Fertilization

Objectives

After going through this lesson, the learners will be able to understand the following:

- Fertilisation
- Post-fertilisation Events
  - Zygote
  - Embryogenesis

Content Outline

- Introduction
- Fertilisation
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  - Zygote
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Introduction

The most vital event of sexual reproduction is perhaps the fusion of gametes. This process called **syngamy** results in the formation of a diploid **zygote**. The term **fertilisation** is also often used for this process. The terms syngamy and fertilisation are frequently used though, interchangeably.

Fertilization is the process of fusion male gamete, or sperm, with the female gamete, or ovum. The product of fertilization is a cell called a zygote.

However, it has to be mentioned here that in some organisms like rotifers, honeybees and even some lizards and birds (turkey), the female gamete undergoes development to form new organisms without fertilisation. This phenomenon is called **parthenogenesis**.

Lazzaro Spallanzani in 1784, established the need for interaction between the female's ovum and male's semen to form a zygote. Oscar Hertwig in 1876, described the fusion of nuclei of spermatozoa and of ova in sea urchin.

Fertilization in Plants

Fertilization in plants occurs through various ways. Let's discuss the fertilization in Bryophyllum, Pteridophytes, Gymnosperms and Angiosperms.

a. Fertilization in Bryophyllum

Bryophyte is a traditional name used to refer to all embryophytes (land plants) that are "non-vascular plants", such as mosses, hornworts, and liverworts.

In all bryophytes fertilization is dependent on water — usually a film of water or the splashing of raindrops — for the transfer of sperm to the egg. Chemical stimuli direct the motile flagellated sperm to the archegonium. The fertilized egg (zygote) grows out of the gametophyte, which is also the source of its nourishment. Typically the sporophyte is a slender stalk from 1 to 2 in. (2.5–5 cm) long, with a capsule at the tip; in some species it may be green and manufacture some of its own food. Cells within the capsule undergo meiosis (reduction division) to produce haploid spores. In many mosses the capsule has a lid, the operculum, which is shed, releasing spores. In other bryophytes the mature capsule ruptures in other ways to release spores.

b. Fertilization in Ferns

Ferns are a member of a group of about 10,560 known extant species of vascular plants that reproduce via spores and have neither seeds nor flowers. They belong to Pteridophyta.

The general cycle involves the production of asexual spores on the sporophyte which are shed and germinate to grow into gametophytes which produce male organs with motile sperm and female organs with non-motile egg cells. Fertilization follows and the egg cell develops into a new sporophyte to complete and continue the cycle.

Some pteridophytes dispense with the sexual aspect of the development cycle entirely in a process known as **apogamy** whereby a haploid sporophyte develops directly from the prothallus (gametophyte). It is not common but has been reported in a wide range of genera such as *Asplenium*, *Cheilanthes*, *Pellaea*, *Pteris*, *Trichomanes*, *Isoetes*. Sporelings develop directly from the prothallus without fertilization.

c. Fertilization in Gymnosperm

Gymnosperms are seed-bearing vascular plants, such as cycads, ginkgo, yews and conifers, in which the ovules or seeds are not enclosed in an ovary. The word "gymnosperm" comes from the Greek word *gymnospermos*, meaning "naked seeds".

Gymnosperm seeds develop either on the surface of scale or leaf-like appendages of cones, or at the end of short stalks.

The female gametophyte contains several archegonia, where the egg cells originate and develop. The gametophyte itself is surrounded by layers of sporangia and integument; all of these elements comprise an ovule, which is found on the surface of a female cone. Fertilization occurs when pollen grains (male gametophytes) are carried by the wind to the open end of an ovule, which contains the eggs, or female gametophyte. There, the pollen grain develops an outgrowth called a pollen tube, which eventually penetrates to the egg cell within one of the archegonia. The sperm cells within the pollen tube then vie to fertilize the egg. Once fertilization has occurred, the embryo develops within the female gametophyte, and the ovule becomes the seed, complete with a food source (the gametophyte tissue) and a seed coat (the integument). This embryo, which will eventually become a new sporophyte, consists of two embryonic leaves, the epicotyl and hypocotyl.

d. Fertilization in Angiosperms

Angiosperms are seed-producing plants; they are distinguished from gymnosperms by characteristics including flowers, endosperm within the seeds, and the production of fruits that contain the seeds. Etymologically, angiosperm means a plant that produces seeds within an enclosure. The term "angiosperm" comes from the Greek composite word (angeion-, "case" or "casing", and sperma, "seed") meaning "enclosed seeds", after the enclosed condition of the seeds.

In plants, fertilization takes place by the participation of sperm and the egg cell. In flowering plants a second fertilization event involves another sperm cell and the central cell which is a second female gamete. In seed plants, after pollination, a pollen grain germinates, and a pollen tube grows and penetrates the ovule through a tiny pore called a micropyle. The sperm are transferred from the pollen through the pollen tube. Sperms travel down the pollen tubes and fertilize an egg. Most angiosperms undergo **double fertilization**, where both an egg and the polar nuclei in the embryonic sac are fertilized.

Fertilization in Animal

In most aquatic organisms, such as a majority of algae and fishes as well as amphibians, syngamy occurs in the external medium (water), i.e., outside the body of the organism. This type of gametic fusion is called **external fertilisation**.

Organisms exhibiting external fertilisation show great synchrony between the sexes and release a large number of gametes into the surrounding medium (water) in order to enhance the chances of syngamy. This happens in the bony fishes and frogs where a large number of offspring are produced. A major disadvantage is that the offspring are extremely vulnerable to predators threatening their survival up to adulthood. So, to overcome this disadvantage they release a large number of gametes.

In many terrestrial organisms, belonging to fungi, higher animals such as reptiles, birds, mammals and in a majority of plants (bryophytes, pteridophytes, gymnosperms and angiosperms), syngamy occurs inside the body of the organism, hence the process is called **internal fertilisation**.

In all these organisms, eggs are formed inside the female body where they fuse with the male gamete. In organisms exhibiting internal fertilisation, the male gamete is motile and has to reach the egg in order to fuse with it. In these even though the number of sperms produced is very large, there is a significant reduction in the number of eggs produced. In seed plants, however, the non-motile male gametes are carried to female gametes by pollen tubes.

Post-fertilisation Events

Events in sexual reproduction after the formation of zygote are called **post-fertilisation events**.

a. The Zygote

A **zygote** is a eukaryotic cell formed by a fertilization event between two gametes. The zygote's genome is a combination of the DNA in each gamete, and contains all of the genetic information necessary to form a new individual. In multicellular organisms, the zygote is the earliest developmental stage. In single-celled organisms, the zygote can divide asexually by mitosis to produce identical offspring.

Oscar Hertwig and Richard Hertwig made some of the first discoveries on animal zygote formation.

Formation of the diploid zygote is universal in all sexually reproducing organisms. In organisms with external fertilisation, zygote is formed in the external medium (usually water), whereas in those exhibiting internal fertilisation, zygote is formed inside the body of the organism.

Further development of the zygote depends on the type of life cycle the organism has and the environment it is exposed to. In organisms belonging to fungi and algae, zygote develops a thick wall that is resistant to desiccation and damage. It undergoes a period of rest before germination. In organisms with haplontic life cycle, zygote divides by meiosis to form haploid spores that grow into haploid individuals. Zygote is the vital link that ensures continuity of species between organisms of one generation and the next. Every sexually reproducing organism, including human beings, begins life as a single cell – the zygote.

In fungi, the sexual fusion of haploid cells is called karyogamy. The result of karyogamy is a diploid cell called a zygote or zygospore. This cell may then enter meiosis or mitosis depending on the life cycle of the species.

In plants, the zygote may be polyploid if fertilization occurs between meiotically unreduced gametes.

In land plants, the zygote is formed within a chamber called the archegonium. In seedless plants, the archegonium is usually flask-shaped, with a long hollow neck through which the sperm cell enters. As the zygote divides and grows, it does so inside the archegonium.

In human fertilization, two haploid cells (1n) — an ovum (female gamete) and a sperm cell (male gamete) — combine to form a single 2n diploid cell called the zygote. DNA is then replicated in the two separate pronuclei derived from the sperm and ovum, making the zygote's chromosome number temporarily 4n diploid. After approximately 30 hours, fusion of the pronuclei and subsequent mitotic division produce two 2n diploid daughter cells called blastomeres.

Between the stages of fertilization and implantation, the developing human is called the *preimplantation conceptus* or the proembryo. It is not correct to call the conceptus an *embryo*, because it will later differentiate into both intraembryonic and extraembryonic tissues, and can even split to produce multiple embryos (identical twins).

A Chlamydomonas zygote that contains chloroplast DNA (cpDNA) from both parents, such cells generally are rare since normally cpDNA is inherited uniparental from the mt+ mating type parent. These rare biparental zygotes allowed mapping of chloroplast genes by recombination.

b. Embryogenesis

Embryogenesis refers to the process of development of the embryo from the zygote. During embryogenesis, zygote undergoes **cell division** (mitosis) and **cell differentiation**. While cell divisions increase the number of cells in the developing embryo; cell differentiation helps groups of cells to undergo certain modifications to form specialised tissues and organs to form an organism.

Embryogenesis is the process by which the embryo forms and develops. In mammals, the term refers chiefly to early stages of prenatal development, whereas the terms fetus and fetal development describe later stages.

Embryogenesis starts with the fertilization of the egg cell (ovum) by a sperm cell, (spermatozoon). Once fertilized, the ovum is referred to as a zygote, a single diploid cell. The zygote undergoes mitotic divisions with no significant growth (a process known as cleavage) and cellular differentiation, leading to development of a multicellular embryo.

Although embryogenesis occurs in both animal and plant development, this article addresses the common features among different animals, with some emphasis on the embryonic development of vertebrates and mammals.

All embryonic structures are derived from a single cell formed by the union of two gametes. Every individual organism began as a single cell, which divided and differentiated into various types of cells that make up the diverse tissues and complex structures found in the adult. Ontogeny, or the development of an organism from fertilization to adulthood, begins with the fusion of two cells, the sperm and an egg. The sperm and egg are haploid cells (gametes) formed through the process of meiosis. The haploid cells have no function outside of their involvement in reproduction.

Many invertebrates have isolecithal eggs (yolk is evenly distributed throughout the egg). These eggs have relatively little yolk and various patterns of holoblastic cleavage (the cells divide completely and evenly). The arthropod egg has a moderate amount of yolk, concentrated in the egg's center. The eggs of amphibians and cartilaginous fishes have a moderate amount of yolk, mostly in the lower half of the egg (the vegetal hemisphere). Birds have extremely telolecithal eggs (yolk is concentrated in the vegetal pole, opposite the nucleus) that have a large amount of yolk.

A shell membrane surrounds the embryo, yolk, and albumin, or egg white. It offers mechanical protection and provides a surface for diffusion of oxygen and other gases. Within the egg the allantois acts as a compartment for the storage of nitrogenous excretory products such as uric acid, and may remain after birth or hatching as the urinary bladder. The amnion is filled with amniotic fluid to cushion the embryo that it surrounds. The chorion surrounds the amnion and yolk sac. Mammalian eggs contain some yolk but not nearly as much as found in bird eggs. The typical mammalian egg contains little yolk which is evenly distributed throughout the egg (it is microlecithal and isolecithal).

Plant embryogenesis is the process that produces a plant embryo from a fertilized ovule by asymmetric cell division and the differentiation of undifferentiated cells into tissues and organs. It occurs during seed development when the single-celled zygote undergoes a programmed pattern of cell division resulting in a mature embryo. A similar process continues during the plant's life within the meristems of the stems and roots.

In flowering plants, the zygote is formed inside the ovule. After fertilisation the sepals, petals and stamens of the flower wither and fall off. The pistil however, remains attached to the plant. The zygote develops into the embryo and the ovules develop into the seed. The **ovary** develops into the **fruit** which develops a thick wall called **pericarp** that is protective in function (Figure 1.8). After dispersal, seeds germinate under favourable conditions to produce new plants.

Animals are categorised into **oviparous** and **viviparous** (**Oviparous animals** are animals that reproduce by laying eggs. This is how most fish, amphibians, reptiles, insects, and arachnids reproduce. All birds and monotremes also reproduce like this. **Viviparous** animals have internal fertilisation and the eggs develop inside the mother. The key idea is that the growing embryo gets its nutrition from a placenta in the mother's womb. It is the standard method for all mammals except monotremes.) based on whether the development of the zygote takes place outside the body of the female parent or inside, i.e., whether they lay fertilised/unfertilised eggs or give birth to young ones. In oviparous animals like reptiles and birds, the fertilised eggs covered by hard **calcareous shell** are laid in a safe place in the **environment**; after a period of incubation young ones hatch out. On the other hand, in viviparous animals (majority of mammals including human beings), the zygote develops into a young one inside the body of the female organism. After attaining a certain stage of growth, the young ones are delivered out of the body of the female organism. Because of proper embryonic care and protection, the chances of survival of young ones are greater in viviparous organisms.

Human embryogenesis is the process of cell division and cellular differentiation of the embryo that occurs during the early stages of development. In biological terms, human development entails growth from a one celled zygote to an adult human being. Fertilisation occurs when the sperm cell successfully enters and fuses with an egg cell (ovum). The genetic material of the sperm and egg then combine to form a single cell called a zygote and the germinal stage of prenatal development commences. Embryogenesis covers the first eight weeks of development and at the beginning of the ninth week, the embryo is termed a fetus. **Human embryology** is the study of this development during the first eight weeks after fertilisation. The normal period of gestation (pregnancy) is nine months or 38 weeks.

Summary

Reproduction enables a species to live generation after generation. Reproduction in organisms can be broadly classified into asexual and sexual reproduction.

Sexual reproduction involves the formation and fusion of gametes. It is a complex and slower process as compared to asexual reproduction. Most of the higher animals reproduce almost entirely by sexual methods. Events of sexual reproduction may be categorised into pre-fertilisation, fertilisation and post-fertilisation events. Pre-fertilisation events include gametogenesis and gamete transfer while post-fertilisation events include the formation of zygote and embryogenesis.

Organisms may be bisexual or unisexual. Sexuality in plants is varied, particularly in angiosperms, due to the production of diverse types of flowers. Plants are defined as monoecious and dioecious.

Flowers may be bisexual or unisexual flowers. Gametes are haploid in nature and usually a direct product of meiotic division except in haploid organisms where gametes are formed by mitosis. Transfer of male gametes is an essential event in sexual reproduction. It is relatively easy in bisexual organisms. In unisexual animals it occurs by copulation or simultaneous release. In angiosperms, a special process called pollination ensures transfer of pollen grains which carry the pollen grains to the stigma. Syngamy (fertilisation) occurs between the male and female gametes. Syngamy may occur either externally, outside the body of organisms or internally, inside the body. Syngamy leads to the formation of a specialised cell called zygote. The process of development of the embryo from the zygote is called embryogenesis. In animals, the zygote starts developing soon after its formation. Animals may be either oviparous or viviparous. Embryonal protection and care are better in viviparous organisms. In flowering plants, after fertilisation, the ovary develops into fruit and ovules mature into seeds. Inside the mature seed is the progenitor of the next generation, the embryo.