Bio 101 Ms. Bledsoe

Making Sense of Genetics Problems

Monohybrid crosses

Let's start with something simple: crossing two organisms and watching how one single trait comes out in the offspring.

Let's use peas, as Mendel did. Suppose you are working with the height gene in peas. The height gene has two alleles: tall and short. We'll use **T** to represent the tall allele, and **t** for the short allele. Each individual pea plant is diploid, so it must have two copies of the gene (one from each parent) in every body cell. However, gametes are haploid. When a pea plant reproduces, it can only donate one of its height genes to each offspring — either the one it got from the female parent, or the one it got from the male parent.

What height alleles can any one pea plant put in its gametes? Depends upon the genotype of the plant. Here is how the alleles will be distributed to the gametes in the following individuals:

condition of parent	genotype		gametes
Homozygous dominant	TT	------>	( ) T only
Heterozygous	Tt	------>	(T) and (t)
Homozygous recessive	tt	------>	(t) only

A Punnet square is a way of finding out what the ratios of phenotypes and genotypes of the offspring will be. When we make a Punnet square, we put the gametes of the parents outside the square and combine them in all possible ways to get the offspring. In monohybrid crosses, the gametes will all be represented by a single letter, since we're following only one trait and each gamete is haploid. The resulting offspring should each be represented by a pair of letters, since they will all be diploid individuals.

Here are some examples, crossing various parents:

TT x tt

	t	t
T	Tt	Tt
T	Tt	Tt

(note: this could be a single-square Punnet square)

Tt x Tt

	T	t
T	TT	Tt
t	Tt	tt

Tt x tt

	t	t
T	Tt	Tt
t	tt	tt

TT x Tt

	T	t
T	TT	Tt
T	TT	Tt

(note: these two could be two-square Punnet squares)

However, these squares do not describe *actual* outcomes. They predict the chances of the offspring having a particular trait. For instance, the second square shows us that each offspring has a 3 in 4 chance (75% or 0.75) of being tall.

Dihybrid Crosses

Here's where many people get into trouble when they do genetics problems. They do fine putting single letters on top of boxes, even if they don't understand what the letters mean. But give them two traits at once, and they start putting single letters on top of the Punnet square boxes and don't understand how to interpret the results.

Let's have a look at how to handle crosses where we follow two traits at once. Again, we'll work with pea plants. Suppose we want to follow the traits of height at pea color. The height gene has two alleles: tall and short. We'll use **T** to represent the tall allele, and **t** for the short allele. The color gene also has two alleles: yellow and green, where yellow is dominant and green is recessive. We'll use **Y** to represent the yellow allele, and **y** for the green allele. Remember, pea plant body cells are diploid, so each cell will have a *pair* of the height alleles and a *pair* of the color alleles. Gametes are haploid, so each gamete will have *one* of the height alleles and *one* of the color alleles.

What height and color alleles can any one pea plant put in its gametes? Depends upon the genotype of the plant. Here is how the alleles will be distributed to the gametes in the following individuals:

genotype	gametes
TTYY	TY only
TtYY	TY and tY
TTYy	TY and Ty
TtYy	TY and Ty and tY and ty

Note that each individual puts one allele of each gene in each gamete. Since we're following two traits at once, each gamete must have one allele of each of the two genes — that's why there are two letters in each gamete.

What gametes would the following individuals be able to make?

genotype	gametes
TTyy	
Ttyy	
ttYY	
ttYy	
ttyy	

Now — how do we cross two individuals and track the traits as they sort out in the offspring? Remember, the letters that go across the top and the sides of the Punnet square represent the possible gametes each parent produces. Use the table above to help you figure out what possible gametes each parent in a cross can donate.

For example, what if we cross two individuals who are both heterozygous for each trait? We write the genotypes of these pea plants as TtYy. Using the table above, you can see that these pea plants can produce four kinds of gametes: TY, Ty, tY, and ty. We're going to have to use a Punnet square that is four squares by four squares:

	TY	Ty	tY	ty
TY	TTYY	TTYy	TtYY	TtYy
Ty	TTYy	TTyy	TtYy	Ttyy
tY	TtYY	TtYy	ttYY	ttYy
ty	ttYy	Ttyy	ttYy	ttyy

The phenotypic ratio of this cross (between two individuals who are heterozygous for both traits is the classic 9:3:3:1 ratio. But — nine what? Three what? One what? If you count up the individuals with each of the following phenotype, we'll see:

phenotype	frequency
Tall, Yellow	9/16
Tall, green	3/16
short, Yellow	3/16
short, green	1/16

So, on your exams and quizzes, be sure to state what the numbers of your ratios refer to.

But is this the only ratio we can get with a dihybrid cross? Let's find out. Suppose we start with an individual who is tall and yellow, and one that is tall and green. Suppose also we know the genotype of each individual: TtYy, Ttyy. Let's do this cross as follows:

1) Figure out what alleles each parent can put in its gametes.

Parent	possible gametes
TtYy	(TY) and (Ty) and (tY) and (ty)
Ttyy	(Ty) and (ty)

2) Set up the square for this cross:

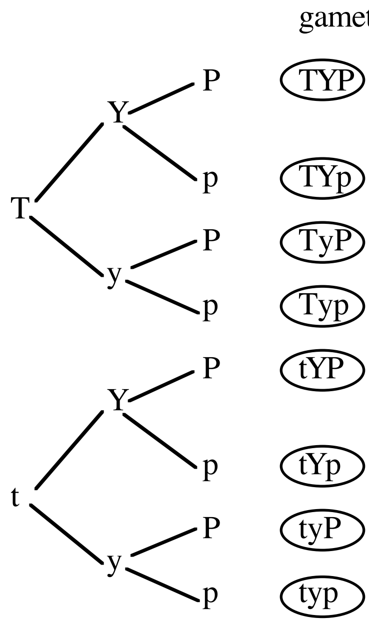
	TY	Ty	tY	ty
TY	TTYY	TTYy	TtYY	TtYy
ty	TtYy	Ttyy	ttYy	ttyy

phenotype	frequency
Tall, Yellow	5/8
Tall, green	1/8
short, Yellow	1/8
short , green	1/8

Trihybrid crosses and beyond

Okay, Punnet squares for monohybrid crosses are fairly simple. Dihybrid crosses are harder, but understandable. But what if we want to watch three, four, or more traits all at once?

Well, we could start with the traits of the parents, find their genotypes, and then figure out their gametes, and make a Punnet square. Let's see how we could do that with three traits in peas. Suppose you have a plant that is tall and has green peas. Suppose it also has purple flowers, which are dominant over white. And suppose you know the pea plant is heterozygous for all three traits (**TtYyPp**). What alleles will this individual put in its gametes? You can set up a forked diagram to figure this out, like so:



Let's see — that's eight different possible gametes. If you cross two pea plants that are heterozygous for all three traits, you'll have to make a Punnet square that is eight by eight, or *sixty-four squares total*. Do you really want to do that? I didn't think so.

Would you like an easier way? (This will work for dihybrid crosses as well.)

Let's consider each of the traits separately, then use the rules of probability to figure out the probability of several traits occurring at once. The basic rules of probability are as follows:

Probability of two events happening at once (event 1 AND event 2)
= (probability of event 1) (probability of event 2)

Probability of either event 1 OR event 2 occurring
= probability of event 1 + probability of event 2

So, let's consider the above pea plant, TtYyPp. Let's try crossing this plant with another plant of the same genotype, that is, another TtYyPp. First, use Punnet squares to figure out the probabilities for each individual trait in the offspring:

height

	T	t
T	TT	Tt
t	Tt	tt

Tall: 3/4 or 0.75
short: 1/4 or 0.25

pea color

	Y	y
Y	YY	Yy
y	Yy	yy

Yellow: 3/4 or 0.75
green: 1/4 or 0.25

flower color

	P	p
P	PP	Pp
p	Pp	pp

Purple: 3/4 or 0.75
white: 1/4 or 0.25

Suppose we cross those two peas that are heterozygous for all three traits and want to know what the probability is of getting offspring that are tall, with yellow peas and purple flowers. Here's how it works:

Probability of an offspring being tall = 0.75
Probability of an offspring having yellow peas = 0.75
Probability of an offspring having purple flowers = 0.75

Probability of an offspring being tall AND having yellow peas AND having purple flowers
= (0.75)(0.75)(0.75) = **0.42** (that is, 42%)

We can also find out the probability of any other combination of traits in the offspring of these two parents:

Probability of an offspring being short AND having green peas AND having white flowers
= (0.25)(0.25)(0.25) = **0.015** (or 1.5%)

Probability of an offspring being tall AND having green peas AND having white flowers
= (0.75)(0.25)(0.25) = **0.047** (or 4.7%)

What if the parents aren't heterozygous for all three traits?

But suppose those peas we already discussed aren't the two parents we start with? Let's see what happens when we cross the following two peas:

TtYyPp x ttYypp

Now if you work out the Punnet squares for each separate trait, the probabilities are:

Tall = 0.5
short = 0.5

Yellow = 0.75
green = 0.25

Purple = 0.5
white = 0.5

Now consider the offspring:

Probability of an offspring being tall AND having yellow peas AND having purple flowers
= (0.5)(0.75)(0.5) = **0.19** (or 19%)

Probability of an offspring being short AND having green peas AND having white flowers
= (0.5)(.25)(0.5) = **0.06** (or 6%)

Probability of an offspring being tall AND having green peas AND having white flowers
= (0.5)(0.25)(0.5) = **0.06** (or 6%)

Let's throw in another complication. What if the traits include one that shows incomplete dominance, codominance, or sex linkage? We can still solve the problem using the probability method.

Suppose a married couple knows that they are both carriers for Cystic Fibrosis. In addition, the woman has a father who was color blind (a sex-linked trait), which means she has to carry one recessive color blind allele on the X chromosome she got from her father. What are the odds that a son of theirs will have Cystic Fibrosis and be color blind?

Cystic fibrosis gene	Color blind gene
normal child = 0.75	normal girl = .5
CF child = 0.25	normal boy = .25
	color blind boy = .25

To find out the probability of getting a color blind son with CF, we multipy the probability of any one child having CF by the probability of getting a color blind boy:

(0.25)(0.25) = **0.062** (or 6.2%) chance of getting a color blind CF boy.

Consider incomplete dominance, also. Let's try crossing two of the common garden flowers, the Four O'clocks. These flowers come in tall or dwarf (short) forms, and their flowers are red, pink, or white. Use T for tall and t for short as in peas. Use R for red and R' for white, where RR results in red flowers, RR' will produce pink flowers, and R'R' will result in white flowers. Cross a plant that is heterozygous for height (Tt) and is red (RR) with one that is heterozygous for height (Tt) and white (R'R'). The probabilities for these traits showing up in the offspring are:

Height gene	Flower color gene
Tall = 0.75	Red = 0.25
short = 0.25	Pink = 0.5
	White = 0.25

What is the probability of getting plants that are:

tall and red flowered? (0.75)(0.25) = 0.187

tall and pink flowered? (0.75)(0.5) = 0.375

short and white flowered? (0.25)(0.25) = 0.0625

And so on with any other combination of traits.