9.2 Laws of Inheritance

Learning objectives

By the end of this section, you will be able to:

- *Explain Mendel's work and the significance of his results*
- *Understand the relationships between phenotype and genotype, dominant and recessive alleles of a gene, and homozygous and heterozygous genotypes*
- *Use a Punnett square to calculate the expected proportions of genotypes and phenotypes in a monohybrid cross*
- *Understand Mendel's laws and how his experimental results support them*
- *Diagram dihybrid genetic crosses using uppercase and lowercase letters to symbolize two alleles of a gene and create Punnett squares to keep track of all possible offspring*
- *Be able to define and explain all bolded terms*

To fully examine each characteristic, Mendel generated large numbers of F_1 and F_2 plants, reporting results from 19,959 F_2 plants alone. His findings, based on a large sample size, were both reproducible and consistent. Furthermore, Mendel used quantitative statistical analysis to verify his results, making it difficult to refute his findings. Let's take a closer look at some of Mendel's results.

Mendel's Data and Results

What were Mendel's results when he crossed plants with different flower colors? First, Mendel confirmed that he was using plants that were true-breeding for white or violet flower color. Mendel found that regardless of the number of generations he looked at, true breeding white-flowered plants that self-fertilized always produced white-flowered offspring. The same result was confirmed for true-breeding violet-flowered plants; they always produced offspring with violet flowers. Mendel also confirmed that, other than flower color, the pea plants were physically identical. This was important because it confirmed that the two varieties of pea plants only differed with respect to one trait, the flower color.

Once these results were validated, Mendel performed a cross between a plant with violet flowers and a plant with white flowers. After gathering and planting the seeds from this cross, Mendel found that 100 percent of the F_1 hybrid generation had violet flowers. Conventional wisdom at that time would have predicted the hybrid flowers to be pale violet. In other words, the parental traits were expected to blend in the offspring. Instead, Mendel's results demonstrated that the violet flower trait was retained and the white flower trait had disappeared entirely in the F_1 generation.

Importantly, Mendel did not stop his experimentation there. He allowed the F_1 plants to self-fertilize and found that 705 plants in the F_2 generation had violet flowers, and 224 had white flowers (Figure 9.4). This was a ratio of 3.15 violet flowers to one white flower, or approximately 3:1 ratio. For the other six characteristics that Mendel examined, the F_1 and F_2 generations behaved in the same way that they behaved for flower color. One of the two traits would disappear completely from the F_1 generation, only to reappear in the F_2 generation at a ratio of roughly 3:1.

Why did Mendel repeatedly obtain a 3:1 ratio in his crosses? To understand how Mendel deduced the basic mechanisms of inheritance that lead to such ratios, we must first review probability.

Probability Basics

Probabilities are mathematical measures of likelihood. The empirical probability of an event is calculated by dividing the number of times the event occurs by the total number of opportunities for the event to occur. It is also possible to calculate theoretical probabilities by dividing the number of times that an event is *expected* to occur by the number of times that it could occur. Empirical probabilities come from observations, like those of Mendel. Theoretical probabilities, on the other hand, come from knowing how the events are produced and assuming that the probabilities of individual outcomes are equal. A probability of one for some event indicates that it is guaranteed to occur, whereas a probability of zero indicates that it is guaranteed not to occur. An example of a genetic event is a round seed produced by a pea plant.

In one experiment, Mendel demonstrated that when one true-breeding parent has round seeds, and one true-breeding parent has wrinkled seeds, the probability of the F_1 offspring having "round seeds" was one. When the F_1 plants were subsequently self-crossed, the probability of any given F_2 offspring having round seeds was now three out of four. In other words, in a large population of F_2 offspring chosen at random, 75 percent were expected to have round seeds, whereas 25 percent were expected to have wrinkled seeds. Using large numbers of crosses, Mendel was able to calculate probabilities and use these to predict the outcomes of other crosses. The fact that Mendel confirmed his work with statistical analysis made it relatively easy for others to repeat his experiments and verify his results.

Mendel's Laws of Inheritance

Mendel simplified the results of his pea plant experiments into four hypotheses, some of which are sometimes called "laws." These hypotheses or laws describe the basis of inheritance in diploid organisms, as understood by Mendel.

Mendel first hypothesized that for each characteristic, plants have two copies of the heritable trait, one from each parent. Today, we use the word **gene** to describe the basic unit of heredity. Based on what he saw in pea plants, Mendel recognized that different versions of genes must exist for the same characteristic. These different gene versions are called **alleles**. For example, because pea plants could have either violet or white flowers, he argued that there had to be at least two different alleles for flower color. Mendel hypothesized that it was possible for a plant to either have two identical alleles or to have two different alleles for a specific gene. Individuals that have two identical alleles are said to be **homozygous**. Mendel's true-breeding violet-flowered and white-flowered pea plants are both homozygous; they have two identical alleles, both resulting in either violet or white flower color. When individuals have two different alleles for a gene, they are said to be **heterozygous**. For example, a plant that has one allele for violet flowers and one allele for white flowers is heterozygous for the characteristic of flower color.

Mendel suspected that each parent passed on only one of its two alleles to its offspring. For example, both the male and female gamete would each only carry one copy of an allele for flower color. When fertilization occurred, the new zygote would then have two alleles for flower color, just like the parents that produced it.

Mendel found that when he crossed true-breeding violet-flowered pea plants and true-breeding white-flowered pea plants, all the offspring were violet. The violet flower color is therefore considered dominant. An allele is considered **dominant** when it is expressed in heterozygous individuals. Mendel's F_1 pea plants were heterozygous because they had one violet-flowered allele and one white-flowered allele. Violet flower color was expressed in this generation, making that the dominant allele. The white-flowered allele is therefore considered recessive. An allele is considered **recessive** if it is masked (does not appear) in the F_1 offspring. The recessive trait does, however, reappear in the F_2 generation. Mendel hypothesized that if he saw the recessive trait being expressed, it meant that the plant did not have a dominant allele, rather they must carry two recessive alleles. He also suggested that because the recessive trait reappeared in the F_2 generation, this meant that the traits remained separate and not blended in the F_1 generation plants.

Based on his observations of the F_1 and F_2 generations, Mendel proposed the **law of segregation**. This law states that paired unit factors, today called genes, must segregate equally into gametes such that offspring have an equal likelihood of inheriting either gene. Recall that in meiosis, homologous chromosomes are separated into different haploid gametes arbitrarily (Figure 9.5). An individual's characteristics are a result of the genes carried on chromosomes. When a haploid gamete from one parent fertilizes a haploid gamete from another parent, a diploid offspring is formed. The diploid offspring has two copies of each chromosome, and therefore two copies of each gene, supporting Mendel's hypothesis.

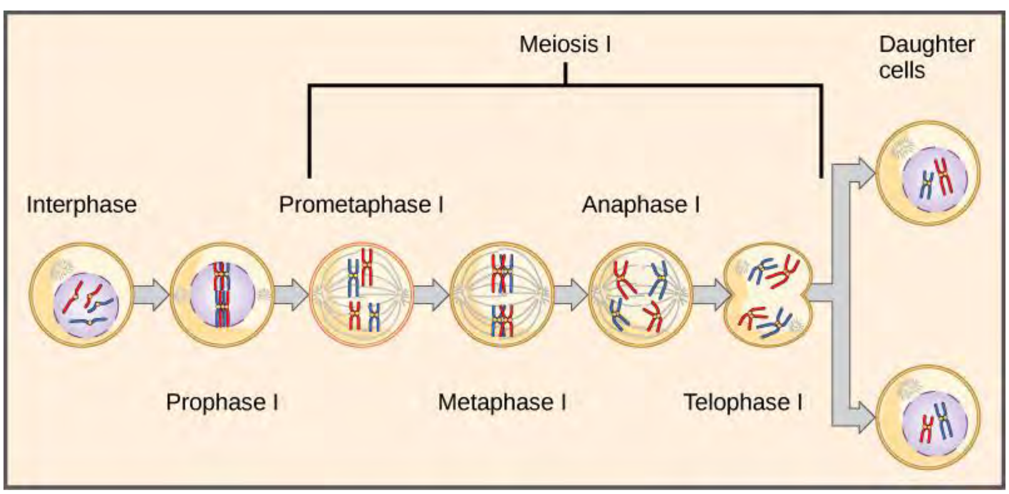

Figure 9.5 The random segregation into daughter nuclei that happens during the first division in meiosis supports Mendel's law of segregation. (credit: Fowler et al. / Concepts of Biology OpenStax)