CHAPTER 10

Biology of Heredity (Genetics)

Introduction

In Chapter 8 we learnt about variations in a population. In the chapter, we observed that no two organisms look alike (even within the same species) due to the differences in their genetic make-up. Children of the same mother and father show differences not only in their physical appearance but also in their behaviour and intelligence. Even identical twins that are formed from the same zygote (one ovum and one sperm) show specific differences by which they can be distinguished. Such variations are hereditary.

The particular genes an organism inherited from its mother and father were simply the result of chance. This is partly due to the way the parents chromosomes behaved during mieosis (Figs 10.7 and 10.8) when the eggs and sperms were formed.

What is heredity? This is the transmission of characters or traits from parents to offspring. It took centuries for how this is done to be discovered. When the knowledge of heredity was yet to be understood by people, it was believed that whatever a woman looked at during her pregnancy will defintely affect the look of her child/baby when born. But this was only superstition. Some children through mere observation are found to take after their grandparents. Recent development in research on genetics has however helped erase the fallacious superstition held by the people of old, and clarify peopleâ€™s views on the processes involved in heredity (transmission of charaters)

Transmission and expression of characters in organisms

Genetics is the study of heredity and variations in living things. Common experience has shown that plants and animals produce offsprings which look like them but still are not exactly like the parents. Every member of a species shares in common, a set of traits. These traits or characters distinguish one species from the other.

Hereditary variation

Hereditary variation refers to differences among individuals which can be passed from parents to their offspring (progeny).

Characters that can be transmitted

It is not all characters that can be transmitted from the parents to the offspring. It is only those traits that constitute the genetic make up of the parents that can be transmitted and expressed in the offspring. These traits (characters) include, colour of the skin, eye, teeth, hair and hair texture, size, shape of the head, ear, hand, mouth, nose, lips, finger and finger prints, length of the neck, legs, jaw, shoulder. Similarly, characters such as voice, intelligence, composure, aptitude, sickle-cell anaemia are also transmissible in animals while in plants, such hereditary variations as, plant height, colour of leaves, shoot, seed, flowers, size of the seed, flowers, fruits and pigmentation are noticed.

Hereditary variations may be simple and easy to identify as listed above. They may be described as being continuous or discontinuous (see chapter 8).

Variations in any living organism that are caused by environemtal factors are not transmissible. Examples are:

(a) In animals, such traits, as the development of muscles, stunted growth etc. are called **acquired traits** or characters and so are not genetically transferred from parents to offspring.

(b) In plants, disease may affect a plant and thereby cause the plant to be stunted in growth. This is not carried on to the next generation.

Discontinuous hereditary variations

There is no in-between feature of a particular trait. Variation is usually one of a number of options either A or B or C. Examples are:

(i) Sex (male or female).

(ii) Blood groups (an individual has only one of A, B, AB or O

(iii) A person is either a sickler (has sickle cell anaemia), a carrier or has no sickle-cell trait.

(iv) Tongue roller or non-tongue roller persons.

(v) â€œTasterâ€ or â€œnon-tasterâ€ individuals.

Continuous hereditary variations

In this type of variation, there is a range of ever-changing intermediate values of a given trait. Eamples are as follows:

(i) The height of a plant or person at a given period, or among others in its family

(ii) Size of leaves, fruits and roots.

Continuous variations are controlled by a number of genes as well as environmental factors. (See Chapter 8 for more details). Plant and animal breeders apply the knowledge acquired from continuous variation to improve crop and livestock production.

Transmission and expression of characters in organisms from parents to their offspring is called heredity or inheritance. The differences among individuals of the same specie are called **variations.**

How characters get transmitted

Characters are transmitted on the basis of heredity. This was discovered by Mendelian work on genetic

Mendelâ€™s work in genetics

Gregor Mendel (1882–1884) was an Austrian monk. He carried out simple experiments on heredity for nine years (1856–1865) using the common garden pea. He published his research findings *Experiments on Hybridization* in *The Journal of Natural History* in Austria in 1866/67. The great work was not popularly credited to him until 1900 afer he had died.

Mendelâ€™s experiments

Mendel studied how hereditary characters were transmitted from generation to generation. His work is now regarded as the foundation for scientific study of heredity and variation. He is in fact called the â€˜father of geneticsâ€™.

He worked with the garden pea (*Pisum sativum*). He most probably chose to work with the pea because he could not conduct his experiments on heredity with human beings. Besides, peas are normally self-pollinating and peas are fast maturing plants, and within a single family, many different pairs of obvious contrasting characters occur. (See Table 10.1)

Table 10.1 Contrasting characters worked upon by Mendel (Mendelian traits)

Garden pea.	***Dominant***	***Recessive***
1. Height of the stem	Tall	Short
2. Flowers	Red	White blossoms
3. Position of flowers	Axial	Terminal Axial
4. Pods	Green	Yellow
5. Surface of pods	Smooth	Constricted
6. Colour of Seeds	Yellow	Green
7. Surface of testa or seeds	Round/Smooth.	Wrinkled

Mendelâ€™s experiment with red and white flowered pea

(Monohybrid inheritance)

Mendel started with the cultivation of garden pea with pairs of distinct contrasting characteristics such as tallness and shortness in their stems. He worked on them for about two years. After six generations, he was convinced that they **bred true.** That is, they were always producing the same results of a particular feature. A summary of Mendelâ€™s experiment is as follows:

1. Mendel took a pea with red flowers and another with white flowers (pure breeds).
2. He crossed the two together i.e. took pollen grains from one and deposited them on the stigmas of the other. (Peas that have self-pollinating flowers).
3. He collected the seeds from the offspring from this cross and planted them.
4. The seeds grew into all the red-flowered peas (F_1). F_1 means first filial generation.
5. He allowed these offsprings (all red flowers) to naturally self-fertilize themselves later on.
6. He gathered all the seeds from the new generation of peas and planted them again.
7. He obtained the following results (F_2): Red-flowered peas were 705 and white flowered peas were 224 i.e. they appeared in ratio 3:1 (See Fig. 10.1)
8. He carried out other similar experiments with the other pairs of contrasting characters.

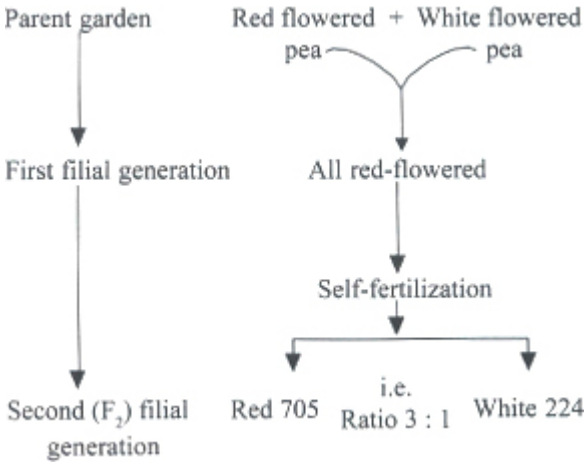


Fig. 10.1 Diagrammatic representation of Mendelâ€™s work on garden pea (Monohybrid inheritance)

Figure 10.1 summarizes the Mendelian experiment on the pair of contrasting characters (flower colours) i.e. monohybrid cross.

Discussion on Mendelâ€™s work on red and white flowered garden peas.

The initial pure breeding varieties are called parents or parental generation. Mendel knew that something he called germinal unit or factor was responsible for each character in each parent. The factor which is found in gametes (ovules or pollen grains is now known as a gene).

The products of the fertilization of gametes of both parents are regarded as F_1 or first filial generation. It was observed that all the flowers produced were red. White flowers were not shown (manifested). The characters which appear in the F_1 are called **dominant characters,** while the ones that are masked are called **recessive characters** e.g. white flower in this case.

When F_1 offsprings were allowed to self-pollinate themselves, both characters (red and white flowers) appeared. These products are called F_2 or second filial generation. They usually appear in the ratio 3:1 (dominant: recessive). The significant point here is that the masked character in F_1 (white) was not lost, killed or cancelled. Also, there, were no intermediate or transitional colour types to suggest a blending of characters.

Experiments which involve the crossing of two pure strains and only one pair of contrasting characters are called **monohybrid crossing** or inheritance.

Symbolic representation of genetic experiment result

Dominant characters are usually represented in double capital letters e.g. red flower colour **= RR,** while the recessive characters are represented by the corresponding small, double letters e.g. white flower colour = **rr.** Genes occur singly in gametes; in this case either as **R** or **r.** However, in zygotes or other plant parts, they occur in pairs e.g. **RR** or **Rr.**

Mendelâ€™s experiment on red and white coloured flowers may be symbolically represented as shown in Fig. 10.2

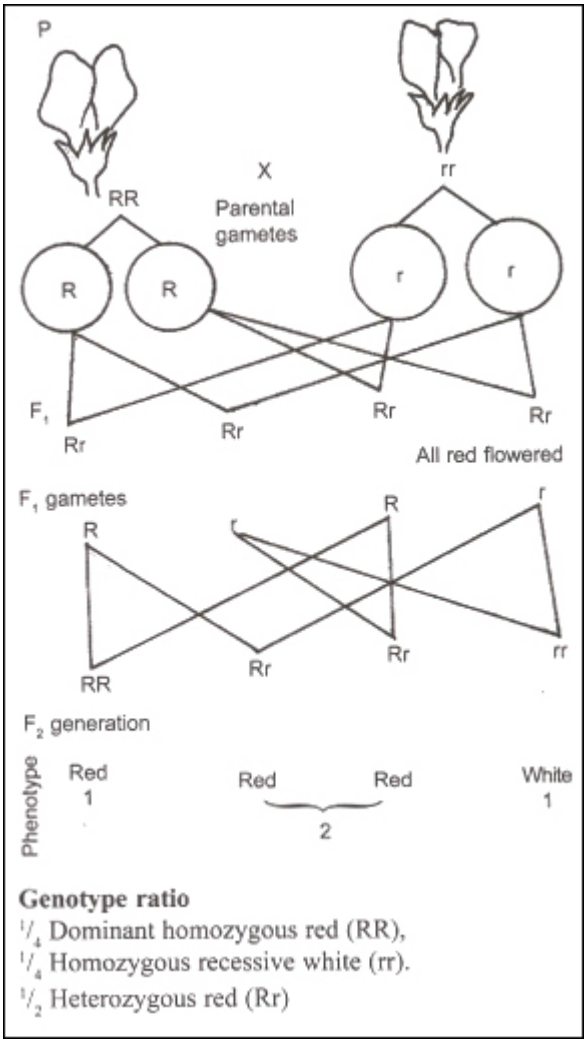


Fig. 10.2 Symbolic representation of Mendelâ€™s monohybrid cross of red and white flowered peas

Some basic genetic terms

Before we go on with our study of genetics, it is necessary to learn the meanings of some genetic terms. The following are the definitions of some of the terms commonly used in genetics

1. *Alleles:* These are alternate (contrasting) forms of a gene, located on the same position on a chromosome pair, that control a particular trait. The allele that produces a dominant character is always represented by a capital letter e.g. R (red-flowered pea) and the allele producing the recessive character by a small letter r (white-flowered pea).
2. *Character or trait:* It is any feature possessed by an organism e.g. skin of a human or height of plants.
3. *Chromosome:* It is a threadlike structure in the nucleus with strands of DNA, each of which contains thousands of genes.
4. *Gene:* This is a chemical substance composed of DNA, located on a chromosome, which controls the appearance of a particular trait or

character in an organism. Genes usually occur in pairs (one inherited from each parent). More than one gene control the appearance of traits like eye, hair and skin colours, shortness and tallness, shape of body and leaf size. Genes result in the genotype and phenotype of organisms. It is the genetic constitution of each organism – a permanent feature.

5. *Genotype:* It is all the set of genes present in each somatic cell which an offspring inherits from both parents.
6. *Phenotype:* This is the visible feature of an organism. It includes the general physical features like body size, shape, colour and height of all organisms, physiological make up and observable behaviours of some animal species. It can be modified by the environment.
7. *Hybrid:* This is the offspring produced when two pure strains interbreed. All offspring from sexual reproduction are hybrids which are genotypically different from one another and their parents.
8. *Homologous chromosomes:* These are the pairs of chromosomes formed during meiosis which are similar in shape and size.
9. *Heterozygote organism (hetorozygous):* This is one that possesses two different (contrasting) alleles located on the same position on a pair of chromosomes. A heterozygous tall organismâ€™s alleles can be represented as Tt.
10. *Homozygote organism (homozygous):* This is one that possesses two identical alleles at the same position on a pair of chromosomes. A homozygous tall organismâ€™s alleles can be represented as TT.
11. *Dominant character:* This is the physical trait (phenotype) that is manifested in an offspring when two organisms with contrasting characters interbreed or are crossed. For example, when a red-flowered pea, plant genotype RR or Rr is crossed with a white variety (genotype rr) all the offspring are red. The red trait is the dominant character and, the dominant gene.
12. *Recessive character:* This is the phenotypic trait that does not appear when two organisms with contrasting characters (e.g. redness and whiteness) are crossed. For example, the white trait in 11 above (with genotype rr) is a recessive character and the gene r is a recessive gene. It is only phenotypically expressed when in the homozygous state.
13. *Incomplete dominance:* This occurs when the offspring from two parents has a physical appearance (phenotype) that is intermediate between the parents. For example, when a white-coloured four oâ€™clock plant (*Mirabilis jalapa*) and a red-coloured variety are crossed, the first filial (F_1) generation has pink colour. Thus, the genes for redness and whiteness contribute to the offspringsâ€™s phenotype and are said to be co-dominant.
14. *Hybridization:* It is a crossing of plants with contrasting

characters. Monohybridization involves the crossing of two pure (true breeding) strains and looking out for only one pair of contrasting characters.

15. *Dihybridization:* It involves the crossing of plants with two pairs of contrasting characters. For instance, crossing pure-breeding tall plants with red flowers together with short plants with white flowers. Hybridization is also done with animals e.g. livestock.

Mendelian traits

Mendelian traits or characters in garden pea plants are listed in Table 10.1. The following examples are such traits in animals. See Table 10.2.

Table 10.2 Mendelian traits in animals

Human red blood cell	**Normal**	**Sickle-cell**
Human blood group gene	A or B gene	O gene
Human skin pigmentation	Normal	Albinism
Human colour of eye	Brown	Blue or grey
Human colour sight	Normal colour	Night or colour blindness
Human tongue rolling	Tongue-rolling	Non-tongue rolling
Guinea pig coat colour	Black	White
Drosophila wing	long	Short/vestigial
Cattle colour/horn	Black colour/hornless	Red colour/horned
Leghorn chicken	White plummage	Pigmented plummage

Mendelian laws

Mendel formulated two principles of inheritance. They were based on the conclusions he arrived at during his experiments with the garden pea. They are popularly known as the first and second Mendelian laws.

First Mendelian law

It is known as the law of segregation. This law states that â€œthe two factors (e.g. redness or whiteness) segregate or separate from one another unaltered and unblended as they pass from one generation to the nextâ€. The pair of factors or genes segregate during the formation of gametes (meiosis). Only one passes into a single gamete. During fertilization, genes pair up in new ways. This law was propounded from evidences Mendel obtained from his monohybrid crosses with garden peas.

Second Mendelian law (Law of Independent Assortment)

This law states that â€œtwo pairs of factors in the same, cross assort

or separate independently of each otherâ€. In other words, a member of a pair of genes can combine separately with any other member of another pair. It acts randomly and it is thus inherited.

Mendel arrived at this law from his findings on the experiments he carried out with two pairs of contrasting characters (dihybridization). For example, in the crossing of round yellow seeds with wrinkled green seeds, the F_1 generation showed the dominant character of round and yellow, and the F_2 generation showed a proportion that was the square of 3:1. Hence, the F_2 ratio was 9:3:3:1 (round-yellow: wrinkled-yellow: round-green: wrinkled-green)

Other scientific contributions of Mendel include:

1. That what is transmitted from parents to offspring is the germinal unit (gene) in the gametes (e.g. pollen grains or ovules) and not blood or any other part of the plant or animal.
2. The experimental method used to arrive at his two laws. That is, the guidelines on how to test and improve on his work.

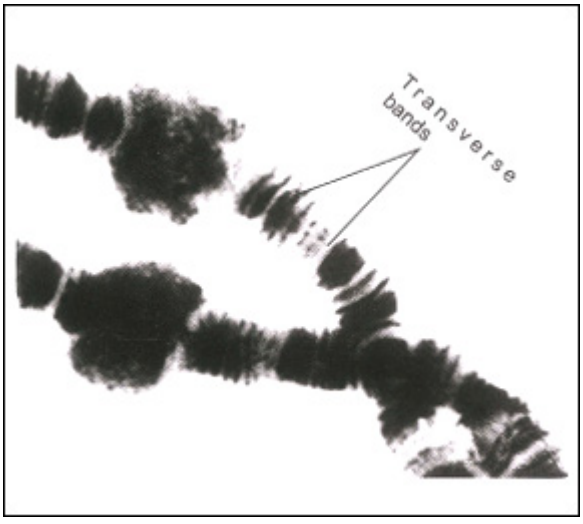


Fig. 10.3 Structure of a Blackfly chromosome.

Chromosome: the basis of heredity

Extensive modern researches in science have identified the location of chromosomes as being in the nucleus of each living cell of plants and animals.

Plants and animals consist of two types of cells: somatic or vegetative cells and gametes or sex cells. Somatic cells are the body cells which are not concerned with reproduction. They contain most of the body chromosomes. They carry diploid (double set), 2N chromosomes. They are obtained as a result of fertilization. That is, the contribution of a set of chromosomes from a male and a female individual. Nuclear divisions in somatic cells is called mitosis.

Sex cells (gametes) are cells which are found in the reproductive organs of the male and female organisms. Nuclear division which occurs in them, results in meiosis (reduction division). The gametes

(e.g. ovum, pollen grain or sperm) are haploid. That is they carry half the number of chromosomes of sormatic cells.

Each organism has a specific number of chromosomes in its somatic cells i.e. the number of chromosomes in a species is constant. Every human has 23 pairs of chromosomes in each somatic cell, while each gamete has half i.e. 23 chromosomes. *Drosophila* (fruit fly), maize and tomato plants have 4, 10 and 12 pairs of chromosomes respectively.

Each chromosome is made up of two nuclear threads called chromatids. Homologous or identical chromosomes naturally occur in pairs. Each chromosome has several transverse bands along its length as is shown in Fig. 10.3. Many modern scientific researches have shown that numerous hereditary materials (genes) are located in these bands, and that they are DNA (Deoxyribose nucleic acid) molecules. It is estimated that there are 2–3 million genes in every human cell.

DNA

The DNA (Deoxyribonucleic acid) was first discovered by Crick and Watson in 1953. They described it as a spiral or double helix structure: the missing link btween living and non-living matter which resembles a ladder which can zip apart. See Fig. 10.4. DNA is found in all living cells. It is a very complex structure found in the chromosome of the cell nucleus. It can replicate itself in the chromosome i.e. it can make an exact copy of itself, as shown in Fig. 10.5 during mitosis.

DNA determines the make up of proteins, enzymes and other substances in a cell. It controls the chemical and physical activities of each cell as well as the entire organism. The DNA molecule is structurally the same in all organisms but **instruction or genetic codes** are arranged along it in different sequences for every species. It is these codes that determine the pattern of growth and behaviour of every member of a species.

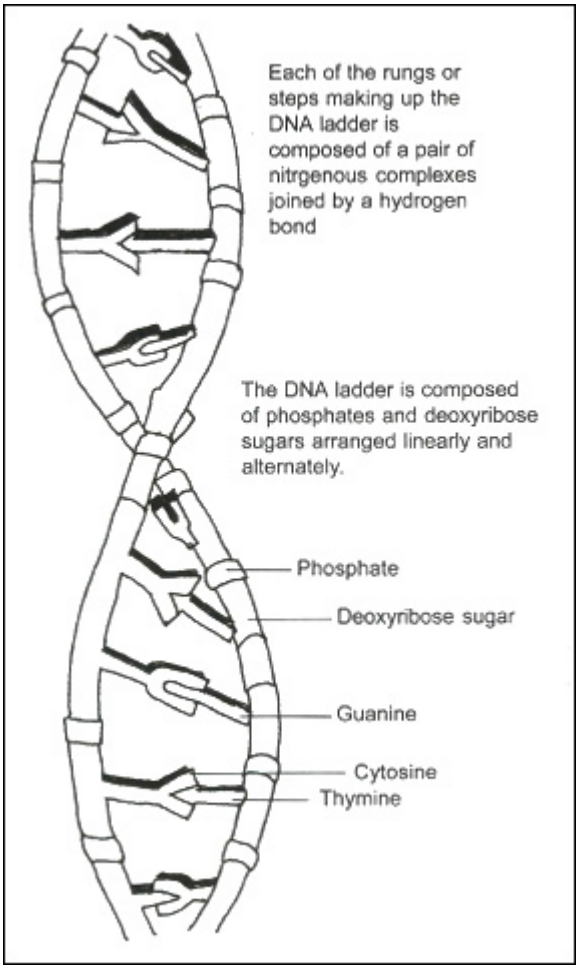


Fig. 10.4 Structure of a DNA molecule

Structure of DNA

DNA (Fig. 10.4) has the shape of a double helix. The rung of the ladder consists of four pairs of organic (nitrogenous) bases called Adenine, (A), Cytosine (C), Thymine (T) and Guanine (G). A always pairs with T, and C with G. There are always equal numbers of each pair in all organisms. Deoxyribose sugars are linked by phosphoric acid molecules. The two chains of DNA are coiled double and they are held together by hydrogen bonds formed by the hydrogen atoms in the nucleotides.

Replication of DNA

When the spiral unwinds, the linkages A-T and C-G are split. When T is exposed, only A is added from the nuclear fluids (cytoplasm). Similarly, when C is exposed, only G is added. Thus, the unwinding of the double helix in the dividing nucleus ensures the construction of two identical, new chains (Fig. 10.5)

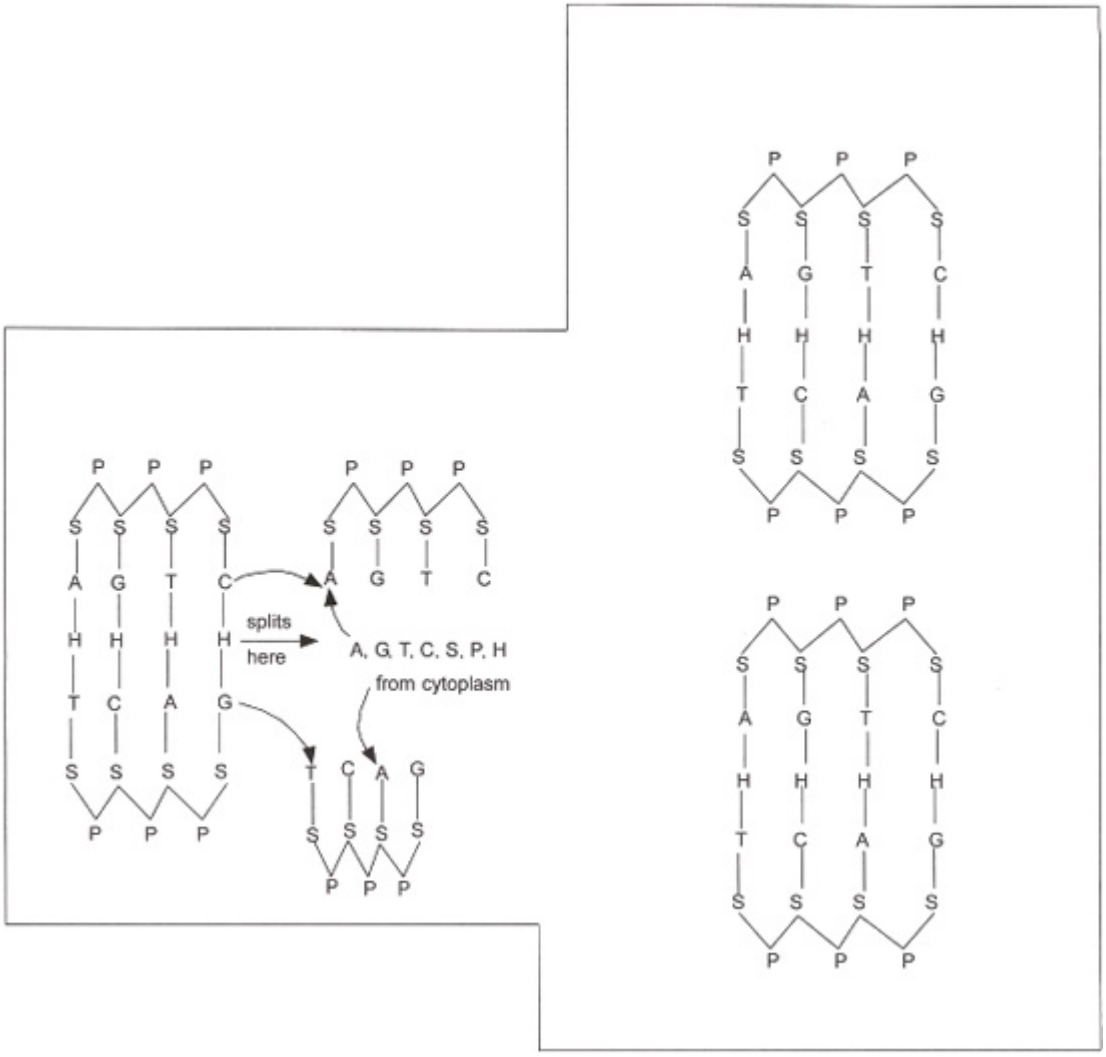


Fig. 10.5 Replication of DNA

P = Phosphoric acid molecule.
S = Deoxyribose sugars.
H = Hydrogen bond.
A = Adenine
C = Cytosine.
T = Thymine
G = Guanine.

The process of transmission of hereditary characters from parents to offspring

This process involves the segregation of genes at meiosis, and the recombination at fertilization within parents during sexual reproduction. Mitosis and mutations are also involved in heredity.

Alleles are located on homologous chromosomes. When these segregate randomly during meiosis (Fig. 10.7), the alleles they carry also segregate and pass into different gametes. The crossing over in meiosis mixes up the DNA in the chromosomes. Hence, no two gametes are identical, though, they contain chromosomes that are

alike in shape and size (homologous chromosomes).

During fertilization, 50% of each zygoteâ€™s chromosomes are contributed by each parent. This is likely to bring about a combination of chromosomes and genes that has never occurred before in any member of the species (i.e. variation). This explains why an organism reproduced sexually resembles its two parents in certain respects and yet is uniquely different from both parents and from other organisms of the same species.

Since chromosome segregation during meiosis, and pairing during fertilization occur by chance, variations are continually introduced steadily in sexually reproducing species. It is now known that several genes, not a pair of alleles, are responsible for a particular trait e.g. colour of eye, skin etc. About four pairs of genes (alleles) are known to control the height of humans.

The genes an organism inherits during fertilization (genotype) remains constant throughout life. The phenotype (physical features) of an organism is determined by its genotype and the environment in which it lives. Hence, organisms with the same genotype may possess different phenotypes if they live in different environments. However, it is often hard to distinguish the individual contributions of the genotype from that of the environment.

Mitosis and meiosis

Mitosis is the process by which two new somatic/body cells are formed by the division of the parent somatic cell. Mitosis enables animals and plants to grow. The chromosomes in the new (daughter) cells are similar in all respects (appearance, genetic constitution and number) to those of the parent cell (diploid number, 2N). This is because each chromosome has replicated itself. The main stages of mitosis are outlined in Fig. 10.6

Meiosis

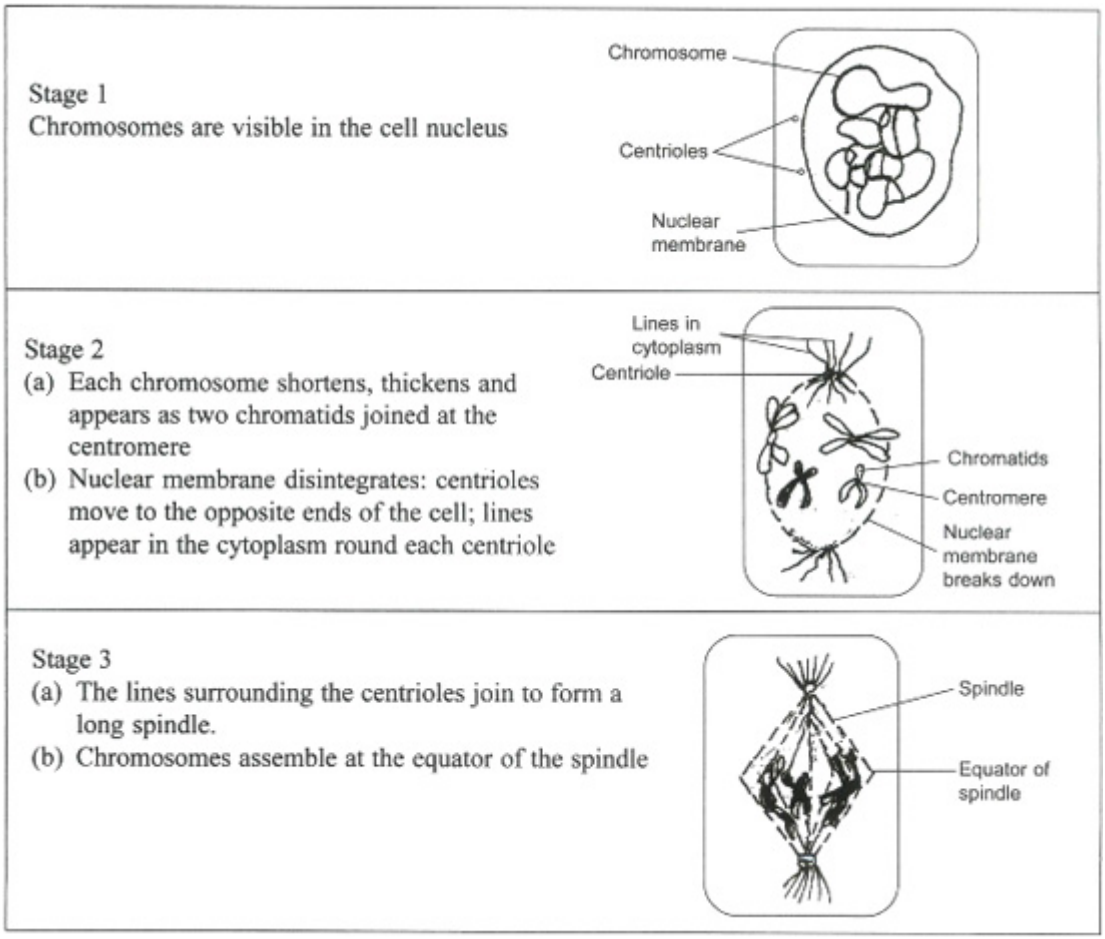
Meiosis is a cell division that occurs during the formation of gametes in gonads, e.g. testes, and pollen grains. Meiosis results in the formation of gametes that have half the number of chromosomes found in the somatic cells (haploid, N, number). But during fertilization (see Fig. 10.8), the diploid number of chromosomes in somatic cells is restored in the zygote. The main stages of meiosis are outlined in Fig. 10.7. Table 10.3 compares mitosis and meiosis.

Table 10.3 Comparison of mitosis and meiosis

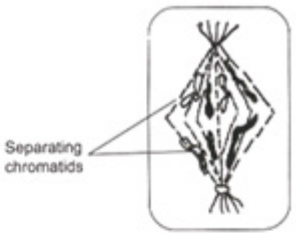
Mitosis	Meiosis
1. Occurs during growth of somatic (body) cells.	Occurs during the formation of gametes
2. Number of chromosomes of parent and new cells is	Number of chromosomes of new cells is half that in the parent cell (haploid).

Mitosis	Meiosis
the same (diploid)	
3. Cells of two offsprings are formed.	Cells of four offsprings are formed.
4. In both parents and new cells, chromosomes can be arranged in pairs.	Chromosomes can be arranged in pairs only in the parent cell.
5. No exchange of material between chromatids.	Exchange of material can occur between the chromatids of homologous chromosomes. This causes varation so that offsprings differ a bit from their parents and other members of the same species

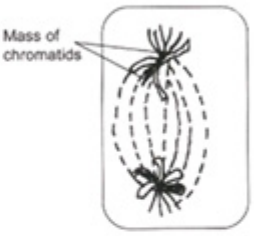
Stages of mitosis



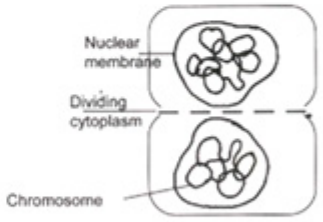
Stage 4
Chromatids of every chromosome separate and move towards the opposite ends of the spindle.



Stage 5
(a) The chromatids at each end become the chromosomes of the new cells.
(b) Gradually, the spindle breaks down.



Stage 6
Around each group of new chromosomes is a nuclear membrane. The cytoplasm divides into two, and two new cells are formed.



Stage 2
The new cells enlarge and their chromosomes are no longer visible.

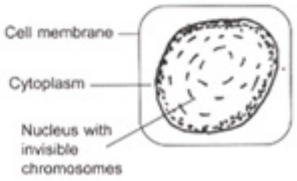
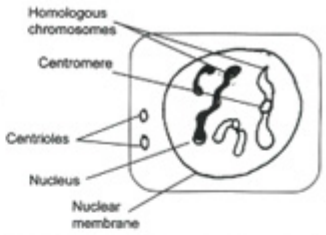


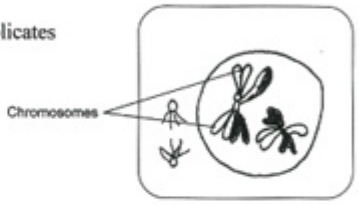
Fig. 10.6 Main stages of mitosis

Main stages of meiosis

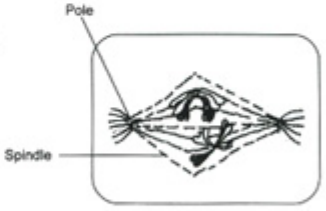
Stage 1
Chromosomes can be seen in the cell of the gonad (parent cell).



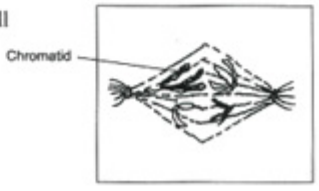
Stage 2
Each of the pair of homologous chromosomes replicates and forms two chromatids.



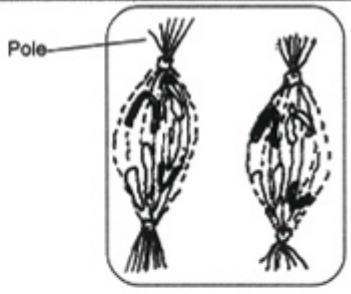
Stage 3
Nuclear membrane breaks down and a spindle is formed. The paired chromatids assemble at the equator of the spindle



Stage 4
Pairs of chromatids move to the opposite ends of the cell along the spindle



Stage 5
Each pair of chromatids separates as in mitosis. Four cells are formed as gametes. Each cell has half the number of chromosomes of the parent cell.



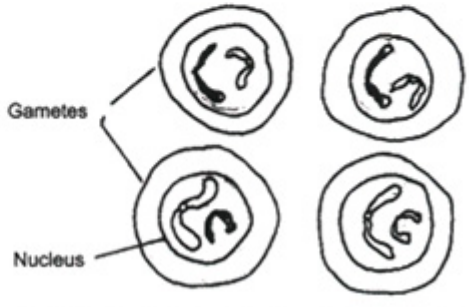


Fig. 10.7 Main stages of meiosis

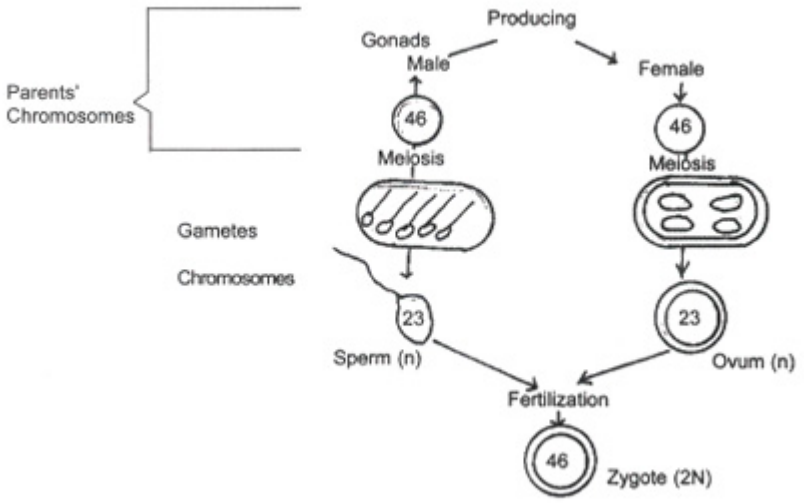


Fig. 10.8 Formation of diploid number of chromosomes during fertilization in humans. Each somatic cell has 46 (23 pairs) of chromosomes (2n) – diploid number. Each gamete has 23 chromosomes (n = haploid number)

Mutations

Hugo de Vries (1848–1935) was the first to report the occurrence of mutation. He was named the father of mutation. He propounded the mutation theory of evolution. See Chapter 9.

Mitosis, meiosis and mutations are the basic processes through which hereditary characteristics are transmitted from parents to offspring. Mutations are sudden and persistent changes which occur in genes and chromosomes of gametes. The changes are pure and inheritable. They bring about variations in organisms, formation of new alleles and hence, new individuals within a species of plants and animals.

Mutations can be induced artificially by exposing the gametes of animals and plants to the following treatments:

1. Radiations: e.g. X-rays, gamma rays and ultraviolet rays.
2. Changes in temperature and light intensity.
3. Some chemicals, e.g. colchicine, oxides of nitrogen, mercury, some substances in tobacco smoke and certain dyes. Mutation is also caused by a loss of a piece of chromosome during cell division, and the relocation of a chromosome onto other chromosomes at crossing over.

Examples of mutation include the following:

1. Mongolism, albinism, sickle cell anaemia, muscular dystrophy and haemophilia in humans.

2. Production of double flowers from single flowers in petunias, roses and daisy.

Mutations have been used extensively by plant breeders to produce high-yielding crops, e.g. large seedless citrus fruits, rice and wheats. The introduction of these varieties in many developed countries is commonly called *Green Revolution.*

Probability in genetics

Probability is also called chance in daily usage. It is a mathematical term which exhibits the degree of belief which we have about something. The probability of an event is its relative frequency of occurring. This is the sum of all the weights attached to the outcomes making up the event.

Without tossing an unbiased coin, one can assign a value of p = 0.5 = $\frac{1}{2}$ = 50% where p = probability. Similarly, the probability that an unbiased die will fall with a given face up is $^1/_6$. It is easy to decide on the probability of success in such cases.

If the probability that an event will succeed is *p,* and the probability that it will fail is *q* then the probability of either success or failure is *p + q.* But if it is certain that the event must either succeed or fail, then *p + q = 1, p = 1-q.* A familiar case of probability in genetics is the determination of the sex of a baby. The probability that an unborn child will be a boy or a girl is 1:1, 50% or $\frac{1}{2}$. That is, it is either a boy or a girl.

Another way of looking at probability is to mix 30 white maize grain and 30 yellow maize grains in a container. If a grain is randomly selected, the probability or chance that a yellow maize grain will be picked out is given by

$$\frac{\text{number of yellow maize grains}}{\text{Number of yellow maize grains + Number of white maize grains}}$$

$$\text{The probability (P)} = \frac{30}{30+30} = \frac{30}{60} = \frac{1}{2} \text{ or } 50\%$$

Principles of probability vital to genetics

Probability is a tool for dealing with random or chance events. There are two significant principles of probability that you need to know before you can understand genetics clearly.

The first, which contradicts a commonly accepted superstition, is as follows:

The result of one trial of a chance event does not affect the results of later trials of the same event.

Let us consider the following example. Assuming you are holding a

normal coin but have not yet made a toss. What is the chance of tossing a head? What is the chance of tossing a tail? In each of the cases the probability is $\frac{1}{2}$ (50%). Now, suppose you made 12 tosses and all of them come up tails. What is the chance that you will toss a tail during the thirteenth toss? Superstition says the probability is more than $\frac{1}{2}$. But this is not the case! The coin is â€œnot awareâ€ of what happened in earlier tosses. It is just as likely to fall a tail on the thirteenth toss as on the first toss.

The second principle of probability is as follows:

The chance that two independent events will occur together (simultaneously) is the product of their chances of occurring separately

To illustrate this principle, suppose you toss three dice at once. What is the chance of each one of them rolling four-face up? The answer is

$$\frac{1}{6} \times \frac{1}{6} \times \frac{1}{6} = \frac{1}{216}$$

the product of their independent chances.

Numerical examples

1. Suppose on a farm, one fruit in every four is ripe and two fruits in every five are sweet. What is the chance that the fruit you pluck will be ripe and sweet? The answer is

$$\frac{1}{4} \times \frac{2}{5} = \frac{2}{20} = \left(\frac{1}{10}\right)$$

The answer is obtained by finding the product of their independent chances (2nd principle of probability).

2. Supposing a parent has a genotype of Tt and is mated to another parent with a genotype tt. What will be the probability of the genotypes of their offspring?

Solution

Multiply the gametes produced by one parent with those produced by the other thus:

Gametes from Tt parent = $\frac{1}{2}T + \frac{1}{2}t$

Gametes from tt parent = $\frac{1}{1}t$

Offspring $\frac{1}{1}t(\frac{1}{2}T + \frac{1}{2}t) = \frac{1}{2}Tt + \frac{1}{2}tt$

3. Supposing a parent has a genotype of RR and another has a genotype of Rr. What kinds of gamete will each produce, and in what proportion?

Solution

Probable gamete from RR parent

$\frac{1}{2}$R + $\frac{1}{2}$R (all R)

Probable gamete from Rr parent

$\frac{1}{2}$R + $\frac{1}{2}$r

4. Explain why the probability of each of the following events is correct.
   (a) The probability that a brown bean seed will be picked when 25 black bean seeds are mixed together with 50 brown bean seeds is $\frac{2}{3}$.
   (b) The chance of a *W* gamete from a *WW* parent is $\frac{1}{1}$.
   (c) The probability of a *b* gamete from a *BB* parent is $\frac{0}{1}$.
   (d) The probability of an *A* gamete from an *Aa* parent is $\frac{1}{2}$.
   (e) The probability of an *a* gamete from an *Aa* parent is $\frac{1}{2}$.

Sex determination in humans

A human somatic cell contains 23 pairs of chromosomes. Out of this number, a male and a female has a different pair of chromosomes called sex chromosomes i.e, XY and XX chromosomes respectively. The gene of the X and Y chromosomes respectively, determines whether a zygote will become a boy or a girl. Y chromosome determines maleness in children.

It is during fertilization that an individualâ€™s sex is determined (see Fig. 10.9). Half of a mature maleâ€™s sperms have an X chromosome in the nucleus and the other half, a Y chromosome. All the ova of a mature female have one X chromosome each. This is because each gamete has only half the number of chromosomes in each somatic cell (Fig. 10.9)

During fertilization, there is an equal chance that an ovum will be fertilized by a sperm with a Y chromosome to form a male zygote (XY) or by an X chromosome to form a female zygote (XX) (Fig. 10.9). Therefore, it is the mature male that naturally determines a babyâ€™s sex by chance. For this reason, a mother, who consistently has female children, one after the other, is not to blame genetically for this condition as most fathers of such children tend to believe.

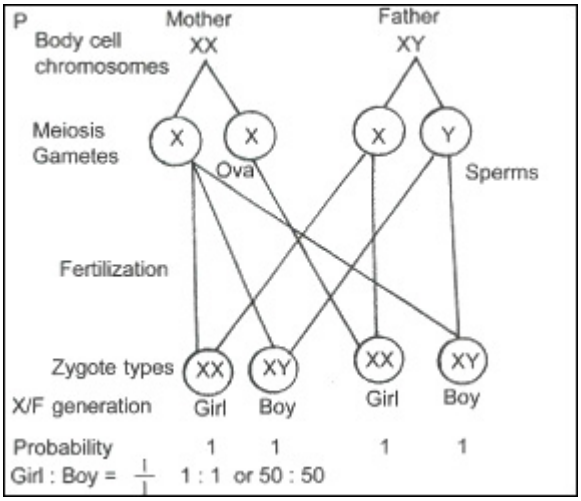


Fig. 10.9 Sex determination (probability) in humans

Moreover, the sex of a baby has nothing to do with how strong or weak the sperm cells are, or whether the blood of the father is stronger or weaker than that of the mother, or vice versa.

The probability of inheritance of sickle-cell anaemia by children of two parents who carry the trait of the disease is in the ratio 1 (normal): 2 (carriers of the trait): 1 (sickler). The probability of the inheritance of colour blindness and haemophilia, also follows this pattern.

Application of the principles of heredity

The knowledge of the principles of heredity (genetics) is used in animal and plant husbandry to selectively crossbreed and produce desirable varieties, the offspring of which have the following qualities:

1. High quality yield. These being more cash and food crops per hectare, more chicks which can be raised to produce more eggs than the local ones, more beef and milk per cow.
2. High adaptation to unfavourable climatic and environmental conditions, insects or pests.
3. High resistance to diseases.
4. Rapid rate of maturity.
5. Breeding of unusual and new varieties of plants and animals.

Genetics has been applied in the production of more beautiful flowers, shorter fruit trees e.g. coconut, oil palm, cocoa, mango and oranges. Also, it is used in the improvement of the flavour of fruits. For example, sweet, fleshy and more juicy fruits have been produced. Experts at the *International Institute for Tropical Agriculture* (IITA), Ibadan and many universities and research institutes are continuously producing new and better crop varieties. We now have cassava plants which mature between 9 to 12 months instead of 18 to 24 months in the older varieties. Yam, maize, tomato and citrus fruits are other examples. The use of *miniset* yam production technique at IITA Ibadan

has led to the production of very big yam tubers which are also resistant to diseases. There are both white and yellow varieties of maize. Beans of different varieties have also been produced, as a result of crossbreeding among desirable varieties. Similarly, we have Sokoto and brown varieties of beans.

Animal husbandry

A poultry or cattle farmer, with previous experience may select a mutant with desirable features from his flock. He will crossbreed it with another good variety in his collection. This way, the superior features of the pair is passed down to the next generation. Examples of animal that have been so crossbred to improve their quality and performance include, goats, fowls (poultry), pigs, rabbits and cattle.

1. Crossbreeding a local cattle (Ndama breed) which is resistant to trypanosomiasis and tropical climate, with a foreign one (e.g. German brown) which is a heavier variety at all ages, leads to the improvement of the weights of the offspring. See Table 10.4. The weights of offspring are better than that of the Ndama and the average weights of Ndama and German brown.
2. Friesian cow from the Netherlands is not resistant to trypanosomiasis. It was crossbred with the local breeds. This led to offsprings with improved milk-producing capacity and resistance to trypanosomiasis.

Table 10.4 Crossbreeding experiments in cattle

Type of cattle	**Weight at birth (kg)**	**Weight at 6 months (kg)**	**Weight at 18 months (kg)**
Ndama	17	86	183
German brown	32	126	250
Average	24.5	106	216.5
Offspring	22	115	233
Difference	–	+9	+17.5

Source: Dettmers et al, Heterosis in animal production, *Nigerian Journal of Animal Production*

3. Hornless cattle, which are therefore safer to manage and less dangerous, are now being produced from crossbreeding a dominant hornless cattle with long-horned, recessive ones.
5. Crossbreeding of certain varieties of the local fowls with White Rock (a foreign variety) has led to improved flesh and weight as shown in Table 10.5.

Table 10.5 Crossbreeding experiment in chicks

Type of fowl	**Weight at 12 weeks (g)**

Type of fowl	Weight at 12 weeks (g)
Local fowl	345
White rock (foreign)	466
Average	405
Offspring	477
Difference	+72

Source: Oluyemi, *Evaluation and improvement of the indigenous fowl of Nigeria,* Ph.D. Thesis, University of Ibadan

Application of genetics in medicine

The knowledge of genetics is used in medicine in the following ways:

1. Determination of compatibility of blood groups, prior to blood transfusion to prevent agglutination and death of the recipient.
2. Determination of the paternity of a child whose father is being legally disputed.
3. Genetic counselling: By analysing the blood of prospective couples, it is possible to detect those who have genes of certain hereditary diseases and advise them on the chances of their children having such diseases as haemophilia and sickle-cell anaemia.
4. Crime detection (a) By analysing the blood stains obtained at the scenes of certain crimes, it is possible to identify the real criminals. (b) By using the fingerprints of suspected persons, it is possible to establish the real criminals.
5. Determination of the sex of a baby soon after fertilization (conception), even before it is born, using certain techniques.
6. Choosing the particular sex of the baby a couple wants through sperm separation techniques in special clinics.
7. Production of children conceived outside their motherâ€™s wombs (test-tube babies). Since about two decades ago, it has been possible for some barren women to have children. The ovum of a fertile woman (the donor) is fertilized in a special man-made equipment (called test tube) with the sperm of the barren womanâ€™s husband. The zygote is then implanted into the womb of the barren woman where it will develop normally and it is then born like any normal baby.
8. Use of someoneâ€™s ancestral line (pedigree) in accumulating information about several hereditary human features such as the colour of the eye, skin and hair as well as the inheritance of blood groups.
9. Recognition of some sex-linked human features. These include, haemophilia (bleederâ€™s disease), baldness in males and sickle-cell anaemia in both males and females.
10. Study of the Rhesus factor in man (Rh) Rhesus factor (positive or

negative) is an inherited dominant human feature. There is no problem if both parents are either rhesus (R) positive or (-) negative, or when mother is rhesus positive and father is rhesus negative. Only 15% of humans are said to be rhesus negative. However, if mother is Rh^- and father Rh^+, a Rh^+ child may be produced. The motherâ€™s blood may react against this. Antibodies of the mother may attack the Rh^+ antigens of the foetus and haemolyse the foetal erythrocytes. This may weaken or cause the death at birth of the baby. Such a child may be saved by giving him total blood transfusion as soon as it is born.

Sickle-cell anaemia

It is a fatal hereditary disease. Certain children are born with badly formed sickle shaped erythrocytes in whose gene, the abnormal haemoglobin, S is recessive to the normal biconcave, disc-shaped ones. Sickle-cell anaemia causes terrible pains at the body joints. The victim is usually weak and susceptible to infections. The sickled cell is not efficient in carrying enough oxygen, and it is often quickly destroyed. In many cases, the victims die young.

Only homozygous recessives (ss) suffer from sickle-cell anaemia. Carriers of sickle cell (Ss) may not know or manifest the signs of the disease unless they undergo a medical check-up on it. However, if two carriers of sickle cell marry, there is the probability that 25% of their children may be sicklers. That means, they may manifest signs and symptoms of the disease. The probability is shown in Fig. 10.10.

Carriers of sickle cell gene tend to be more resistant to malaria fever. Hence, the large number (about 40%) of such people in the tropics e.g. West Africa.

A medical doctor may arrange for genetic counselling for young couples who intend to go into marriage. The counsellor will make it clear to them the implication of two carriers of certain hereditary diseases going into marriage. One of such implications is that some of their children may inherit such hereditary diseases.

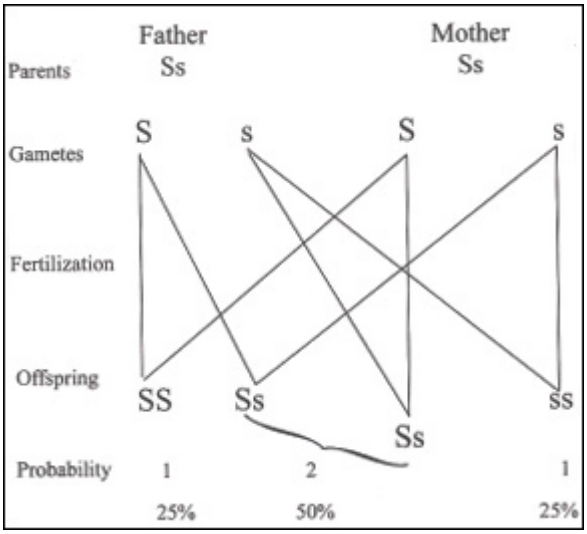


Fig. 10.10 Probability of inheritance of sickle-cell anaemia.

Ss = Carrier of trait but healthy
SS = Normal gene for haemoglobin
ss = Sickler i.e. patient of sickle cell.

Suggested Practicals

1. Crossbreeding of maize

(a) Obtain some grains of improved variety of yellow maize and those of local white maize.

(b) Cross the pollen grains of the white with the yellow, or vice versa.

(c) Plant the seeds obtained from this cross.

(d) Note the type of cobs produced.

(e) Let this new generation of maize plant fertilize itself.

(f) Collect the cobs and seeds from the self-fertilized maize.

(g) Plant them and note the results.

(h) Tabulate your observations as follows

Colour of cob	*No. of groups per cob*
White	
Yellow	

(i) Find the ratio of yellow to white.

2. Observation of mitosis

You will be provided with the following specimen:
Permanently prepared slides of root tips of onion showing mitosis.

(a) Observe the various stages of cell division in the slide.

(b) Note the start – when the chromosomes are stainable. What do they look like?

(c) Note how they are arranged along the middle of the cell.

(d) Note how they separate.

(e) Note how the chromosomes are reformed.

(f) How many new cells are produced?

(g) What is the significance of this process?

(h) Draw and describe your observations.

3. Observation of meiosis

You will be provided with slides of the testis of a locust or grasshopper.

(a) Draw the shapes of the stained structures. What are they?

(b) Note how the chromatids separate from each other. Describe what you see.

(c) Mention two other structures where the behaviour of chromosomes shown can be studied.

Summary

1. Genetics is the scientific study of heredity and variation.
2. Variations occur as a result of environmental factors but these are not inheritable. Hereditary variations are differences among individuals which can be passed down from parents to offspring e.g. shape of nose or lips or facial appearance, tasting, smelling, tongue rolling and colour of skin or eye.
3. Gregor Mendel is regarded as the father of genetics. He worked with the garden pea. He took a pair of distinctly contrasting characters at a time e.g. height of the stem (tall and short). colour of flower (red and white).
4. He gave the world the experimental method of studying the transmission of hereditary materials.
5. He also proposed two laws (Mendelian laws) of inheritance. The first law – the law of segregation – was coined from Mendelâ€™s monohybrid crosses. The second law – the law of independent assortment of genes, was coined from his dihybrid crosses.
6. Characters which are expressed at F_1 are said to be dominant over those that are suppressed or hidden. These are called recessives, they appear at F_2 onwards.
7. Chromosomes are carriers of genes. They are located in the nucleus. Each chromosome consists of two threads called chromatids. Homologous (identical) chromosomes naturally occur in pairs.
8. Each organism has a specific number of chromosomes per cell. For instance, humans, maize and *Drosophila* have 23, 10 and 4 pairs of chromosomes respectively.
9. The genes (DNA) are responsible for the transmission of hereditary characters from parents to offspring.
10. DNA can replicate itself (i.e. make an exact copy of itself). It consists of a set of genetic codes (coded instructions) which order each organism on how to develop.
11. DNA has the shape of a double helix. It consists of nitrogenous bases, phosphorous, and sugars. The chains are bound together by hydrogen bonds.
12. Cells undergo two types of division – mitosis and meiosis (reduction division).
13. Haploid cells (N) are produced by meiosis during gamete formation.
14. Diploid (2N) cells are produced during fertilization of two gametes.
15. The knowledge gained from the study of heredity is applied in

agriculture and medicine.

16. Agriculturists now use selection which may be of individual or a mass of mutants as a basic procedure in plant and livestock breeding.
17. Breeding is the mating of two selected individuals for certain purposes.
18. Genetic counselling is now available for those intending to go into marriage. This is particularly so because of sex-linked hereditary diseases e.g. sickle-cell anaemia and rhesus factor.

Objective Questions

1. Which of the following statements is **not** true?
   A. Genetics is the study of heredity and variation.
   B. Hereditary variations refer to the influence of environments on each organism.
   C. Blood groups, sickle-cell anaemia, and flower colour, are examples of hereditary variations.
   D. Hereditary variation may be continuous or discontinuous.
   E. Albinism and haemophilia are hereditary diseases.
2. Who of the following, gave us the knowledge that hereditary material is the gene and not blood or any body fluid?
   A. Morgan.
   B. Crick.
   C. Hugo de Vries.
   D. Mendel.
   E. Watson
3. An individual is homozygous for a trait when the genes
   A. controlling his traits are identical.
   B. are inherited from the father only.
   C. are inherited from the mother only.
   D. are inherited from both parents
   E. are associated with autosomes.
4. If a tall woman (TT) is married to a short man (tt) and they have four male children, the offspring will be
   A. three short and one tall.
   B. two short and two tall.
   C. all short
   D. one short and three tall
   E. all tall.
5. Which of the following statements is **false?**
   A. Mendel gave two laws of inheritance

B. Nuclear division in gametes produces four haploid cells.

C. DNA consists of four nitrogenous bases, deoxyribose sugars and phosphoric acid molecules in a double helix shape.

D. Genes have specific locations on chromosomes and they can replicate themselves.

E. DNA is found in reproductive cells of plants and animals only.

Essay Questions

1. Explain briefly the following terms
   (a) dominant characters.
   (b) recessive characters.
   (c) hereditary variations.
   (d) mitosis.
   (e) genotype.
   (f) phenotype
2. (a) Describe simply, the structure of DNA.
   (b) Mention its location and how it replicates.
3. (a) State four physical features in plants which show variation amongst offsprings from the same parents.
   (b) With the aid of a diagram, explain briefly one way in which sickle-cell anaemia is passed from parents to offspring.
   (c) How is the sex of a child determined at fertilization?
   (d) What are the effects of inbreeding in animals?
4. (a) Tabulate four examples each of crops and livestock obtained through crossbreeding. What are the advantages of crossbreeding?
   (b) State ten ways in which the principles of genetics are applied in medicine.