BASIC AGRICULTURAL GENETICS

Genetic concepts

- **GENETIC TERMINOLOGY:**

  1. **Genetics/heredity:** The study of inheritance/genes.
  2. **Heredity:** Transfer of genetic factors from one individual to the next/is the way in which characteristics are inherited.
  3. **Genes:** A unit of heredity that carries information for each characteristic of an organism.
  4. **Chromosomes:** Threadlike structures in the nucleus of the cell, made up of DNA.
  5. **Alleles:** Variations of the same gene/different form of the same gene.
  6. **Homozygous:** Having identical (same) alleles for a particular gene, e.g TT or tt.
  7. **Heterozygous:** Having different alleles of a gene, e.g Tt.

- **THE DISTINCTION BETWEEN GENOTYPE AND PHENOTYPE, DOMINANT AND RECESSIVE GENES**

  1. **Genotype:** Genetic makeup of an organism.
  2. **Phenotype:** Physical appearance of an individual due to genetic makeup.
  3. **Dominant:** Allele that overrides or masks the characteristics of a recessive allele.
  4. **Recessive:** An allele that is masked by the presence of a dominant allele and which only appears in the phenotype if the organism is homozygous.

- **THE MONOHYBRID INHERITANCE/CROSSES (SINGLE-TRAIT CROSSES): MENDEL’S SECOND LAW: LAW OF SEGREGATION**

  - **Monohybrid inheritance/crosses:** Is a genetic cross between two individuals involving a single pair of contrasting characteristics, e.g green seeds versus yellow seeds in pea plants.
  - **Mendel’s First Law (Law of Segregation):** States that pairs of alleles segregate (separate) during the formation of gametes (during meiosis) and randomly combine during fertilisation.

- **THE DIHYBRID INHERITANCE/DIHYBRID CROSSES: MENDEL’S SECOND LAW: LAW OF INDEPENDENT ASSORTMENT**

  - **Dihybrid inheritance/crosses:** Is a cross between two individuals that have different alleles for two selected traits.
  - OR A genetic cross that involves two pairs of a contrasting characteristics.
- Mendel’s Second Law: Law of independent assortment / Independent Recombination: State that pairs of alleles separate independently during the formation of gametes. This means that traits are passed to offspring independently of one another.

- The use of various methods such as Punnett Square/Chequer Board, Genetic Diagrams and Schematic Representations to illustrate the crosses

- **Punnett Square/Chequer Board**

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- **Genetic Diagrams**

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BB  bb
B B  B B
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- **Schematic Representations**

- Mendel’s Law of Segregation and Independent Recombination of Characteristics

- Qualitative and Quantitative Characteristics

- **Qualitative Characteristics**

  - Characteristics such as Eye Colour or Gender (e.g. whether the organism is male or female). In other words, qualitative characteristics involve a particular quality of the organism.

- **Quantitative Characteristics**

  - Involve a quantity such as height, weight, egg or milk production.
  - The number of genes an organism has for a particular trait determine this type of characteristic. This is called polygenic inheritance.
  - In this case, the genes have an additive effect. For example, if a person has a few genes for shortness and a few genes for tallness, then that person will be of medium height.
THE PATTERN OF INHERITANCE

THE PATTERN OF INHERITANCE THAT LEADS TO DIFFERENT PHENOTYPES:
1) Incomplete Dominance
2) Co-dominance
3) Multiple alleles
4) Polygenic inheritance
5) Epistasis

1. **Incomplete dominance**: Inheritance of two alleles that are partially expressed, when often produces an intermediate characteristic.

2. **Co-dominance**: Inheritance of two alleles that are dominant and fully expressed in the phenotype.
3. **Multiple alleles**: A mechanism of inheritance that involves more than two alleles for one gene. OR when there are more than two alleles for the same gene.

4. **Polygenic inheritance**: Trait controlled by many genes.

5. **Epistasis**: Masking of the phenotypic effect of alleles at one gene by the alleles of another gene.

- **THE CONCEPTS**: Prepotency
  
  : Atavism/Throwback (With relevant example)

  1. **Prepotency**: Ability of one parent to transmit more characteristics to its offspring than the other parent.
  
     - Or ability of some animals to transmit their characteristics to their progeny

  2. **Atavism/Throwback**: The reappearance of a characteristic in an organism after a period of absence.

- **THE SEX CHROMOSOMES AND SEX –LINKED CHARACTERISTICS (EXAMPLES)**
  
  - Female humans and mammals have two (XX) chromosomes
  
  - While the male have (X) chromosome and a small (y) chromosome e.g (Xy)
  
  - Humans and animals have 50:50 chance of producing male or female offspring.
  
  - Sex linked genes are located on the Sex chromosomes

<table>
<thead>
<tr>
<th>FEMALE</th>
<th>MALE</th>
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<tr>
<td>X X</td>
<td>X y</td>
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- **THE FOLLOWING GENETIC TERMINOLOGY:**
  
  1. Variation
  
  2. Mutation
  
  3. Selection

  a) **Variation**: Differences between individuals of the same species

  b) **Mutation**: A sudden/random change in the structure of DNA
c) **Selection**: Choosing individuals to be used for breeding purposes due to superior characteristics. /is the process of choosing individuals with desirable characteristics to be used as parents.

- **THE TYPES OF VARIATION**
  1. **Continuous variation**: Type of variation in which the characteristics can take on a complete range of forms from one extreme to the other.
  2. **Discontinuous variation**: Type of variation that has a few clear-cut forms with no forms in between.

- **THE TYPES OF MUTATIONS**
  1. Gene mutations
  2. Somatic mutations
  3. Induced mutations

- **THE TYPES OF SELECTION (SELECTION METHODS)**
  1. **Mass selection**: Type of selection that is based on the individual animal's performance in the field.
  2. **Pedigree selection**: Type of selection that is based on the quality of the animal's ancestors
  3. **Family selection**: Type of selection that is based on the quality of the animal’s relatives of its generation (full/half siblings)
  4. **Progeny selection**: Type of selection that is based on the quality of the animal's offspring.

- **THE IMPORTANCE OF VARIATION AND SELECTION**

  **The Importance of Variation**
  
  1. Animals/plants with superior characteristics can be selected for breeding purposes.
  2. Helps to improve the progeny/ offspring.
  3. Generate new varieties/ breeds/ cultivars
  4. Maintains biodiversity
  5. It improves the ability of an organism to survive or adapt.
  6. It is the foundation of selection and breeding programmes.

  **The Importance of Selection**
  
  1. It results in livestock improvement
  2. Only allow animals with the best characteristics to be bred/ desired characteristics to be bred
  3. Allow animals with desired characteristics/ traits to be used in the production of quality offspring

  **Characteristics Considered For Selection**
1. Growth
2. Health
3. Fertility

❖ THE EXTERNAL (ENVIRONMENTAL) AND INTERNAL (GENETIC) CAUSES OF VARIATION.

The External (Environmental) Causes of Variations

1. Climate/Temperature/Light intensity
2. Feeding/Nutrition
3. Exercise
4. Diseases
5. Topography/Relief/Terrain

The Internal (Genetic) Causes of Variations

1. Recombination of genes
2. Crossing-over of chromosomes

❖ THE TYPES OF MUTAGENIC AGENTS AND THEIR EFFECTS.

- **Mutagenic agent** or **mutagen** is any factor that causes a mutation to occur.

  ➢ **Types of Mutagenic Agents**
  
  - X-rays
  - Cosmic rays
  - Ultraviolet radiation
  - High-energy radiation
  - Numerous chemicals/ e.g thalidomide, phenol and formaldehyde

  ➢ **Effect of Mutagenic Agents**
  
  - Many mutations cause cancer,
  - Gamma rays. X-rays may cause DNA breakage and other damage

❖ THE GENERAL PRINCIPLES OF SELECTION: Heritability and Biometrics

- **Heritability**: The degree to which genetics determines a characteristic.
- **Biometrics**: The use of statistics in biology.

❖ THE SELECTION METHODS USED BY PLANTS AND ANIMAL BREEDERS (Mass, Pedigree, Family and Progeny Selection)

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THE FOLLOWING BREEDING SYSTEMS AND TERMINOLOGY: Breeding, Inbreeding, Cross Breeding, Species- Crossing, Out Crossing, Line-Crossing with relevant examples.

1. **Breeding**: Process of producing plants or animals by sexual reproduction.

2. **Inbreeding**: The crossing of two plants or animals that are closely related.
   - E.g Father and daughter, mother and son, brother and sister.

3. **Cross-breeding**: The breeding of two plants or animals that are not closely related. Is the mating of two pure bred animals of different breed.
   - Practiced by stock farmers to obtain hybrid.
   - Is the mating of two pure-bred animals of different breeds, but of the same species
   - E.g Afrikaner bull X Aberdeen Angus cow = Heterosis or hybrid cow
   - Herford bull X Africaner cow= Bonsmara
   - Shorthorn bull X Afrikaner cow = Bonsmara

4. **Species-crossing**: Is the mating of individuals of two different species.
   - E.g A horse mated with a donkey produces a mule.
   - Or Donkey stallion X horse mare= mule
   - **Uses of the MULE**: Used as draught animals for pulling implements/ploughing/working.
   - To carry loads/Transport.

5. **Out-crossing/out-breeding**: Is the mating of unrelated animals or of animals that are not closely related.

6. **Line-breeding**: Is the breeding of animals that share common ancestors but which are not closely related.

7. **Upgrading/Grading up**: Is the repeated mating of thoroughbred (pure-bred) male animals with inferior female animals. Excellent pure-bred males of a specific breed are mated generation after generation with females of inferior quality.

THE ADVANTAGES AND DISADVANTAGES OF CROSS BREEDING AND INBREEDING

**ADVANTAGES AND DISADVANTAGES OF CROSS BREEDING**

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
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<tbody>
<tr>
<td>Increases genetic variation</td>
<td>Expert knowledge is required</td>
</tr>
<tr>
<td>Greater production (e.g more wool, milk, eggs, beef)</td>
<td>Different pure-bred bulls are expensive</td>
</tr>
<tr>
<td>Greater disease</td>
<td>Cross breeds are not suited for</td>
</tr>
<tr>
<td>Resistance/Greater Resistance to Disease</td>
<td>Breeding Purpose</td>
</tr>
<tr>
<td>----------------------------------------</td>
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</tr>
<tr>
<td>• Increased fertility / Greater fertility</td>
<td>• Hybrids do not breed true / progeny is of poor quality</td>
</tr>
<tr>
<td>• Better adaptation to conditions / Better adapted</td>
<td>• Leads to dystocia (Calving problems)</td>
</tr>
<tr>
<td>• Leads to increased heterosis</td>
<td>• Destroys characteristics / more heterozygote's</td>
</tr>
<tr>
<td>• Hybrid vigour / Better performance</td>
<td></td>
</tr>
<tr>
<td>• Faster growth rates</td>
<td></td>
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<tr>
<td>• Possess better motherly instincts</td>
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**Advantages and Disadvantages of Both Inbreeding and Line-breeding**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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</thead>
<tbody>
<tr>
<td>• Speeds up uniformity / it ensures genetic uniformity</td>
<td>• Causes a loss of genetic variation / Decrease genetic variation</td>
</tr>
<tr>
<td>• They are uniform in appearance.</td>
<td>• Fertility, productivity and adaptability decrease in in-breds</td>
</tr>
<tr>
<td>• Strengthens good characteristics</td>
<td>• Reduced vigour and production.</td>
</tr>
<tr>
<td>• Greater prepotency is obtained</td>
<td>• Lowers viability of the progeny</td>
</tr>
<tr>
<td>• Best characteristics are transferred to the progeny</td>
<td>• Leads to inbreeding depression</td>
</tr>
<tr>
<td>• The quickest way to pure lines</td>
<td>• Increases the expression of lethal genes</td>
</tr>
<tr>
<td>• Bad recessive genes are eliminated</td>
<td>• Leads to deformed offspring</td>
</tr>
<tr>
<td></td>
<td>• Undesirable traits found in offspring</td>
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</table>

**Advantages and Disadvantages of Species Crossing (Hybridisation)**

<table>
<thead>
<tr>
<th>Advantages / Characteristics / Reasons for species crossing</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>• They are hardy animals / Mules are more hardy and adaptable than horses.</td>
<td>• Offspring are sterile</td>
</tr>
<tr>
<td>• They are drought animals / Mules are useful draught animals</td>
<td>• Male mule is sterile</td>
</tr>
<tr>
<td>• They are highly durable</td>
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<tr>
<td>• Can work better under unfavourable conditions than horses.</td>
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<tr>
<td>• Less susceptible to digestive problems, lameness and diseases</td>
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<tr>
<td>• Faster than donkeys and heavy draught horses</td>
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<tr>
<td>• Much stronger than the donkey</td>
<td></td>
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<tr>
<td>• Male mule more reliable and</td>
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</table>
better worker than mares

ADVANTAGES AND DISADVANTAGES OF UPGRADING

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
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<tbody>
<tr>
<td>• Improve the quality of the farm animal</td>
<td>• Time consuming</td>
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<td>• Most economical method of improving herd.</td>
<td>• It is expensive/Bulls must always be bought from outside to reduce inbreeding</td>
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<td>• Requires no specialised knowledge</td>
<td>• The commercial value of first few generation is low</td>
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<tr>
<td>• Possibility of deficient progeny is small</td>
<td>• The offspring can never be bred 100% pure/ 100% pure progeny cannot be obtained</td>
</tr>
<tr>
<td>• New breed gradually imported into a new environment</td>
<td>• Same bull for too many generations results in deformities</td>
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<tr>
<td>• Few adaptation problems</td>
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GENETIC MODIFICATION/ GENETIC ENGINEERING

- **THE CONCEPT GENETIC MODIFICATION/ GENETIC ENGINEERING IN PLANTS AND ANIMALS** (with relevant example)
  1. **Genetic modification**: technique of changing the characteristics of an organism by inserting genes from another organism into its DNA
  2. **Genetically modified organism (GMO)**: organism that contains genes from another organism. /OR an organism whose genetic characteristics have been changed by inserting the gene(s) of another organism into its DNA

- **THE AIM OF GENETIC MODIFICATION OF PLANTS AND ANIMALS**
  - Increase genetic diversity (by inserting variant alleles into other species)
  - Improve quality and productions of crops and livestock
  - Introduce specific desirable traits/ characteristics
  - GMO plant and animals are genetically prone to certain diseases and treating them in advance

- **THE ADVANTAGES OF GENETIC ENGINEERING OVER TRADITIONAL METHODS**
  - Precise/ desired genes are transferred
  - Not limited to crossing of the same species
  - More convenient
  - Faster/ requires only one generation to complete
  - More resistant to pests/ drought/ diseases/ herbicides
  - Higher yields
THE DISADVANTAGES OF GMO/ SOCIO-ECONOMIC EFFECT
- Small scale and poor farmers cannot afford GM Crops/ GM Crops are expensive
- A farmer is not allowed to re-use seeds from GM Crops
- The farmer may not use some seeds as they are sterile.
- Some consumers will not buy from the farmer due to ethical concerns
- It encourages monopoly which does not allow small companies to develop/ favours the producers and encourages exploitation of emerging farmers

THE CURRENT USES/ APPLICATION OF GENETICALLY MODIFIED PLANTS
- .
- .
- .
- .

THE TECHNIQUES USED TO GENETICALLY MODIFY PLANTS/ ANIMALS
- Electroporation
- Micro-injection
- Agrobacterium tumefaciens/ agrobacterial transfer
- Gene gun/ biolistics
- Recombinant DNA
- Viral carriers/ Viral vectors

THE DESCRIPTION (DESCRIBE) OF TECHNIQUES USED TO GENETICALLY MODIFIED PLANTS/ ANIMALS
- The gene is incorporated into (maize plant/tomatoes/oranges/farm animal) where it produces toxins.
- To protect the (maize plant/ tomatoes/oranges/farm animal) against the diseases (e.g maize stalk borer)

THE POTENTIAL BENEFITS OF GENETICALLY MODIFIED CROPS

- Potential benefits of GM Crops on Environment (Environmental benefits)
  a) Pest and insect resistance
  b) Use less chemicals
  c) Less susceptible to diseases

- Potential benefits of GM Crops on Economy (Economic benefits)
  a) Higher yields or production
  b) Mature quicker.

- Potential benefits of GM Crops on Health (Health benefits)
  a) Healthier
b) Tastier
   c) More nutritious foods.

**BENEFITS OF GM Crops**
- More productive with higher yields
- Resistant to pests and diseases hence reduce the use of chemicals
- Tolerant to harsh conditions/ resist hot temperatures
- Longer shelf life and better properties
- Better flavour, colour, texture and nutritional value
- Cheaper and more plentiful food.
- Keeping germination ability over a longer period of time/ longer viability of seed
- Formation of new substances
- Shorter/ longer growing period/ early/ late maturing

❖ **THE CHARACTERISTICS OF GMOs**

- Herbicide resistance
- Insect resistance/ pest resistance
- Resistance to harsh environmental conditions/ Drought resistance
- Improved nutritional value/ starch/ vitamins
- Modified/ improved quality
- Adaptability to environmental conditions
- Disease resistance
- Early maturing to escape harsh conditions

❖ **THE POTENTIAL RISKS OF GMOs**

- Food safety
- Environmental issues
- Socio-economic effects

  .

  **Negative effects of GM Crops on the environment**

- Production of super weeds
- Insect resistant plants also kill beneficial insects/ Beneficial insects can be killed
- Indiscriminate use of weed killers can destroy useful plants/ indiscriminate use of herbicides pollute the environment

❖ **DIFFERENCE BETWEEN HYBRID SEED AND GMO SEED**

<table>
<thead>
<tr>
<th>HYBRID SEED</th>
<th>GMO SEED</th>
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<tbody>
<tr>
<td>DNA not altered</td>
<td>Altered DNA</td>
</tr>
<tr>
<td>Crossing of two in-bred lines (cultivars)</td>
<td>Genes from another organism are inserted into a cell</td>
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