PennState Extension

Honey Bee Genetics Basics

This article describes the basics of genetics within a honey bee colony.

Drone, worker and queen honey bees. Illustrations by Michael Hill.

Humans and many other organisms are **diploid**, so males and females receive chromosomes from both of their parents. In contrast, honey bees have a haplodiploid system. The concept of **haploidy** can be a source of confusion when it is first introduced. By understanding how **haplodiploidy** affects honey bee reproduction, beekeepers can better understand the influence of genetic traits and improve breeding efforts.

Haplodiploidy

Honey bees have haplodiploid sex determination. This is common in many insects and is present in bees, wasps and ants. The word **haploid** describes an organism that receives a single set of chromosomes. Haploid individuals develop from unfertilized eggs and are males or drone honey bees. The word **diploid** describes an organism that receives two sets of chromosomes, one from each parent. Diploid individuals develop from fertilized eggs and become females; queens or workers. Honey bees have 16 different chromosomes, so individuals developing from fertilized eggs will have 2 sets of 16 (2 x 16 = 32 total chromosomes), where individuals developing from unfertilized eggs will have one set of 16 (1 x 16 = 16 total chromosomes; Image 1).

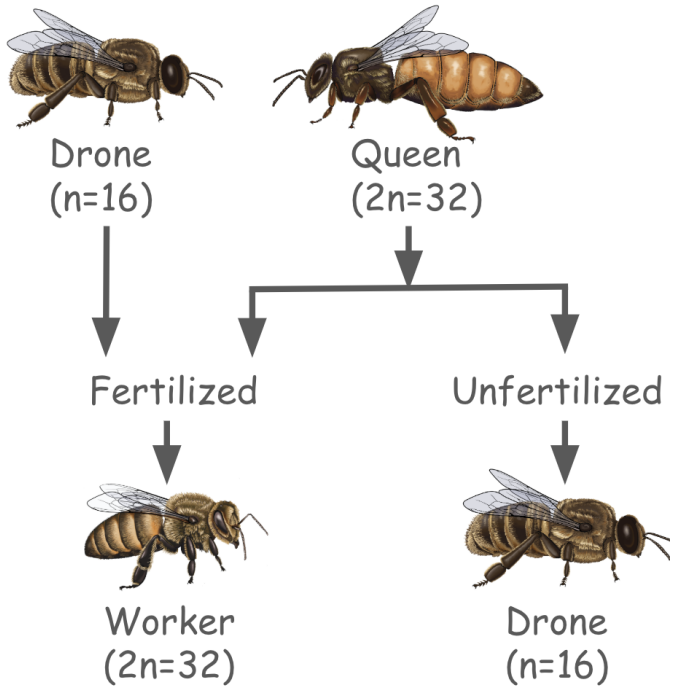

Image 1. Haplodiploidy in honey bees. Females have two sets of chromosomes (2n) and are diploid, while males have only one set of chromosomes (n) and are haploid. Thus a female bee has a mother and a father while a male bee has only a mother. Images drawn by Michael Hill

Relatedness

A queen has 16 pairs of chromosomes - one set of the pair is from her mother and one is from her father. When the queen produces eggs, one chromosome of each pair is incorporated into the egg. Which chromosome of each pair is included is random. So, eggs receive half of the queen's chromosomes on average, and are 50% related to the queen.

A drone has 16 chromosomes, and there is only one set of chromosomes. 100% of a drone's chromosomes come from the queen, because he developed from an unfertilized egg. But since the queen has 32 chromosomes each drone is not a copy of the queen and brother drones will not be identical.

When a drone's sperm fertilizes a queen's eggs, the resulting diploid offspring (which will develop into females) share 100% of their father's genes, and 50% (on average) of the mother's genes. Thus, the offspring (full sister workers) share 75% of their genetic material overall, and have 75% relatedness (Image

2). The female offspring of the same father are thus called "supersisters." Workers with different fathers are 25% related, because all of the chromosomes from the father will be different. In humans, full siblings (with the same mother and father) share half (50%) of their DNA on average, so relatedness in the honey bee colony is an exciting topic for exploration. Indeed, studies from Penn State have found that the father's genes drive selfish behavior in honey bee workers, since the queen usually mates with more than 10 males, so the father's genes are only shared by a small subset of the colony (see Galbraith et al 2016). In contrast, genes inherited from the queen drive altruistic behavior (see Bresnahan et al 2024).

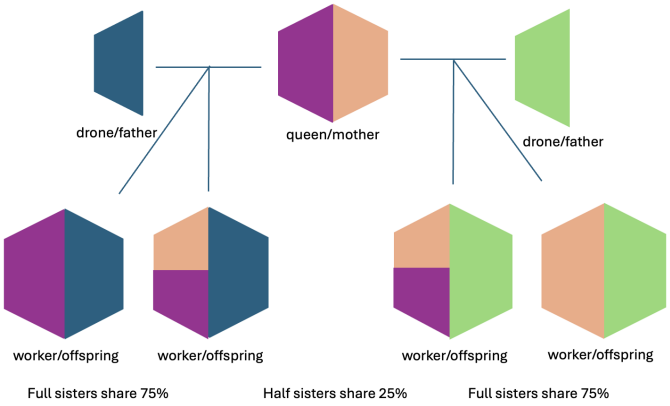

Image 2. Relatedness in a honey bee colony.

Sex Determination, Genes, Alleles

In humans, male or female sex is determined by the X and Y chromosomes. In honey bees, sex is determined by the complementary sex determiner gene (csd). Genes are sections of DNA on a chromosome. Different versions of genes, are called alleles. The csd gene comes in more than 20 different types or alleles. When a bee inherits a single allele of the csd gene they become a male. Queens and workers receive one version of the csd gene from their mother and another one from their father. The two alleles that are received are nearly always different, so this signals that the bee will develop into a female.

In simple terms, if the bee has two different versions of the csd gene, it becomes a female. If there is only one version it is a male. In cases where the father and the mother share the same csd allele - which could happen if the drones and queens are highly related to each other due to inbreeding - two identical copies of the csd gene can be inherited from both parents, resulting in a diploid drone. When an egg hatches with these characteristics, the workers sense that this has occurred and will destroy the larva. The most telling sign of this is a shot brood pattern, where many brood cells are empty (Image 3).


Image 3. A shotgun brood pattern. Credit: Robyn Underwood

Production of Eggs: Meiosis and Recombination

Oogenesis, the creation of eggs, occurs in the ovaries of the queen. Eggs are made by a process known as meiosis. Meiosis is known as reduction division, because one cell with 16 pairs of chromosomes is made into two cells (eggs) with one set of 16 chromosomes each. Each egg contains one set of 16 chromosomes from the queen, but they are not all alike. They can be any combination of the queen's 32 chromosomes that she inherited from her parents. So, for example, one egg may have chromosome 1 and 2 from the queen's father and the other has chromosome 1 from the queen's father and chromosome 2 from the queen's mother.

The process of meiosis also includes some mixing of genes through a process called crossing over or recombination. Crossing over describes a process that occurs during meiosis where the chromosomes from each of the queen's parents line up and exchange segments of DNA resulting in blended alleles. Honey bees have among the highest rate of crossing over of any animal, emphasizing the evolutionary drive for genetic diversity.

The eggs created by the queen are not identical - due to both independent assortment of the chromosomes and recombination - and so there is genetic diversity among the eggs of a single queen.

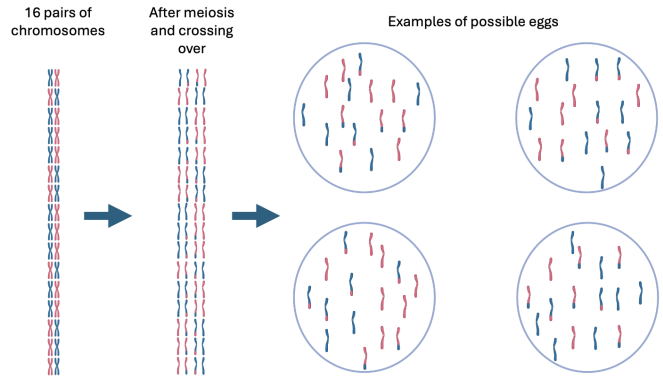

Image 4. Oogenesis in honey bees. Sixteen pairs of chromosomes separate, with some DNA crossing over, making new chromosomes. The resulting eggs are highly genetically diverse and contain one set of 16 chromosomes.

Production of Sperm: Incomplete Meiosis

Spermatogenesis, the creation of sperm, occurs in the testes of the drone. Sperm are made by a process of incomplete meiosis. Because drones are haploid, germ cells or sperm do not undergo complete meiosis. The cells that are involved in making sperm are already haploid, having only one set of 16 chromosomes, so there is no need to reduce the number of chromosomes (via true meiosis). Thus, crossing over cannot occur. Instead, a copy of the drone's chromosomes is made. Every sperm cell made by an individual drone is a nearly identical copy and all of his offspring will inherit 100% of his DNA.

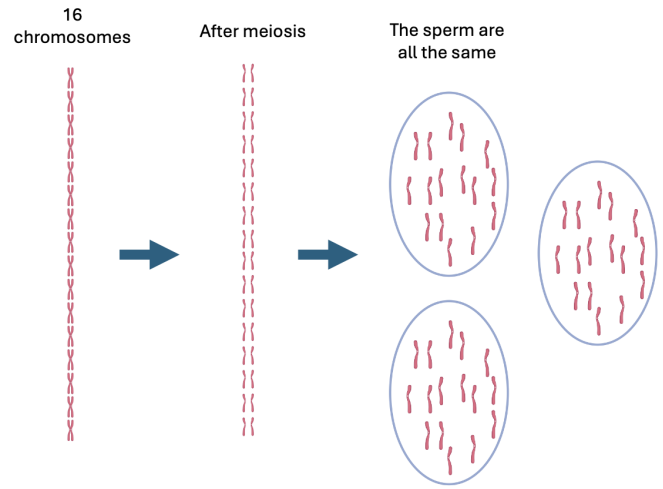

Image 5. Spermatogenesis in honey bees. Sixteen chromosomes separate. The resulting sperm are genetically identical and contain one set of 16 chromosomes.

Conclusion

Genetic diversity is essential in healthy worker populations in honey bee colonies. While each individual drone's genetic contribution is homogenous, queens mate with potentially dozens of drones, producing diverse daughters from many different fathers which allow the colony to thrive. This system, haplodiploidy, helps the colony to maintain a strong, varied population while ensuring that drones can quickly contribute their mother's genetics to future generations.

For breeders of honey bees, it is important to understand these genetics. In particular:

1. Each daughter queen that is produced is unique. The new queens must, therefore, be tested for desired traits and cannot automatically be considered desirable even if their mother was exceptional.
2. An open-mated daughter queen has the sperm from many drones stored in her spermatheca. Therefore, the worker population she creates is highly diverse and may or may not exhibit the desired traits of a breeding program.
3. The drones from a breeder queen will contain 100% of that queen's genetics. Therefore, rearing drones from these queens is very much encouraged. This is true even if a virgin queen was introduced and allowed to open mate.
4. Due to the sex determination process in honey bees, inbreeding can result in diploid drones that are not functional and removed by worker bees during development, resulting in a "shot brood." Thus, breeding programs need to avoid mating related males and females.

References

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