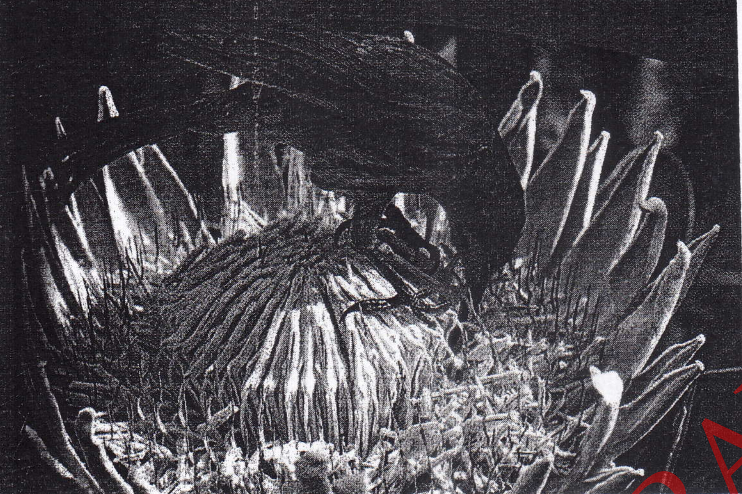
CHAPTER 13

Natural Selection in Action



13.1 CONCEPT OF NATURAL SELECTION

The evolutionary agents discussed in the previous chapter bring in changes in the frequencies of alleles and genotypes in Mendelian populations. The new genotypes that produce more efficient adaptive relationship with the environment, ensure better survival and comparative reproductive success are favoured by natural selection. In genetic terms, natural selection favours individuals that contribute more offspring to the next generation and ensures perpetuation of those genotypes and alleles which change the gene pool for more efficient adaptive relationship with their environment. This results in 'descent with modification'.

Definition

13.1.1 Natural Selection Defined

Natural selection is the force which ensures differential contribution of alleles of a gene to the gene pool of a population in the next generation and maintains polymorphism in the genotypes of individuals generation after generation.

Salient features:-

13.1.2 Essential Features of Natural Selection

Based on the above definition, natural selection has two essential features:

13.1.2.1 Reproductive Success or Differential Reproduction

Differential multiplication of genes and gene combinations means that the individuals which are best adapted to their environment, produce more offspring than those which are less adapted. They contribute proportionately more alleles to the gene pool of subsequent generations. In case differential reproduction continues for several generations in a population, the alleles present in those individuals which produce more offspring increase in frequency over time. The change in the gene frequency and genotype frequency in the gene pool of a population by natural selection can be illustrated by following example:

EXAMPLE 1: When allele *A* makes an organism more efficient in reproduction than its allele ***a***, the frequency of allele *A* gradually increases in the gene pool generation after generation and the frequency of allele ***a*** gradually decreases. Thus, natural selection is a **creative force** and is achieved either by increased rate of reproduction or by the decreased vulnerability to environmental agents responsible for mortality.

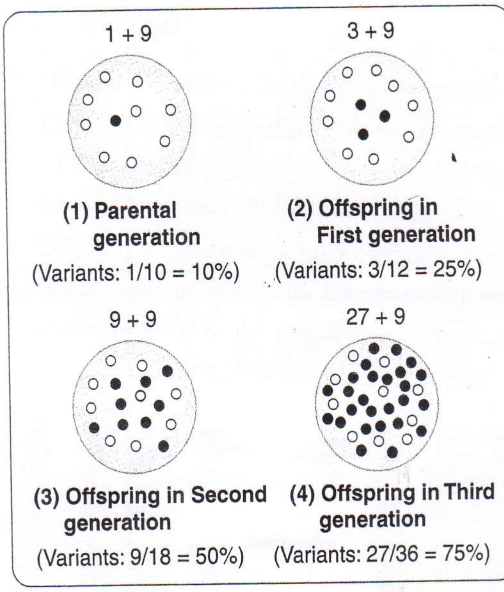


Fig. 13.1 Spread of genetic variability by differential reproduction.

Which Individuals Produce More Offspring

- Individuals which are best adapted to the environment, *i.e.*, which have adaptive or beneficial mutations.
- Individuals in which **positive selection pressure** due to the presence of beneficial mutations is more than the **negative selection pressure** of harmful mutations.
- Individuals which have better chances of sexual selection.
- Organisms who are able to overcome the physical and biological environmental factors.

13.1.2.2 Encouragement to Beneficial Genes

Natural selection encourages conservation and multiplication of those genes and genotypes that assure the highest level of adaptive efficiency to the population in its existing environment. It means when two or more gene combinations are present, selection favours increased reproduction of the gene combination which is most suitable under the existing environmental conditions. Therefore, natural selection brings about improved adaptive relations between organisms and environment. How natural selection favours beneficial genes and gene combinations can be illustrated by following examples:

any 2 examples

Example 1: Evolution of Green-coloured beetles from Red beetles.

In the population of red beetles, a green beetle appears due to colour mutation. The green body colour is heritable and has survival advantage. It is difficult for crows to spot green coloured beetles on green leaves while the red coloured beetles on green leaves are spotted even from a distance. As a result, red coloured beetles are eaten away by crows more often and green beetles escape. Gradually, the number of green beetles increases in the beetle population, and at one time, the entire beetle population has only green beetles. The natural selection has encouraged the increase of alleles for green colour as against red because green beetles could conceal them on green leaves more effectively from their predator crows than the red beetles which crows could locate from a distance.

Fig. 13.2 **A.** Red beetle; **B.** Green beetle (Green-coloured beetle is at an advantage of not being spotted out in the green background).

Example 2: In a population of *Drosophila melanogaster*, all the females (whether white-eyed or red-eyed) prefer to mate with the red eyed males, but if white-eyed males are the only mates available, they are compelled to mate with them. It means white-eyed gene is eliminated from the population as a result of selection, which acts through mating preference. In addition, selection produces an adaptive improvement, since red-eyed males have better environmental relation. Natural selection is, therefore, a creative force in evolution as it favours efficient gene combinations.

Example 3: Changes in Beak Size, Beak Shape, and Body Size in Galapagos Finches.

Peter and Rosemary Grant studied changes in the beak size, beak shape, and body size in the populations of Darwin's finches on the Daphine Major Island of Galapagos Islands from 1973 onward. There was drought on the island in 1977. Grant's team compared the population of finches before and after the drought and found that:

- Birds that survived the drought had deeper beaks than the birds that died, because during this draught period finches could get only tough shelled seeds which could be cracked by large and deep beaks.
- In 1983, when environment changed and small, soft seeds were available in plenty, small finches with small, pointed beaks became more numerous.

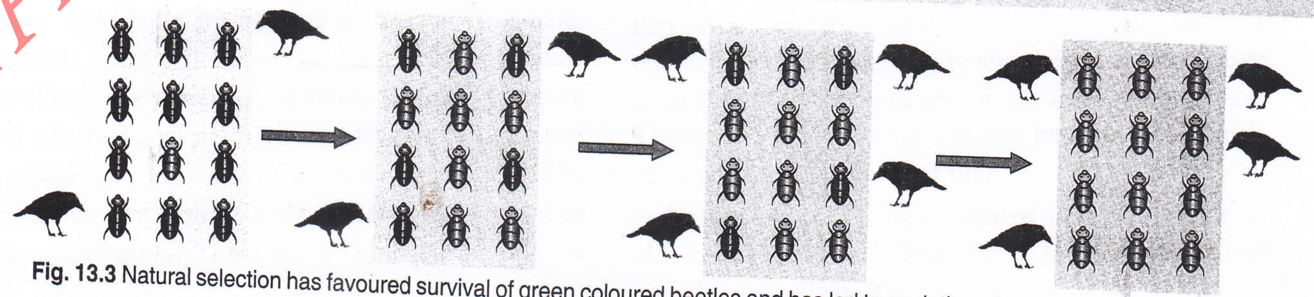


Fig. 13.3 Natural selection has favoured survival of green coloured beetles and has led to evolution of green body colour in beetles.

At molecular level, the recent work of Abzhanov *et.al* on the development of beak size and shape in finches at Galapagos Islands showed that variation in beak size is controlled by the degree of expression of a single gene, *Bomp-4*. The expression of this gene is influenced by the type of food available.

13.2 SALIENT FEATURES OF NATURAL SELECTION

Some of the special features of natural selection are:

1. Natural selection acts on individuals but the evolutionary changes occur due to changes in the allele frequencies in populations. For example, in *Microbacterium tuberculosis* the individual bacterial cells did not change during the evolution of antibiotic resistant strain, when rifampin was introduced to their environment. They had the same rifampin - resistant polymerase allele. But the frequency of this antibiotic resistant allele increased in the bacterial population over generations and changed the characteristic of the population. In other words, an individual's allele frequencies cannot change over time but allele frequencies in the gene pool of a population change generation after generation with the change in environment due to selection pressure of the environment.

2. Evolution by natural selection is not goal directed. It means natural selection is non-progressive. Adaptive modifications do not occur because organisms need them. Rather they are already present in the organisms and are retained because they increase survival and fecundity for reproduction. For example, there was an increase in the size of beak of ground finches on Daphne Major Island of Galapagos during drought period because they could survive by feeding on hard shelled seeds. But the average beak size in finch population declined when the island got torrential rains, because the availability of food supported the survival of finches of average beak size. It means natural selection simply favours individuals that happen to be better adapted. It is neither progressive nor goal directed.

3. Not all traits in the organisms are adaptive. Although, organisms are adapted to their environment, adaptation is never perfect because the traits an individual or individuals of a population have, increase survival. Natural selection does not lead to perfection. Nonadaptive traits appear due to changes in DNA sequences caused by the redundancy of genetic code. These are described as **genetic constraints.** There are several reasons for the genetic constraints:

- Because of **pleiotropy** (*i.e.*, a single gene sometimes influences more than one characters) selection on alleles of one trait causes a correlated selection or increase of the alleles of other trait. This trait may or may not have survival value but persists in the population. This is called **genetic correlation.**
- Lack of certain genetic traits or absence of genetic variations also makes adaptations imperfect. For example, birds can sense magnetic field and see UV light but man can not. Though these traits will be beneficial for human beings but the requisite genes for these traits are not present.

Hence, a variety of unuseful or harmful traits persist in populations.

Example : Carry 2)

13.3 NATURAL SELECTION IN NATURE

13.3.1 Industrial Melanism

The industrial melanism in peppered moth, *Biston betularia*, provides the best example of directional selection. In early nineteenth century, there was a dramatic rise of industrialisation in Europe. The black sooty smoke covered the forests and fields. This changed the usual colour of tree trunks from mottled greenish-grey to black.

The wing colour of typical peppered moth was mottled grey that blended perfectly with lichen-covered tree trunks and protected it from the enemies. Until 1845, only light-coloured moths were known in England. In 1845, the first dark-coloured peppered moth (melanic form) was seen in the region east of Manchester. This variant was named *Biston betularia carbonaria.* During next 50 years, dark individuals gradually increased from less than 1 to about 99% in the vicinity of industrial areas. The reason for this striking increase in the number of melanic variety was explained by E.B. Ford and H.B.D. Kettlewell. Ford found that the caterpillars of melanic variety (Carbonaria) were more vigorous and viable, capable to withstand the environmental hardships. But Kettlewell showed that moths of melanic variety were at a disadvantageous position and could not survive in the non-sooty forests, because the birds could locate them on lichens and could eat them. So they were maintained at a very low frequency. With the elimination of lichens in sooty atmosphere, the carbonaria were cryptically coloured and blended with the tree trunk. Therefore, the melanic variety became abundantly distributed in due course of time.

Natural selection has operated in the direction of eliminating gene for light-colour and gradual increase of gene for dark pigment.

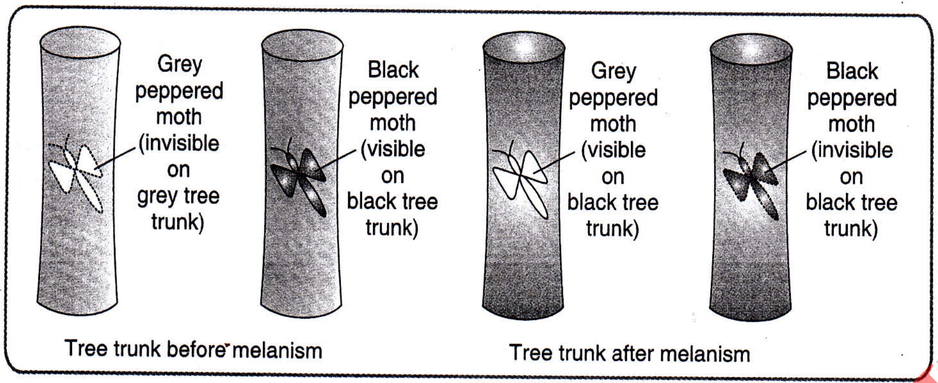


Fig. 13.4 Role of natural selection in the directional evolution of melanic variety of peppered moth (*Biston betularia*) due to industrial melanism.

13.3.2 Resistance to Pesticides (DDT) in Insects

When DDT was introduced to control mosquitoes, it proved to be a successful insecticide. But, now it has become ineffective against mosquitoes. It can be explained as below:

The original population of mosquitoes had some DDT-resistant individuals. In the absence of DDT, such DDT-resistant individuals had no additional adaptability or survival value over DDT sensitive mosquitoes. Natural selection favoured them only when DDT was sprayed on a large scale. Therefore, DDT-resistant genotype became more and more numerous. Over a period of time, the entire population became DDT-resistant type. Likewise, new insecticides were developed, but they remained effective for some time and insects developed resistance to them also.

13.3.3 Antibiotic Resistance in Bacteria

Penicilin was the first antibiotic discovered. It was widely used against bacterial infection. Soon it was found to be ineffective against many bacteria. It was replaced by **chloromycetin** (chloroamphenicol) and then by a third antibiotic **ciproflaxacin.** Reduction in effectiveness of an antibiotic is due to the development of resistance in bacteria against that antibiotic. The antibiotic resistance in bacteria arose due to gene mutation. Such antibiotic-resistant bacteria survive and multiply to produce resistant strain.

13.3.4 Antibiotic Resistance in *Mycobacterium tuberculosis*

In 1980s, bacteria causing tuberculosis (*Mycobacterium tuberculosis*) was treated with antibiotic **rifampin.** But in 1993, a new strain of *M. tuberculosis* was found, that was resistant to rifampin and other antibiotics and TB became a global threat. Scientists found that the genome of resistant strain of *M. tuberculosis* developed a point mutation in gene **rpoB**, where a cytosine was replaced by thymine and the normal codon TCG mutated to TTG. The polymerase produced by mutated gene had leucine instead of serine at 153^{rd} amino acid in the polypeptide chain. The drug rifampin was unable to bind to mutant RNA polymerase and *M. tuberculosis* became resistant to the drug.

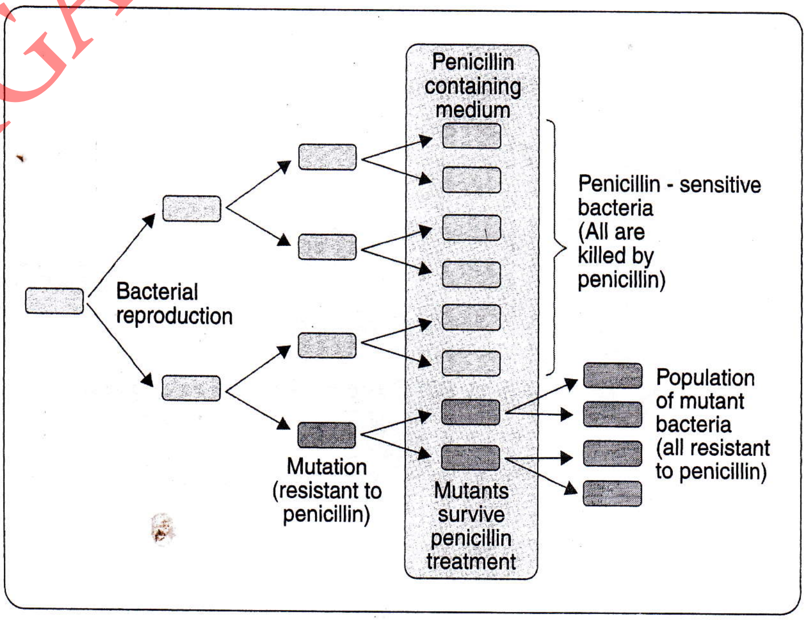


Fig. 13.5 Selection of penicillin-resistant bacteria by natural selection.

Such antibiotic-resistant bacteria survived and multiplied to produce more and more bacteria of resistant strain. The normal bacteria non-resistant to antibiotics died off.

Resistance to a wide variety of insecticides, fungicides, antibiotics, antiviral drugs and herbicides has evolved in some insects, fungi, bacteria, viruses and plants, and such resistant varieties have been favoured by natural selection.

13.3.5 Evolution of Drug Resistant Bacteria

Evolution of **methicillin-resistant** *Staphylococcus aureus* (MRSA) is another an example of natural selection. In 1945, more than 20% of *Staphylococcus aureus* bacteria were found to be penicillin-resistant in American hospitals, because they were producing enzyme *penicillinase* to destroy penicillin. When more powerful antibiotic methicillin was used against them, within two years methicillin-resistant strain of *S. aureus* appeared. These bacteria were able to synthesise a cell wall around them that was not affected by methicillin. They survived methicillin treatment and became increasingly more numerous spreading MRSA more rapidly.

Initially, MRSA bacteria could be controlled by antibiotics other than methicillin. Later on, some MRSA strains became resistant to multiple antibiotics because of gene exchange with members of their own and other species. The present day multi-drug resistant strains of *Staphylococcus aureus* are presumed to have evolved as MRSA strains and became resistant to different antibiotics by exchanging genes with other similar bacterial populations.

13.3.6 Sickle Cell Anaemia

Sickle cell anaemia is a genetic disorder of human beings, found specially in Blacks from Tropical Africa. In a sickle cell anaemic person, normal haemoglobin (Hb^A) is replaced by Hb^S whose oxygen-carrying capacity is less than Hb^A. The RBCs in sickle cell anaemic persons become sickle-shaped in venous blood owing to the lower concentration of oxygen. This causes rupture of RBCs and severe haemolytic anaemia. Individuals homozygous for abnormal haemoglobin (Hb^SHb^S) die at an early age. In heterozygotes (Hb^AHb^S), the RBCs containing HB^S allele become sickle-shaped and unable to bind oxygen, but RBCs with Hb^A allele remain normal. These heterozygotes (Hb^A/Hb^S) and homozygotes (Hb^A/Hb^A) have normal life expectancy.

The question arises that why has this character not been eliminated from human population by natural selection? The geographical distribution of sickle cell anaemia provides answer to the above question. It is found in tropical Africa where malaria is widespread. Malarial parasites that live in RBCs are unable to grow in sickle-shaped RBCs. It means individuals heterozygous for sickle-celled gene are able to cope with malarial infection whereas the normal persons with normal RBCs suffer from severe malarial infection in malaria infested areas. This shows that natural selection favours the sickle-celled character in malaria-infested areas and the gene controlling it is fixed in such populations by natural selection, because of its survival value in malaria-infested regions. Therefore, this character is found in blacks living in malaria infested belt of the world **(Fig. 13.6)**.

13.3.7 Malaria in Relation to G-6PD Deficiency

G-6PD deficiency is a X-linked hereditary disease in humans. It represents the deficiency of an enzyme *glucose-6 phosphate dehydrogenase.* This enzyme is essential for the regeneration of NADP (nicotinamide adenine dinucleotide phosphate) from its reduced form NADPH, formed due to electron transfer during glucose metabolism.

Persons suffering from G-6PD deficiency suffer from haemolytic anaemia and prolonged neonatal jaundice. Due

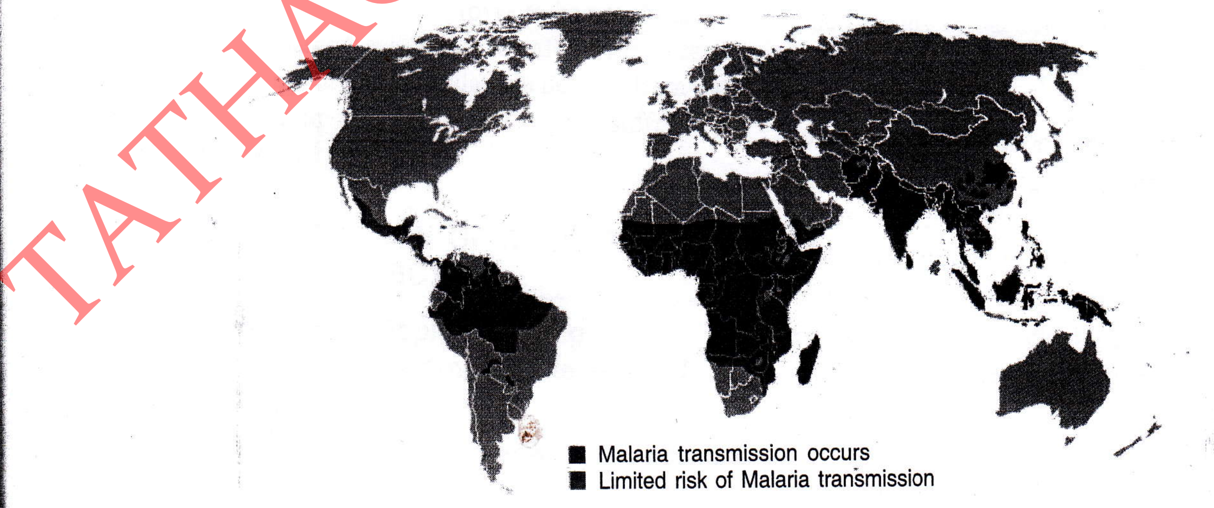


Fig. 13.6 Malaria infested belt of the world.

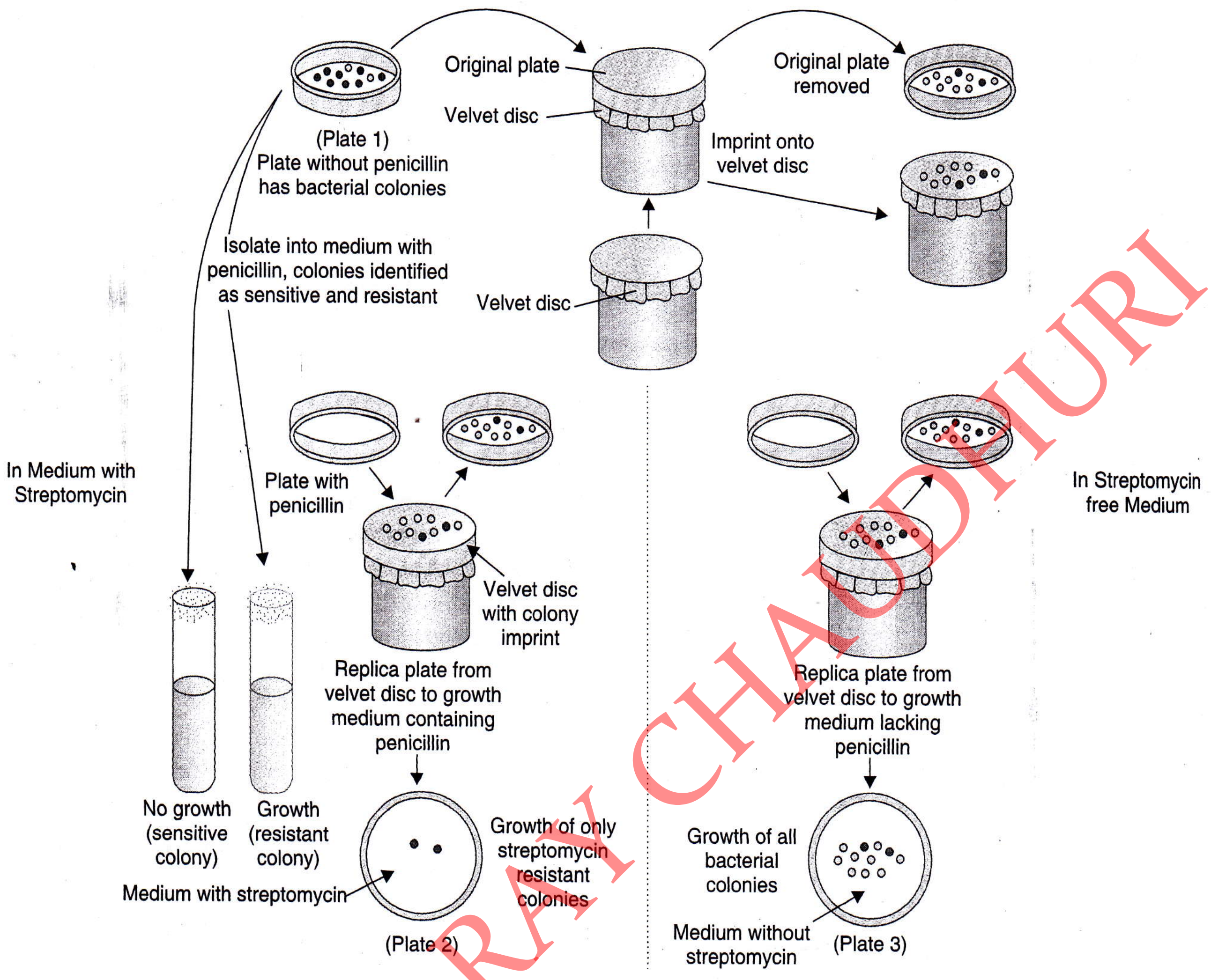


Fig. 13.7 Lederberg's replica plating experiment revealing that drug resistant mutation in bacterial cells is not induced by the drug but was present prior to exposure of bacteria to drug.

to haemolysis of RBCs, malarial parasites are unable to survive and multiply in the RBCs. Therefore, the decreased activity of G-6PD within the RBCs provides resistance against malarial fever. In malaria infested regions like sub-sahara region, this feature proves to be beneficial and is favoured by natural selection. Therefore, fifty percent population of Negroes and populations derived from their ancestors living in malaria infested areas suffer from G-6PD deficiency.

13.4 DEMONSTRATION OF ROLE OF NATURAL SELECTION

13.4.1 Lederberg's Replica-Plating Experiment to Demonstrate Role of Natural Selection

Joshua Lederberg and Esther Lederberg conducted experiments to demonstrate genetic basis of drug-resistant mutations in the bacteria, *Escherichia coli.*

Colonies of bacteria were grown on streptomycin-free agar medium in a petridish by inoculating suspension of bacteria on an agar plate. This formed the 'master plate' of bacterial culture. It contained several bacterial colonies. Each colony of bacteria represented a clone.

Replicas of master plate were prepared on new plates in the following manner. The agar surface of master plate was pressed gently on a piece of a sterile velvet. Some bacterial cells from each bacterial colony clung to the fine fibres of velvet. These were then transferred to new agar plates, where these grew into new colonies.

Lederberg tried to culture bacteria on agar plates containing streptomycin or penicillin. Most colonies of the master plate failed to grow in the medium containing antibiotic. The few colonies that could be formed were resistant to antibiotic. Fig. 13.7 shows that only two colonies were drug-resistant. These two antibiotic resistant colonies appeared at the same position in all replica plates.

The above experiment indicates that some bacterial cells had acquired penicillin resistant mutation even before they were exposed to penicillin. Natural selection has selected and supported the progeny carrying the beneficial mutation.

13.5 WORKING OF NATURAL SELECTION

The working of natural selection is exceedingly complex because it acts at all the levels of organisation and upon all stages of life cycle of an organism. Examples of levels at which natural selection makes differential discrimination are: Intermolecular, intergene, interchromosome, intergamete, inter-individual, interdemic, inter-racial, interspecific and inter-community. It may be caused by differential viability, differential mortality, differential fertility, or differential natality. Selection creates new adaptive relations between population and environment by favouring some combinations and constantly moulding and modifying the gene pool.

Working of natural selection can be discussed under following heads:

13.5.1 Selection for Single Gene Traits

The natural selection operates for traits determined by a single gene pair. The selection may be against or for a dominant or a recessive allele. For understanding this selection, we need to know following terms:

1. The **survival rate** of each genotype is defined as the fraction of that genotype that contributes to the next generation. It is represented by λ.

2. The **relative fitness (W)** of each genotype is its survival rate expressed as a fraction of maximal survival rate. The relative fitness of optimal genotype is considered equivalent to 1.00 and relative fitness of genotypes are calculated as fraction or percentage of optimal genotype.

3. The **selection coefficient (S)** of each genotype is defined as 1 minus its relative fitness (i.e I-W).

Selection for single gene traits may operate against dominant or recessive alleles or against homozygotes or heterozygotes.

(a) **Selection against Dominant Alleles (*i.e.*, Selection for recessive alleles):** Selection against dominant genotypes leads to the elimination of dominant alleles and complete fixation of the recessive ones. Selection against dominants operates rapidly. In case of dominant lethal traits, the dominant lethal alleles are eliminated in a single generation of organisms because with lethal trait either homozygous or heterozygous fail to survive.

(b) **Selection against Recessive Allele (*i.e.*, Selection for dominant alleles):** Selection against recessive traits and recessive alleles proceeds very slowly. It leads to total elimination of homozygous recessive genotypes but recessive gene is retained in heterozygous organisms. The recessive gene is never lost completely because when recessive trait becomes rare, selection becomes weak. The only way these can be lost is through genetic drift.

(c) **Selection against Homozygotes (*i.e.*, Selection for heterozygotes):** The selective superiority of heterozygotes leads to equilibrium in which both alleles in the population are fixed.

(d) **Selection against Heterozygotes (*i.e.*, Selection for both homozygotes):** In this situation both the alleles are favoured by selection. The natural selection may eliminate either of the allele or one of the allele may get eliminated by genetic drift.

13.5.2 Selection for Multigene Traits

In case of multigenes, selection operates against each pair. The genes which do not contribute to any phenotypic expression are not selected.

13.6 COMPONENTS OF NATURAL SELECTION OR LEVELS OF NATURAL SELECTION

Evolution by natural selection depends on changes in allele frequencies determined by the components of fitness of genotypes. In sexually reproducing populations, selection

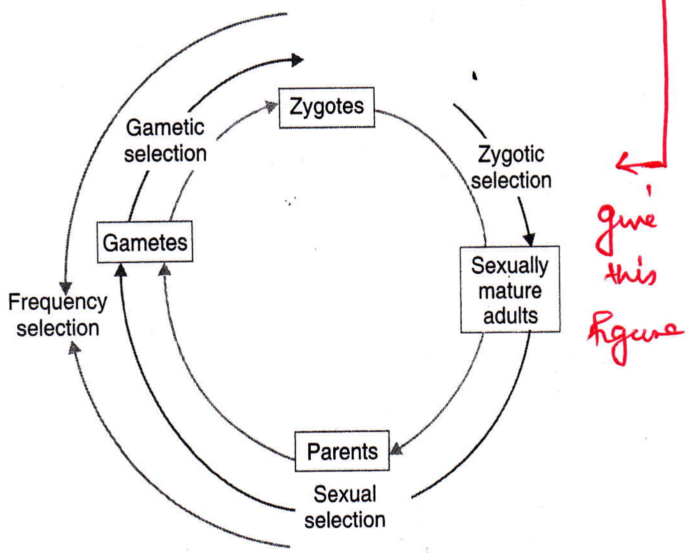


Fig. 13.8 Different stages in the life cycle of organisms at which selection operates.