NINTH EDITION

PART 2

Life Sciences

Fundamentals and Practice

PRANAV KUMAR USHA MINA

Life Sciences

Fundamentals and Practice

Part-2

Ninth edition

PRANAV KUMAR
Former faculty,
Department of Biotechnology,
Jamia Millia Islamia (JMI),
New Delhi, India

USHA MINA
Professor,
School of Environmental Sciences,
Jawaharlal Nehru University (JNU),
New Delhi, India

Pathfinder Publication
New Delhi, India

Pranav Kumar
Former faculty,
Department of Biotechnology,
Jamia Millia Islamia (JMI),
New Delhi, India

Usha Mina
Professor,
School of Environmental Sciences,
Jawaharlal Nehru University (JNU),
New Delhi, India

Life Sciences: Fundamentals and Practice

Ninth edition

ISBN: 978-81-956333-8-8 (paperback)

Publisher : Pathfinder Publication
Illustration and layout : Pradeep Verma
Cover design : Pradeep Verma
Marketing director : Arun Kumar
Production coordinator : Murari Kumar Singh

Pathfinder Publication
A unit of Pathfinder Academy Private Limited, New Delhi, India.
pathfinderpublication.in

Contents

Chapter 1

Genetics

Chapter 2

Recombinant DNA Technology

Chapter 3

Plant Physiology and Development

Chapter 4

Human Physiology

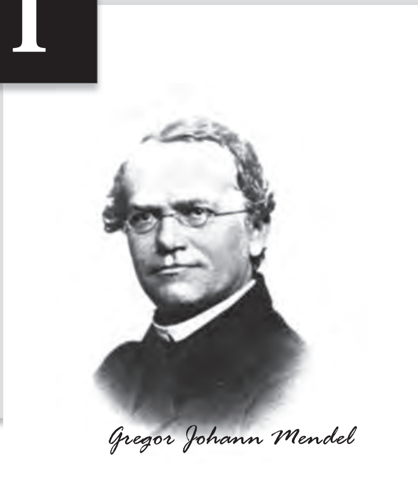
Chapter 5

Animal Development

Chapter 6

Evolution

1



Genetics

Learning objective

- **1.1** Mendel's principles
- **1.2** Chromosomal basis of inheritance
- **1.3** Gene interaction
- **1.4** Linkage and gene mapping
- **1.5** Tetrad analysis
- **1.6** Sex determination
- **1.7** Pedigree analysis
- **1.8** Quantitative inheritance
- **1.9** Extranuclear inheritance
- **1.10** Cytogenetics
- **1.11** Genome
- **1.12** Eukaryotic chromatin
- **1.13** DNA replication
- **1.14** Recombination
- **1.15** DNA repair
- **1.16** Transcription
- **1.17** RNA processing
- **1.18** mRNA degradation
- **1.19** Regulation of bacterial genes
- **1.20** Genetic switch in phage lambda
- **1.21** Regulation of eukaryotic genes
- **1.22** RNA interference
- **1.23** Epigenetics
- **1.24** Genetic code
- **1.25** Protein synthesis
- **1.26** Mutation

All living organisms reproduce. Reproduction results in the formation of offspring of the same kind. However, the resulting offsprings need not and, most often, do not completely resemble the parents. Several characteristics may differ between individuals belonging to the same species. These differences are termed **variations**. The mechanism of transmission of characters, resemblances, and differences from the parental generation to the offspring is called **heredity**. The scientific study of heredity and variations is known as **genetics** (from the Greek word genno = give birth). The word 'genetics' was first suggested by prominent British scientist William Bateson. Genetics can be divided into three areas: *classical genetics, molecular genetics*, and *evolutionary genetics*. **Classical genetics** is concerned with the basic principles of heredity and how traits are passed from one generation to the next. It also addresses the relationship between chromosomes and heredity and the arrangement of genes on chromosomes. **Molecular genetics** covers the chemical nature of the gene and how genetic information is replicated and expressed, i.e., cellular processes of replication, transcription, and translation. **Evolutionary genetics** is the study of how genetic variation leads to evolutionary change. It is concerned with the evolution of genome structure, the genetic basis of speciation and adaptation, and genetic change in response to evolutionary processes such as natural selection, genetic drift, mutation, and gene flow in populations.

Classical genetics

1.1 Mendel's principles

Gregor Johann Mendel (1822–1884), known as the *father of genetics*, was an Austrian monk. He conducted a series of experiments using pea plants and showed that traits are passed from parents to offspring in predictable ways. By quantitative data analysis of results, he concluded that each trait in the pea plant is controlled by a pair of factors

2

Recombinant DNA technology

Learning objective

Recombinant DNA technology (also known as **genetic engineering**) is the set of techniques that enable the DNA from different sources to be identified, isolated and recombined so that new characteristics can be introduced into an organism. The invention of recombinant DNA technology—the way in which genetic material from one organism is artificially integrated into the genome of another organism and then replicated and expressed by that other organism—was largely the work of Paul Berg, Herbert W. Boyer and Stanley N. Cohen, although many other scientists also made important contributions to the new technology as well. Paul Berg developed the first recombinant DNA molecules that combined DNA from the SV40 virus and lambda phage. Later in 1973, Herbert Boyer and Stanley Cohen develop recombinant DNA technology, showing that genetically engineered DNA molecules may be developed and cloned in foreign cells. One important aspect of recombinant DNA technology is **DNA cloning**. It is a set of techniques that are used to design recombinant DNA molecules and to direct their replication within host organisms. The use of the word 'cloning' refers to the method used to generate identical DNA molecules.

2.1 DNA cloning

DNA cloning is the production of a large number of identical DNA molecules from a single ancestral DNA molecule. The essential characteristic of DNA cloning is that the desired DNA fragments must be *selectively amplified,* resulting in a large increase in copy number of selected DNA sequences. In practice, this involves multiple rounds of DNA replication catalyzed by a DNA polymerase acting on one or more types of the template DNA molecule. Essentially two different DNA cloning approaches are used: *Cell-based* and *cell-free DNA cloning*.

3

Plant Physiology and Development

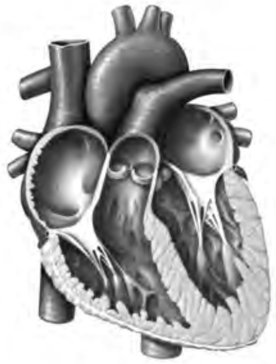
Learning objective

Plants are multicellular, photoautotrophic eukaryotic organisms. It includes algae, bryophytes, pteridophytes, gymnosperms, and angiosperms. Bryophytes, pteridophytes, gymnosperms, and angiosperms are usually referred to as **land plants**. Angiosperms (also called **flowering plants**) are a major group of land plants. These plants are by far the most numerous, diverse, and successful terrestrial plants, representing more than 90% of all land plant species alive today. They range in size from tiny, almost microscopic *Wolfia* to tall trees of Eucalyptus (over 100 meters). Angiosperms are **vascular plants** containing two types of vascular tissue – **xylem** that conducts water and dissolved minerals upward from the roots and **phloem** that conducts food throughout the plant. Vascular tissues develop in the sporophytic body but (with a few exceptions) not in the gametophytic body. Angiosperms are also classified as **spermatophytes** (also known as **phanerogams**) because they produce seeds. A **seed** is an embryo packaged with a supply of nutrients inside a protective coat. In angiosperms, seeds develop inside ovaries, which mature into fruits. The seed is a crucial adaptation to life on land because it protects the embryo from drying out.

A typical flowering plant body can be divided into the **root** and **shoot systems**. The underground part of the flowering plant is the *root system*, while the portion above the ground forms the *shoot system*. The shoot system consists of stems, leaves, flowers and fruits.

Root is typically a non-green underground structure. The first root in a vascular plant develops from the **radicle** of the embryo. The root develops from the direct elongation of the radicle is known as the **primary root**. Any root that develops from plant organs other than radicle is called an **adventitious root**. The primary root continues to grow and develops **lateral roots** (or **branch roots**) of several orders that are referred to as *secondary roots*, *tertiary roots* and so on. The primary roots and its branches constitute the **tap root system**. Commonly, the primary root in monocots such as wheat is short-lived, and it is replaced by the roots developing from the base of the stem. These stem-borne roots and their lateral roots constitute **fibrous root system**. The main functions of the root are absorption of water and minerals from the soil, anchorage, storage of reserve food material and synthesis of plant growth regulators. But, roots in some plants become modified to perform functions (such as respiration, support) other than anchorage and absorption of water and minerals.

4



Human Physiology

Learning objective

Like all multicellular animals, human body is composed of different types of cells. Groups of cells similar in structure and function are organized into *tissues*. Different tissues grouped together into a structural and functional unit called *organs*. An *organ system* is a group of organs that function together to carry out the principal activities of the body.

4.1 Tissues

A *tissue* is a group of similar cells that usually have a common embryonic origin and functions together to carry out specialized activities. On the basis of structure and function, animal tissues can be classified into four basic types: epithelial tissue, connective tissue, nervous tissue and muscular tissue.

1. Epithelial tissue

An *epithelial tissue* or **epithelium** consists of cells that form membranes, which cover and line the body surfaces and glands, which are derived from these membranes. Epithelial cells arranged in continuous sheets, in either single or multiple layers. Because the cells are closely packed and are held tightly together by many cell junctions, there is little intercellular space between cells. Three types of cell junctions are found in the epithelium and other tissues. These cell junctions are called as *tight*, *anchoring* (adherens junction and desmosome) and *gap junctions*. Epithelial tissue has its own nerve supply, but is **avascular**; that is, it lacks its own blood supply. The blood vessels that bring in nutrients and remove wastes are located in the adjacent connective tissue. Exchange of substances between epithelium and connective tissue occurs by diffusion. Epithelial tissue plays many roles such as protection, filtration, secretion, absorption and excretion. Because epithelial tissue subjected to wear and tear and injury, it has high capacity for renewal.

5 Animal Development

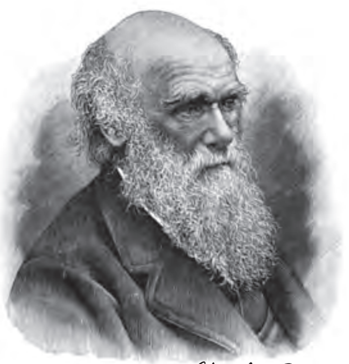
Learning objective

Animal development is a highly complex process that begins with a fertilized egg (or zygote) and leads to the birth of a complex organism with organs at precise positions and shapes. The stages of development between fertilization and birth are collectively called **embryogenesis** and its study is called **embryology**. Embryonic development begins with the fusion of the male and female gametes (**fertilization**). After fertilization, a multicellular organism's development proceeds through a process called **cleavage**, a series of mitotic divisions. Cleavage divides the zygote into numerous cells called *blastomeres*. By the end of cleavage, a solid or hollow fluid-filled ball of the blastomeres develops, known as a **blastula**. Cleavage is followed by **gastrulation**, a process that rearranges the blastomeres and forms the germ layers — *ectoderm*, *mesoderm*, and *endoderm*. Over time and space, these cells interact with one another and rearrange themselves to produce tissues and organs. This process is called **organogenesis**. Many animals have life cycles involving a larval stage specialized for feeding and dispersal. The larva undergoes **metamorphosis** to become a sexually mature adult.

5.1 Patterns and processes of animal development

Developmental biology aims to understand how an organism develops. During development, the zygote divides repeatedly to produce many different kinds of cells arranged in a specific pattern i.e., cells are organized in space and time so that a well-ordered structure develops within the embryo. Several key processes fundamentally occur during animal development. These processes include *cell proliferation*, which produces many cells from one; *cell-cell communications*, which coordinate the behavior of each cell with that of its neighbors; *cell differentiation*, which creates cells with different characteristics at different positions; and *cell movement*, which rearranges the cells to form structured tissues and organs.

6



Charles Darwin

Evolution

Learning objective

- **6.1 Origin of Life**
- **6.2 Biological evolution and theories of evolution**
- **6.3 Natural selection**
- **6.4 Pattern of evolution**
- **6.5 Population genetics**
- **6.6 Evolutionary processes**
- **6.7 Species and speciation**
- **6.8 Macroevolution**
- **6.9 Molecular phylogeny**
- **6.10 Phylogenetic tree**
- **6.11 Geological time scale**

Evolution refers to the changes that occur in life forms over time, leading to the development of many different forms of life. By understanding evolution, we can gain insight into how and why life has changed and diversified. It includes the study of evolutionary processes—how they operate, what they produce, and how they are likely to proceed in the future. It deals mainly with how life changed after its origin. It does not discuss about the *origin of life*. To understand evolution, it is also very important to understand how life originated? We should understand the physical and chemical conditions prevailing on the prebiotic Earth that could drive the first steps of the origin of life. We also have to address a simple question central to our understanding of the origin of life: how complex organic molecules formed and how they have become organized into cells?

6.1 Origin of Life

Life is characterized by the three functions: 1. **compartmentalization**: the ability to keep its components together and separate itself from the environment, 2. **replication**: the ability to process and transmit heritable information to progeny, and 3. **metabolism**: the ability to capture and utilize the energy and material resources, staying away from thermodynamic equilibrium.

The origin of life on Earth is a unique event and also one of the great mysteries. *Where and how did life on Earth originate*? It is difficult to determine because it began almost four billion years ago. Did life come from outer space? For a long time, it was believed that life didn't begin on Earth. It came from outside (i.e. extraterrestial origin). However, due to lack of any validation, it remained merely speculative. For many years it was also believed that life came out of decaying and rotting organic matters. This theory was termed as **theory of spontaneous generation**. Scientists have disproved this theory by performing controlled experiments. Louis Pasteur by careful experimentation demonstrated that life comes only from pre-existing life. Living things, no matter how small, do not come spontaneously from non-living matters. Living things come only from other living things (**biogenesis**). However, this did not answer how the first life form came on Earth.

A letter from Bruce Alberts

(author of Molecular Biology of the Cell)

To: "Usha Mina" <ushamina@mail.jnu.ac.in>
Sent: Tuesday, January 3, 2023 11:14:02 AM
Subject: Re: Review of book

Some feedback on your two Life Sciences volumes – for authors only
Bruce Alberts

Dear Usha and Pranav,

I have finally finished reading through many sections of your large two-volume introductory biology textbook, and I write to provide some feedback that might possibly help with your next edition.

Let me start by saying how impressed I am that such a wide-ranging textbook was written by only two authors. For those sections where I am most knowledgeable – which I read closely -- I find it to be remarkably accurate. As you well know, most such textbooks that attempt to cover all of biology are written by a sizeable team of authors – each with a different expertise -- who in addition acknowledge help from a large number of other experts. And it is great to learn that you are able to provide these two volumes at a low price that Indian students can afford.

My first question concerns the way that this material has been divided up into two separate volumes. If I were a student, I would have felt a need to learn about genetic mechanisms (which you call "genetics") in volume 1, before learning about how proteins are sorted through internal membranes, for example.

A major concern that I would have is one of level. I find that in many places you go into considerably more detail that we do in MBOC (molecular biology of the cell), even though the latter book is aimed at a more advanced student population than I believe yours is. Biology is such a huge subject that we can easily lose students in all the details, when what is most important for them learn are the concepts. Students often feel a need to memorize such details: in our interviews with sets of students who had just used our textbook, we found that many (most?) lack the judgement to ignore them when preparing for exams. For the same reason, we also leave out many of the scientific words in our book, like 2.2_7 helix, linking number, abzyme, etc.

I hope that you find these comments useful, and I write to wish you the very best in 2023, as well as to encourage you in all of your future efforts!

With my best wishes,

Bruce