CRP 305 CROP GENETICS AND BREEDING

NATIONAL OPEN UNIVERSITY OF NIGERIA

COURSE CODE: **CRP 305**

COURSE TITLE: **CROPS GENETICS AND BREEDING**

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COURSE GUIDE

CRP 305 CROP GENETICS AND BREEDING

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INTRODUCTION

CRP 305 Crop Genetics and Breeding is a one semester two (2) credit units course designed for undergraduate students in 300 Level.

The course consists of three major parts, with five modules and eighteen 18 units. In writing this study guide, I have given primary consideration to the students' background. It has been assumed that students usually enroll in the crop genetics and breeding course after they have completed courses in botany, genetics statistics and other related courses in agriculture.

WHAT YOU WILL LEARN IN THIS COURSE

CRP 305 – Crop genetics and breeding consists of five major components arranged in modules.

The first module which is on crop genetics and breeding will introduce you to the concept of what:

a. Crop breeding is, and the purpose is suppose to serve.
b. Plant cell concepts, gene symbols which will help you to understand Mendel's experiments and Law of Inheritance.
c. Differences between qualitative and quantitative traits constitute.

The study in the second module: You shall learn about heritability and selection responses.

The third part of this course, which is on methods of sexual reproduction in crop plants will discuss the importance, concepts of self incompatibility, male sterility and steps involved in making crosses.

The fourth module relates to breeding procedures for self pollinated crops which involves pedigree, bulk and back-cross methodologies.

Module five focuses on breeding methodologies for cross pollinated crops where you will learn mass selections, recurrent selection, hybrid varieties development (in maize), synthetic varieties (in maize) and seed production and distribution.

COURSE AIMS

The aim of this course is to give a clear understanding of what plant breeding is and the processes involve in developing varieties of crop for mankind that are:

1. efficient in their use of plant nutrients.
2. able to give the greatest return of high quality products per hectare or unit area.
3. able to meet the needs of the growers and consumers.
4. able to withstand conditions of cold, heat or drought.
5. resistant or tolerant to pests and diseases.

OBJECTIVES

In order to achieve the aims of this course, there are sets of overall objectives:

1. The first is to look at essential features of reproduction and the basic principles of genetics and to relate them to plant breeding procedures.
2. To familiarize the students with the established methods and techniques of plant breeding.
3. Procedures involved in increasing and distributing seed of new and improved varieties.

The unit objectives are always included in the beginning of the unit. You need to read them before you start working through the unit.

COURSE REQUIREMENTS

To complete this course, you are required to read the study units, read suggested books and other materials that will help you achieve the stated objectives. Each unit contains self assessment exercises and Tutor Marked Assignment (TMA) which you are encouraged to answer and at intervals as you progress in the course, you are required to submit assignment for assessment purpose. There will be a final examination at the end of the course.

COURSE MATERIAL

You will be provided with the following materials for this course:

1. Course guide
   The material you are reading now is called course guide, which introduces you to this course.
2. Study Guide
   The textbook prepared for this course by National Open University of Nigeria is called study guide. You will be given a copy of the book for your personal use.
3. Text Books
   At the end of each unit, there is a list of recommended textbooks which though not compulsory for you to acquired or read, are necessary as supplements to the course materials.

STUDY UNITS

There are eighteen (18) study units in this course divided into five modules as follows:

Module 1: **Pages**

At intervals in each unit, you will be provided with a number of exercises or self-assessment questions. These are to help you test yourself on the materials you have just covered. The value of these self-test is to help you evaluate your progress and to re-enforce your understanding of the

material. At least one tutor-marked assignment is provided at the end of each unit. The exercise and the tutor-marked assignment will help you in achieving the stated objectives of the individual unit and that of the entire course.

TEXTBOOKS AND REFERENCES

For detailed information about the areas covered in this course, you are advised to consult recent editions.

Allard, R.W. (1960). *Principle of Plant Breeding*. John Wiley and Sons, Inc. New York, London

Briggs, F.N. and Knowles, P.F. (1967). *Introduction to Plant Breeding*. Reinhold Pub. Corp. New York. 426 pp.

Falconer, D.S. (1981). *Introduction to Quantitative Genetics.* 2nd ed. Longman Inc. New York.

Gardner, E.J. (1972). *Principles of Genetics*. 4th ed. By John Wiley & Sons. Inc. 525 pp.

King, W.S., and M.R. Cummings (1997). *Concepts of Genetics*. 5th Ed. Prentice Hall, Upper Saddle, NJ., USA

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York 427 pp.

ASSESSMENT

There are two components of assessment for this course:

1. Tutor-Marked Assignment (TMA)
2. End of course examination

TUTOR MARKED ASSIGNMENT (TMA)

The TMA is the continuous assessment component of this course. It account for 30 percent of the total score. You will be given about four TMAs to answer where the facilitator will pick the last three for you. You must submit all you TMAs before you are allowed to sit for the end of course examination.

FINAL EXAMINATION AND GRADING

This examination concludes the assessment for the course. It constitutes 70 percent of the whole course.

SUMMARY

CRP 305 – Crop Genetics and Breeding is a course designed for students in Agricultural Sciences. By the time you complete studying this course, you will be able to answer basic questions concerning genetics and breeding.

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Module 1

CRP 305: CROP GENETICS AND BREEDING

Unit 1: What is Crop Breeding? Purpose of Breeding and Biological Variation.

Unit 2: Introduction of Plant Cell, Cell Division (mitosis), Gametogenesis (meiosis) and Fertilization in Plant.

Unit 3: Gene, Symbols and Terminology

Unit 4: Mendel's Experiment, Law of Inheritance and use of Chi-Square Calculations.

Unit 1: What is Crop Breeding? Purpose of Breeding and Biological Variation.

1.0 Introduction

Crop breeding is the art and science of changing and improving plants genetically. The art of breeding lies in the ability of the crop or plant breeder to observe plant differences which, may have economic value which include yield and number of pods per plant to mention a few.

The scientific aspect of crop breeding is based on Gregor Mendel's laws of heredity; where the expected outcome of crosses could be predicted. The primary purposes of crop breeding are as follow:

To obtain or develop varieties that are:

A. Efficient in their use of plant nutrients.
B. Give the greatest return of products per-hectare or unit area.
C. Improve nutritional quality (vitamins, minerals) of crop.
D. Adapted to the needs of the growers and consumers.

E. Able to withstand conditions of cold, heat, drought or flooding.
F. Resistant or tolerant to pests and diseases.

2.0 Objectives

By the end of this unit, you should be able to:

- Explain what crop breeding is and its primary purposes.
- Explain what causes differences in plants.
- Put phenotype of plant in equation form and explain it.
- Explain what is crossing and why it is necessary.

3.0 Main Body

3.1 Biological Variations:

In the introduction, it was said that the art of breeding lies in the ability of the plant breeder to observe plant differences. In this section, we refer to plant differences as biological variations in plant traits like yield, height and pods per plant etc. It is these variations that plant breeders manipulate to develop new varieties of crops.

What causes biological variation?

A. Genetics – This is the genetic constitution of an individual plant (this is what is passed on from parent to offspring from generation to generation.
B. Environment: - The environment is where the plant is planted. In that environment where the plant is planted, there may be availability or lack of water, nutrients, insects, diseases and sun-shine. These (water, nutrients, insects, diseases and sun-shine) constitute the environment of the plant. (These environment factors may modify the inherited characteristics).
C. Interaction between genetics and environment: Differences you see in plants is a function of genetics, environment and interaction between genetics and environment.
   Let us put it in equation form:
   The outlook of the plant, which can be represented as
   $V_P = V_G + V_E + V_{GE}$
   Where V = Variance or Variation
   P = Phenotype (How plant looks)
   G = Genotype (Genetic constitution of the plant)
   E = Environment (where the plant is planted)
   Crossing – Is the transferring of pollen from anther to the stigma of the same plant or another plant by man or by nature (wind or insects). Crossing is a phenomenon where plant breeders create variation in plants (that is, breeders cross to create variability in crops).

4.0 Conclusion

The primary purpose of crop breeding is to develop crop varieties that are high yielding for the use of mankind either as food, feed (for his animals), fibre to produce clothes to wear and wood to prepare houses to live in and also satisfy the nutritional requirements.

5.0 Summary

- Crop breeding is an art as well as a science which offer breeders opportunity to develop improved crop varieties.
- Phenotype is a function of genetics, environment and interaction between genetics and environment:
  $V_P = V_G + V_E + V_{GE}$
- Crossing is essential for plant breeders to create variability in crops.

6.0 Tutor – Marked Assignment

Explain the factors that contribute to the expression of the phenotype.

Self Assessment Exercise

A. Write phenotype equation
B. Why is crossing essential in crop breeding?

7.0 References:

Gardner, E.J. (1972). *Principles of Genetics*. 4th ed. By John Wiley & Sons. Inc. 525 pp.

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York 427 pp.

Unit 2: Plant Cell, Cell Division (mitosis), Gametogenesis (meiosis) and Fertilization in Plant.

1.0 Introduction

Cells vary widely in structure and function, they have some important properties in common and all cells represent unit of living materials. Great variation occurs among the cells of different organisms and among cells in different areas of the same organism.

Cell division is the process through which cells reproduce themselves and multicellular organisms grow (mitosis). When cells divide, each resultant part is a complete, although at first a smaller cell (daughter cell). Following division, the newly formed daughter cells grow rapidly to get to the size of the original cell. Cell division is really a process of duplication or multiplication.

Gametogenesis is a process in which gametes are formed which includes meiosis by which the chromosome number is changed from the diploid or 2n number to the haploid or n number. The process also includes the development of eggs and sperm.

Fertilization is the union of male and female gametes to restore the chromosome number to 2n or diploid.

2.0 Objectives

By the end of this unit and the relevant readings, candidate should be able to:

- Draw and label a typical plant cell
- Explain gametogenesis and fertilization
- Differentiate between mitosis and meiosis and indicate their importance
- Differentiate between haploid and diploid.

3.0 Main Body

3.1 Plant – cell

This is the smallest unit of life. All living organisms are composed of these basic units which range from simple unicellular structures of bacteria and protozoa to complex structures of plants and animals. The generalized plant cell (figure 1) is composed of a cell-wall, cytoplasm and nucleus.

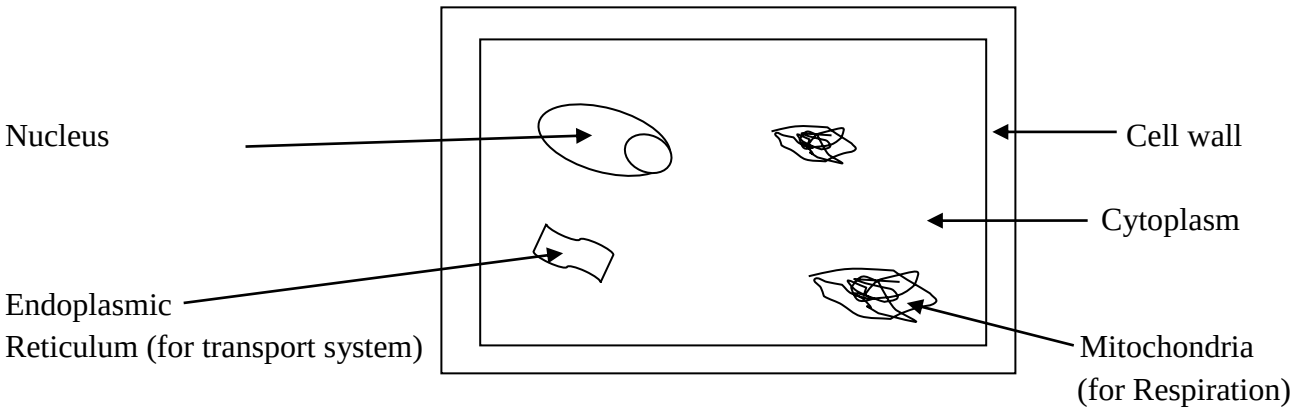


Fig. 1: A Generalized plant cell

However, the parts of the cell are far more complex than indicated. A typical animal cell is like the plant cell except for the absence of cell-wall.

3.2 Cell Division

The most fundamental part of cell division is the replication of Deoxyribonucleic acid (DNA) which must occur before any changes related to the early stages of mitosis can be observed. Two interrelated processes are involved in cell division. (1) Mitosis, the nuclear division and (2) Cyto-kinesis, the changes in the cytoplasm. The process (mitosis) of cell division is continuous from the time a cell first shows evidence of beginning to divide until the two daughter cells are completely formed.

Mitosis therefore is the mechanism by which new cells are formed and by which these cells retain identical chromosome numbers and hereditary factors before and after every cell division. Each cell still has full chromosome numbers. If we are talking of a man having 46 chromosomes, after each mitotic division, each cell will still have 46 chromosomes.

3.3 Gametogenesis and Fertilization

Sexual reproduction in plant involves the production of gametes by the process called gametogeneis and the union of these gametes is known as fertilization. Gametogenesis only occurs in specialized cells of the reproductive organs (Anthers and Ovary). Gametes contain half the number of chromosomes usually referred to as haploid and denoted with letter "n". During gametogenesis the numbers of chromosomes are reduced by half. This reduction division is known as MEIOSIS. In higher plants, meiosis takes place in the flower just before seed formation. Thus, meiosis occurs in anthers to produce pollen grains and in ovary to produce eggs.

Let us have examples of how gametogenesis works. Man has 46 chromosomes denoted as 2n or diploid (44 autosomal and 2 sex chromosomes). During gametogensis, the chromosome number will be reduced into half. Therefore, it will be 23 chromosomes which is known as haploid; denoted by "n".

Maize has 20 chromosomes number which is denoted as 2n or called diploid. During gametogenesis, the chromosome number will be reduced to 10 chromosomes. This is known as haploid and denoted as n.

Diploid is complete complement chromosome number of a species denoted as 2n. Haploid is half of diploid denoted with n. This reduction division is called Meiosis. Meiosis therefore, is the process by which chromosome numbers are halved in the process of sex cells or gametes formation.

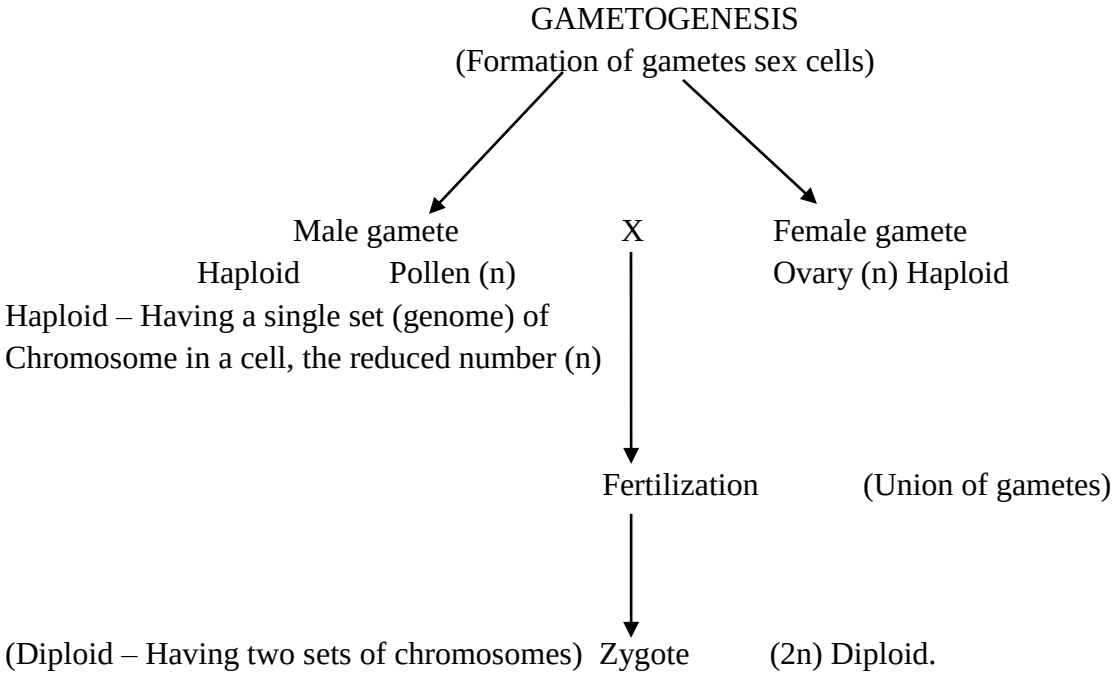


Fig. 2: Diagrammatic representation of sexual reproduction in the cell

Fertilization – This is the union of male and female gametes to restore the chromosome number characteristics of the species. In higher plants, the anthers split to release pollen grains which come in contact with the stigma either naturally or artificially. The pollen grain wall splits and a pollen tube penetrates the receptive stigma and grows down the style. The pollen grains and egg cell nuclei both of which have half the chromosome number and gene complements unite to produce the embryo mother cell with the chromosome number characteristic of the species.

3.4 Characteristics between Mitosis and Meiosis

	Mitosis	Meiosis
A.	Two products (daughter cells) produced per cycle.	Four cellular products (gametes) produced are per cycle.
B.	Genetic content of mitotic products are identical.	Genetic content of meiotic products are different.
C.	Chromosome number of daughter is the same as that of mother cell.	Chromosome number of meiotic products is cells half that of the mother cell.
D.	Mitotic products are usually capable of undergoing additional mitotic division.	Meiotic products cannot undergo another meiotic division, although they may undergo mitotic division.
E.	Normally occurs in most or all somatic cells.	Occurs only in specialized cells, pollen grain and ovary.
F.	Associated with asexual reproduction.	Associated with sexual reproduction.

4.0 Conclusion

In this unit, we examine plant cell, cell division (mitosis), gamete formation (meiosis), fertilization and distinguished characteristics between mitosis and meiosis.

5.0 Summary

A. Cell is the smallest unit of life and is composed of cell-wall, cytoplasm and

nucleus.

B. Mitosis is the mechanism by which new cells are formed and by which these cells retain identical chromosome numbers and hereditary factors before and after every cell division. Each cell still has full chromosome numbers as mother cell (zygote) which is 2n or diploid.

C. Gametogenesis is the production of male and female gametes (pollen grain and ova). The gametes contain half the number of chromosome numbers of the species and known as haploid and denoted as "n". This reduction division is known as meiosis.

D. Fertilization is the union of male and female gametes to restore the chromosome number characteristics of the species.

6.0 Tutor – Marked Assignment

A. Distinguish between mitosis and meiosis.

B. Distinguish between diploid and haploid.

Self Assessment Exercise

What is fertilization?

What is gametogenesis?

7.0 References

Gardner, E.J. (1972). *Principles of Genetics*. 4th ed. By John Wiley & Sons. Inc. 525 pp.

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York 427 pp.

Unit 3: Gene, Symbols and Terminology

1.0 Introduction

The gene is the hereditary units which are transmitted from parent to offspring from one generation to the next. The genes reside on a long molecule called deoxyribonucleic acid (DNA). The DNA, in conjunction with a protein matrix, forms nucleo proteins and becomes organized into structures with district staining properties called chromosomes found in the nucleus of the cell. Letters of the alphabets were used by Mendel as symbols for genes to avoid confusion as to which particular gene is being referred to. Certain terminologies were equally used by Mendel. These will be described in this unit and one needs to be familiar with them to appreciate genetics.

2.0 Objectives

By the end of this unit, candidate should be able to:

- Understand the characteristics of genes
- Know the letters of the alphabets used by Mendel as symbols for genes
- Familiarize with some genetic terminologies.

3.0 Main Body

3.1 The Gene Characteristics

(a) Genes are the hereditary units that are transmitted from parent to offspring from one generation to the next.
(b) The genes reside in a long molecule called Deoxyribonucleic acid (DNA).
(c) DNA plus protein make up chromosomes. Chromosomes are found in the nucleus of the cell.
(d) The behavior of the genes is parallel to that of the chromosomes.
(e) Each gene occupies a specific position on a chromosome called the gene locus (loci, plural).
(f) All the genes on any single chromosome form what is called a linkage group.
(g) Wherever the chromosome goes, it carries all the genes in its linkage group. Linked genes are not transmitted independently of one another.
(h) Genes in different linkage groups (on different chromosome) are transmitted independently of one another.

3.2 Alphabet Symbols

Mendel used alphabet symbols to describe genes. Capital (for example, A) signified the dominant, and lower case (for example, a) the recessive member of a pair of allele.
For example, let us use alphabet to describe a tall plant and a dwarf/short plant. Lower case d will be used for dwarf plant while capital D for tallness. The parents (we use letter D) (d), each with two members of the two alleles.

Tall parent	X	Dwarf/short parent
DD		dd

3.3 Terminology

Phenotype – This is the external appearance of an individual or plant which distinguishes it from other species or plant. The phenotype is determined by the genetic constitution of the plant, its environment and interaction between its genetic constitution and the environment.

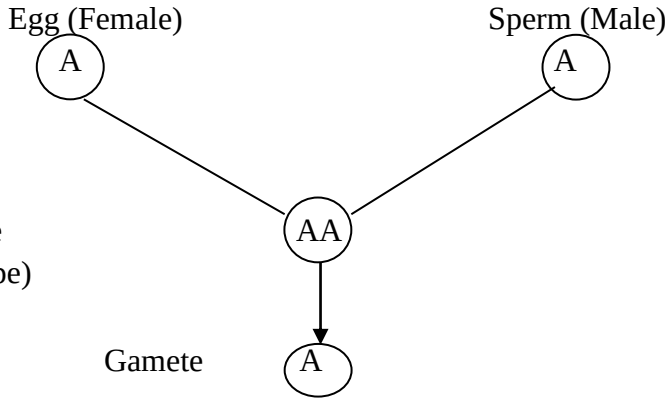
The scenario can be represented in an equation:
$V_P = V_G + V_E + V_{GxE}$ or V_{GE}

The last two components V_E and V_{GxE} is the reason why two individuals with the same genotype can have different phenotype.

Genotype – All genes possessed by an individual constitute its genotype. The genotype is what is inherited or genes passed on from the parents.

Homozygous – Union of gametes carrying identical alleles produce a homozygous genotype. A homozygous produces only one kind of gamete.

Example:
Uniting gametes

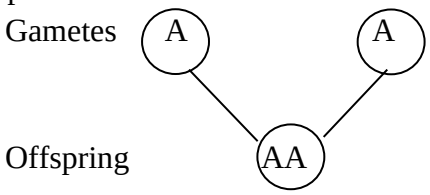


Note: (1) In crosses, the female parent is always written first (by the left hand side).

(2) The homozygote genotype produces only one kind of gamete.

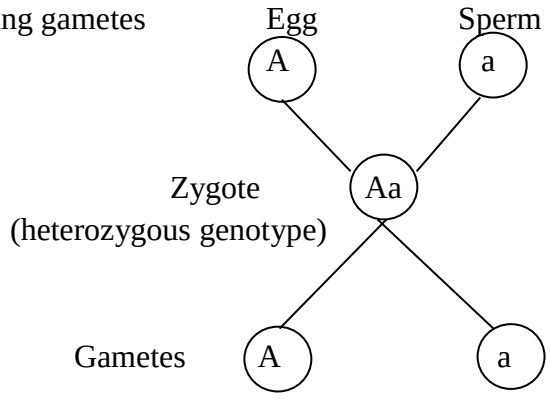
Pure line – A group of individuals with similar genetic background is often referred to as a line or variety. Matings between the homozygous individuals of a pure line produce only homozygous offspring like the parents.

Example: Pure line parents: AA X AA



Heterozygous – The union of gametes carrying different alleles produces a heterozygous genotype. Different kinds of gametes are produced by a heterozygote individual during gametogenesis.

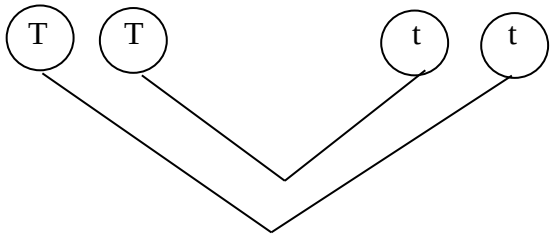
Example of uniting gametes



When a pair of alleles comes to phenotypic expression only in the homozygous genotype, the allele is said to be recessive while an allele which phenotypically expresses itself in the

heterozygote as well as in homozygote is dominant. These terms can be illustrated by considering a cross between tall and short plants.

Parents (Homozygote) TT X tt
(phenotypically) Tall Short
Then we say is homozygote tall Homozygous short
Gametes



Genotype = Heterozygote Tt
Phenotypically Tall (we say is heterozygous tall)

Thus, tall is dominant while short is recessive.

4.0 Conclusion

In this unit, we have learned about the gene, alphabets used as symbols for genes and some terminologies.

5.0 Summary

(1) Genes are the hereditary units, reside in a long molecule called deoxyribonucleic acid (DNA).
(2) The behavior of the genes is parallel to that of the chromosomes. All the genes on any single chromosome form what is called a linkage group.
(3) Wherever the chromosome goes, it carries all the genes in its linkage group. Linked genes are not transmitted independently of one another.
(4) Genes in different linkage groups are transmitted independently of one another.

Mendel used alphabet symbols to describe the genes. Capital letter for example 'A' signify the dominant while the lower case for example 'a' denote the recessive member of a pair of allele.

The following terminologies have been spelt out:
Phenotype, genotype, homozygous, pure line, heterozygote, dominant and recessive genes.

6.0 Tutor – Marked Assignment

Give five gene characteristics

Self Assessment Exercise

Define dominant and recessive allele

7.0 References

Briggs, F.N. and Knowles, P.F. (1967). *Introduction to Plant Breeding*. Reinhold Pub. Corp. New York. 426 pp.

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York USA 427 pp.

Unit 4: Mendel's Experiments, Law of Inheritance and Use of Chi-square Calculations.

1.0 Introduction:

Gregor Mendel is called "father of genetics". His experiments and his conclusions constitute the foundation of the modern science of genetics. From his work he proposed two basic genetic principles. The first principle is known as the principle of segregation and the second principle is that of independent assortment. These two principles will be explained later in the text. The use of chi-square calculation will be demonstrated to predict results for various crosses (monohybrid, dihybrid and trihybrid).

2.0 Objectives

By the end of this unit, you should be able to:

- Explain Mendel's experiment
- Explain the concept of segregation
- Explain the principle of independent assortment
- Handle monohybrid, dihybrid and trihybrid crosses
- Handle chi-square calculations.

3.0 Main Body

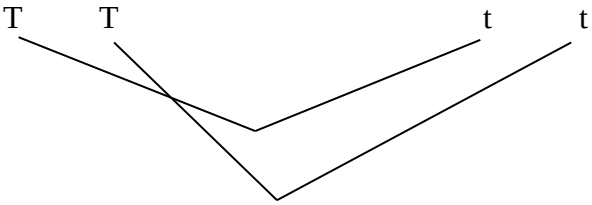
3.1 Mendel's Experiment

Mendel crossed a tall with a dwarf/short sweet pea by placing the pollen of the dwarf to the stigma of the tall plant and planted the resulting seed (F_1 seed). The F_1 seeds were planted to produce F_1 plants which were all tall. These F_1 plants were selfed (F_1 plant multiplied with F_1 plant) to produce F_2 seeds. The F_2 seeds were planted and given the opportunity to cross themselves (selfed) some of the F_2 plants produced were tall while some were short/dwarf in the phenotypic ratio of 3 tall to 1 dwarf (segregation). This is the beginning of crop breeding which you will appreciate as the course progresses.

These results can be illustrated as follows:

Parents TT (Tall) x tt (Dwarf/short)

Gametes T T t t



Tt

F_1 Tall

F_1 x F_1 Tt x Tt

Splitting of alleles

Gametes from F_1 plants T t T t

The crossing is done in a tabular form which is called Punnet square

	T	t
T	TT Tall	Tt Tall
t	Tt Tall	tt dwarf

← These are F_2 generation

From this illustration, TT is homozygous tall where as tt is homozygous dwarf. The resulting F_1 is heterozygous tall. Thus, tall is dominant while dwarf is recessive.

Summary of phenotypic and genotypic results in F_2 generation

Phenotype	Genotype	Genotypic Frequency	Phenotypic Ratio
Tall	TT - Tall	1	3 (1+2)
	Tt - Tall	2	
Dwarf/short	tt - Short	1	1

Please note that in F_2 the genotypic ratio is 1:2:1 while the phenotypic ratio is 3:1 when dealing with monofactorial crosses.

3.2 Mendel's Principles

Principle of segregation states that in any parent, only one allelic form of a gene is transmitted through a gamete to the offspring. For example, a plant with a factor or gene for round shaped seed and also allele for wrinkled shaped seed would transmit only one of these two alleles through a gamete to its offspring. Alleles are capable of segregation, that is the members of each pair of alleles separate into different sex cells or gametes and hence into different offspring. Mendel called this separating process the "splitting of alleles".

Principle of independent assortment states that the segregation of one factor pair occurs independently of any other factor pair, if gene pairs are on different chromosome.

3.3 Monohybrid Cross

A cross in which only a single pair of alleles is considered is called a monohybrid cross. Monohybrid cross involves one gene with two alleles.

Examples – A pair of alleles governs colour in seed; a dominant allele "B" produces black and its recessive allele "b" produces white. The parental generation is symbolized as P and the first filial generation of offspring is symbolized "F_1". Have a look at these monofactorial crosses and the type of gametes involved.

1. P Homozygous black x Homozygous black

BB x BB

Gametes B B

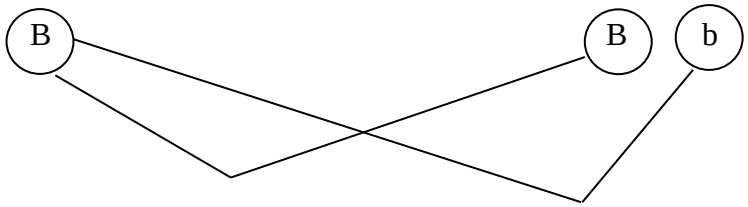
BB

F_1 black

2. P Homozygous black x Heterozygous black

BB x Bb

Gametes B B b



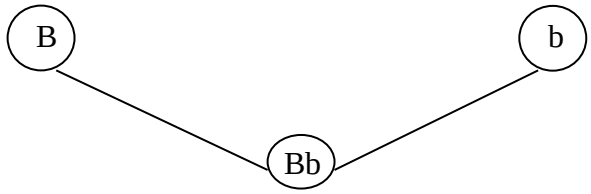
F_1 BB Bb

black black

3. P Homozygous black x Homozygous white

BB x bb

Gametes B b



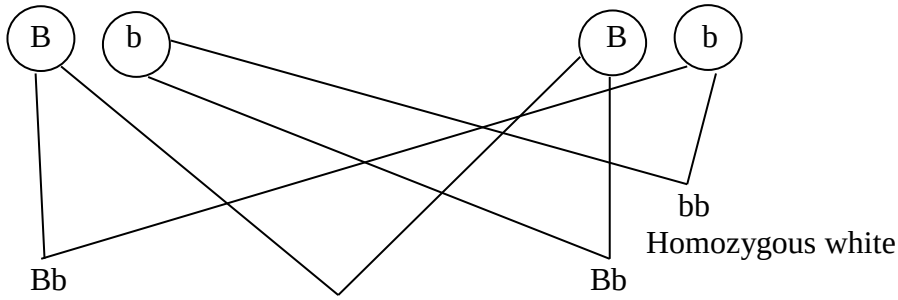
Bb

F_1 Heterozygous Black

4. P Heterozygous black x heterozygous black

Bb x Bb

Gametes B b B b



bb

Homozygous white

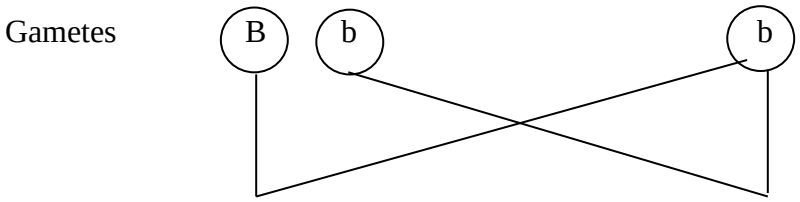
F_1 Bb Bb

Heterozygous black BB Heterozygous black

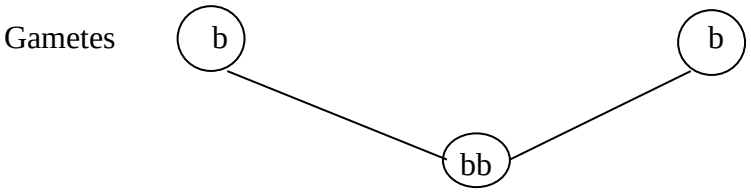
Homozygous black

5. P Heterozygous black x Homozygous white

Bb x bb



6. P Homozygous White bb x Homozygous White bb

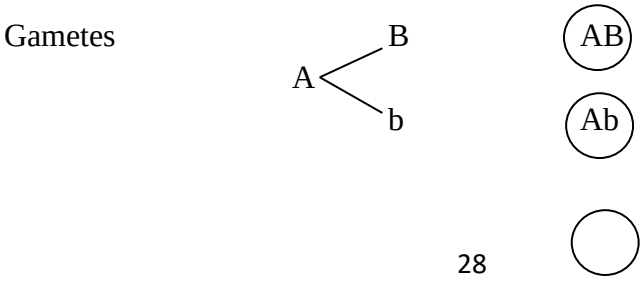


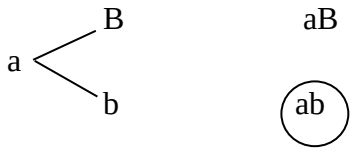
Dihybrid cross: Involves two genes with four alleles. For example crossing pea with yellow round seeds with another variety with green wrinkled seeds. The results are as follows:

Parents	AABB Yellow round	x	aabb Green wrinkled
F_1	AaBb Yellow round		

When AaBb is selfed to produce F_2 the following situation results.

AaBb (X) This symbol means selfing, i.e. crossing of F_1 plant to another F_1 plant.

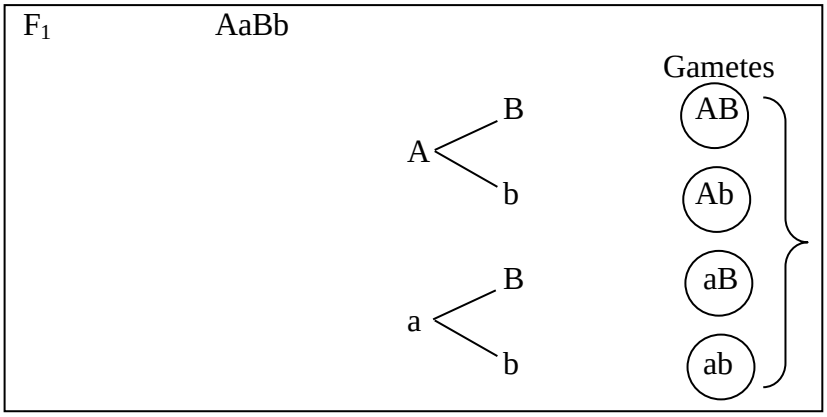




Note: Number of heterozygous loci will help you to predict the number of gametes.
For number of gametes the formula = 2^n
For number of genotypes the formula = 3^n
Where n is equal to number of heterozygous loci or number of heterozygous genes involved.

For example AaBb genotype has two heterozygous loci
Aa is heterozygous
Bb is heterozygous
Therefore, number of gametes = $2^2 = 4$
Number of genotypes = $3^3 = 9$

The genotype of F_1 = AaBb. (two heterozygous loci)
i.e. n = 2. Substitute 2 for n in the formula
Number of gametes = $2^n = 2^2 = 4$



Therefore, F_1 x F_1 (selfing) will produce 16 products at F_2 as shown below:

	AB	Ab	aB	Ab

(AB)	AABB	AABb	AaBB	AaBb
(Ab)	AABb	AAbb	AaBb	Aabb
(aB)	AaBB	AaBb	aaBB	aaBb
(ab)	AaBb	Aabb	aaBb	aabb

Result:	Phenotype	Genotype	Phenotypic frequency	
	Yellow round	AABB	1	
		AABb	2	
		AaBB	2	9
		AaBb	4	
	Yellow wrinkled	AAbb	1	
		Aabb	2	3
	Green round	aaBB	1	
		aaBb	2	3
	Green wrinkled	aabb	1	1

In dihybrid cross, the phenotypic ration is 9:3:3:1. This is classical Mendelian ratio for dihybrid.

Trihybrid cross: Three pairs of contrasting traits are involved. For example, consider the cross between AABBCC and aabbcc individuals. All F_1 individuals are heterozygous for all three gene pairs. Their genotype, AaBbCc, results in the phenotypic expression of the dominant A, B, and C traits. When F_1 individuals are parents, they all produce 8 different gametes in equal frequencies.

P_1 AABBCC x aabbcc

Gametes ABC abc

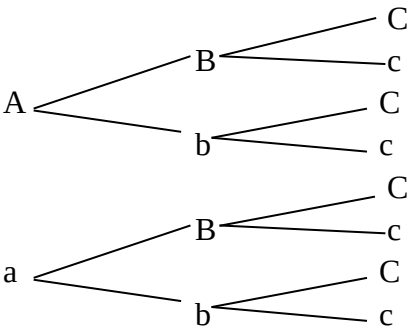
F_1 genotype AaBbCc

Remember the formula to get the number of gametes. 2^n where n is equal to the number of the heterozygous loci. In this case we have 3 heterozygous loci. Let us substitute 3 for n in the formula. Number of gametes = 2^3 = 2x2x2 = 8 gametes.

We have been using Punnet-square which involves construction of boxes and a bit cumbersome when many factors are involved.

Forked – line <u>OR</u> Branch diagram, method. This is much simpler to figure out the number of gametes.

F_1 Plant with genotype AaBbCc will produce 8 gametes



ABC
ABc
AbC
Abc
aBC
aBc
abC
abc

How many genotypes do we expect to see in F_2 generation? Formula to figure out the number of genotypes 3^n. In this case n = 3 which is the number of heterozygous loci. Let us substitute 3 for n.

3^3 = 3x3x3 = 27 genotype

Rules which may be applied to crosses involving any number of gene pairs.

Number of Heterozygous gene pair	Number of different gametes	Number of different F_2 Genotypes produced	Number of different F_2 phenotypes produced
N	2^n	3^n	2^n
1	2	3	2
2	4	9	4
3	8	27	8

4 10	16 1024	81 59049	16 1024

Another example of trihybrid

DdGgWw x DdGgWw

a How many gametes do we expect?

b. How many genotypes can we get?

c. Use Punnet-square to get the expected genotypes and the ratio.

Chi-square (x^2)

The chi-square (x^2) test is a valuable tool that aids the investigator in determining goodness of fit. It is important in genetics to be able to evaluate observed deviation. By statistical analysis we can evaluate how well observed data fit the expected ratios.

Plant breeders use chi-square mostly when dealing with qualitative traits such as leaf colour, flower colour and seed colour, etc. These are traits that are not affected by environment and their inheritance can be easily followed. These traits are governed by major genes, they separate out into clear-cut classes that can be observed and counted. These different classes (phenotypes) are expected to fit into definite segregating ratios.

In monohybrid cross - phenotypic ratio expected in F_2 population is 3:1
In dihybrid cross – phenotypic ratio expected in F_2 is 9:3:3:1

How to use x^2 (chi-square)

Formula $x^2 = \sum_{i=1}^{n} \frac{(O - E)^2}{E}$

where n is the last observation

i = 1 start from the first observation

O = Observed

E = Expected

$\sum$= Sum up

Example: Using a monohybrid cross

Data observed on the field for the segregating ratio may not form perfect ratios. For example, consider a monohybrid cross of yellow x white cotyledon. The F_{1s} are Yy all yellow. In the F_2 however, there is segregation into yellow and white coloured cotyledons. Let us assume that there are 1000 F_2 plants. Since, it is a monohybrid, the F_2 segregation is expected to be 750 yellow cotyledon;

250 white cotyledon. The actual data observed is 740 yellow: 260 white. Can you accept this result as good enough to fit to the expected Mendelian ratio of 3:1 within the limits of experimental error?

In monohybrid we have 2 classes in ratio 3:1. Addition of ratio 3:1 gives 4 out of 1000 plants, how many plants do we suppose to have for each class.

$\frac{1000}{4} = 250$ so, each class suppose to have 250 plants multiplied by the expected ratio.

For class 1 with ratio of 3 we will be expecting 750 yellow cotyledons (3 x 250 = 750).
For second class with ratio of 1 will have 250 white cotyledons (1 x 250 = 250).

	Expected	Observed
Yellow cotyledon	750	740
White cotyledon	250	260
Total	1000	1000

$$x^2 = \sum_{i=1}^{n} \frac{(O - E)^2}{E}$$

Chi-square for yellow cotyledon with a ratio of 3

$$\frac{(740 - 750)^2}{750} = \frac{(10)^2}{750} = 0.13$$ x^2 value = 0.13

Chi-square for white cotyledon with a ratio of 1

$$\frac{(260 - 250)^2}{250} = \frac{(10)^2}{250} = 0.4$$

$\sum x^2$ (that is summation of chi-squares values for each class) = 0.13 + 0.4 = 0.53

Therefore, calculated chi-square is 0.53
X^2 from table with 1 df at 0.05 level of probability = 3.84
Degree of freedom (df) = n – 1 where n is equal to number of classes not observation. Now, you have to compare the values, x^2 calculated with the table value so that decision could be made. To be

significant, x^2 calculated must be greater than table value. In this case, x^2 table is greater than x^2 calculated. So not significant. What was observed on the field is good enough to be accepted as fitting into the Mendelian ratio of 3:1.

Chi-square calculation using a dihybrid cross:
A breeder made dihybrid cross and he expected to see a phenotypic ratio of 9:3:3:1, but if he cannot see the expected ratio, then he suspects there is linkage in the chromosome. The man planted 800 plants and he observed the following:

439 to be yellow round
168 to be yellow wrinkled
133 to be green round
60 to be green wrinkled

The question is, is this what the breeder expects to see?
Let us write hypothesis to this question:

H_O: Is always an hypothesis of equality while
H_A: Is the alternative hypothesis
Therefore, we can write our hypothesis as follows:
H_O: Observe = Expected
H_A: Observe ≠ Expected. (This is two tails) (That is, observed is either > or < than expected).

OR H_A: Observed > Expected } One tail test. These are specific
H_A: Observed < Expected }

In dihybrid we expect to see 4 classes at a ratio of 9:3:3:1. Add the ratio number, it will give you 16. Out of 800 plants, how many plants do we suppose to have for each class?

Divide 800 by 16

$\frac{800}{16} = 50$ So, each class suppose to have 50 plants multiplied by the expected ratio.

Class I with ratio of 9 will be expecting 9x50 = 450 plants
Class II with ratio of 3 will be expecting 3x50 = 150 plants
Class III with ratio of 3 will be expecting 3x50 = 150 plants
Class IV with ratio of 1 will be expecting 1x50 = 50 plants

$$x^2 = \sum_{i=1}^{n} \frac{(O - E)^2}{E}$$

For the first class with a ratio of 9
chi-square will be observed = $\frac{(439 - 450)^2}{450} = \frac{(11)^2}{450} = \frac{121}{450}$

X^2 value = 0.27

For the second class with a ratio of 3
X^2 therefore = $\frac{(168 - 150)^2}{150} = \frac{(18)^2}{150} = \frac{324}{150} = 2.16$

For the third class with a ratio of 3
X^2 therefore = $\frac{(133 - 150)^2}{150} = \frac{(-17)^2}{150} = \frac{284}{150} = 1.89$

For the fourth class of a ratio of 1
X^2 therefore = $\frac{(60 - 50)^2}{50} = \frac{(10)^2}{50} = \frac{100}{50} = 2$

$$x^2 = \sum_{i=1}^{n} \frac{(O - E)^2}{E}$$

The symbol $\sum$ says we should add chi-square values from each class.

1st class has a chi-square value of 0.27
2nd class has a chi-square value of 2.16
3rd class has a chi-square value of 1.89
4th class has a chi-square value of 2.00
Total chi-square = 6.32

X^2 calculated = 6.32
X^2 from table = 7.81 at 3df and 0.05 level of probability
Using 3df df=n-1 therefore 4-1=3

To be significant x^2 calculated must be greater than table value. In this case, x^2 table is greater than x^2 calculated. So not significant. So, the number of plants observed did not deviate from what is expected. Therefore, the data is good enough to be accepted as fitting into the Mendelian ratio of 9:3:3:1. Therefore, there is no need to suspect linkage. Independent assortment of genes took place.

4.0 Conclusion: In this unit, Mendel's experiment, genetic principles and the use of chi-square calculations were discussed.

5.0 Summary:

The principles of segregation says that members of each pair of alleles separate into different sex cells or gametes and hence into different offspring while principle of independent assortment says that the segregation of one factor pair occurs independently of any other factor pair, if gene pairs are on different chromosome.

The genotypic ratio in F_2 population is 1:2:1 while the phenotypic ratio is 3:1 when dealing with monofactiorial crosses (monohybrid crosses).

Dihybrid cross involves two genes with four alleles. The phenotypic ratio in F_2 population is 9:3:3:1.

The formula to calculate the number of gametes to be produced in any heterozygous loci is 2^n where n is number of heterozygous loci. For example, F_1 with genotype AaBb which has two heterozygous loci will produce 4 gametes. Therefore, 2^n in this case n=2 substitute 2 for n in the formula, number of gametes will be $2^2 = 2x2 = 4$ gametes.

Table IV – 1 Accumulative distribution of Chi-Square (from Snedecor)

Degree of Freedom	Probability of a Greater Value												
	0.995	0.990	0.975	0.950	0.900	0.750	0.500	0.250	0.100	0.050	0.025	0.010	0.005
1.	……	……	……	……	0.02	0.10	0.45	1.32	2.71	3.84	5.02	6.63	7.88
2.	0.01	0.02	0.05	0.10	0.21	0.58	1.39	2.77	4.61	5.99	7.38	9.21	10.60
3.	0.07	0.11	0.22	0.35	0.58	0.21	2.37	4.11	5.25	7.81	9.35	11.34	12.84
4.	0.21	0.30	0.48	0.71	1.06	1.92	3.36	5.39	7.78	9.49	11.14	13.28	14.86
5.	0.41	0.55	0.83	1.15	1.61	2.67	4.35	6.63	9.24	11.07	12.83	15.09	16.75
6.	0.68	0.87	1.24	1.64	2.20	3.45	5.35	7.84	10.64	12.59	14.45	16.81	18.55
7.	0.99	1.24	1.69	2.17	2.83	4.25	6.35	9.04	12.02	14.07	16.01	18.48	20.28
8.	1.34	1.65	2.18	1.73	3.49	5.07	7.34	10.22	13.36	15.51	17.53	20.09	21.96
9.	1.73	2.09	2.70	3.33	4.17	5.90	8.34	11.39	14.68	16.92	19.02	21.67	23.59
10	2.16	1.56	3.25	3.94	4.87	6.74	9.34	12.55	15.99	18.31	20.48	23.21	25.19

Greater than or equal .05 – Reject Ho

For the number of genotypes, the formula is 3^n using the same F_1 genotype of AaBb, the number of genotypes to produce equal 9. In this case, n = 2, i.e. the number of heterozygous loci. Therefore, $3^2 = 3x3 = 9$.

With trihybrid with genotype AaBbCc, the number of gametes = $2^3 = 2x2x2 = 8$ gametes. Number of genotypes = $3^3 = 3x3x3 = 27$ genotypes.

Chi-square (x^2) calculation formula:

$$x^2 = \sum_{i=1}^{n} \frac{(O - E)^2}{E}$$

6.0 Tutor – Marked Assignment

A breeder made a monohybrid cross and he expected to see a phenotypic ratio of 3:1. He observed 215 plants to be resistant and 85 plants to be susceptible out of 300 plants he planted. Use chi-square to prove whether what he observed is what he was expected to see. Draw up hypothesis and valid conclusion.

Self Assessment Exercise

Explain the two principles of Gregor Mendel that came out from his experiment.

7.0 References

Gardner, E.J. (1972). *Principles of Genetics*. 4th Ed. John Wiley and Sons, Inc. New – York.

King, W.S., and M.R. Cummings (1997). *Concepts of Genetics*. 5th Ed. Prentice Hall, Upper Saddle, NJ., USA

Module 2

Unit 1: Qualitative Vs Quantitative Traits

Unit 2: Heritability

Unit 3: Selection Responses

Unit 1: Qualitative Vs Quantitative Traits

Contents:

1.0 Introduction

In Module 1, we concentrated on qualitative traits, traits which are classified into distinct phenotypic categories. But now we will be dealing with traits that are governed by many genes known as quantitative traits. Each gene contributes a small amount to the phenotype that

individual effects cannot be put into distinct phenotypes. The traits are said to be continuous. Genes of this nature are called polygenes.

2.0 Objectives

At the end of this Unit, the candidate should be able to:

- Distinguish between qualitative and quantitative traits
- Explain that quantitative traits demand the use of sophisticated experimental techniques to analyse data.

3.0 Main-Body

3.1 The major differences between qualitative and quantitative traits are summarized below:

	Qualitative	**Quantitative**
1.	Discontinuous Variation e.g. Flower colour.	Continuous Variation e.g Body-weight, grain-yield.
2.	Governed by single or few genes.	Governed by many genes.
3.	Concerned with individual matings and their progenies.	Concerned with a population with all possible kinds of matings.
4.	Not affected by environment. For example, Cowpea flower, if it is purple colour, grow the seed of that cowpea anywhere, the flower colour will be purple.	Affected by environment. For example, seed yield.
5.	Analysed by making counts and ratios.	Analysed with sophisticated experimental techniques using estimates of population parameters such as mean and standard deviation, etc.

4.0 Conclusion

Qualitative traits are governed by single or few genes while quantitative traits are governed by many genes.

5.0 Summary

This Unit treated the differences between qualitative and quantitative traits.

6.0 Tutor – Marked Assignment

Distinguish between qualitative and quantitative traits. Give practical examples of each.

7.0 Reference

Falconer, D.S. (1981). *Introduction to Quantitative Genetics.* 2nd ed. Longman Inc. New York.

Unit 2: Heritability

Contents:

1.0 Introduction

Heritability is one of the most important factors in the designing of an effective breeding plan. Heritability determines what can be possibly gained during a selection process. Heritability (symbolized h^2) is the measure of contribution of the genotype to the total phenotypic variability. It is the portion of the total variability that can be inherited.

2.0 Objectives

At the end of the Unit, student should be able to explain:

- Types of heritability
- What heritability values depend on

- Ways of calculating heritability.

3.0 Main-Body

3.1 Types of heritability

There are two types of heritability

A. Broad – sense

Broad sense heritability (h^2) = $\frac{V_G}{V_{ph}}$

Where V_G = Genotypic variance

V_{ph} = Phenotypic variance

Where $V_{ph} = V_G + V_E + V_{GE}$

Heritability values depend:

1. Method used in its computation (Narrow sense or Broad sense)
2. Estimate of genetic variance should be free from GxE (Genotype by environment interaction).
   How can estimate of genetic be free from GxE?
   (a) By growing in multiple locations
   (b) By growing for number of years
   If not grown in sufficient locations and years, heritability values will be inflated or biased.
3. Population from which the heritability is calculated from. To compare heritability values, it must be from the same population and the same method used to estimate the values and the same test conditions.

B. Narrow sense heritability

$h^2 = \frac{V_A}{V_{ph}}$

Note $V_{ph} = V_G + V_E + V_I$ (V_I = Variance due to interaction or epistalsis)

$V_G = V_A + V_D + V_I$ (V_I is the same if I write V_{GxE}).

V_{ph} = Phenotypic Variance
V_G = Genotypic Variance
V_E = Environmental Variance
V_I = Epistalsis or Interaction Variance

V_A = Additive Variance
V_D = Dominance Variance

V_A is the only component that determines selection and retained in selection. It is an index of transmissibility.

Which one should be bigger, broad sense or narrow sense heritability? From the equation for calculation of the two heritabilities (broad sense and narrow sense), broad sense should be bigger. Check the numerators in the calculation of the two heritabilities.

3.2 Calculations

Broad-sense heritability using variance ratio.

$$h^2 = \frac{V_A}{V_{ph}}$$

Where $V_{ph} = V_G + V_E + V_{GE}$

Let us assume that a plant breeder generated four populations (Parent 1, Parent 2, F_1 and F_2). These four populations were planted and the following variances were generated. Let us analyse the variances that exist in the four populations.

1. Assume each of the parents is homozygous, that is, identical genetically. So, any variability among plants is caused by the environment. What then, can we say that constitute environment in this case?
    - Rainfall and nutrient distribution in the soil
    - Incidence of insect and diseases, etc.
2. Likewise, plants from parent two (2) are all identical. Any variability among the plants is also caused by the environment.
3. F_1 plants are heterozygous and identical genetically, so any variability in F_1 is environmental.
4. F_2 plants are different genetically. In F_2 we have segregation. So in F_2 we have genetic variability as well as environmental variability.

Let us summarize in a table form:

	Variance Value	Type of Variance
Parent 1	4.0 unit^2	Environmental
Parent 2	4.9 unit^2	Environmental
F_1 (Genetically the same Heterozygous)	8.5 unit^2	Environmental
F_2 (Segregation takes place)	34.9 unit^2	Environmental plus Genotypic.

Note: To estimate environmental variability in F_2, we need to add the environmental differences in P_1, P_2 and F_1 and take average.

Total variance in F_2 population = 34.9

$V_{ph} = V_G + V_E + V_{GE}$

V_{f2} = 34.9 (is made up of Genotypic and non-genotypic)

Non-genotypic variance = $\frac{4+4.9+8.5}{3} = 5.8$

$V_{Genetic} = 34.9 - 5.8 = 29.1$

i.e. $V_G = 29.1$

Broad sense $h^2 = \frac{V_G}{V_{ph}} = \frac{29.1}{34.9} = 0.8338$

0.833 x 100 (To bring it to percentage)

= 83.4%

Heritability can be reported in percentages.

Example 2: Broad sense

Let us assume that:

F_2 population has a variance of 50 units^2

F_1 population has a variance of 30 units^2

Calculate heritability in broad sense

h^2 in Broad sense = $\frac{V_G}{V_{ph}}$

Variance in F_1 population must be due to environmental

Given that variance for F_1 population = 30 units^2

$F_2 \quad V_{ph} = \underbrace{V_G}_{20 \text{ units}} + \underbrace{V_E + V_{GE}}_{30 \text{ units}}$

Note: We have only F_1 in this example. In the first example, we had P_1, P_2 and F_1, and took average to estimate for environment.

If we have two population, just take average of the two to estimate for environmental variance.

Therefore, broad sense heritability

$$h^2 = \frac{V_A}{V_{ph}} = \frac{20}{50} = 40\%$$

40% is due to Genetic

60% is due to non-genetic.

Example: Calculation of narrow sense and broad sense heritability. If the following estimates were found for a population of maize plants:

$V_A = 20$ units^2 $V_D = 10$ units
$V_E = 35$ units $V_{GE} = 10$ units, $V_I = 5$ units^2

Calculate broad sense heritability

Broad sense $h^2 = \frac{V_G}{V_{ph}}$ $V_G = V_A + V_G + V_I$
$20 + 10 + 5 = 35$ units^2

$V_{ph} = V_G + V_D + V_{GE}$
$35 + 35 + 10 = 80$ units^2

Broad sense $h^2 = \frac{35}{80} = 0.4375$ or 43.75%

Narrow sense $h^2 = \frac{V_A}{V_{ph}} = \frac{20}{80} = \frac{1}{4} = 25\%$

4.0 Conclusion

In this unit, heritability calculations in both broad sense and narrow sense were discussed.

5.0 Summary

Heritability (symbolized as h^2) is the measure of contribution of the genotype to the total phenotypic variability. It is the portion of the total variability that can be inherited. There

are two types of heritability: Broad sense and Narrow sense. Broad sense is calculated as V_G while narrow sense is calculated as V_A V_{ph}

V_{ph}

The heritability of a given trait may be any fraction from zero to one.

6.0 Tutor – Marked Assignment

If the environmental component of variance is three <u>times</u> as large as the genetic component, what percentage is due to genetic?

Self Assessment Exercise

A. Given $V_{ph} = 50 \text{ units}^2$
$V_A = 10 \text{ units}^2$
$V_D = 5 \text{ units}^2$
$V_G = 20 \text{ units}^2$
$V_I = 5 \text{ units}^2$

Calculate both broad and narrow sense heritability values

7.0 References

Briggs, F.N. and Knowles, P.F. (1967) *<u>Introduction to Plant Breeding</u>*. Reinhold Pub. Corp. New York. 426 pp.

Falconer, D.S. (1981). *<u>Introduction to Quantitative Genetics</u>*. 2nd Ed. of publication. Longman Inc. New York.

Unit 3: Selection Responses

Contents:

1.0 Introduction

The objective of population improvement is to increase the frequency of favourable alleles. This is accomplished by intermating only the superior ones which provide a wide array of different types from which selection of favourable ones can be practiced, while the unfavourable ones are eliminated. The change produced by selection is the interest, that is, the change of the population mean.

2.0 Objectives

At the end of this unit, students should be able to explain:

- The importance of heritable variation in selection

- The variables involved in the calculation of genetic advance
- How genetic advance can be improved.

3.0 Main-Body

3.1 Definition and Calculation of Genetic Advance (GA)

Selection is the process by which certain individuals are allowed to contribute more towards progeny at the expense of others. The well accepted features of selection are:

A. Selection is effective only if heritable variation is present
B. Selection does not act on the gene itself but acts on genotype through phenotype and this ultimately changes frequency of genes and genotypes.
C. Selection itself does not create new genes or genotypes but influences their relative frequency to the progeny.

To calculate genetic advance, (progress) after selection has been practiced from a population, the following parameters are needed:

1. K – value – which is selection differential. Usually there is a table. These values are provided in the book of Allard (see below).
2. V_{ph} – That is phenotypic variance for the trait you are working on.
3. h^2 – That is heritability (narrow sense estimate)

Selection Differential Values – K

Proportion of population selected

Percentages	Fractions	K-values
1%	0.01	2.64
2%	0.02	2.42
5%	0.05	2.06
10%	0.10	1.76
20%	0.20	1.40
30%	0.30	1.16

Reproduced from the book of W.R. Allard. *Principles of Plant Breeding* (1960).

Note: As we increase the proportion of the population selected, the K-value decreases.

Genetic Advance (GA) = $K\sqrt{Vph}$ x h^2

Working example

Suppose a plant breeder started with a population with a mean ($\bar{x}$) of 8" tall. His desire is to increase the mean height. From the population he calculated heritability to be 0.17 or 17% with phenotypic variance of 2 inches. The breeder decided to select the top 10% of 100 individual plants. Calculate the genetic advance and what will be the mean in the next generation.

GA = K$\sqrt{Vph}$ x h^2

10% of 100 individual plants have a K – value of 1.76

GA = 1.7$\sqrt{2}$ x 0.17

1.76 x (1.41) x 0.17 = 0.422

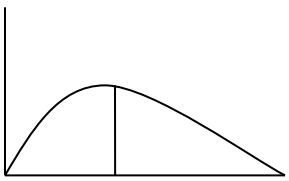
The breeder would make a progress. He would be able to increase height by 0.422 inches. The next generation should have a mean of 8.422" (inch) (i.e. 8" + 0.422).

What percentage improvement would this be?

As a percentage of initial mean

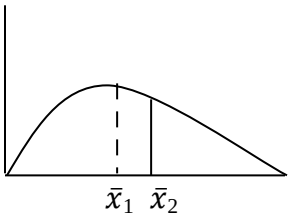
$\frac{0.422}{8.0}$ x 100 = 5.3% Improvement

Genetic advance is usually expressed in percentages or actual number.



8"

Base population



$\bar{x}_1$ = original mean

$\bar{x}_2$ = mean after one selection (of the best 10%)

How can a breeder improve the genetic advance?

This can be achieved by:

i. Reducing the proportion of individual selection, increases the K-value. Using the same data, but only changing the selected proportion to 5%, the k-value will now be 2.06 (check the table of k-value)

Under 5% selection, the GA will be:

GA = 2.06$\sqrt{2}$ x 0.17

2.06 x 1.41 x 0.17 = 0.494$\simeq$ 0.50

ii. By increasing heritability. To increase heritability, reduce environmental influences by evaluating in many locations and years.

Using the same data, but this time assume heritability to be 0.20

The new GA will be:

$GA = K\sqrt{2}$ x 0.20

2.06 x 1.41 x 0.20 = 0.58

4.0 Conclusion

Genetic advance is a useful tool to guide plant breeder in his breeding programme. He can use it to make certain decisions.

5.0 Summary

Genetic advance (progress) depends on:

(a) Selection differential
(b) Genetic Variability/Variance
(c) Heritability

$GA = K\sqrt{Vph}$ x h^2

6.0 Tutor – Marked Assignment

As a plant breeder, your responsibility is to increase seed yield in cowpea. You know that the narrow-sense heritability for seed yield is 0.25 with your testing procedure. Furthermore, in your selection population of 1,000 individuals, the phenotypic variation for yield was determined to be 4kg with an average yield of 22kg for the individuals in the population.

Predict the genetic advance that would be expected by selecting and intermating the 100 highest yielding individuals.

Self Assessment Exercise

Using the same data above, predict the genetic advance that would be expected by selecting and intermating the 10 highest yielding individuals.

7.0 Reference

Allard, R.W. (1960). *Principle of Plant Breeding*. John Wiley and Sons, Inc. New York, London

Module 3 Methods of Sexual Reproduction in Crop Plants

Unit 1: Reproduction in Crop Plants

Unit 2: Self Incompatibility and Male Sterility

Unit 3: Steps for Controlled Crosses and Sourcing for Breeding Materials

Unit 1: Reproduction in Crop Plants

Contents:

1.0 Introduction

The mode of reproduction in crop plants affects the breeding method to use and largely determines the kind of variety to be produced. It is necessary at this point to understand why the mode of reproduction is essential in practical breeding.

2.0 Objectives

At the end of studying this unit, you should be able to:

- Differentiate between kinds of flowers
- Explain different modes of reproduction and types of variety to produce.

3.0 Main-Body

3.1 Kinds of Flower

Complete flowers contain all four organs (sepals, petals, stamen and pistil). Incomplete flowers lack one or more of these floral organs. Example of crops carrying complete flowers are cotton, tobacco, potatoes, soybean and other crop plants. Crops belonging to the grass family, including corn, sorghum, wheat, rice have incomplete flowers in which the petals and the sepals are lacking.

A. Perfect flowers: Both stamen and pistil are in the same flower structure, e.g. most crop plants have perfect flowers, wheat, rice, sorghum, cotton, tobacco, soybean, etc.

B. Imperfect flowers: Stamen and pistil are not in the same flower structure. Imperfect flower may be staminate, bearing stamen but no pistil, or pistillate, bearing a pistil but without stamen.

C. Monoecious: Both female and male flowers on the same plants e.g. corn and castor-bean. That is, corn has staminate flowers in the tassel and pistillate flowers on the shoot.

D. Dioecious: Male and female flowers on different plants e.g. buffalo grass, hemp, hops.

3.2 Types of Reproduction

A. Vegetatively propaged crops – These are crops produced by using the vegetative parts of the plants, e.g. cutting, rhizomes, bulb and many more.

B. Sexual reproduction – Reproduction involving germ cells and union of gametes. Sexual reproduction is divided into self and cross pollination.

Self pollinated crops – These are crops that pollinate themselves. For example cowpea, soybean, rice, groundnut, tobacco, tomatoes, potatoes, etc. The amount of natural out-crossing varies from none up to 4 or 5 percent.

Features that encourage self pollination are:

i. The flowers may not open
ii. The pollen grains may shed before the flowers open
iii. The stigma and stamens may be hidden by floral organs after the flowers open
iv. The stigma may elongate through the stamina column shortly after the anthers open.

The flowering process in crop is called anthesis.

Cross pollinated crops – These are crops that are fertilized by the union of an egg with a sperm from a different plant, e.g. maize, etc.

Features that encourage cross pollination are:

i. Mechanical obstruction to self pollination
ii. Different periods of maturity of pollen and the stigma
iii. Self-sterility or incompatibility
iv. Presence of monoecious or dioecious flowers.

C. Apomitic crops – There is no union of gametes. Seeds are formed without union of gametes.

D. Parthenogenesis – The egg cell develop into embryo without fertilization. The egg cell is unreduced (2n), the embryo will have the same genotype as the parent plant.

3.3 Significance of Mode of Reproduction

i. The mode of reproduction affects the breeding procedure to use
ii. Determines the kind of variety to be produced.

	Mode of reproduction	**Types of variety to be produced**	**Genetic make-up**
i.	Vegetative	Clonal	Homozygous
ii.	Self pollination	Pure line or variety	Homozygous
iii.	Cross pollination	Open variety	Heterozygous

	Mode of Reproduction	**Major component of variation**	**Homozygous**	**Heterozygous**
i.	Vegetative	Environment (Ve)	High	Low
ii.	Self pollination	Environment (Ve)	High	Low
iii.	Cross pollination	Genotype and Environment	Low	High

4.0 Conclusion

The mode of reproduction in crop plants dictates both the breeding method to use and determines the kind of variety to produce.

5.0 Summary

In this unit, we have looked at the different flower structures and the mode of reproduction. This is necessary to enable us understand their importance in practical breeding.

6.0 Tutor – Marked Assignment

Define or explain the following:

i. Perfect flower
ii. Imperfect flower
iii. Monoecious plant
iv. Dioecious plant

Self Examined Exercise

Why the knowledge of mode of reproduction is important to crop plants.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. Pp 427.

Unit 2: Self Incompatibility and Male Sterility

Contents:

1.0 Introduction

This Unit introduces the students to factors that encourages self and cross pollination in crop plants which could be due to flower structure, gametophytic, sporophytic incompatibility or sterility systems.

2.0 Objectives

(a) To let students explain the factors that encourage self incompatibility in self and cross pollinating crops.

(b) Explain male sterility

3.0 Main-Body

3.1 Self pollination is the process of transfer of pollen grains from the anther of a flower to the stigma of the same flower.

Factors that encourage self pollination:

1. Cleistogamy – The flowers do not open at all. E.g. wheat
2. Chasmogamy – The flowers open but after pollination. E.g. rice
3. Homogamy – The stamens and carpels of a flower mature at the same time so there is greater chance for self pollination.
4. Position of anther lobes and stigma are very much close to promote self pollination in crops like tomato.

Transfer of pollen grains from one flower to the stigma of another flower borne in different plants is called cross pollination. The pollination needs some agencies like wind, water or animal e.g. insects, birds, snails, etc.

Factors that encourage cross pollination:

Dichogamy: The phenomenon of maturation of male and female sex organs at different times.

(a) Anthers mature before stigma protandry
(b) Stigma matures before anther protogeny

These are common with MONOECIOUS plants. Monoecious plants are plants that have both male and female parts (e.g. maize) on the same plant.

3.2 Incompatibility Systems

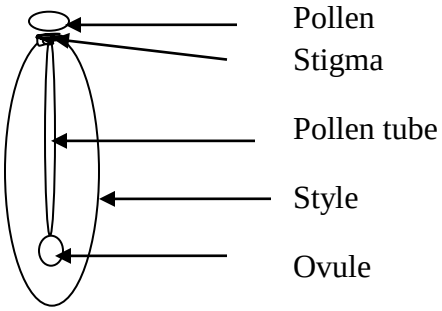
Self incompatibility refers to the situation when in a bisexual flower, fertile pollen and ovule are produced but the pollen is unable to fertilize the ovule due to some physiological hindrance which prevents fertilization. That is, failure of plants with normal pollen and ovules to set seeds. This is quite common in plant species. It is a genetically controlled system. It enforces cross pollination.

Homomorphic Incompatibility – There is no morphological dissimilarities in the flower. There are two of this:

A. gametophytic (the incompatibility is imposed by the genotype of the gametophyte) governed by multiple alleles of "s" gene in pollen.

In gametophytic incompatibility, pollen tube does not grow down the style so that fertilization does not occur.

In compatible matings of the same species, the pollen tube grows at a normal rate and fertilization occurs after the tip of the pollen tube enters the ovule.



The rate at which pollen-tube grows is controlled by a series of alleles S_1, S_2, S_3 etc. The ability of the pollen to function is determined by its own genotype. That is, the type of allele it carries. Pollen tube growth is very slow in a style which contains the same "S" allele as in the pollen nucleus. In other words, if the alleles present in the pollen-tube are identical with alleles in the stylar tissue, the pollen tube normally grows at a very slow rate. However, if the alleles in the pollen tube differ from the alleles in the stylar tissue, the pollen tube grows at the normal rate and there will be fertilization and seeds be produced.

Example: If a plant with the genotype S_1, S_2 is pollinated with its own pollen or with pollen from another plant with S_1, S_2 genotype, the pollen tubes rarely penetrate the style enough to reach the ovule.

Female		Male	Reaction
S_1S_2	x	S_1S_2	Incompatible
S_1S_2	x	S_3S_4	Compatible
S_1S_2	x	S_2S_3	Partially compatible (50%)

Gametophytic – Governed by multiple alleles of "s" gene in the pollen.

S/N	System Gametophytic	Cross		Male Gametes		Genotype of progeny
		Female	Male	Functional	Non Functional	
1	Both parents with the same genotype. Fully incompatible. Alleles	S_1S_2	S_1S_2	None	All	None

	are common in both parents					
2	A. Plants differing in one allele B. Plants differing in one allele	S_1S_2 S_1S_3	S_1S_3 S_1S_2	S_3 S_2	S_1 S_1	S_2S_3 S_2S_3
3	A. Plants differing in both alleles B. Plants differing in both alleles	S_1S_2 S_3S_4	S_3S_4 S_1S_2	S_3S_4 S_1S2	None None	S_1S_3, S_2S_3 S_1S_4, S_2S_4 S_1S_3, S_1S_4 S_2S_3, S_2S_4

In some cases, seeds may set from pollen carrying the same alleles as the stylar tissue. In some plants species e.g. tobacco, self fertility alleles (sf) have been found which renders the alleles for incompatibility ineffective.

Cross		Male Gametes		Genotype of progeny
Female	Male	Functional	Non functional	
SFS_2	SFS_2	SF	S_2	SFSF, SFS_2

A plant with SF allele in the homozygous or heterozygous condition is fertile.

B. Sporophytic incompatibility: Here the incompatibility is governed by multiple alleles but has the dominant – recessive reaction. Here the pollen tube growth is controlled by the genotype of the pollen but not by the genotype of the plant on which it is being produced (female). For example, multiple alleles for incompatibility are S_1, S_2, S_3, S_4; S_1 is dominant over others, S_2 is dominant over S_3 and S_4, S_3 is dominant over S_4, etc. Sporophytic – the genotype of pollen producing plant determining.

In other words, the pollen genotype controls the reaction rather than the nucleus. This dominance is for pollen ONLY. In the female – that is stylar tissue – NO DOMINANCE

Examples

S/N	System Sporophytic	Cross		Male Gametes		Genotype of progeny
		Female	Male	Functional	Non Functional	

1	Both plants (male and female) with the same genotype	S_1S_2 S_1S_2 S_1S_2 in male will act S_1. S_1S_1 produces nothing	No functional gametes		None
2	A. Plants differing in one allele	S_1S_2 x S_2S_3 S_2S_3 in male acts as S_2	None	S_2S_3	None
	B. Plants differing in one allele	S_2S_3 x S_1S_2 act as S_1	S_1S_2	None	S_1S_2, S_1S_3
3	A. Plants differing in both alleles	S_1S_2 x S_3S_4 Act as S_3	S_3S_4 All pollen functional	None	S_1S_3, S_2S_3 S_1S_4, S_2S_4
	B. Plants differing in both alleles	S_3S_4 x S_1S_2 Act as S_1	S_1S2	None	S_1S_3, S_2S_3 S_1S_4, S_2S_4

3.3 Sterility Mechanisms

Male sterility is the incapability of plant to produce or release functional pollen. Male sterility enforces cross pollination. It is used extensively in hybrid seed production. Male sterility is enforced when:

A. The pollen production is absent or extremely scarce.
B. Severe malformation or absence of the stamens or male flowers; called stiminal sterility.
C. Pollen may be normal but fails to open.

In a nut-shell, male sterility means pollen sterility and can result from different situation.

1. Male sterility may be inherited; that is, it results from gene action
2. It may be due to factors in the cytoplasm
3. Interaction between genes and cytoplasm

Genetic male sterility – arises as a result of gene action, usually by a single recessive gene pair often termed msms.

The genotypes will be:

MsMs - Fertile

Msms - Fertile

msms - Sterile

Maintenance of Male Sterility

Male sterility is generally maintained in heterozygous condition. For example: It is necessary to use pollen from a heterozygote (Msms). In this case, half the progeny will be male-sterile (msms) and half male fertile (Msms).

Female msms x Male Msms — Crossing of heterozygous male fertile line with female sterile line

Gamete ms ms Ms ms

Ms: ms → Msms; ms → Msms } Fertile

ms: ms → msms; ms → msms } Male sterile

It will produce $^1/_2$ male fertile plant, $^1/_2$ male sterile plant. Then <u>rogue</u> out or discard male sterile plants.

Cytoplasmic male sterility is controlled by factors in the cytoplasm. Genetic factors are not involved. However, the action of cytoplasmically inherited male sterility may be modified by the action of pollen – restoring genes. This type is common in crops which are grown from their vegetative parts e.g. onion.

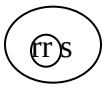
Genotype with sterile cytoplasm can be designated as "S" and will produce progenies that are male sterile genotype with fertile cytoplasm can be designated as "F" and will produce progenies that are fertile.

<u>NOTE</u> Matenal cytoplasm dictates the kind of progenies to produce.

Example:

Female rr S x Male rr F

Sterile Fertile



Sterile progeny because the cytoplasm is transmitted through the egg only. Cytoplasmically inherited sterility will be transmitted only through the mother parent.

1. Male fertility is restored by a dominant gene Ms.
2. Male-sterile plants have sterile cytoplasm with the recessive genes for male sterility Smsms
3. Male-fertile plants may have sterile cytoplasm and with the dominant genes for fertility. SMsMs or SMsms OR may have normal cytoplasm with genes for fertility – NMsMs or NMsms.

Cytoplasmic – Genetic Interaction Male Sterility: This depends on the interaction between genes and cytoplasm. That is, genetic alone or cytoplasmic factors alone cannot cause sterility.

Symbols S = Sterile Cytoplasm

Rf = Fertility Restorer. Fertility restoring gene is dominant

NOTE: Restorer gene can override sterile cytoplasm.

RfRf = Indicate the nuclear genetic restoring fertility

Let us look at the following situations:

1. A plant with (Srfrf) genotype has the cytoplasm sterile and recessive fertility restoring genes. The plant is male sterile.

2. SRfRf or SRfrf: Plant with sterile cytoplasm and dominant fertility restoring genes. The plant is male fertile.

3. NRfRf; NRfrf; Nrfrf. Normal cytoplasm and either dominant or recessive fertility restoring genes. The plants are male fertile.

Let us examine the following crosses:

1. Female x Male
   Srr ↓ Frr (Fertile cytoplasm)
   (Sterile cytoplasm) Srr
   (Male sterile)

   Restorer gene is homozygous recessive ⟶ This kind of mating will produce male sterile

2. Female x Male
   Srr SRR
   ↓

(Sterile cytoplasm) (Male fertile)

SRr
(Male fertile with heterozygous restorer gene)

3. Srr x FRR
(Sterile cytoplasm) (Male fertile)

SRr
(Male fertile)

4. Srr x SRr
(Sterile cytoplasm) (Male fertile)

$^1/_2$ SRr (Male fertile)
$^1/_2$ Srr (Male sterile)

5. Srr x FRr
(Sterile cytoplasm) (Male fertile)

SRr (Male fertile)
Srr (Male sterile)

4.0 Conclusion

This unit is more of practical demonstration of the principles. This is important because it assists us to understand why self and cross pollination happen in crop plants. It also points out how sterility mechanisms occur.

5.0 Summary

Self or cross pollination occur in crop species. It could be due to flower structures or due to gametophytic, sporophytic incompatibility systems or sterility mechanisms.

6.0 Tutor – Marked Assignment

Explain both gametophytic and sporophytic systems of incompatibility.

Self Appraised Exercise

In sporophytic incompatibility system give the genotype that will arise from the following crosses.

A. Female Male
S_1S_2 x S_1S_2

B. Female Male

S_1S_2 x S_3S_4

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York.

Unit 3: Steps for Controlled Crosses and Sourcing for Breeding Materials

Contents:

1.0 Introduction

Plant breeders depend on existence of genetic variability to select superior genotypes for onward development of varieties. That is why it is necessary to know how to make crosses to create variability. Sourcing for breeding materials in sequence is equally important to prevent disruption of genes and quickening the development of new varieties of crops.

2.0 Objectives

At the end of this unit, you should be able to:

- Describe steps involved in making crosses
- Steps to take in sourcing for breeding materials

3.0 Main-Body

3.1 Steps for Controlled Crosses

Before the beginning of any hybridization programme, the breeder should decide the objective of the programme. The whole hybridization programme involves the following procedures.

(a) Choice of parents
(b) Emasculation – removal of anthers or male organ. Removal is done by using forceps
(c) Pollination
(d) Tagging
(e) Harvesting and storage of F_1 seed.

Choice of Parents

The following criteria are essential for choosing parents for hybridization.

- Homozygosity of Parent: The parent chosen for hybridization must be in homozygous condition for the character, that is, pureline.
- Agronomic base: Any well established local cultivar used as seed parent or female parent should have agronomic base for that area (that is adapted).

Emasculation

In case of hybridization for self pollinated crops, it is very much essential to emasculate the plants to avoid self pollination. Emasculation is removal of male sex organs of the flower without any damage or disturbances to female reproductive organ.

There are various techniques that breeders can use to emasculate:

1. Hand emasculation: A general procedure for hand emasculation is as follows:
   (a) Emasculation is done before the anthers mature and the stigma has become receptive. This is to minimize self pollination.
   (b) The petals of selected flowers are opened with the help of fine tip forceps and the anthers are removed.

2. Suction method: This method is useful where small flowers are involved, where hand emasculation is not possible. The petals are generally removed with forceps exposing the anthers and stigma. A thin rubber tube or glass tube attached to a suction hose is used to

suck the pollen grains from its surface. This method is not very efficient, as 15% of self pollination takes place.

3. Hot water emasculation: Pollen grains are more sensitive to hot water than the female reproductive organs. So, treatment with hot water at particular temperature and for fixed time period is helpful for killing the pollen grains without damaging the female organ. Treatment at $40 – 44^0$c for 10 minutes is effective in rice.

4. Alcohol treatment: It is not a popular method; a particular concentration of alcohol is used for a fixed time period to kill the pollen grains. But a little bit more exposure, that is, few seconds more than the recommended time period will reduce the female receptivity, that is, seed set as female organs (ovule) would also be killed by this treatment.

5. Cold treatment: Like hot water treatment, cold treatment can also kill pollen grains without killing the female organ. Keeping rice plant at $0 – 6^0$c kills the pollen grain. Cold treatment is less effective than hot treatment.

6. Genetic emasculation: Genetic or cytoplasmic male sterility may be used to eliminate the necessity of emasculation

Pollination: Mature, fertile and viable pollen from donor plant (male parent) should be placed on the receptive stigma to bring about fertilization. During pollination, pollen viability is a major factor. Detail procedure for pollination varies in case of different crops.
Tagging: The emasculated flower is tagged. The tags are made up of light weight tin-plate and are written in carbon pencil. The tag should bear the following information:
(a) Date of emasculation
(b) Date of pollination
(c) Names of female and male parents involved in the cross
(d) Name(s) of pollinator.

Bagging: After pollination, the flower is enclosed in suitable bag to prevent random cross pollination. As the moisture and temperature become higher within the bag, fungus may develop, which may be prevented by removing the bag after 2 – 3 days after pollination.

3.2 Sourcing for breeding materials, it will be an advantage to look for materials that are already adapted. The steps are:
1. First look for commercial varieties that are available.
2. Old standard varieties from farmers' unselected population. There is a lot of variability in these varieties.
3. Breeding lines from breeders. It may be less desirable because of one trait or the other.
4. From National Centre for Genetic Resources and Biotechnology (NACGRAB).

5. Germplasm collections in your area.
6. Introduction – sourcing for materials outside your own country, but other countries where the same crop is cultivated.

4.0 Conclusion

Variability is the key to plant breeding which could be achieved by making cross that involve materials that are diverse with respect to traits of interest.

5.0 Summary

This unit treated steps to take to achieve controlled crosses and for introduction of breeding materials to a programme.

6.0 Tutor – Marked Assignment

Why is crossing necessary in breeding programme?

Self – Appraised Exercise

What are the steps involved in controlled crosses?

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. Pp 427.

Module 4: Methods of Breeding Self Pollinated Crops

Unit 1: Pure-line Selection
Unit 2: Mass Selection
Unit 3: Hybridization

Unit 1: Pure-line Selection

Contents:

1.0 Introduction

Breeding methods for crop improvement depend on the reproductive system of the crop. This module will focus on the methods that are used often for the improvement of self-pollinated crops. Pure-line is a progeny of a single homozygous self pollinated plants.

2.0 Objective

At the end of this unit, the students should be able to explain how to improve self pollinating crops using pure-line selection.

3.0 Main Body

3.1 Methodology of Using Pure-line Selection to improve self-pollinated crops

(First year) Make a large number of selections from a genetically variable population. That is, the population is a mixture of genotypes (Heterogeneous population).

(Second year)

A. Seeds from each selected individual are grown into a row or rows known as the progeny row. Evaluate plants in the progeny row and then eliminate all bad rows.
B. Select best rows
C. Harvest all plants in a row selected and put the seeds together
D. Identify those lines as experimental strains

(Third year) Repeat what you did in second year to eliminate more entires.
(Fourth year) Continue observation and selection.

Selection is the ability to recognize superior plants in a limited or vast array of variability. Johannsen 1926, a Danish Biologist defined pure-line as a progeny (baby) of a single selfed homozygous individual. He (Johannsen) hypothesized that once the genes are fixed, differences within pure-line are due to environment and would not be utilized by selection.

(Fifth – sixth year) Replicated yield evaluation (trials) at several locations and years with other varieties. Use the best variety as check. Once best line or strain can be identified, increase the seed and release as new variety. This variety should be uniform.

4.0 Conclusion

a. The plants are selected for their desirability of characters that may not be of similar phenotype.
b. The selected plants are subjected to progeny test.
c. The procedure is more effective as careful progeny test and yield trials are conducted.
d. Generally 9 – 10 years are required to develop a new variety.
e. This method is used in self pollinated crops only.
f. The new variety is a pure-line.

g. The new variety is highly uniform, genetic variation is very less.

5.0 Summary

Selection is the ability to pick superior plants in a limited or vast array of variability. Pure-line is a progeny of a single selfed homozygous individual plants. Once a variety is identified via pure-line selection, in a self pollinated crop, any further selection will result to no improvement. In other words, once a pure-line has been identified further selection within the pureline will not lead to more improvement because of lack of hereditary variation within the pure-line.

6.0 Tutor-Marked Assignment

Briefly discuss Johannsen theory of pure-line selection in self pollinated crops.

Self Assessment Exercise

Briefly discuss how pure-line varieties are developed in self-pollinated crops.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York.

Unit 2: Mass Selection

Contents:

1.0 Introduction

The procedure for selection involves the retention of superior healthy, good looking plants from mixed population. This can be done in different ways. In mass selection, large number of plants of similar phenotype are selected and their seeds are mixed together to constitute a

new variety. In other word, mass selection is a breeding method that improves the general performance level of population by selecting and bulking outstanding individuals from a population.

2.0 Objective

At the end of this unit, students should be able to describe process of mass selection and its usefulness.

In case of self pollinated crops, mass selection procedure has the following objectives:

(A) Improvement of local varieties: Local varieties sometimes mix up which may differ in flowering, maturity time, disease resistance, plant height etc. Elimination or rogueing of different plants will help to get uniform variety.

(B) Purification of existing pureline varieties: Maintenance of purity of the existing pureline varieties is done through mass selection procedure. The pureline varieties sometimes tend to become variable with time due to mechanical mixtures, natural hybridization (crossing) and mutation (sudden variation in the hereditary material of a cell). Through regular mass selection the purity of the pureline varieties is maintained.

(C) Production of new varieties from heterogeneous local land races: By increasing the frequency of superior genotype, the population character can be changed. This change is a function of heritability and the number of genes conditioning the trait under selection.

In case of cross pollinated crops e.g. maize, inbreeding (crossing closely related organisms) must be avoided as it leads to loss in vigour and yield. In mass selection, several plants are selected and their seeds are mixed together to raise the next generation, so inbreeding is avoided or kept minimum.

3.0 Main Body

3.1 Methodology for mass-selection without progeny test with respect to the trait of interest.

1st year: Select many plants on their performance and phenotypic characters like vigour, plant type, disease resistance or other desirable characteristics. Harvest and compose/bulk the seeds.

2nd – 4th year: Repeat the process of year one. Then compose/bulk the seeds. The composed seed is the new improved population.

Advantages of mass selection

A. Simple to follow.
B. New variety can get to farmers more quickly.
C. Reduces time and effort (No extensive testing).

D. Since a large number of plants are selected, the variety is more stable in performance over different environments.

Traits that can best be used in mass-selection

A. Traits that can be easily identified by visual observation or simple test. Examples, determinate and indeterminate growth habit in soybean, plant height, seed colour, flower colour, etc.

B. Traits with high heritability (h^2) value, so that they can be expressed and easily identified.

Note: New genotypes or variety are not created in either pure-line or mass selection. Improvement is just isolation of superior genotypes present in a mixed population.

4.0 Conclusion

Mass selection can be used to purify the existing variety and the improved variety can get to farmers quickly.

5.0 Summary

A. The phenotype and the source of pollen are uncontrolled, so selection is based on material parent.

B. Progeny testing is minimal.

C. Composed seed is the new variety or improved population.

6.0 Tutor-Marked Assignment

Contrast pureline and mass selection methods of breeding in self pollinated crops.

Self Assessment Exercise

Define mass selection. Write down the purpose and procedure of the process.

7.0 Reference

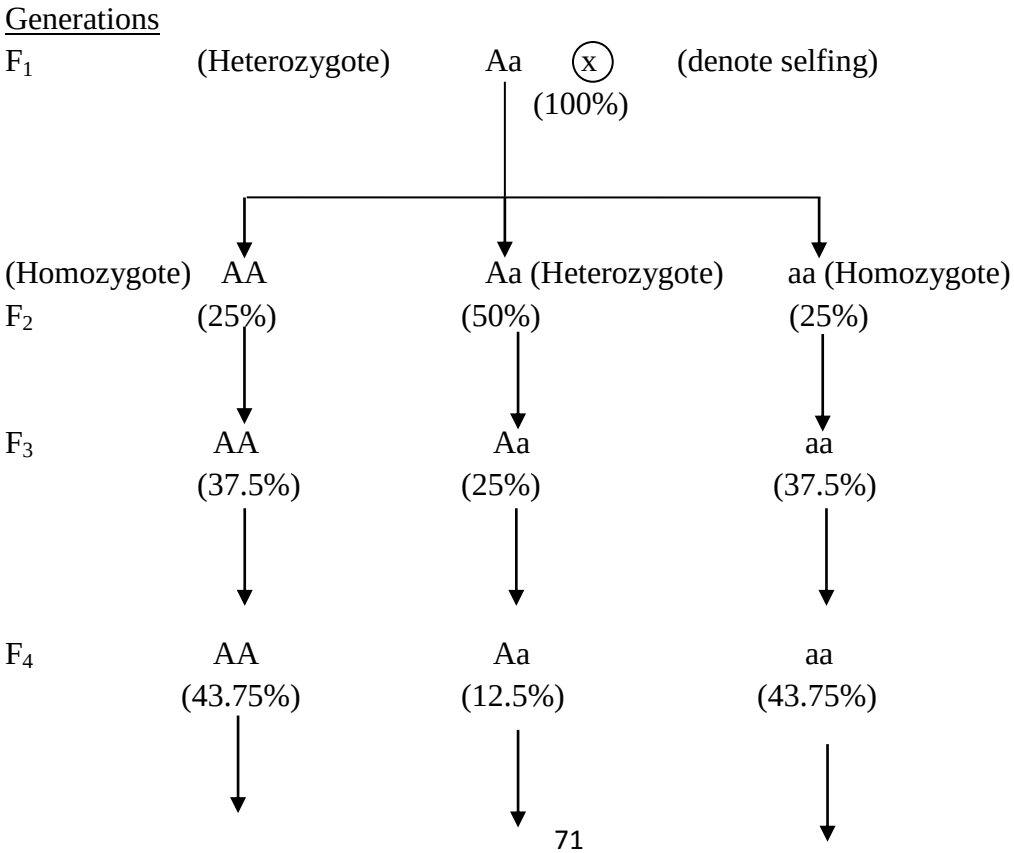
Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. 427 pp.

Unit 3: Hybridization

Contents:

1.0 Introduction

Pure line and mass selection methods utilize the existing genetic variability within the particular variety. Hybridization aims at creating new genetic variation of characters. It is the method of crossing two pure line plants of dissimilar genotypes, which will produce the F_1 hybrids and then the subsequent generations will be segregating generations. Success or failure of the hybridization programme is largely determined by the proper choice of parents. Genetic consequences of selfing F_1 hybrid is illustrated below. There is reduction in heterozygosity by 50% in each successive generation on selfing.



F_5	AA	Aa	aa
	(46.875%)	(6.25%)	(46.875%)
	↓	↓	↓
F_6	AA	Aa	aa
	(48.4375%)	(3.125%)	(48.4375%)

Genetic consequences of selfing F_1 hybrid

With continuous selfing what happens to genotypes?

Heterozygosity decreases
Homozygosity increases

For each generation of selfing, we loss half ($^1/_2$) heterozygosity to homozygosity.

The formula to calculate the percentage of heterozygosity left = $(^1/_2)^g$ after each generation of selfing.

Where g = number of generation

$g = n - 1$

what will "g" be in F_3?

$F_3 = 3 - 1 = 2$

In this case "g" = 2

Therefore, percentage of heterozygosity genotype left in F_3 will be

$(^1/_2)^g = (^1/_2)^2 = {}^1/_2 \times {}^1/_2 = {}^1/_4 = 0.25$

OR $0.5 \times 0.5 = 0.25$

Percentage of heterozygosity in F_1 = 100%
F_2 = 50%
F_3 = 25%

If selection is delayed until F_5 generation applying formula $(^1/_2)^g$ what percentage of heterozygosity is remaining in the population?

$F_5 = (n - 1) = (5 - 1) = 4$. In this case, "g" = 4

$(^1/_2)^4 = 0.5 \times 0.5 \times 0.5 \times 0.5 = 0.0625 \times 100 = 6.25\%$

$F_6 = (^1/_2)^g\ n - 1 = (6 - 1) = 5$

$(^1/_2)^5 = 0.5 \times 0.5 \times 0.5 \times 0.5 \times 0.5 = 0.03125 \times 100 = 3.125\%$

0.03125 or 3.125% of heterozygosity is remaining in the population. It is small.

2.0 Objectives

At the end of this unit, students should be able to explain what hybridization is suppose to do. These are:

A. Create new variability which is further used for development of improved varieties with respect to existing varieties.
B. Remove bottle-neck genes. The appearance of new problems (diseases, insects) to yield can be protected through the creation of new recombinants which will help to come out from this kind of situation.
C. The breeding methods to use in self pollinating crops from a segregating population after hybridization.

For selection of a new variety from a segregating population after hybridization, the methods to use in self pollinating crops are pedigree method, bulk method and back-crossing method.

3.0 Main - Body

3.1 Pedigree Method of Breeding Self-pollinated Crops

Pedigree method of breeding is one of the methods used to develop new varieties in self pollinating crops after hybridization from segregating population. Individual plants progeny is selected from F_2 and subsequent generations and their progenies are tested. During this process the records of parents as well as offsprings are kept for which it is known as pedigree method.

3.1.1 Methodology of handling pedigree method of breeding in self pollinating crops

Yr. 1: The hybridization is done among two selected parents

Yr. 2: F_1 generation seeds are space planted and selfing is allowed. Each F_1 plant will produce more F_2 seeds. From 15 – 30 selected F_1 plants, the F_2 seeds are collected to get a sizable F_2 population.

Yr. 3: In F_2 population, 2000 – 10,000 plants are space planted. Select 100 – 500 plants and their seeds are harvested separately.

Yr. 4: In F_3 generation, the individual progenies are space planted. Each progeny should have about 30 or more plants. Individual plants will desirable traits are selected. Harvest the plants individually. Keep record straight. Diseased plants and with other bad attributes to be eliminated. During this selection, if the numbers of superior progenies are very small then the whole cross programme may be rejected.

Yr. 5: Grow F_4 progeny row from selected plants in F_3. The selection procedure is the same as previous year. If two or more progenies coming from the same F_3 progeny are similar and comparable, then only one may be saved between and among families. Harvest individual plants and keep record straight.

Yr. 6: Grow F_5 family row. Eliminate entire undesirable families. Eliminate undesirable plants from the best family and harvest entire family rows intact.

Yr. 7 & 8: Preliminary yield tests (F_6 and F_7) if great uniformity is observed among the selections.

Yr. 9 & 10: Yield and quality tests for years at several locations.

Yr. 11: Increase seeds and distribute as <u>New Variety</u>.

3.1.2 Modified Pedigree Method for Early Generation Yield Testing

The methodology for modified pedigree method of breeding is just like that of pedigree method except that preliminary yield trials start early starting from year 4, using F_3 population.

3.2 Bulk Method of Breeding Self-pollinated Crops

After hybridization programme, the F_2 and subsequent generations are harvested in bulk to raise the next generation, hence, it is called <u>bulk method</u>. Selection is not done during segregating phases. Selection is delayed until a later generation, usually during F_5 or F_6 after hybridization. At F_5, or F_6, the percentage of heterozygosity has reduced drastically. At the end of bulking period, individual plants are selected and evaluated in the same manner as pedigree method.

3.2.1 Methodology of Handling Bulk Method of Breeding in Self-pollinated Crops

Yr. 1: Make the cross between two parents (A x B)

Yr. 2: Grow F_1 plants and harvest in bulk

Yr. 3: Starting from F_2 generation onwards, the seeds are planted at commercial seed rate and spacing. The seeds of subsequent generations are harvested in bulk.

Many environmental factors, disease outbreak and other bad attributes may select out the particular genotype from this bulk population.

Yr. 4 – Yr. 6: Plant a portion of the bulk seed harvested the previous year. Harvest in bulk ($F_3 – F_5$).

Yr. 7: Space plant F_6 seeds. Select among plants using high heritable and qualitative traits. This is the first selection. Now you practice single plant selection. Harvest individual plants and keep separately.

Yr. 8 & 9: Preliminary yield trials.

Yr. 10: National yield trails. Identify superior lines and increase the seeds.

Yr. 11: Release as the new variety.

3.3 Back-cross Method of Breeding Self-pollinating Crops

Back-cross is the event of crossing F_1 with either of the parents. Backcross method of breeding is the ideal procedure to improve an otherwise excellent variety (Adapted Variety) which may be deficient in one or two traits. Backcross is useful to transfer a single gene, for example, disease or insect resistance genes from a donor parent to an adapted, elite recipient parent. The results obtained are predictable and repeatable.

GENETIC CONSEQUENCES OF REPEATED BACK-CROSSING

Repeated back-crossing results in decreasing the frequency of heterozygosity by 50% in each subsequent generation and rapid increase in homozygote. The genotype of the backcross progeny becomes increasingly similar to that of the recurrent parent.

Non-recurrent Parent (Resistant to stem rust)	OR Donor		Recurrent Parent (Well adapted, high yielding)
	aa	x	AA
	F_1	Aa	
	BC_1	Aa x AA	
	BC_1F_1	AA + Aa 50% 50%	
	BC_2		Aa x AA
	BC_2F_1	AA + Aa 75% 25%	
	BC_3		Aa x AA
	BC_3F_1	AA + Aa 87.5% 6.25%	
	BC_4		Aa x AA

BC_4F_1	AA + Aa
	93.75% 6.25%
BC_5	Aa x AA
BC_5F_1	AA + Aa
	96.875% 3.125%
BC_6	Aa x AA
BC_6F_1	AA + Aa
	98.438% 1.562%

The plan of back-cross method differs on the gene which is to be transferred (dominant or recessive).

3.3.1 Methodology on how to transfer a dominant gene

Selection of parents: Variety A – Recurrent parent (well adapted and high yielding but susceptible to a disease – e.g. stem rust). Let its genotype for the susceptibility condition be "rr".

Variety B – Non recurrent parent, dominant gene that controls the disease (stem rust resistant). Let its genotype be symbolized "RR". This is the Donor parent. The parent that will supply recurrent parent (i.e. adapted variety) the gene for resistance. This donor parent is not desired agronomically, except for its disease resistance.

Note: With every backcrossing to the recurrent parent, the average proportion of the gene from the donor variety is reduced by one-half (similar to selfing; where heterozygosity losses its contribution by $^1/_2$).

Yr. 1: Make a cross between the recurrent parent (Variety A) and the non-recurrent parent (Variety B). The recurrent parent should be used as female parent and the donor parent as male.

	Recurrent Parent		Donor Parent	Percentage of Recurrent Parent
Genotype	rr	x	RR	
	F_1	Rr	(Heterozygous Resistant Plants)	50
	BC_1 rr	x	Rr	
	Gametes r		R r	
	BC_1F_1	R	r	
	Recurrent Parent: r	Rr retain	rr discard → Test and discard	75
	BC_2 rr	x	Rr	
	BC_2F_1 Rr	:	rr ← discard	87.5
	BC_3 rr	x	Rr	

BC_3F_1	Rr	:	(rr)	discard	93.75
BC_4	rr	x	Rr		
		↓			
BC_4F_1	Rr	:	(rr)	discard	96.875
BC_5	rr	x	Rr		
		↓			
BC_5F_1	Rr	:	(rr)	discard	98.4375

In each back-cross generation, segregation would occur for rust resistance. Rust resistant plants are selected and backcross to recurrent parent (Variety A).

Self BC_5F_1 plant with genotype Rr to obtain homozygous plant with genotype RR.

BC_5F_1 Rr (x) self i.e. Rr x Rr

Gametes

	(R)	(r)
(R)	RR	Rr
(r)	Rr	rr

1RR: 2Rr : 1rr

Genotype RR is the new variety that will look identical to the recurrent parent but with additional gene for resistance. Harvest and bulk the seeds.

The new variety is tested in replicated yield trail along with Variety "A" as a check. The new variety will be like Variety "A" in performance only with rust resistant character.

3.3.2 Methodology of transferring a recessive gene

Procedure for transferring a recessive gene is different from that of dominant gene, as the recessive gene will be expressed only in homozygous condition. So, the selection for that recessive gene requires the F_2 generation, i.e., selfing is needed after every back-crossing and testing has to be done for the recognition of the genotype carrying the needed trait.

	Genotype	Recurrent parent		Donor parent	Percentage of recurrent parent
Yr. 1	F_1	RR	x	rr	
			↓		
			Rr	ⓧ (denote selfing)	50

Selfing the F_1 (Rr x Rr) gives three genotypes out of which you are selecting only "rr"

F_2	RR	Rr	rr	(test for rust)
	Discard		Retain	
BC_1	RR	x	rr	
		↓		
BC_1F_1		Rr	ⓧ	75

RR	:	Rr	:	rr	(Testing)
1		2		1	
Discard				Retain	

BC_2	RR	x	rr	
		↓		
BC_2F_1		Rr (x)		87.5
		⋮		
BC_6	RR	x	rr	
BC_6F_1		Rr (x)		98.4375

Rr (x) self i.e. Rr x Rr

Gametes

	(R)	(r)
(R)	RR	Rr
(r)	Rr	rr

1: 2: 1 Test

RR Rr r

RR Rr : rr (Testing)

Discard New Variety

After progeny testing RR and Rr genotypes are discarded while the genotype rr is retained as the new variety.

3.3.3 Calculations

A. To know the proportion of donor genes left after 'n' backcrosses. Donor parent is the parent donating resistant genes (non-recurrent) to the recurrent parent that is adapted and high yielding.

Formula for calculation = $(^1/_2)^n$

Where 'n' is equal to number of backcrosses

Example: After 6 backcrosses what would be the proportion of donor gene in the population.

Formula = $(^1/_2)^g$ in this case 'g' = 6

$= (^1/_2)^6 = {}^1/_2 \times {}^1/_2 \times {}^1/_2 \times {}^1/_2 \times {}^1/_2 \times {}^1/_2 = {}^1/_{64}$ or 0.015625

B. The proportion of recurrent parent in the population

Formula = $\frac{2^n - 1}{2^n} = \frac{2^6 - 1}{2^6}$ = 2.2.2.2.2.2

$\frac{64 - 1}{64} = \frac{63}{64}$ or 0.0984375

After 6 backcrosses
The proportion of donor parent = 0.015625
The proportion of recurrent = 0.984375
Total = 1.000000

C. If the transfer involves (number of gene pairs) more than one gene pair.
The formula that is used is $\frac{2^n - 1}{2^n}$

Where n = number of backcrosses
p = number of gene pairs

Example: After 4 backcrosses involving 5 gene pairs, what would be the proportion of recurrent parent in the population?

$$\left(\frac{2^n - 1}{2^n}\right)^p = \left(\frac{16 - 1}{16}\right)^5 = \left(\frac{15}{16}\right)^5$$

$$\left(\frac{15}{16}\right)^5 = 0.9375 \times 0.9375 \times 0.9375 \times 0.9375 \times 0.9375 = 0.7241964339 \times 100 = 72.4\%$$

After 4 backcrosses with 5 gene pairs, 72.4% of the population would have gene recurrent parent. That is, the recovery of recurrent parent after 4 backcrosses will be 72.4%.

4.0 Conclusion

Hybridization creates new variability which is further used for development of improved varieties. For selection of a new variety from a segregating population after hybridization, the methods followed in self pollinating crops are pedigree method, bulk method and backcrossing methods of breeding.

To get the best from using pedigree method of breeding, the traits to be used should be seen easily and should be qualitative in nature. These traits could serve as indices for selection during the early generation.

Bulk method of breeding is simple, convenient and less expensive. The natural disease epidemics eliminate the undesirable types of plants and increase the frequency of desirable types, which is more helpful for isolation of desirable types. Less attention and labour is needed for this method.

Backcross methods of breeding are techniques available to breeders to transfer alleles from one variety to the other. It is effective when only one or two genes control the trait of interest.

This method does not change the genotype of adapted variety it only helps to transfer a single desirable trait into the existing variety.

5.0 Summary

Hybridization is the most potential breeding method for improvement of crop. Hybridization aims to create genetic variability. Is the method of crossing two pure line parents of two dissimilar genotypes, which will produce the F_1 hybrids and then the subsequent generation which will be segregating.

In pedigree method, selection starts in F_2 phenotypically and individual plant progenies are grown in subsequent generations. Record keeping of each progeny is maintained in such a way that the final selection progeny can be traced back to the particular F_2 plant. It is more laborious, time consuming and expensive. The undesirable segregant plants are rejected in each generation especially in F_2. Yield testing can be done in F_4 or F_5 because heterozygosity within row decreases rapidly.

Modified pedigree method of breeding is similar to pedigree method except that preliminary yield trails start early from fourth year using F_3 population. This is faster in generating new variety.

In bulk-method of breeding, no selection is made in F_2 and the subsequent generations are maintained as bulk. Selection is delayed until homozygosity is attained (F_5 or F_6). Natural selection is operative here, which determines the composition of population at the end of bulking period. Pedigree records are not maintained.
Bulk method of breeding is simple, convenient and requires less attention of the breeder during the period of bulking. It is less laborious and less expensive. Generally, large populations are grown.

Back-cross method of breeding is useful to improve the specific defect of a well adapted popular variety. The new variety developed via this method of breeding is totally similar to recurrent parent except that it bears a new trait transferred from the donor parent. The method is suitable for introducing a specific highly heritable character. Back-crossing is independent of the environment. Vigorous testing is not necessary to release a variety since the method is just improving trait of recurrent parent or upgrading known adapted variety. Back-cross requires small number of plants to work with, it is predictable and repeatable.

6.0 Tutor – Marked Assignment

What is back-cross method of breeding? Mention the genetical consequences of the method.

Self Examined Exercise

Define bulk method of breeding. Write the procedure in brief.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. 427 pp.

Module 5 Breeding Methodologies For Cross Pollinated Crops

Unit 1: Mass Selection
Unit 2: Recurrent Selection
Unit 3: Hybrid Varieties Development (in Maize)
Unit 4: Synthetic Varieties (in Maize)
Unit 5: Seed Production and Distribution

Unit 1: Mass Selection in Cross Pollinated Crops

Contents:

1.0 Introduction

When a large number of plants of similar phenotype are selected and their seeds are mixed together to constitute a new variety, this procedure is known as mass selection. In phenotypic mass selection, the basis of selection could be a qualitative trait, such as flower colour or reaction to disease, or quantitative characters such as height, earliness and seed yield.

Qualitative traits are governed by major genes (few genes or one or two genes) which have distinct effect on plant appearance and their expression is not influenced by the environment and their inheritance can be followed in breeding. In cowpea for example, such genes control leaf shape, colour pattern on flower and seeds, resistance to most diseases and pests. While quantitative traits are governed by minor or poly genes. Many genes are involved. These quantitative traits are affected by the environment. Many economic traits fall in this category. For example, seed yield and milk yield.

The stage of plant development when selections are made will have a bearing on the advance made by mass selection. If selection is made before flowering, the rejected plants can be removed from the population and only the selected plants will mate and contribute genes to the next generation. If selection is made after flowering, the selected plants would have already crossed to all plants in the population and many genes would have come from the unwanted plants. In case of cross pollinated crops, inbreeding must be avoided as it leads to loss of vigour and yield. Mass selection can be used both as a method for maintaining existing varieties and for developing new varieties.

2.0 Objectives

At the end of this unit, students will be able to explain that:

- Cross and self-pollinated crops respond similarly to mass selection. Both tend to move in the direction of selection pressure.
- In self-pollinating crops, the end product is a homozygous genotype, while with cross pollinating crops; the end product is an heterozygous genotype.

3.0 Main-Body

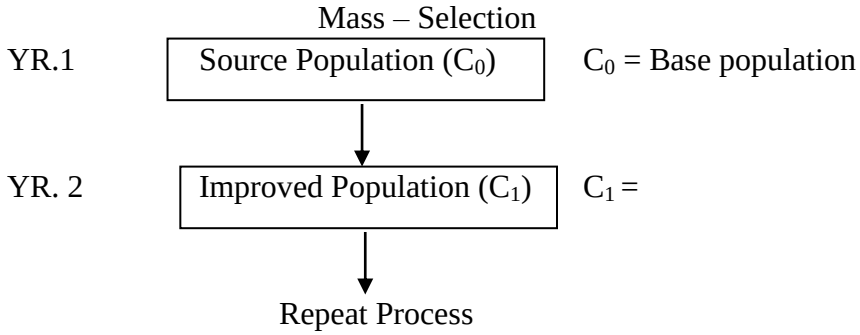
3.1 Mass Selection – When a large number of plants of similar phenotype are selected and their seeds are mixed together to constitute a new variety is called mass selection. The population obtained from the selected plants would be more uniform than the original population.

3.2 Methodology for Phenotypic Mass-Selection

A. The process involves selection of a large number of individual plants on the basis of superior phenotype. Selection is done on maternal parents because the pollen is uncontrolled. For example ear characteristics in maize.

B. Mix the seeds of the selected plants without progeny testing. The mixed seeds are planted en masse to raise the next generation.

C. This process continues till the desired level of uniformity is achieved.



3.3 Methodology for Mass-Selection with a Progeny Test

A. Similar and superior phenotypes are selected from base population. The seeds from individual plant are kept separately.

B. The harvested seeds from individual plants are planted in equal number of rows. The remnant seeds are kept. The inferior or segregating progeny and the remains are rejected.

C. The seeds from the remaining superior progenies are harvested together.

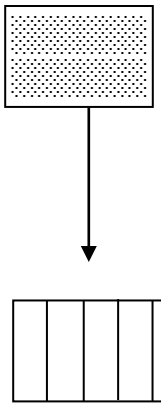
D. Plant the bulk seeds from superior progenies in isolation.

E. Select superior phenotypes which are now the new varieties.

The process may be repeated every few years to keep the variety pure as often as it is found necessary.

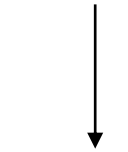
Mass Selection with a Progeny Test

1st Year

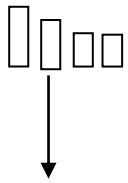


(a) Source population which may be open-pollinated or superior plants. Similar and superior phenotypes are selected (200 – 1000 plants).
(b) The seeds are harvested from individual plants separately.

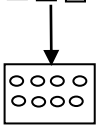
2nd Year — The harvested seeds from individual plant are planted in rows. The inferior or segregating progenies are rejected. The seeds from the selected plants are harvested together.



3rd Year — The composite or bulk seeds are used for preliminary yield trials along with standard checks (standard checks are varieties that are adapted and well accepted in that community).



4th to 7th Yr. — Multilocation coordinated yield trials.



8th Year — Superior phenotypes are released as new varieties. Seeds are multiplied and distributed.

3.4 Ear-to-Row Selection

Ear-to-row is a procedure that offers opportunity of improving intrapopulation. Ear-to-row involves the selection of a number of good maize ears and evaluation of the ears by a progeny test.

Ear-to-row was a modification of mass selection. This procedure involves planting seeds of an ear-to-a-row and measuring the yielding ability. Seeds from the most productive rows are planted and selected. Ear-to-row selection differs from mass selection because of its isolation requirement and progeny testing. Hopkins (1897), used the method in improving maize seed in oil and protein content over a period of time.

Procedure

Yr. 1 Select fifty to one hundred maize ears from source population (pollinated population) and shell separately.

Yr. 2 Part of the seeds from each ear are planted as ear-to-row. The remainder of the seed from each ear is labeled and kept. Each row is scored for desirable characters and yield and the best rows are selected.

Yr. 3 Plant seeds from the remnant seed of ears of first year which gave superior progenies in the second year.

4.0 Conclusion

Self and cross-pollinated crops respond similarly to mass selection. Both tend to move in the direction of selection pressure. The self pollinated crop will produce a uniform progeny whereas the cross-pollinated crops will not.

5.0 Summary

When a large number of plants of similar phenotype are selected and their seeds are mixed/bulk together to constitute a new variety, the procedure is known as mass selection.

Phenotypic mass-selection, mass selection with a progeny test and ear-to-row selection are discussed in this unit.

6.0 Tutor-Marked Assignment

Briefly describe a general mass selection procedure for a cross-pollinated crop.

Self Examined Exercise

Briefly describe mass selection in cross pollinated crop with a progeny test procedure.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. 427 pp.

Unit 2: Recurrent Selection

Contents:

1.0 Introduction

Recurrent selection involves cycles of selection and recombination of the selected individuals to form a new population in each cycle from which selection can again be initiated. This method of population improvement is used for increasing the frequency of superior genotypes or superior genes in the gene pool. It is suitable for improving quantitative traits.

2.0 Objectives

At the end of this unit, students will be able to describe the steps involved in using recurrent selection to improve quantitative traits like yield, height, etc.

3.0 Main-Body

3.1 Types of Recurrent Selection

There are four main types of recurrent selection.

1. Phenotypic or simple recurrent selection.
2. Recurrent selection for specific combining ability (S.C.A).
3. Recurrent selection for general combining ability (G.C.A).
4. Reciprocal recurrent selection.

Phenotypic or Simple Recurrent Selection

In phenotypic recurrent selection, a number of plants with desirable phenotypes are selected and self pollinated. The following year, the progenies from the selected plants are grown separately and intercrosses maybe aided by hand. This method is more suitable to cross pollinated crops e.g. maize. Equal amount of seeds from each plant are composed to be planted to produce the next generation. This completes the first cycle of selection. To start the next cycle of recurrent selection, several desirable plants are selected from the composite population and self pollinated. Progeny rows are grown and all possible intercrosses are allowed to happen. Equal amount of seeds from all the intercrosses are composited to produce the next generation. All systems of recurrent selection are cyclic in nature. Each cycle requires:

1. Evaluation and selfing of selection and
2. Crossing of the progenies of superior selfed plants in all combinations and bulking of equal amounts of seed from each cross.

Recurrent Selection of General Combining Ability (G.C.A)

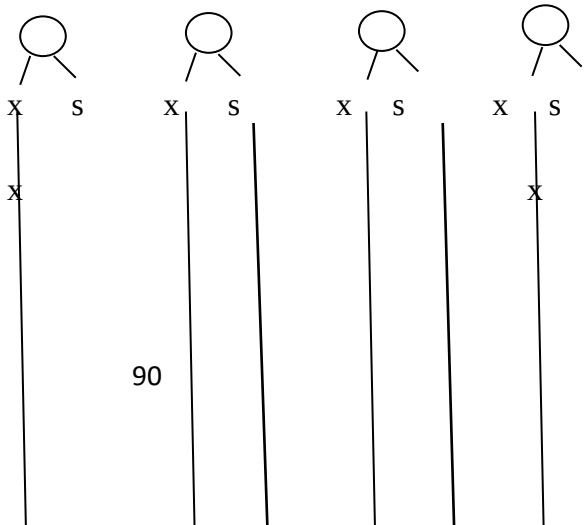
This is a three year one selection cycle. In this system, a number of superior plants are selected from the source population. The selected plants are called S_0 plants, which are selfed and crossed to heterozygous tester which has broad genetic base. The selfed seed is kept in cold storage. The crossed seeds of S_0 plants with tester is used to evaluate the combining ability of various S_0 plants. In the third year, the S_0 plants with good performance are grown from the selfed seeds kept in storage. These are allowed to intermate in all combination and composite to produce a new population for further selection. This cycle may be repeated.

<u>First year</u>

Self pollinated and crossed to a broad based heterozygous tester.

x = cross

First cycle



s = self

Second year
Evaluate crosses (G.C.A) and identified those that are superior.

x x

Discard Select Select Discard

Third year

Reserved self-seed from selected plants are planted to recombine and composite the new seed lot.

This cycle may be repeated

Recurrent Selection for Specific Combining Ability (S.C.A)

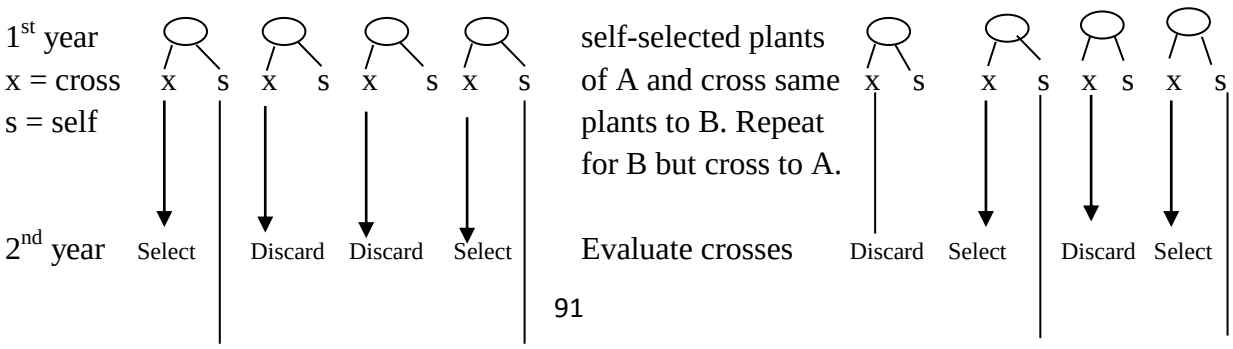
This method is the same as recurrent selection for general combining ability except that the tester is with narrow base tester preferably an inbred line. The differences in the performance of S_0 plants in crosses are due to specific combining ability alone. Great care should be taken in selection of inbred line which will be used as tester. If the inbred is of inferior quality, then the whole scheme may fail.

Reciprocal Recurrent Selection

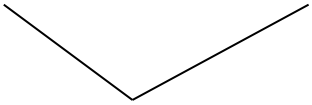
Two populations are involved (populations A and B). Each population is handled in the same manner as in recurrent selection for general combining ability except that population A is the tester of B, and B for A. The two populations should be genetically different and able to combine well together.

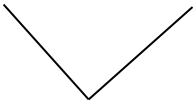
Population 'A' Population 'B'

First cycle



from both A and B

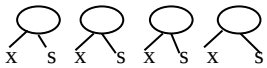




3rd year Bulk Good cross of A Bulk

in the second year,
grow out selfed seed of the first
year and cross in all possible
combinations. Do the same for B.
Bulk seed of A and B separately.

Second cycle



4.0 Conclusion

Recurrent selection is selection from generation to generation with intermating of selects to provide for genetic recombination. Selection among inbred-lines is not recurrent until selects are intermated and a new cycle of selection is initiated.

5.0 Summary

The basic idea of recurrent selection is to increase the frequency of superior genes. There are four main types of recurrent selection:

1. Phenotypic recurrent selection
2. Recurrent selection for specific combining ability (S.C.A)
3. Recurrent selection for general combining ability (G.C.A)
4. Reciprocal recurrent selection

6.0 Tutor – Marked Assignment

Describe the procedures involved using phenotypic recurrent selection to improve a population.

Self Appraised Exercise

What is recurrent selection? Write down the different types of recurrent selection.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New

York. 427 pp.

Unit 3: Hybrid Maize Development

Contents:

1.0 Introduction

Hybrid maize is the first generation progeny from a cross involving inbred lines. Hybrid – An offspring of homozygous parents differing in one or two genes. Development of hybrid maize has had greater impact in increasing food throughout the world. The success in developing maize hybrid has spread to other crops; including both cross and self-pollinated species. Several kinds of hybrids are possible, depending upon the number of arrangement of the parent inbred lines. These include single, double, three-way, multiple, top and back crosses. However, only single, double and three-way hybrids will be discussed in this unit.

2.0 Objectives

At the end of this unit, students will be able to describe/differentiate:

i. Between hybrid vigour or heterosis and inbreeding
ii. How to develop types of hybrid maize.

3.0 Terminologies

Hybrid vigour or heterosis have been used interchangeably. Hybrid vigour can be defined as the increase in performance or vigour of a hybrid over its parents. That is, the superiority of F_1 hybrid over both the parents in terms of yield and other characteristics. Heterosis is expressed at the F_1 generation. Heterosis may be positive or negative.

Positive heterosis - Increase in grain yield, tiller number, protein content, etc.
Negative heterosis – Early maturity, dwarf height. Negative heterosis is also desirable in some cases of agricultural practices.

Genetic basis of heterosis

There are two main theories of heterosis:

1. Dominance hypothesis – This hypothesis suggest that at each locus, dominant allele has the favourable traits, whereas the recessive allele has the unfavourable character. When they are combined together in heterozygous conduction in the hybrids, the favourable traits get expresses whereas the unfavourable traits are masked. So, heterosis results from the masking of harmful effects of recessive alleles by their dominant alleles.

   Dominance hypothesis works with the assumptions that: Dominant genes are beneficial and recessive genes are deleterious.

2. No recombination barrier between the genes. With the help of following example, heterosis can be explained.

   Example: In a cross between inbred 'A' with genotype (AAbbCCdd) and inbred 'B' with genotype (AAbbCCdd), there will be no heterosis in F_1 hybrid. There is no masking of recessive gene in hybrid. But in another cross, inbred 'A' (AAbbCCdd) is crossed with inbred 'B' (aaBBccDD), where the F_1 hybrid is (AaBbCcDc) with all the genes having dominant allele. As a result, the harmful effects of a,b,c,d are hidden by the dominant alleles A, B, C, and D. Generally, parents of diverse or different origin are more likely to produce heterotic progeny than those of similar origin.

AAbbCCdd	AaBbCcDd
No heterosis	Heterosis

Overdominance Hypothesis

This is also known as single gene heterosis or superdominance. This hypothesis says heterozygotes are superior to both homozygote parents. So, the heterozygote Aa would be superior to both the homozygotes AA and aa. Consequently, heterozygosity is essential for the cause of heterosis. Example, in maize, the gene 'ma' affects maturity. The heterozygote 'Mama' matures late than the homozygote 'MaMa' or 'mama'.

Inbreeding Depression – Decrease in vigour due to selfing. Inbreeding increases the degree of homozygosity in the progeny reducing the degree of heterozygosity; whereas hybridization develops heterozygosity.

The rate of increase of homozygosity and decrease of heterozygosity during repeated inbreeding or selfing was discussed in earlier unit. However, let us recast it again to refresh memory.

Generation Selfed	Heterozygosity %	Homozygosity%
0	100	0
1	50	50
2	25	75
3	12	88
4	6	94
5	3	97
6	1	99

3.2 Types of Hybrids

The process of exploitation of hybrid vigour/heterosis is in the hybrid seed production. Heterosis or hybrid vigour has been commercially utilized in both cross pollinated and in some self pollinated species. In most of the cases, the utilization of heterosis is not successful in self pollinated species because of difficulty in production of large quantities of hybrid seeds.

The development of hybrids mainly consist of the following steps:

1. Choice and development of seed parent i.e. the inbred that will be used as female.
2. Choice and development of pollen parent i.e. the male plant.
3. Production of F_1, hybrid seeds.

A. Single Cross

- This is a hybrid made by crossing two unrelated inbred lines (AxB). The hybrid seed being the seed sold to farmers for planting.
- Single cross hybrids are generally more uniform more than other types of hybrids because all plants are genetically identical.
- Single cross hybrids tend to have greater yield potential under favourable environmental and production conditions.
- Less dependable when grown in marginal areas for production or when poor production practices are involved.
- Cost per unit of seed is higher than other types of hybrids because the seed parent is generally not high yielding.
- Usually have higher yields than other types of hybrids.

B. Three-way cross

- Cross two inbreds to form a single cross, and then cross the single cross with a third, unrelated inbred (generally using the single cross as the seed parent).

  (AxB) x C

- As compared to a single cross, the three-way cross is less uniform, usually costs less to produce, tends to have less yield potential and tends to have more stability of production in marginal growing conditions.
- The parents have not contributed equally in the formation of the hybrid.

C. Double Cross

- From two single crosses, then cross them to form a double cross.

  (AxB) x (CxD)
- The most genetically and phenotypically variable hybrid giving high yield stability but lower yield potential.
- Can often be less expensive to produce than a three-way cross (because of greater pollen production, the proportion of pollen parent plants in the seed production field can be reduced).

3.3 Comparison between Hybrid Vigour and Inbreeding Depression

S/N	EFFECTS	HYBRID VIGOUR	INBREEDING DEPRESSION
1	Increase in homozygosity Vs Development of heterozygosity	Hybridization always favour heterozygosity. Due to heterozygosity the effects of many recessive alleles are not expressed in heterosis. Only the dominant effects are	Due to inbreeding, each line becomes homozygous. As a consequence, the variation within a line decreases rapidly.

		expressed.	
2	Harmful traits	Harmful effects are not found in heterosis or hybrid vigour as most of the lethal traits are not expressed.	Inbreeding may result in appearance of many harmful traits due to accumulation of harmful recessive alleles after selfing.
3	Reduction in Vigour	The hybrids are generally more vigorous, healthier and increase in size and yield.	Due to inbreeding, there is a general reduction in vigour and plants become shorter, weaker and loss in yield.
4	Loss of immunity	The heterozygosity in hybrids offers greater flexibility and grants buffer against diseases and pests.	Due to inbreeding, homozygosity increases, there may be rapid loss in vigour as well as disease resistance properly.
5	Adaptability	The hybrids are generally more adaptable to environmental changes.	The inbreds are homozygous. They are less adaptable to changes in environment. This explains why they are adversely affected when there is an epidemic.

4.0 Conclusion

Development of hybrid has had greater impact in increasing food throughout the world. The success in developing hybrid maize has spread to other crops including both cross and self pollinated species.

5.0 Summary

- Hybrid vigour or heterosis can be defined as the increase in performance of a hybrid over its parents.
- Inbreeding depression occurs when the hybrid is selfed. Inbreeding is decrease in vigour. Increases the degree of homozygosity and reducing the degree of heterzygosity in the progeny.
- The three types of hybrids are: single, three-way cross and double crosses.

6.0 Tutor-Marked Assignment

How do we produce the following types of hybrids: single, three-way and double crosses.

Self-Appraised Exercise

Discuss the dominance and overdominance hypothesis to explain hybrid vigour.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. 427 pp.

Unit 4: Synthetic Varieties (Mixture of Genotypes)

Contents:

1.0 Introduction

The development of synthetic varieties in maize was suggested as early as 1919 by Hayes and Garber. Only genotypes which combine well with each other in all possible combinations are put into the synthetic variety. Synthetic variety has greater variability than the hybrid and hence could be grown in areas that have variable growing conditions. They are also cheaper than hybrids for farmers, because they can use previous harvest for seed which is not so for hybrid. A synthetic might be preferable to a hybrid in low-income areas of the world.

2.0 Objectives

At the end of this unit, students should be able to:

- Describe how to develop a synthetic variety.
- Indicate the differences between hybrid and synthetic.

3.0 Main-body

Synthetic variety is an advanced open-pollinated seed mixture of a group of strains or inbred.

3.1 Development of Synthetic Varieties

Steps:

1. Plant in isolatioin 50 – 100 inbred lines which have been evaluated over one or two years. Select the best 25 to 40 lines for top-cross.
   Top-cross – is crossing of selected inbreds to a common pollen parent (plant with high combining ability).
2. (a) Top-cross the selected 25 – 40 inbred lines with the tester which will serve as common pollen
   (b) Test for yield and other traits
   (c) Based on the test cross performance, select the best 10% and inter-cross.
3. Bulk the inter-crossed seed as synthetic I.
4. Repeat the above steps for about 3years using the prevailing synthetic (synthetic I) as base population to produce synthetic II.

3.2 Prediction of Performance of F_2 Synthetic Variety

1. $F_2 = \bar{F}_1 - \frac{(\bar{F}_1 - \bar{P})}{n}$ Formula to show the expected performance of F_2 from a synthetic formed from a number of inbred lines

   Expected performance of F_2

   Where $\bar{F}_1$ = Average performance of all possible single crosses among parental lines.
   $\bar{P}$ = Average performance of parental lines.
   n = Number of inbreds or lines involved in the synthetic variety.

2. $(\bar{F}_1 - \bar{P}_1)$ This formula measures heterosis.
   Note: maximum heterosis is in F_1.

   Heterosis of the F_2 and subsequent generations may be increased by.
   (a) Increasing F_1 yields or any trait in question.
   (b) Increasing yields of the parental inbred lines.
   (c) Increasing the number of parents in the synthesis.

   In developing a synthetic variety, the plant breeder has to decide on the number of inbred lines that will give the optimum values of n, p and F_1.

   Example of prediction of performance of F_2 of a synthetic variety.

   Number of inbred lines used = 5 with a mean of 50.2cm tall.

How many single crosses do we expect from 5 inbreds?

$\frac{n(n-1)}{2} = \frac{5x4}{2}$ = 10 single crosses.

A, B, C, D, and E. These are 5 inbreds, let us cross them in all possible combinations.

1. A x B	5. B x C	8. C x D	Ten single crosses with a mean of 63.1cm Tall.
2. A x C	6. B x D	9. C x E	
3. A x D	7. B x E	10.D x E	
4. A x E			

Heterosis = $\bar{F}_1 - \bar{P}$

= 63.1 – 50.2 = 12.9

Expected performance of F_2

$\bar{F}_1 - \frac{(\bar{F}_1 - \bar{P})}{n}$

$63.1 - \frac{63.1 - 50.2}{5} = \frac{12.9}{5} = 2.6$

63.1 – 2.6 = 60.5

Predicted F_2 performance = 60.5
There is a decrease in height of F_2 compared to F_1.

4.0 Conclusion

Synthetic variety has greater variability than the hybrid and hence could be grown in areas that have variable growing conditions.

5.0 Summary

Synthetic varieties involves, selection of inbreds, top-crossing, evaluation of selected top-cross inbreds, intermating of selects and bulking of inter-crossed seeds.

6.0 Tutor-Marked Assignment

Which of these two varieties of maize, synthetic or hybrid will you recommend in low income areas to raise the standard of living and why?

Self-Examined Exercise

Describe briefly the synthesis of synthetic varieties.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. 427 pp.

Unit 5: Seed Production and Distribution

Contents:

1.0 Introduction

The impact of plant breeding programmes on food production depends on the quality and efficiency of seed distribution and its availability to farmers. Good quality seeds ensure genetic purity of variety, high germination capability, freedom from seed borne diseases, freedom from impurities and seeds of noxious weeds.

2.0 Objectives

At the end of this unit, students should be able to:

(a) Understand that seed production programme is to supply good quality seeds of high yielding varieties to farmers.
(b) Realize that there are four different classes of seed.

3.0 Main-Body

3.1 Different Classes of Seed

There are four classes of seed recognized by Seed Certification Agencies.

(a) Breeder Seed: This is small quantity of pure seed directly produced by the plant breeder or originating institution.
(b) Foundation Seed: This is the progeny (baby) of breeder seed. The genetic identity and purity of the variety is maintained in foundation seed. Foundation seed is the source of all certified seed classes, either directly or through registered seed.
(c) Registered Seed: This is the direct increase from foundation seed. Registered seed is used as the source of certified seed in some crops.
(d) Certified Seed: This is the progeny of foundation seed or registered seed. Its production is guaranteed by inspection and certification by an independent agency. In Nigeria, we have National Agricultural Seeds Council (NASC) which serves in this capacity.

3.2 Maintenance of Varieties

In self-pollinated crops like cowpea, soybean, the maintenance of varietal purity is not a serious problem provided the right class of seed is used and mechanical mixtures are avoided. By adequate rouging, avoidance of volunteers and by using approved source of seed for planting, the danger of varietal contamination is reduced.

The maintenance of varietal purity in cross-pollinating varieties is the same for self-pollinating crops except that the field must be isolated from other fields with a distance of about 400 meters.

3.3 Elements of Seed Production

Production of high quality seeds requires a number of steps as described below:

(a) Use of genetically pure seeds of the given variety from a dependable source.

(b) Seed should be multiplied on clean land to prevent volunteer plants.

(c) The variety should have proper isolation of specified distance from other varieties of the same species. In self-pollinating crops 3 to 4 meters between the different varieties is adequate.

(d) Proper cultural practices, fertilizer application, insecticides and weed control have a great influence on seed quality and quantity as well as the economics of the seed production.

(e) Field inspection is important. It involves identification of the variety, determination of variety purity and recognition of diseases and off-types. Rouging of diseased plants and varietal mixture should be done at the appropriate stages of growth. Rouging should be done at least three times: first at pre-flowering stage, flowering stage and at maturity using flower colour, leaf shape, pubes cent (hair), etc.

(f) Harvesting must be done at the right maturity and moisture content to ensure good quality seed.

(g) Drying and threshing should be done timely and carefully to prevent damages and mechanical mixtures. Seeds are often treated with chemicals as a protection against seed-borne and soil borne diseases.

(h) There should be a timely, proper testing of seeds in the laboratory. Laboratory seed tests include verification of identity and varietal purity: moisture content, germination percentage and health status.

3.4 Seed Distribution

A variety is ready for release and distribution when it has been proved to be distinctly superior to existing commercial varieties in at least one or more traits and satisfactory in all other important attributes.

First distribution of foundation seed is usually made to selected farmers who by past experience have proved their ability to produce registered and certified seed with a high standard of quality. Distribution of certified seed is made to certified growers throughout the country. The certified seed harvested from this increase then becomes available without restriction to any grower as the seed supplies are available.

4.0 Conclusion

The primary aim of crop breeding is to supply good quality seeds of high yielding to farmers and there are four classes of seeds recognized by the seed certification agencies.

5.0 Summary

The four classes of seeds are: breeder seed, foundation seed, registered seed and certified seed. Adequate isolation distances must be adhered to during maintenance of varieties to maintain varietal purity.

In self-pollinated crops, distance between 3 – 4 meters is adequate while isolation of 400 meters is ideal in cross-pollinated crosses.

6.0 Tutor-Marked Assignment

Describe the four classes of seeds and their importance in producing high quality seeds for farmers.

Self Assessment Exercise

Briefly describe the steps involved in seed production.

7.0 Reference

Poehlman, J.M. (1959). *Breeding Field Crops*. Holt, Rinehart and Winston, Inc. New York. 427 pp.