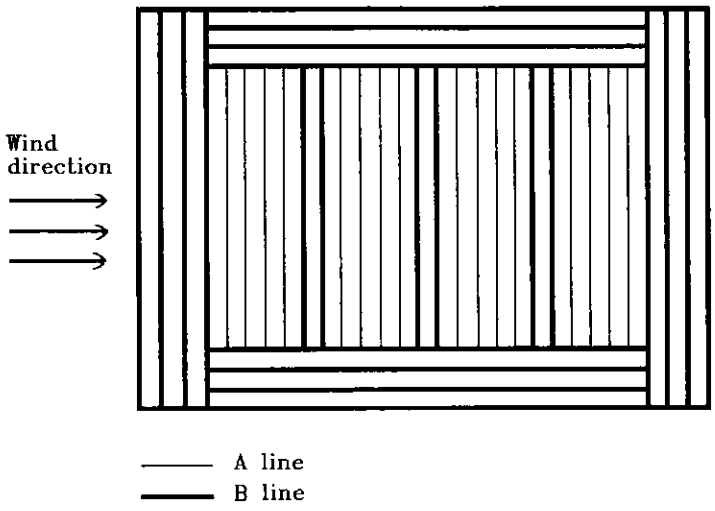

Figure 3. A male-sterile seed production plot.

MP 4. Development of New Male-sterile Lines

A specific male-sterile line may become susceptible to a disease or pest and become undesirable for making hybrids. Under such circumstances the breeder may improve the male-sterile line to improve its future hybrids.

When test crosses are made between the susceptible male-sterile line and unrelated fertile lines to identify the suitable hybrid combinations, some of the progenies often exhibit complete male sterility. The male parents of such sterile progenies should carry a pair of allelic recessive genes of the male-sterile line used in the cross. When such male parents are associated with desirable characters that are missing in the male-sterile line, a new male-sterile line can be developed by back crossing the sterile progeny to its male parent. With six backcrosses almost all the genes of the male parent are transferred to a new male-sterile progeny that looks like the male parent, but the backcrossed progeny are sterile. The newly developed male-sterile line is an 'A' line and the male parent is the 'B' line.

Tift 23A and Tift 23B developed by Burton (1965) were found to display premature germination. Tift 18 had dormancy and was found to maintain male sterility in Tift 23A. The sterile progeny from Tift 23A x Tift 18 were backcrossed six times to Tift 18 and a new male-sterile line looking like Tift 18 was developed. The resulting male-sterile line is Tift 18A and Tift 18B is its maintainer. The newly developed male-sterile line now carries the male-sterility inducing cytoplasm of 556 (same as Tift 23A) and the nuclear factors of Tift 18 (Fig. 4) (Anand Kumar and Andrews 1984).

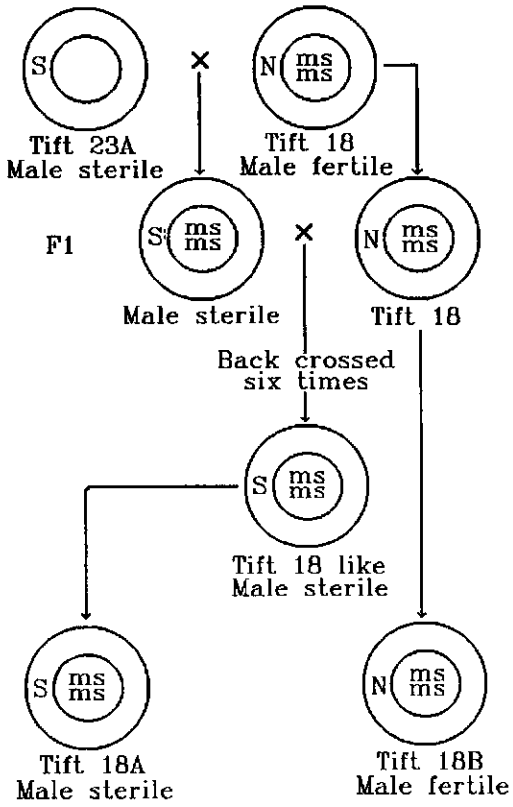

Figure 4. Development of a new male-sterile line.

MP 5. Development of Hybrids with Cytoplasmic Genetic Male-steriles

Cytoplasmic-genetic male sterility is used for developing high yielding hybrids of pearl millet. This is achieved by identifying a suitable combination of a male-sterile line and a male parent resulting in a high-yielding hybrid.

All the combinations may not provide fertile progenies, some may be partially fertile and some male-sterile. The first step is to identify a combination that yields a fertile hybrid; the yield potential will be tested later. The male-parents that synchronize in flowering with the 'A' line are selected so that the identified combinations will nick for hybrid seed production. However, the male

parents that are early or late are also selected if they possess very desirable characters. The nicking of such a combination can be achieved with staggered dates of sowing for hybrid-seed production.

The male-sterile line and the rows of male parents are sown close to each other in the nursery (Fig. 5). Staggered sowing dates are used for the parents that differ for flowering dates. The partially exposed earheads (without stylar emergence) in the 'A' line and the male-parent heads are bagged with semitransparent paper bags. A male-parent earhead with more than half the anthers emerged in the specific row is identified, shaken, and the pollen collection bag removed. Another bag is immediately placed on the earhead if selfed seed of that male parent is required.

The bag on the 'A' line nonpollen-shedding earhead is removed and the pollen-containing bag is rapidly inverted on the 'A' line head and shaken. Then the pollen bag is folded and stapled closely to the peduncle. The details of the cross ('A' line × male parent), date, and person's name are printed on the bag with a waterproof marker.

Use insecticide-treated bags to prevent damage by insects.

The crossed heads and the selfed heads of the parents are harvested at physiological maturity. The heads are dried, threshed, and stored for further study (Burton 1980; Rachie and Majmudar 1980; and Anand Kumar and Andrews 1984).

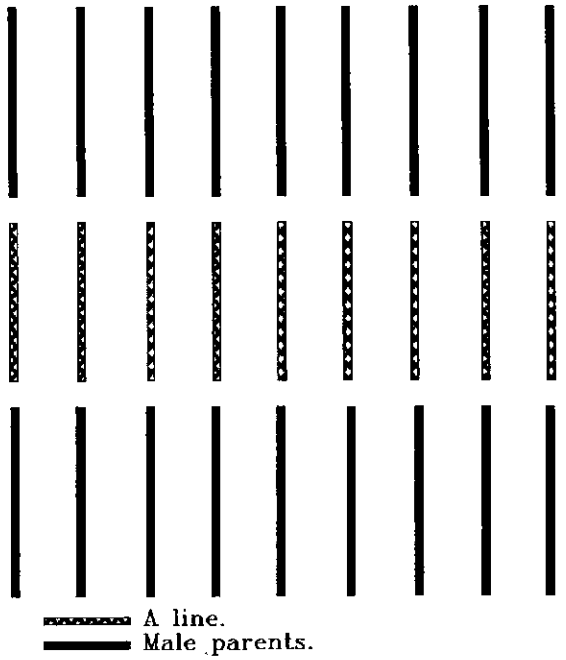

Figure 5. Development of hybrids.

MP 6. Hybrid Seed Production

The pearl millet hybrid seed is produced on a large scale by sowing the male-sterile (A) line and the restorer 'R' line together in isolation of at least 200 m from other millet. The female (A) and the male (R) rows are sown perpendicular to the normal wind direction at the time of flowering. Difference in the 'A' line and 'R' line flowering dates for a specific location, can be adjusted by staggered sowing dates. For example if the 'A' line flowers earlier than the 'R' line, the 'R' line is sown earlier than the 'A' line, to ensure that pollen will be shed when the 'A' line stigmas are receptive.

Usually four rows of 'A' line for two rows of 'R' line are sown in the hybrid seed production plot. The exact ratio may be adjusted for a specific location to achieve maximum pollination and seed setting in the 'A' line. Four rows of 'R' line are sown as a border on all sides of the plot to ensure an adequate pollen supply to the 'A' line (Fig. 6).

All plant protection measures are adopted for pest and disease control.

It is easy to identify rows of 'A' lines and 'R' lines when they are phenotypically different. Roguing to remove offtypes and 'A' line pollen shedders is done three times during the vegetative stage. As anthers first emerge, the pollen shedders are removed from the 'A' line rows. The final roguing for offtypes in the 'R' line is done just before the emergence of anthers. 'R' line roguing after anthesis would serve no purpose as contamination from offtype pollen would have occurred. When the 'A' and 'R' lines attain physiological maturity, the 'R' line is harvested first to reduce contamination of the hybrid seed. The 'R' line is separately threshed and processed for further use as a male parent (Burton 1980; Gill 1983).

The hybrid seed from the 'A' line rows is harvested, dried, threshed, processed, and stored after treating with the fungicide.

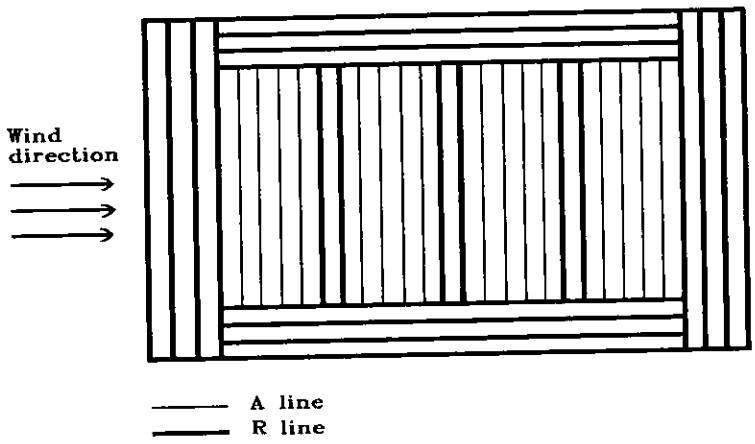

Figure 6. Hybrid seed production plot.

MP 7. Developing a Composite C_o Bulk

Before starting to improve a population, a composite bulk (C_o) is constituted and developed in three generations or more.

Generation 1

The seeds of the selected entries are identified and the pollinator-bulk 'B_o' is constituted by mixing them based on their geographical origins.

a) Each of the entries mixed in the bulk is sown alternately with the 'B_o' bulk.

b) At harvest, 4 to 8 heads from each entry are selected and bulked.

c) Equal quantities of seed from the bulk of each selected entry are mixed to form the pollinator bulk B_1.

Generation 2

a) Seed of each entry used is sown alternately with the bulk B_1.

b) Four to eight heads in each entry are selected to form an entry bulk.

c) Equal quantities of seed of the selected entries are mixed to form the pollinator bulk B_2.

Generation 3

The above procedure is repeated and the pollinator bulk B_3 is developed.

The procedure is followed until the individual entries loose their identity; which is usually by the third generation.

When some of the derived entries exhibited their individual characters, because of incomplete random mating, one or two more generations of random mating may be produced.

When random mating appears to be complete, equal quantities of seed of the derived entries are mixed and the composite C_o is constituted. The C_o bulk is used as the base population for improvement by recurrent selection (Gupta and Andrews 1977).

MP 8. S_2 and S_1 Selection System

This system can be used where two generations can be grown in one year. Generation 1 was started with the half-sibs of the selected plants from a C_0 bulk.

Cycle 1

Generation 1

a) 700-800 half-sibs of selected plants of the C_0 bulk are sown in head rows.

b) Three to five of the best plants are selfed in each of 600 good-looking progeny rows.

c) Selfed heads (S_1) from the 400 best selected progeny rows are harvested based on the head mass, grain-set, grain mass, height, and date of 50% flowering.

Generation 2

a) 400 S_1 heads are sown as the progeny rows in a replicated yield trial.

b) Three to five heads are selfed in each progeny row.

c) One to three of the best selfed (S_2) plants are harvested from the best looking progeny rows.

d) S_2 heads from 250 progeny rows are retained based on head mass, plant height, date of 50% bloom, disease resistance, and other desired characters.

Generation 3

a) 300 S_2 families from the selected heads of generation two, are sown in a replicated yield trial with two replications at three or more locations; one replication is sown in the disease nursery/sick plot.

b) Ten plants are selfed in each entry in the disease-nursery. The five best plants with low levels of downy mildew, smut, ergot, and other diseases are selected.

c) Twenty-five entries are selected, some from specific locations and others from those which performed uniformly across the locations.

d) The 5-10 best progenies for each location and across the locations are selected and experimental varieties for the specific locations and across the locations are constituted.

Generation 4

a) Equal quantities of the selected 25-40 entries from generation 3 step 'c' are mixed and the C_1 bulk is constituted. This completes the first cycle of the S_2 selection system.

b) The experimental varieties for each location and across locations are developed by mixing the five to ten selected entries.

c) The successful experimental varieties from the varietal trials are passed on for commercial production.

d) Population improvement is continued but the developed experimental varieties are separately retained.

Cycle 2 Generation 1

a) Seven-hundred half-sibs from the random mated C_1 bulk are selected and the second cycle is repeated.

b) The composite C_2 bulk is produced by mixing the best entries.

c) The experimental varieties for the locations and across the locations are developed (Gupta and Andrews 1977).

MP 9. Full-sib Selection System

Out of the 400 plant-to-plant crosses (full-sibs) made from a third or fourth random-mated population, 300 are retained at harvest and one head from each plant involved in the 400 crosses is selfed.

Cycle 1

Generation 1

a) The 300 crosses are tested in the progeny trials in several environments with adopted checks. They are evaluated for yield and other agronomic characters.

b) The crosses are tested simultaneously for disease reaction in the disease nurseries.

c) The 20–40 best parents involved in the crosses are identified from the progeny trials, location trials, and the disease nurseries.

Generation 2

a) The 25-40 best entries are sown with selfed seed from generation 1 step 'c'.

b) At least 300 crosses are made among the 25–40 best entries in a partial diallel system to force recombination.

c) The parents of the diallel crosses are tested simultaneously to confirm disease resistance.

d) Equal proportions of seed from each of the 300 crosses are mixed to prepare the C_1 bulk.

e) The selfed seed of the best parents are mixed (equal amount of seed from each parent) and experimental varieties are developed for locations and across locations.

This completes the first cycle of full-sib selection.

Cycle 2

300 plant-to-plant crosses (full-sibs) are made from the cycle 1 population (C_1 bulk) and the process is repeated.

The cycle 2 generations and experimental varieties for locations and across the locations are developed and identified as for the first cycle (Gupta and Andrews 1977).

MP 10. Inbred Tester Method

This system requires three generations to complete a cycle. A third or fourth generation randomly mated population is chosen.

Cycle 1

Generation 1

a) 300-400 half-sibs selected from the randomly mated population are sown in individual rows. 400 selected plants from these rows are crossed with an inbred line.

b) One head from a tiller on each of the selected 400 plants is selfed.

Generation 2

a) The crosses are evaluated under several environments for yield, disease reaction, and other agronomic characters.

b) 25-40 of the best crosses are identified.

c) 5-10 parents, which are involved within the best 25-40 crosses for each location and across the locations, are identified.

Generation 3

a) Equal amounts of the selfed seed of the 25-40 parents of the best crosses are mixed to form cycle 1.

b) The selected 5-10 entries are mixed and experimental varieties for locations and across the locations are developed.

Cycle 2

The 300-400 half-sib rows (from open-pollinated heads after 3 or 4 random matings) are sown and the process is repeated as in cycle 1.

Experimental varieties for locations and across the locations are identified as for the first cycle (Gupta and Andrews 1977).

MP 11. Mass Selection System

The two methods of mass selection usually adopted are:

a) Gridded mass selection (GMS) (Gardner 1969).

b) Recurrent restricted phenotypic selection (RRPS) (Burton 1983).

Gridded Mass Selection (GMS)

In this method the entire population is divided into plots of equal size and an equal number of plants are selected from each plot and bulked, and another cycle of mass selection is started.

Recurrent Restricted Phenotypic Selection (RRPS)

In this method the entire population is divided into grids (plots) as in GMS. In each grid an equal number of good plants is selected before anthesis. Pollen is collected from the plants in each of these plots, mixed and used to pollinate one or two selected plants in each plot.

An equal quantity of seed from each selected phenotype is collected, mixed, and a new cycle is started with the bulked seed.

The RRPS procedure provides the opportunity for paternal and maternal selection, which results in the advancement of desirable characters in the population.

The selection of 100 plants out of 5000 plants appeared to be good for improving selected characters (Gupta and Andrews 1977).

MP 12. Reciprocal Recurrent Selection System

A selected inbred tester is withdrawn from each of the populations and used as a parent for the crosses with plants from the other population.

In the first cycle, the entry that is contributing a specific character to the opposite population is employed as the tester.

The following procedure is adopted:

Two populations which are randomly mated for three to four generations are selected.

Generation 1

a) 1000 lines grown from the open-pollinated heads of the randomly mated population are sown along with the inbred tester from the opposite population.

b) 500 lines are selected based on disease incidence.

c) Selected plants from the 500 lines are crossed with the inbred from the opposite population.

d) One head in each of the rows of plants crossed with the inbred is selfed.

e) The 300 best crosses are retained.

Generation 2

The 300 crosses are evaluated in the yield trials for all the important characters across environments.

One replication is sown in a disease nursery/sick plot and the best 25-40 crosses are selected.

Generation 3

The selfed seed of 25-40 selected entries are recombined to constitute the C_1 bulk.

The whole process is carried out simultaneously for the second population by using the appropriate tester from the first population.

In the third generation of the second population the selfed seed of the chosen 25-40 selected entries are recombined and a C_1 bulk is constituted.

Experimental Varieties

Selfed seed of the best 6—10 entries (three to five from the first population, and three to five from the second population) are mixed and experimental varieties for a location and across locations are developed.

Cycle 2

Generation 1

One-thousand lines (from the open-pollinated heads of cycle 1) along with the inbred tester from the second population are sown and the process is repeated as in the first cycle.

The same procedure was carried out at the same time for the second population.

The cycle 2 bulks for the two populations are constituted by mixing the selfed seed of the best 25-40 entries.

Experimental varieties are developed for locations and across locations by recombining the best three to five entries from each of the populations (Gupta and Andrews 1977).

MP 13. Reciprocal Full-sib Selection System (RPS)

Two populations ('B' and 'R' lines) are separately maintained and reciprocal full-sibs are made between both the populations. The parents are simultaneously selfed.

The finally chosen parents (based on the full-sib performance) are recombined within the population and the advanced bulks are constituted.

Two populations, which are randomly mated three to four generations, are selected and the following procedure is adopted.

Cycle 1

Generation 1

a) 300 half-sibs (from the third or fourth randomly mated population) are sown from each of the populations.

b) 300 full-sib crosses between the populations are made.

c) All the parent plants in both the populations are selfed.

d) Each parent plant from both the populations is testcrossed to a standard 'A' line for verification of maintenance or restoration ability.

Generation 2

The 300 full-sibs are evaluated along with appropriate checks, in selected environments and in the disease nurseries.

Generation 3

a) The selfed parents of the 25-40 best crosses are mixed within the populations and C_1 bulks were constituted.

b) Experimental varieties are constituted by recombining 6-10 of the best parents (3-5 from each population) suitable for a location and across locations.

c) Selfed seed of the selected parents is used for developing maintainer (B) lines and restorer (R) lines to produce single-cross hybrids.

Cycle 2

Generation 1

The 300 half-sib rows (from the open-pollinated plants obtained after generation 3 step 'a') are grown for each population. Full-sib crosses are made between the populations and the cycle is repeated.

The reciprocal full-sib selection is best suited for developing high-yielding hybrids. There is also the potential for selecting adapted varieties (Gupta and Andrews 1977).

MP 14. Synthetic Varieties

A synthetic variety is an improved variety developed through the recombination of several selfed strains. It has an advantage over the hybrid in that the seed of the synthetic variety need not be purchased by the farmer every year, but he can save seed from each crop. Hays and Garber (1919) were the first to suggest the possibility of commercial utilization of synthetic varieties.

The synthetic variety is developed by the hybridization among the genotypes with high general combining ability (GCA) in all combinations. It is maintained from the open-pollinated seed following its synthesis by hybridization in all combinations among a number of selected genotypes; the genotypes can be inbred lines, clones, or mass-selected populations.

In pearl millet, inbred lines are first developed by continuous selfing up to both generation and tested for GCA. The inbreds showing high GCA are mixed to constitute a synthetic variety. An early generation testing after third generation of selfing for GCA will allow to eliminate considerable material with low GCA. The rest of the genotypes are tested for GCA after the 6th generation of selfing.

From the third generation of selfing the inbreds can be simultaneously tested for their resistance to downy mildew, ergot, and smut and the susceptible ones eliminated before they reach the sixth generation.

The GCA of the entries can be estimated by subjecting the inbreds to either topcross test, in a polycross test or diallel crossing.

Topcross Test

A cross between a selection and a common pollen parent that may be a variety, inbred line, or a single cross. The common pollen parent is called the tester parent.

Polycross Test

A polycross is the progeny from the seed of a line that was subjected to outcrossing with selected lines growing in the same nursery. The lines are replicated many times in the isolated natural crossing block to ensure that every line has an equal chance of being pollinated by every other line.

Diallel Cross Test

When all the n(n-1)/2 single crosses among n selected lines are made, the resulting set of crosses is called a diallel cross.

The expected yield of a synthetic variety increases steadily as more lines are added reaching a maximum of five or six entries, after that the expected yield decreases steadily as more lines are included. Hence it is suggested to include only the six best combining inbreds to develop a synthetic variety. When once a synthetic variety is constituted, open-pollination is allowed among the entries and the seed harvested can be used in the subsequent years (Allard 1960).

MP 15. Topcross Hybrids

A topcross hybrid is developed by crossing a cytoplasmic genetic male-sterile (CMS) line with an open-pollinated variety. A population may be developed by grouping several restorer lines of uniform morphological characters for using as male-parents. Suitable populations that are existing can also be used as male-parents. When a population is used as male-parents it is likely that it may contain maintainer plants also in addition to the restorers. This may result in the occurrence of male-sterile plants in the hybrid crop grown with the hybrid seed. However, the pollen from the fertile plants in the hybrid crop will provide enough pollen to the male-sterile plants for good seed setting.

In combining-ability studies carried out at ICRISAT Center, the topcross pollinators and pollinators of single-cross hybrids behaved similarly for general and specific combining ability effects in respect of grain yield, plant height, and 50% flowering (days). The topcross hybrids recorded equal if not marginally increased grain yields over the single-cross hybrids (ICRISAT 1992).

Topcross hybrids may have many advantages over the single-cross hybrids.

a) The more variable pollinator of the topcross hybrid can be constantly selected to maintain downy mildew resistance.

b) The pollinators are more vigorous as they do not suffer from inbreeding depression making the production of seed of both hybrids and pollinators easier.

c) The nicking problems are less in producing the hybrid seed because of the greater spread of flowering in open-pollinated male parents.

d) It does not take as many generations to breed a topcross pollinator on an inbred pollinator of a single cross.

e) The durable disease resistance of the topcross pollinator permits breeding of 'A' lines for high combining ability with the pollinator.

f) The variable topcross hybrid will be less susceptible to diseases such as downy mildew, than the single-cross hybrid (ICRISAT 1989).

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Evaluation

Select the most appropriate answer and check the correct answer at the end of the booklet.

MP 1. Pollination

1. The earheads of pearl millet are bagged prior to
   a) anther emergence. b) earhead emergence.
   c) boot formation. d) stylar emergence.

2. The earhead of the female pearl millet plant is pollinated at
   a) anther emergence. b) stylar emergence.
   c) the boot stage. d) earhead emergence.

3. The rebagged earhead of a male parent (after collecting the pollen) provides
   a) selfed seed. b) hybrid seed.
   c) crossed seed. d) bulk seed.

4. The details of the cross are printed on the bag with a
   a) water-proof pencil. b) pen.
   c) colored pencil. d) ball-point pen.

5. The crossing may be done when the male-sterile and fertile plants are sown close together by
   a) bagging the individual heads.
   b) bagging the heads together.
   c) hand pollinating the male-sterile plants.
   d) bagging the earheads after flowering.

6. The openend of the pollination bag is folded and stapled close to the
   a) primary branches. b) spikelets.
   c) peduncle. d) secondary branches.

7. The pollen from the nonbagged earhead is likely to be
   a) pure. b) contaminated.
   c) dry. d) sterile.

8. The number of female earheads that can be pollinated with a clipped earhead of the male parent is
   a) one. b) two.
   c) three. d) several.

MP 2. Male-Sterile ('A' line) Maintenance

1. The cytoplasmic-genetic male sterility (CMS) develops with an interaction of
   a) male-sterile cytoplasm and recessive genes.
   b) male-fertile cytoplasm and dominant genes.
   c) male-fertile cytoplasm and recessive genes.
   d) male-sterile cytoplasm and dominant genes.

2. The first pearl millet CMS line was developed by
   a) Quinby (1950). b) Burton (1956).
   c) Stephen (1958). d) Atwal (1960).

3. The F_2 generation of the cross between the lines 556 and Tift 23 gave _____ plants.
   a) 9 fertile and 7 sterile b) 1 fertile and 3 sterile
   c) 13 fertile and 3 sterile d) 3 fertile and 1 sterile

4. The progeny of the backcross (male sterile × Tift 23) are
   a) sterile. b) fertile.
   c) partially fertile. c) fertile and sterile.

5. The male sterility related to Tift 23 resulted because of the interaction of the
   a) dominant genes of 556 and cytoplasm of Tift 23.
   b) cytoplasm of Tift 23 and recessive genes of 556.
   c) recessive genes of 556 and cytoplasm of Tift 23.
   d) recessive genes of Tift 23 and cytoplasm of 556.

6. The recurrent parent used in backcrossing the male-sterile plant (found in an F_2) was
   a) 556. b) hybrid of 556 × Tift 23.
   c) Tift 23. d) a population.

7. Tift 23A is maintained by crossing with
   a) Tift 23A. b) a population.
   b) 556. d) Tift 23B.

8. The bagging of 'A' and 'B' lines is done
   a) after anther emergence.
   b) after flowering.
   c) after stylar emergence.
   d) at the partially extended earhead stage.

9. The space that is left above the earhead in the bag is to
   a) provide aeration to the earhead.
   b) prevent contamination of pollen.
   c) accommodate the growing panicle.
   d) provide space to the emerging styles.

10. The phenomenon where the stigmas emerge before the emergence of anthers is
   a) protandry. b) monogyny. c) protogyny. d) monogony.

11. The anthers emerge _____ days after the stigma emergence in pearl millet.
   a) 4-5 b) 2-3 c) 6-7 d) 8-9

12. The anthers of the 'A' line in pearl millet are
   a) yellow, small, and plump.
   b) pale, big, and shrivelled.
   c) big, plump, and yellow.
   d) pale, small, and shrivelled.

13. The pearl millet 'B' line anthers are
   a) shrivelled, pale, and small.
   b) lean, small, and pale.
   c) big, plump, and off-white.
   d) small, collapsed, and pale.

14. The 'A' line is crossed after making sure the anthers are
   a) fertile. b) sterile. c) healthy. d) normal.

15. The seed inside the bagged earheads is protected from insects by using _____ treated bags.
    a) sulfur. b) hormone. c) fungicide. d) insecticide.

16. The 'A' and 'B' lines are harvested at
    a) maturity. b) physiological maturity.
    c) hard-dough stage. d) soft-dough stage.

17. The temperature of the hot air used to dry the seed is
    a) 20°C. b) 100°C. c) 40°C. d) 80°C.

18. The moisture of the seed is brought to _____ by drying.
    a) below 12% b) above 12% c) below 20% d) below 6%

19. The processed seed of 'A' and 'B' lines are mixed with the fungicide _____ and stored.
    a) sulfur b) endosulfan c) thiram d) malathion

20. It is desirable to preserve the seed in _____ containers.
    a) card board b) iron c) plastic d) copper

MP 3. Male-sterile ('A' line) Seed Production

1. The 'A' and 'B' lines look similar throughout their growth except for
    a) pollen shedding. b) period of maturity.
    c) tillering habit. d) the height.

2. The isolation distance required for a pearl millet 'A' line seed-production plot is
    a) >100 m. b) >200 m. c) >1000 m. d) >400 m.

3. The 'A' and 'B' lines in a seed-production plot are sown _____ to the wind direction.
    a) tangent b) perpendicular c) parallel d) close

4. The usual ratio of 'A' and 'B' line rows sown in the 'A' line seed-production plot is
    a) 1 row of 'A' line and 1 row of 'B' line.
    b) 2 rows of 'A' line and 4 rows of 'B' line.
    c) 4 rows of 'A' line and 2 rows of 'B' line.
    d) 4 rows of 'A' line and 4 rows of 'B' line.

5. The purpose of sowing 4 rows of 'B' line around the 'A' line production plot is to
    a) protect the crop from insects.
    b) have adequate 'B' line seed.
    c) ensure an adequate supply of pollen.
    d) protect the crop from diseases.

6. The purpose of the marker plants (other crop) sown in front of 'B' line rows is to
    a) avoid bird damage to 'B' lines.
    b) identify the 'B' line from the 'A' line.
    c) protect 'B' line from insects.
    d) increase the revenue.

7. The 'A' line usually produces a small percentage of
    a) pollen shedders. b) early-flowering plants.
    c) dwarf plants. d) nontillering plants.

8. The anthers of the 'A' line are
   a) shrivelled. b) robust. c) plump. d) normal.

9. The roguing in 'A' and 'B' lines is done
   a) after flowering. b) at the milk stage.
   c) before the stigma emergence. d) at the time of harvest.

10. The staggering of dates for sowing of 'A' and 'B' lines is not usually required since they are
   a) protogynous. b) homogeneous.
   c) nearly isogeneic. d) homozygous.

MP 4. Development of New Male-sterile Lines

1. The new male-sterile lines are developed to
   a) produce more hybrids.
   b) reduce the price of hybrids.
   c) improve the existing varieties.
   d) improve the future hybrids.

2. The progeny of a male sterile × unknown male parent will be male sterile when the
   a) male parent is carrying the recessive genes.
   b) male sterile is carrying the dominant genes.
   c) male parent is carrying the dominant genes.
   d) male parent is carrying the sterile cytoplasm.

3. The desirable number of backcrosses to be made between the male sterile and the nonrestorer are
   a) two. b) three. c) four. d) six.

4. A new male sterile (ms) is developed when the
   a) genes of the restorer are transferred to a male-sterile line.
   b) genes of the ms are transferred to a nonrestorer line.
   c) genes of the nonrestorer are transferred to a male-sterile line.
   d) cytoplasm of the nonrestorer is transferred to a male-sterile line.

5. The maintainer line for the new male-sterile line is the
   a) restorer male parent. b) open-pollinated variety.
   c) other male-sterile line. d) nonrestorer male parent.

6. The defect that was existing in Tift 23A was
   a) delay in germination. b) premature germination.
   c) no germination. d) poor germination.

7. The desirable character that was found in Tift 18 was
   a) seed dormancy. b) early maturity.
   c) bold grain. c) high tillering.

8. The Tift 18 behaved as a _____ to Tift 23A.
   a) restorer b) maintainer
   c) donor parent d) non-recurrent parent

9. The male-sterile cytoplasm carried by Tift 18A belongs to the parent
   a) Tift 18. b) Tift 23B. c) 556. d) Tift 23.

10. A male-sterile line and its nonrestorer carry the same sterility inducing
    a) cytoplasm. b) nucleoplasm.
    c) dominant genes. d) recessive genes.

MP 5. Development of Hybrid with Cytoplasmic-genetic Male-steriles

1. The male sterility that is used to develop hybrids in pearl millet is
    a) genetic. b) somatic.
    c) cytoplasmic. d) cytoplasmic-genetic.

2. The synchronization of flowering between a male-sterile line and the male parent is
    a) paring. b) withering.
    c) nicking. d) synapsis.

3. The synchronized flowering for the parents which differ for flowering dates is achieved by adopting different
    a) depths of sowing. b) spaces of sowing.
    c) seed rates. d) dates of sowing.

4. The 'A' line is bagged with a
    a) transparent bag. b) craft paper bag.
    c) semitransparent bag. d) plastic bag.

5. The bagging of the 'A' line is done after
    a) stylar emergence.
    b) anther emergence.
    c) completion of flowering.
    d) partial exposure of the earhead from the boot.

MP 6. Hybrid Seed Production

1. The lines that are sown together for producing the pearl millet hybrid are
    a) 'A' and 'B' lines. b) 'B' and 'R' lines.
    c) 'A' and maintainer line. d) 'A' and 'R' lines.

2. The isolation distance adopted for pearl millet hybrid seed production is
    a) >1000 m. b) >200 m. c) >100 m. d) >500 m.

3. The female and male rows are sown _____ to the wind direction.
    a) tangent b) parallel c) perpendicular d) diagonal

4. The nicking between two parents with different dates of flowering is achieved by adopting
    a) deep sowing. b) staggered sowing dates.
    c) line sowing. d) shallow sowing.

5. The purpose of sowing the 'R' line around the hybrid seed production plot is to
    a) protect the crop from birds.
    b) increase the 'R' line seed.
    c) ensure adequate pollen supply.
    d) avoid insect damage.

6. The final roguing in 'A' and 'R' lines is done
   a) at the boot stage. b) prior to the stigma emergence.
   c) at the milk stage. d) after flowering.

7. The harvesting of 'A' and 'R' lines is done at
   a) physiological maturity. b) bone-dry stage.
   c) hard-dough stage. d) soft-dough stage.

8. The 'A' and 'R' lines are usually
   a) similar in genotype. b) similar in height.
   c) different in genotype. d) different in height.

MP 7. Developing a Composite C_o Bulk

1. The number of generations needed to develop a C_o bulk is
   a) one. b) two. c) three. d) five.

2. The pollinator bulk (B_o) is constituted by mixing
   a) populations. b) landraces.
   b) hybrids. d) selected entries.

3. The selected entries were sown alternately with the B_o bulk in generation
   a) two. b) three. c) four. d) one.

4. The pollinator bulk from generation two is the
   a) B_4. b) B_1. c) B_o. d) B_2.

5. The pollinator B_3 bulk was developed in generation
   a) one. b) four. c) three. d) two.

6. The generation in which the individual entries loose their identity is
   a) second. b) third. c) first. d) fourth.

7. The _____ composite bulk is constituted with the random-mated entries.
   a) C_o b) C_1 c) C_2 d) C_3

8. The ____ bulk is used as a base population in recurrent selection.
   a) C_3 b) C_2 c) C_1 d) C_o

MP 8. S_2 and S_1 Selection Systems

1. Generation 1 was started with the _____ of the selected plants from a C_o bulk.
   a) progenies b) full-sibs
   c) selfed heads d) half-sibs

2. The selfed heads (S_1) from the best selected progeny rows were harvested in the _____ generation.
   a) first b) second c) third d) fourth

3. The design in which S_1 heads are sown is
   a) an observation plot. b) a replicated trial.
   c) a split-plot design. d) a lattice design.

4. The S_2 families were sown
   a) in a single location. b) in a polycross nursery.
   c) in multilocations. d) as a bulk.

5. The selected material from the _____ is sown in the disease nursery.
   a) S_1 families b) C_o bulk
   c) C_1 bulk d) S_2 families

6. The products that were developed by mixing 5-10 of the best entries of generation 3 from specific families and across locations are
   a) composites. b) experimental varieties.
   c) synthetics. d) hybrids.

7. The product that was constituted by mixing 25-40 entries from generation 3 was a
   a) C_o bulk. b) C_2 bulk.
   c) C_1 bulk. d) C_3 bulk.

8. The product that was finally constituted from the random mated C_1 bulk was the
   a) C_1 bulk. b) C_2 bulk. c) C_3 bulk. d) C_o bulk.

MP 9. Full-sib Selection System

1. The full-sibs that were developed in a third or fourth randomly mated population were
   a) open-pollinated heads. b) plant-to-plant crosses.
   c) multiple crosses. d) hybrid-to-variety crosses.

2. The full-sibs were tested in several environments for
   a) self incompatibility. b) male-sterility expression.
   c) cross incompatibility. d) yield and agronomic characters.

3. The products that were carried forward from generation 1 to generation 2 were the
   a) best parents. b) poor parents.
   c) best hybrids. d) poor hybrids.

4. The product that was constituted by mixing the crosses among the best parents in generation 2 was the
   a) C_o bulk. b) C_2 bulk.
   c) C_1 bulk. d) C_3 bulk.

5. The experimental varieties were constituted by mixing _____ from generation 2.
   a) selfed entries b) hybrids
   c) crosses d) populations

6. The C_2 bulk was constituted from the plant-to-plant crosses made in the populations of the
   a) C_o bulk. b) C_2 bulk. c) C_1 bulk. d) C_3 bulk.

MP 10. Inbred Tester Method

1. The number of generations taken to complete a cycle in the inbred tester system is
   a) two. b) three. c) four. d) one.

2. The selected plants from the half-sibs of randomly mated population were crossed to a/an
   a) variety. b) hybrid. c) inbred. d) composite.

3. The selfed seeds of the crossed plants were produced from the
   a) crossed heads. b) heads of tillers.
   b) border plants. d) early-maturing plants.

4. The generation in which evaluation of the crosses for yield and agronomic characters is generation
   a) two. b) one. c) four. d) three.

5. The selected 5-10 entries which were involved in the best crosses were mixed to develop
   a) experimental varieties. b) inbreds.
   c) hybrids. d) synthetics.

6. The selected 25-40 entries which were involved in the best crosses were constituted to form the
   a) cycle 2. b) C_0 bulk. c) C_3 bulk. d) cycle 1.

MP 11. Mass Selection

1. The system of selection in which bulking of an equal number of plants from each equal sized plot of a field is
   a) mass selection. b) phenotypic selection.
   c) uniform selection. d) gridded mass selection.

2. The selection of good plants in each grid of recurrent restricted phenotypic selection (RRPS) was made
   a) at the milk stage. b) before anthesis.
   c) at anthesis. d) at the soft-dough stage.

3. The two selected plants in each plot were pollinated with the
   a) pollen from the selected plot.
   b) mixed pollen from the selected plant.
   c) pollen from the plants outside the nursery.
   d) mixed pollen from the selected plants in the nursery.

4. The RRPS selection provides opportunity for
   a) maternal selection. b) progeny selection.
   c) paternal and maternal selection. d) paternal selection.

MP 12. Reciprocal Recurrent Selection System

1. The number of randomly mated populations that were selected for reciprocal recurrent selection (inbred tester) system are
   a) two. b) four. c) five. d) three.

2. The inbred tester to be used as a pollinator was withdrawn from
   a) a single population. b) a hybrid population.
   c) each population. d) a synthetic.

3. The tester that was employed in the first cycle is expected to contribute _____ to the opposite population.
   a) nutrition b) pollen
   c) a specific character d) anchorage

4. The crosses are made in this method by crossing the selected plants from a population with the
   a) elite plants of the same population.
   b) tester from the opposite population.
   c) male-sterile from the opposite population.
   d) maintainer from the same population.

5. The crosses in this method were evaluated for yield and agronomic characters
   a) in a single location. b) in a hot spot.
   c) in a sick plot. d) across the environments.

6. The number of best crosses that were selected after the evaluation were
   a) 100-150. b) 200-300. c) 25-40. d) 300-400.

7. The selfed seed of the entries belonging to the best crosses were recombined to constitute the
   a) C_1 bulk. b) hybrid. c) composite. d) synthetic.

8. The selfed seed of the 6-10 best entries from both the populations were mixed to develop the
   a) hybrids. b) experimental varieties.
   c) male-steriles. d) synthetics.

MP 13. Reciprocal Full-sib Selection System (RPS)

1. The full-sib crosses in the reciprocal full-sib selection system were made
   a) within each population.
   b) with a population and a hybrid.
   c) with a population and a tester.
   d) between the two populations.

2. The parent plants in each population in the reciprocal full-sib selection were
   a) isolated. b) selfed. c) rouged. d) labeled.

3. The parent plants from both the populations were test crossed to a/an
   a) 'A' line. b) 'B' line. c) 'R' line. d) landrace.

4. The constituted product that resulted by mixing the selfed parents of the 25-40 best crosses within a population in the generation three was the
   a) C_0 bulk. b) C_2 bulk. c) C_2 bulk. d) C_1 bulk.

5. The product that was developed by mixing the 6–10 selfed parents was a/an
   a) hybrid. b) experimental variety.
   c) landrace. d) polycross.

6. The restorer lines were identified from the selected parents to develop
   a) hybrids. b) synthetics. c) composites. d) varieties.

7. The reciprocal full-sib selection was best suited for developing high yielding
   a) malesteriles. b) hybrids. c) pure lines. d) landraces.

MP 14. Synthetic Varieties

1. The inbreds used to constitute a synthetic variety are tested for their
   a) specific combining ability. b) heritability.
   c) general combining ability. d) genetic advance.

2. The number of generations an open-pollinated variety is selfed to develop an inbred line in the synthetic variety development program is
   a) 1. b) 2. c) 6. d) 12.

3. In the ____ generation an inbred is tested for disease resistance.
   a) first b) second c) third d) sixth

4. The early generation testing for GCA is done in the _____ generation of inbreeding.
   a) second b) third c) sixth d) first

5. The number of lines chosen to constitute a synthetic variety to obtain maximum yield is
   a) one. b) six. c) ten. d) twenty.

MP 15. Topcross Hybrids

1. The pollinator used in producing a topcross hybrid is a/an
   a) inbred line. b) maintainer line.
   c) single-cross hybrid. d) open-pollinated variety.

2. The topcross hybrid crop is likely to produce male-steriles due to presence of _____ plants in the pollinator.
   a) restorer b) maintainer
   c) male-sterile d) late-flowering

3. The nicking problems are comparatively easy in topcross hybrid seed production due to _____ in the pollinator.
   a) early flowering b) spread of flowering
   c) delayed flowering d) reduced flowering

4. The number of generations taken to breed the pollinator of a topcross hybrid are _____ the pollinator of a single-cross hybrid.
   a) less than b) more than
   c) same as d) none of the above for

5. The topcross hybrid will be less susceptible to diseases due to the _____ present in it.
   a) high-yield potential b) variability
   c) high tillering d) early-flowering

Correct responses to the questions.

MP 1. Pollination
1. d); 2. b); 3. a); 4. a); 5. b); 6. c); 7. b); 8. d).

MP 2. Male-sterile ('A' line) Maintenance
1. a); 2. b); 3. d); 4. a); 5. d); 6. c); 7. d); 8. d); 9. c); 10. c); 11. b); 12. d); 13. c); 14. b); 15. d); 16. b); 17. c); 18. a); 19. c); 20. c).

MP 3. Male-sterile ('A' line) Seed Production
1. a); 2. d); 3. b); 4. c); 5. c); 6. b); 7. a); 8. a); 9. c); 10. c).

MP 4. Development of New Male-Sterile Lines
1. d); 2. a); 3. d); 4. c); 5. d); 6. b); 7. a); 8. b); 9. c); 10. d).

MP 5. Development of Hybrids with Cytoplasmic Genetic Male Steriles
1. d); 2. c); 3. d); 4. c); 5. d).

MP 6. Hybrid Seed Production
1. d); 2. b); 3. c); 4. b); 5. c); 6. b); 7. a); 8. c).

MP 7. Developing a Composite C_o Bulk
1. c); 2. d); 3. d); 4. d); 5. c); 6. b); 7. a); 8. d).

MP 8. S_2 and S_1 Selection Systems
1. d); 2. a); 3. b); 4. c); 5. d); 6. b); 7. c); 8. b).

MP 9. Full-sib Selection System
1. b); 2. d); 3. a); 4. c); 5. a); 6. c).

MP 10. Inbred Tester Method
1. b); 2. c); 3. b); 4. a); 5. a); 6. d).

MP 11. Mass Selection System
1. d); 2. b); 3. d); 4. c).

MP 12. Reciprocal Recurrent Selection System (Using an Inbred Tester (RI))
1. a); 2. c); 3. c); 4. b); 5. d); 6. c); 7. a); 8. b).

MP 13. Reciprocal Full-sib Selection System
1. d); 2. b); 3. a); 4. d); 5. b); 6. a); 7. b).

MP 14. Synthetic Varieties
1. c); 2. c); 3. c); 4. b); 5. b).

MP 15. Topcross Hybrids
1. d); 2. b); 3. b); 4. a); 5. b).