About this Website"

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spmdmp@gmail.com

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Old URL: http://home.ezweb.com.au/~kazballea/genetics/about.html Last updated: 13 Nov, 2008

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URL: http://home.ezweb.com.au/~kazballea/genetics/theory_print.html Last updated: 27 May, 2007

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General Introduction into Poultry Genetics:

Genetic terms.	
Genotype:	The genetic makeup of the organism
Phenotype:	The physical appearance of the organism
Sexual Dimorphism:	"Sexual dimorphism" includes differing colour/ pattern forms between the two sexes of a species, i. e. not restricted to physical body traits. The gender colour/pattern differences in the wild type – Red Jungle Fowl (black breasted red roosters, salmon breasted hens, etc) are two alternate colour/pattern forms, the particular form expressed dependent on gender.
P1	Parent 1 (in first cross)
F1 F2	First Filial, Second Filial (1st Generation, etc)

BC1 etc:	Back Cross 1 (cross F1 back to Parent, etc)
Gene	A unit of hereditary , a section of DNA found on a chromosome that codes for a particular protein
Locus (Loci - plural)	The location of an Allele on the Chromosome
Allele	One of two alternate forms of a gene that has the same locus on homologous chromosomes
Chromosome	A threadlike body in the cell nucleus that carries the genes in a linear order
Homozygous	Where alleles of a locus on homologous chromosomes are the same
Heterozygous	Where alleles of a locus on homologous chromosomes are different
Hemizygous	A genetic locus present in one copy only. Of females, in reference to the only one allele at each locus on the single Z chromosome (only one allele possible, as only one Z chromosome in females, therefore not heterozygous or homozygous as no chromosome pair).
Linkage Map Unit, (centiMorgan)	1 map unit, or 1 centiMorgan (cM) is equal to 1% recombination
Inheritance Mode Types:	
Dominant:	Of genes; producing the same phenotype whether its allele is identical or dissimilar
Recessive:	Of genes; producing its characteristic phenotype only when its allele is identical
Incompletely dominant/recessive:	When heterozygous, giving an intermediate phenotype
Co-dominant:	When heterozygous, expressing both alleles
Sex-linked dominant/recessive:	Of genes; on the Z chromosome
Linkages:	Where loci do not segregate independently
Sex-Limited:	Where both genders carrying the gene, but gene expression is with one gender only (eg, egg-shell colour can only be expressed in hens)

Sex-Influenced:	Where a gene may appear dominant with one gender, recessive in another, ie gene expression is different between genders when alleles heterozygous
Autosomal:	Any chromosome that is not a sex chromosome; appear in pairs in body cells
Others:	
Pleiotrophy:	Multiple traits expressed by a single gene
Polygenic trait:	Multiple genes giving accumulative effect on trait expression
Epistasis	Gene expression affected by a gene from another locus
Hypostasis:	The converse of epistasis, applied to the gene pair hidden by the epistatic gene pair
Penetrance:	The proportion of individuals of a specified genotype that express the expected phenotype
Expressivity:	The range of phenotypes expressed by a given genotype
Homologous Chromosomes:	Corresponding or similar in position
Multiple Alleles :	Where more than one mutation has occurred on a specific locus
Diploid:	An organism or cell having two sets of chromosomes
Pheomelanin:	Pigments that account for wild type red colour
Eumelanin:	Pigments that account for wild type black colour
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Genetics Theory:

Chickens have 78 <u>chromosomes</u>. They are <u>diploid</u> animals, therefore the body cell chromosomes are grouped together in pairs- 39. For example, a chicken will have two Chromosome 1's, two chromosome 2's, two chromosome 3's, etc. The exception is the sex-chromosomes, Z and W, where roosters have two Z

chromosomes and hens have only one Z chromosome, plus one W chromosome.



The following diagram may be useful in understanding the genetics terms:

The position along a chromosome where a gene may be found, is its <u>locus</u>. "<u>Alleles</u>" are the alternate genes possible on a specific locus. For example, the lavender gene (lav) may only be found on the Lavender locus. As only one mutation has been known to occur at this locus, there is a total of two alleles possible, ie the lav mutation and the wild type allele - Lav⁺ (wild type alleles are identified by the plus symbol: ⁺). Therefore, the possible locus allele combinations on the two <u>homologous chromosomes</u> are:

- Lav⁺ / Lav⁺
- - Lav^+ / lav
- - lav / Lav+
- - lav / lav







Sometimes <u>multiple alleles</u> have mutated on a given locus. That is, there may be a list of alleles available, not just two (ie, not just one mutation & the wild type allele). For example, E, E^R, E^R- Fayoumi, e^{Wh} , e^+ , e^b , e^s , e^{bc} , e^y , e^q alleles are all on the one locus (E locus). But only two alleles are physically possible in a <u>diploid</u> individual, at any given locus, ie, an individual may have E^R/e^+ , or E/E^R , or e^b/E , etc, but only two alleles from the E Series.



As mentioned previously, sex chromosomes are different to the above <u>autosome</u> pairs, and different again between roosters (2 Z chromosomes) and hens (W & Z chromosomes). The following diagrams may be useful in understanding the differences between male & female sex chromosome pairs:



* Z chromosome pair- Males only



* Z & W chromosome pair- Females only

Males may have two alleles the same- homozygous, or if two different alleles- heterozygous (two different alleles on the one locus), but as females can only have one allele, as only one Z chromosome present, they are referred to as hemizygous.



Wild type (Red Jungle Fowl - Gallus gallus)

The "Wild Type" is what the wild species population appears like. For the domestic fowl, Jaap and Hollander (1954) suggested that the wild type Red Jungle Fowl (*Gallus gallus*) be taken as the standard from which all deviations (or mutations) are measured (Carefoot, 1985).

References:

Carefoot, W.C. (1985) *Creative Poultry Breeding*. Jaap, R.G. and Hollander, W.F. (1954) *Wild type as standard in poultry genetics*. Poultry Sci. 34:389-395.



*photo of Red Jungle Fowl (Photograph from <u>Feathersite.com</u>)

Examples of Domestic Fowl breeds/varieties similar in colour/pattern are Brown Leghorns, Partridge (Light Brown) Dutch Bantams, Black Breasted Red- Partridge Old English Games, etc. The following is a photo of Black Breasted Red- Partridge Rosecombs.



* Black Breasted Red- Partridge Rosecombs (Breeder, & Photography by <u>Katherine Plumer -www.rosecomb.com</u> website)

Pheomelanin and Eumelanin Pigment Areas

"<u>Pheomelanin</u>" equals the red pigment areas, "<u>Eumelanin</u>" equals the black pigment areas. Some genes affect the pheomelanin areas only, eg., if a bird has the cream- ig gene, the red is diluted to cream, if silver- S mutation present, the pheomelanin red areas are changed to silver -white, if mahogany- Mh, the red is darkened to deep mahogany, etc. Some genes affect the eumelanin areas only, eg., if a bird has the blue, dominant white, dun, smoky, etc genes, the eumelanin is diluted to these colours. Other genes affect both eumelanin and pheomelanin, eg the Lavender- lav gene dilutes the eumelanin- black to a pale lavender shade, and the pheomelanin- red to a pale straw-cream shade. The Recessive White gene changes all pigmented plumage (pheomelanin and eumelanin) to white, regardless of other mutations in the genotype.



*Pheomelanin (red) & eumelanin (black) in wild type colour/pattern (e⁺) (Breeder, & Photography by <u>Katherine Plumer -www.rosecomb.com</u> website)

Examples of Pheomelanin and Eumelanin mutations

Eumelanin		
	wild type - black	
ID	Dun>	
I	Dominant White>	1
Bl/bl+	Blue>	
Pheomelanin		
	wild type- red	mate



* (Photographs from the <u>OEGBCA</u> website, & CJR - Cream Light Brown Dutch Bantams)

Inheritance Modes, using Punnett Squares:

The three main inheritance modes are:

- Dominant/ Recessive inheritance
- - Incompletely Dominant inheritance
- - Sex-Linked inheritance

* Images used in the following punnet squares are from <u>Feathersite</u>, and the <u>OEGBCA</u> website.

Dominant / Recessive Inheritance

This inheritance mode is where one dose only of a dominant gene is needed for expression to occur (ie <u>heterozygotes</u> & <u>homozygotes</u>), but two doses are needed for expression of a recessive gene (ie homozygotes only express the gene). The example given below is of Lavender (lav- recessive gene) bird paired with a Black (Lav⁺ - dominant - wild type allele) bird.

* First Generation cross results, using Lavender & Black parents:



*<u>Dominant</u> / <u>Recessive</u> Inheritance Mode, <u>F1</u> generation <u>Genotypic</u> Percentages = 100% Lav⁺/lav <u>Phenotypic</u> Percentages = 100% black

* Second Generation cross (inbreed offspring - F1 X F1) results:

Domi F2 F1 Black	nan X F1	t / RO Blach =	75%	e lach
Lav ⁺ /lav	Lav	lav	25%	dina di seconda di sec
	J Lav ⁺	Lav ⁺	lav Blav	ncA
Black	lav	lav/Lav ⁺	lav/lav	

*Monohybrid Cross: Dominant / Recessive Inheritance Mode, <u>F2</u> generation Genotypic Ratio = 1:2:1 (1 Lav⁺/ Lav⁺ : 2 Lav⁺/lav : 1 lav/lav) Phenotypic Ratio = 3:1 (3 black, 1 lavender)

Breeding <u>homozygous</u> Black (Lav⁺/ Lav⁺) to homozygous Black (Lav⁺/ Lav⁺) will produce all homozygous Black (Lav⁺/ Lav⁺). Breeding homozygous Lavender (lav/lav) to homozygous Lavender (lav/lav) will produce all homozygous Lavender (lav/lav).

Other dominant/ recessive breeding combination examples are: - *Black, carrying Lavender Gene (Lav⁺/lav) paired to homozygous Black (Lav⁺/Lav⁺).* This produces 100% Black phenotype, but 50% are carrying the Lavender gene:

- 50% Lav⁺/ Lav⁺ (homozygous Black)

- 50% Lav+/lav (Black, carrying lavender)

- *Black, carrying Lavender Gene (Lav⁺/lav) paired to Lavender (lav/lav).* This produces 50% Black phenotype, 50% Lavender phenotype. All the Blacks are carrying the Lavender Poultry Genetics Theory

gene:

- 50% Lav+/lav (Black, carrying lavender)
- 50% lav/lav (Lavender)

Incomplete Dominant Inheritance

In the dominant/ recessive example, the Black, carrying lavender (heterozygote) bird is not distinguishable from the <u>homozygous</u> Black (not carrying lavender gene), as the black (wild type- Lav⁺) gene is completely dominant to the lavender gene. With <u>Incompletely Dominant</u> inheritance, the <u>heterozygote</u> gives an intermediate phenotype. For example, a splash (whitish- pale blue) bird (two doses of the Blue gene- Bl/Bl) paired to a black bird (no blue genes - bl⁺/bl⁺ -wild type) will produce an intermediate shade between the whitish/splash and black, ie- blue. The following is a punnet square example of this splash to black cross:

* First Generation cross results, using Splash & Black parents:



* <u>Incomplete Dominant</u> Inheritance Mode, F1 generation <u>Genotypic</u> Percentages = 100% Bl/bl+ <u>Phenotypic</u> Percentages = 100% Blue

Breeding these Blue (F1) birds together will produce the following offspring percentages:

- *Blue (Bl/bl⁺) paired to Blue (Bl/bl⁺):* This produces 25% Black phenotype, 50% Blue phenotype, 25% Splash phenotype:

- 25% bl+/bl+ (Black)
- 50% Bl/bl+ (Blue)
- 25% Bl/Bl (Splash)

* Second Generation cross (inbreed offspring -Blue F1 X Blue F1) results:



*Monohybrid Cross: Incomplete Dominant / Incomplete Recessive Inheritance Mode, F2 generation Genotypic Ratio = 1:2:1 (1 Bl/B1 : 2 Bl/bl⁺ : 1 bl ⁺/ bl ⁺) Phenotypic Ratio = 1:2:1 (1 splash, 2 blue, 1 black) Breeding homozygous Black (bl+/bl+) to homozygous Black (bl+/bl+) will produce all homozygous Black (bl+/bl+). Breeding homozygous Blue-Splash (Bl/Bl) to homozygous Blue-Splash (Bl/Bl) will produce all homozygous Blue-Splash (Bl/Bl).

Other incompletely dominant/ incompletely recessive breeding combination examples are:

- *Black (bl+/bl+) paired to Blue (Bl/bl+).* This produces 50% Black phenotype, 50% Blue phenotype:

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- 50% bl+/bl+ (Black)
- 50% Bl/bl+ (Blue)
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- *Splash (Bl/Bl) paired to Blue (Bl/bl⁺).* This produces 50% Splash phenotype, 50% Blue phenotype:

- 50% Bl/Bl (Splash) - 50% Bl/bl⁺ (Blue)

Sex-Linked Inheritance

Sex-Linked genes are genes on the Z chromosome. Roosters have two Z chromosomes and hens have only one Z chromosome, plus one W chromosome. As the hens only have one sex-linked allele for any given locus, both dominant and recessive sex-linked genes are expressed with just one gene (as <u>hemizygous</u>).

If the sex-linked recessive allele is homozygous in the male, and the sex-linked dominant allele is found in the female, all offspring males will inherit the sex-linked dominant gene from the mother, and all offspring females will inherit the sex-linked recessive gene from the fathers. The following is a punnet square example of a sex-linked cross, where all offspring females are the colour of the father and all offspring males are the colour of the mother. The recipricol cross (ie parent males with sex-linked dominant genes, parent females with sex-linked recessive gene) doesn't work the same, as all offspring will have the dominant gene.

* First Generation cross results, using Gold male & Silver female parents:



*Sex-Linked Dominant / Recessive Inheritance Mode, F1 generation Genotypic Ratio = 1:1 (1 s⁺/ S : 1 s⁺ /-) Phenotypic Ratio = 1:1 (1 silver- all males, 1 gold. all females)

* Second Generation cross (inbreed offspring -Silver F1 X Silver F1) results:



*Sex-Linked Dominant / Recessive Inheritance Mode, F2 Generation Genotypic Ratio = 1:1:1:1 (1 S/S : 1 S/- : 1 s⁺/ S : 1 s⁺/-) Phenotypic Ratio = 1:2:1 (1 silver females, 2 silver males, 1 gold females) or Colour only Phenotypic Ratio = 1:3 (1 gold, 3 silver)

Breeding homozygous gold (s⁺/s⁺) to hemizygous gold (s⁺/-) will produce all homozygous/hemizygous gold (s ⁺/s⁺ or s⁺/-). Breeding homozygous Silver (S/S) to hemizygous Silver (S/-) will produce all homozygous/ hemizygous Silver (S/S or S/-).

Other sex-linked breeding combination examples are:

- Silver, carrying Gold (S/s^+) rooster paired to Gold $(s^+/-)$ hen. This produces 50% Silver phenotype, 50% Gold phenotype, in both genders:

- 25% S/s⁺ (Silver males, carrying gold)
- 25% S/- (Silver females)
- 25% s⁺ /s⁺ (Gold males)
- 25% s⁺/- (Gold females)

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- *Silver (S/S) rooster paired to Gold (s+/-) hen.* This produces 100% Silver phenotype in both genders:

- 50% S/s⁺ (Silver males, carrying gold)
- 50% S/- (Silver females)

Dihybrid and other Multiple Mutation Crosses

When more than one mutation is in the equation, punnett squares become cumbersome. This is where the "Product Rule" comes in to play.

Product Rule: prob(a and b) = p(a)p(b)

*which, in simple terms, is determined by finding the probability of each segregation that may occur in a pairing, then multiplying the probabilities together. For example, if it is determined that 1/4 of offspring will be Lavender, and 1/4 of offspring will be Mottled, it's a simple matter of multiplying the probabilities together to find the probability of segregating both Lavender and Mottled in an individual:

1/4 (Lavender) X 1/4 (Mottled) = 1/16 Lavender Mottled

Two mutations



*Two Mutations, Dominant / Recessive Inheritance Mode, F1 generation Genotypic Percentages = 100% Lav⁺/lav Mo⁺/mo



*Dihybrid Cross: Dominant / Recessive Inheritance Mode, F2 generation Phenotypic Ratio = 9:3:3:1 (9/16 black, 3/16 black mottled, 3/16 lavender, 1/16 lavender mottled)

Dihybrid Genotypes:

Dihybrid Cross: Two Mutations				
F2 Ge	enot	ype	s	
FI Black X FI Bla	nch =		4	
Lav+/lav Mo ⁺ /mo Lav ⁺ /lav	Mo ⁺ ∕mo		Ring	r -
and the second	Mot	Mo	mo	mo Lav ⁺
Mo ⁺	Mo ⁺ Mo ⁺		Mo ⁺ mo	Mo ⁺ mo
Lav ⁺	Lav ⁺ Lav [†]	Lav ⁺ lav	Lav ⁺ lav	Lav ⁺ Lav ⁺
	Мо ⁺ Мо ⁺	Mo ⁺ Mo ⁺	Mo ⁺ mo	Mo ⁺ mo
	tav Lav	lav lav mo Mo ⁺	lav lav mo mo	mo mo
tav	lav Lav	lav lav	lav lav	lav Lav+
Black Two Lav+	mo Mo ⁺ Lav ⁺ Lav	mo Mo ⁺ Lav ⁺ lav	mo mo Lav ⁺ lav	mo mo Lav ⁺ Lav ⁺

*Dihybrid Cross: Dominant / Recessive Inheritance Mode, F2 generation Gametic Ratio = 1.1.1.1 (ie 1/4 Mo⁺ Lav⁺, 1/4 Mo⁺, lav, 1/4 mo lav, 1/4 mo Lav⁺) Genotypic Ratio = 1:2:1: 2:4:2: 1:2:1

- 1 Mo⁺/Mo⁺ Lav⁺/ Lav⁺ - 2 Mo⁺/Mo⁺ Lav⁺/ lav
 - $-1 \text{ Mo}^+/\text{Mo}^+ \text{ lav}/\text{lav}$
- 2 Mo⁺/mo Lav⁺/ Lav⁺ - 4 Mo⁺/mo Lav⁺/ lav
 - $-2 \text{ Mo}^+/\text{mo} \text{ lav} / \text{lav}$
- 1 mo/mo Lav⁺/ Lav⁺
- 2 mo/mo Lav+/ lav
 - 1 mo/mo lav/lav

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Linkages

- <u>Linkages</u> occur where loci do not assort independently. Generally loci do assort independently, with crossover events common (eg, the recessive white gene assorts independently from the Pea Comb gene, as no linkage between their loci). For there to be a linkage between loci, they must be on the same homologous chromosome and in close proximity (less than 50 map units). Linked loci crossover less than 50 percent, as once they reach this distance, they assort independently. It is not uncommon for loci to assort independently of others even if on the same chromosome, as chromosomes can be very long and obtain many loci. For example, the S- Silver locus is not linked with the B - Barring locus, as over 50 map units apart on the Z chromosome.

The distance between the loci is measured in map units (centiMorgans) and is determined by the following equation:

100 X Number of Recombinants Number of Offspring = % of recombinants

* 1 map unit, or 1 centiMorgan is equal to 1% recombination

* The smaller the percentage of recombinants, the smaller the map distance between two loci.

The usual prediction in F1 X F1 dihybrid crosses is 1:1:1:1 gametic ratios (eg 1/4 Mo⁺ Lav⁺, 1/4 Mo⁺ lav, 1/4 mo lav, 1/4 mo Lav⁺ as in the previous dihybrid example with lav (Lavender) and mo (mottled) heterozygotes), ie 25% for each gametes:



*Phenotypic Ratio = 9:3:3:1 (9/16 black, 3/16 black mottled, 3/16 lavender, 1/16 lavender mottled) (56.25% black, 18.75% black mottled, 18.75% lavender, 6.25% lavender mottled)

-but the ratios with linked loci are different, depending on map distance, eg if the lavender locus & mottled locus had 10% linkage, & parental birds were P1: Mo⁺-Lav⁺ plus P2: mo-lav linkage, the F1 X F1 dihybrid crosses gametic ratios would be:

-45% Mo⁺ Lav⁺, 5% Mo⁺ lav, 45% mo lav, 5% mo Lav⁺

Dihybrid Cross- 10% Linkage F2 Genotypes						
FI B	lach X	FIL		=		
			45% ^{Mo⁺} Lav ⁺	5% Mo ⁺ lav	45% mo	5% mo
Mo ⁺ =	45%	Mo ⁺ Lav ⁺	20.25% Mo ⁺ Mo ⁺ Lav ⁺ Lav ⁺	2.25% Mo ⁺ Mo ⁺ Lav ⁺ lav	20.25% Mo ⁺ mo Lav ⁺ lav	2.25% Mo ⁺ mo Lav ⁺ Lav ⁺
mo = mottled	5%	Mo ⁺ lav	2.25% Mo ⁺ Mo ⁺ lav Lav ⁺	0.25% Mo ⁺ Mo ⁺ Iav lav	2.25% Mo ⁺ mo lav lav	0.25% Mo ⁺ mo lav Lav ⁺
lav = lavender Lav ⁺ = black	45 %	mo lav	20.25% mo Mo ⁺ lav Lav ⁺	2.25% mo Mo ⁺ lav lav	20.25% mo mo lav lav	$\frac{2.25\%}{mo mo}$
	5%	mo Lav ⁺	mo Mo ⁺ Lav ⁺ Lav	mo Mo ⁺ Lav ⁺ lav	mo mo Lav ⁺ lav	mo mo Lav ⁺ Lav

* Note, the above is an example only. The lav locus is NOT linked to the mo locus.

*Phenotypic % = 90 % P1 & P2 parental phenotypes, 10% crossovers (70.25% black, 20.25% lavender mottled, 4.75% black mottled, 4.75% lavender) Phenotypic ratio = 14:4:1:1 (14/20 black, 4/20 lavender mottled, 1/20 black mottled, 1/20 lavender)

A real example of close linkage is between the P (pea comb) locus from the O (Blue egg-shell), approximately 5 map units apart. Therefore, recombinants occur 5 % of the time. This is determined by crossing P-O P-O (pea-combed, blue egg-shell) X p+-o+ p+-o+ (single-combed, non-blue egg-shell) (or the opposite, crossing P-o+P-o+ with p+-O p+-O), then breeding the F1 dihybrid offspring together. "Recombinants" is the total of both crossover segregates, ie both P/P o+/o+ (P-o+ P-o+) pea combed, non-blue egg-shell and p+/p+ O/O (p+-O p+-O) single combed, blue egg-shell) offspring (or with the second pairing, segregating F2 P-O P-O & p+-o+ p+-o+, as crossovers can occur both ways). So the number of single-combed blue egg-shell recombinants is half, ie 2.5% (2.5 in every 100 F2 offspring).

Sex-Linked, Linked Loci

It is also possible for linkages to occur on the Z chromosome, ie both sex-linked & linked loci. As only males in avian species have a homologous set of sex chromosomes (ie, only males have two Z chromosomes), crossovers can only occur with males.

For example, if the mo & lav loci were on the Z chromosome (ie sex-linked), with a 10% linkage, the following results would occur:

Sex-linked & - 10% Linkage F2 Genotypes				
Dihybrid Black male X Black female = Lav+- Mo ⁺ Lav-mo				
			50% ^{Mo+} Lav ⁺	50% W
Mo ⁺ = non-mottled	45%	Mo ⁺ Lav ⁺	22.5% Mo ⁺ Mo ⁺ Lav ⁺ Lav ⁺	22.5% ^{Mo+} Lav ⁺ W
mo = mottled	5%	Mo ⁺ lav	2.5% Mo ⁺ Mo ⁺ lav Lav ⁺	2.5% Mo ⁺ W lav
lav = lavender Lav ⁺ =	45 %	mo lav	22.5% mo Mo ⁺ lav Lav ⁺	22.5% mo lav
bruck	5%	mo Lav ⁺	2.5% mo Mo ⁺ Lav ⁺ Lav ⁺	2.5% mo Lav ⁺ W

* Note, the above is an example only. The lav locus is NOT linked to the mo locus, & both are autosomes, NOT sex-linked.

Phenotypic Ratio = 95 % P1 & P2 parental phenotypes, 5% crossovers:

- 50% black males

- 22.5% black females, 22.5% lavender mottled females, 2.5% black mottled females, 2.5% lavender females

Once again, the crossover frequency for any two genes is determined from breeding results, but the fact that crossovers only occur with the males (with 2 Z chromosomes), this needs to be taken into consideration with the calculations. The daughters obtain their Z chromosome from the fathers, the reason why the crossovers are expressed in the females, with the above example. In the above example, since black mottled & solid lavender female offspring can only be produced if crossover occurs, you would record the number of this type offspring produced, divide this number by the total number of offspring, times by 100 (for percentage), then multiply this number by 2 to determine the total crossover rate in percentage. The female recombinant percentage is multplied by two, to obtain the total recombinant rate for both males & females:

eg, if 200 chicks hatched, with 5 females black mottled, 5 females solid lavender:

Step		5 black mottled & 5 lavender	
1:		females	
	100 X		= 5 % recombinants

200 offspring



Epistasis Dihybrid Inheritance Modes

Epistasis is where gene expression is affected by a gene from another locus. As noted above, usually the F2 offspring from a dihybrid pairing (genes not linked) segregate to the phenotypic ratio of **9:3:3:1**. Where there is epistasis, this phenotypic ratio changes, eg:

- Dominant Epistasis: 12:3:1
- Recessive Epistasis: 9:3:4

* Therefore, the dihybrid ratios can be used to determine whether epistasis is affecting inheritance.

Dominant Epistatis Inheritance:

The following diagram is of Dominant Epistatis inheritance, ie E is epistatic - & masks expression of Co (hypostatic). The Columbian gene - Co (on its own - ie no Db, etc) is not expressed on the E, ER alleles (regardless that Co is a dominant gene), but Co expresses the Columbian phenotype on eWh, e+, eb, ey, etc alleles.



* Note the above is not taking into consideration eumelanisers, nor incomplete dominance of E to eWh, etc, ie, the "black" phenotype in some may actually be closer to Brown Red/Grey phenotypes, etc depending on what other modifiers are present.

Recessive Epistatis Inheritance:

The following diagram is of Recessive Epistatis inheritance, ie Recessive white (c) is epistatic -masks all other plumage colours when homozygous, although a recessive gene:



Variable Expressivity & Reduced Penetrance

These two are totally different concepts, with different statistical results. "Variable Expression" complies with expected inheritance ratios, & only relates to variance of phenotype in a bird, compared to his/her mates with the same genotype (eg light gold to dark gold variance, but all (100%) of birds with the same genotype expressing some shade of gold). "Penetrance" refers to how many (%) of the population that express the expected phenotype of a specific genotype, ie more to do with probabilities & the fact that some mutations don't always express (eg some birds of the population with gold gene, not expressing any gold at all). Some mutations/genotypes have both variable expression & reduced penetrance. Hopefully the following definitions & diagram will be clearer:

Definitions from "Genetics and Evolution of the Domestic Fowl" (by Lewis Stevens, 1991).

quote:

Expressivity:

The range of phenotypes expressed by a given genotype under any given set of environmental conditions.

Penetrance:

The proportion of individuals of a specified genotype that show the expected phenotype under a defined set of environmental conditions.



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Poultry Mutations Sub-Menu 1

..... Mutation descriptions, within Categories: E Locus: Eumelanin Enhancers: Eumelanin Restrictors (Columbian Restrictors): Secondary Pattern Genes: Eumelanin Diluters: Pheomelanin Intensifiers & Diluters:

> URL: http://home.ezweb.com.au/~kazballea/genetics/mutations1_print.html Last updated: 27 Oct., 2007

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 and "Old English Bantam Club of America" websites, and have been given with permission by the website administrators.
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This section became quite large, so I've divided the mutation section into three pages: Mutations: <<<u>Page 1</u>>><<<u>Page2</u>>><<<u>Page3</u>>>

- Page 1: Feather Colour/Pattern mutations
- Page2: Leg/Skin, Eye and Ear-Lobe Colour, plus Physical Mutations
- Page 3: Genes Tables

Mutation descriptions, within categories:

Plumage Colour/Pattern genes

- Primary Pattern e locus (E, E^R, E^R- Fayoumi, e^{Wh}, e⁺, e^b, e^s, e^{bc}, e^y, e^q)
- Secondary Pattern genes (Pg, Ml, Db, mo, B, B^{Sd}, Er, Co)
- Eumelanin enhancers (extending black areas, Ml, Cha)
- Eumelanin restrictors (Columbian restrictors, restricting black areas, Co, Db)
- Eumelanin diluters (Bl, lav, I, I^D, I^S, choc, c)
- Pheomelanin intensifiers (red enhancers Mh, Dk1, Dk2)
- Pheomelanin diluters (gold diluters S, Di, Cb, ig,)

Feather mutations

- Feather types (frizzle, silkie, soft feather, hard feather)
- Feather placement (foot feathers, stubs, vulture hocks, crest, ear tufts, muff/beard, naked neck, nakedness)
- Feather rate of growth (slow feathering, tardy)
- Tail & saddle (rumpless, long tail- non-moulting, 8 main tail feathers, wry tail, henny feather)

Leg/Skin colour

- Id locus
- White/yellow W locus
- Sex-linked white/yellow
- Plumage colour influences (dominant white, mottled, sex-linked barring)

Eye Colour & ear lobe colour

- Eye colour (Sex-linked brown, pearl)
- Ear lobe (turquoise, white, Spanish, red)

Physical Mutations

- Comb types (single, pea, rose, buttercup, breda, duplex, rough, sprigs)
- Spurs (multiple spurs, hen spurs)
- Toes (5-toe, Brachydactyl, etc)
- Leg length (creeper gene, Cornish gene)

Size Mutations

• Sex-linked Dwarfing, bantams genes, etc

The E locus Chicken/Down Colour Pattern

Below are the E locus genes.

Genes: E, E^R, E^R- Fay, e^{Wh}, e⁺, e^b, e^s, e^{bc}, e^y, e^q

Gene names: Extended Black, Birchen, Fayoumi Birchen, Dominant Wheaten, wild type, Brown, Speckled, Buttercup, Recessive Wheaten, Queen Silvia

Phenotypes: Black, Brown Red, Brown Red, Wheaten, Black breasted Red (salmon breasted hens), Brown (brown breasted hens), Speckled, Buttercup, Clay Wheaten, Queen Silvia.

* note: "E^R- Fay" is not recognised nomenclature for the Fayoumi Birchen allele, only used here for short hand purposes. Smyth (1994) listed a Birchen allele as E^{RB}, the RB standing for **''red-brown downed birchen''**. Possibly this is the Birchen allele found in Fayoumi fowl.



Above are the typical e locus down patterns, without columbian-like restrictors (except maybe e^{bc} chick-Db). Columbian (Co) will change the appearance of e^+ & e^b down (usually adds eumelanin pigment, particularly on the back), but not E, E^R & e^{Wh} (although e^{Wh} with Co are changed to a buff colour if sex-linked gold is present, but remain cream if sex-linked silver). Both E & E^R down are indistinguishable, with variation from all black (eumelanin) to black with white as shown above.

The E locus is important to learn with poultry genetics. The common E locus alleles are:

- E (Extended Black) –black/cream day-old chicks, adults predominantly black, but may have some pheomelanin (silver or gold) areas in hackles.
- E^R (Birchen)- black/cream day-old chicks, adults predominantly black, but may have more pheomelanin (silver or gold) areas in hackles, wing bows, etc.
- e^{Wh} (Dominant Wheaten)- cream day-old chicks, adult male Black Breasted Red, adult hen wheaten.
- e⁺ (Wild type) dorsal stripes & eye stripe- day old chicks, adult male Black Breasted Red, adult hen salmon-breasted.
- e^b (Brown) brownish day-old chicks, adult male Black Breasted Red, adult hens brown breasted stippling.

The E locus alleles produce the base primary colour/patterns to which varieties are build upon. The e⁺ allele is the wild -type, and produces the typical Black Breasted Red male- salmon breasted female phenotypes (as found in the Red Jungle Fowl, etc). All male phenotypes, except E & E^R, have the Black Breasted Red colour/pattern.

* Images used in the following photos are from <u>Feathersite</u>, and the <u>OEGBCA</u> website.



* Wild type e⁺ adult plumage and chick down



* Wheaten e^{Wh} adult plumage and chick down


* Brown e^b adult plumage and chick down



* Birchen E^R adult plumage and chick down

It is a recent occurrence the DNA sequencing of two Birchen alleles, as once previously thought of as only one allele - ie E^R Birchen. The following is a direct quote from Dr Ron Okimoto on the Extended Black and two Birchen alleles (quote from <u>Polish Chickens</u> - A Discussion of E - extended black):

Dr Ron Okimoto......" We have found three different alleles of the melanocortin 1 receptor locus (MC1-R) that produce black downed chicks on an otherwise wild-type background. Our data indicates that the MC1-R gene is the E locus. The most dominant allele at this locus is the E extended black allele. It differs

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from wild-type e+ by two mutations that change the amino acid sequence of the gene (Met71Thr and Glu92Lys). The Leghorn birchin allele we call E^R only has the Glu92Lys mutation and lacks the Met71Thr. Our hypothesis is that you need both mutations to get the blackest bird and that if you have only the Glu92Lys you end up with the birchin black phenotype. There is a third E^R allele that is found in Fayoumi. The Fayoumi birchin allele has a totally different mutation (Leu133Gln).

The most dominant E allele has varied expression in down color. Some chicks are black with gray bellies, and other show varying amount of cream color on their undersides. This color seems to be due to other genes than the E locus because I get both types of chicks with the most dominant E allele."

The following is another direct quote from Dr Okimito, first discussing the E and E^R alleles, then $e^b \& e^{Wh}$ (quote from The Classroom @ The Coop -<u>Different Kinds of Black</u>):

Dr Ron Okimoto......"At the molecular level these alleles seem to be related. Birchin was probably the first mutation. It has the same mutation that causes black fur in some mouse lines. The E allele probably came second in addition to the birchin mutation the E allele has a second mutation at the same position that causes black wool in sheep. So the E allele has a double whamy that produces more black than the birchin mutation by itself can. The e^b allele has a third mutation. This just means that there was a bird with the E allele and it mutated to the e^b allele. This third mutation seems to be unique among animals and appears to act to attenuate the E allele so that the birds aren't black, but brown.

The wild-type e⁺ allele has none of these mutations. The dominant wheaten allele has a unique mutation that separates it from e⁺. I haven't found a recessive wheaten allele yet. All wheaten samples that I've tested look identical to dominant wheaten. This may mean that the guys that claimed that other modifiers determined the dominance of wheaten may be correct."

The following is direct quote from Dr Okimoto on the DNA sequencing of E locus allele from the Silician Buttercup breed, by Leif Anderson. This indicates that the Buttercup pattern may be produced with the e^b allele in combination with other modifying genes, and that the ebc allele had not been sequenced.

Dr Ron Okimoto (quote from <u>The Classroom @ The Coop</u>)" Leif Andersen has sequenced the buttercup allele (e^{bc}) and it is the identical sequence to the eb alleles that I've sequenced in Partridge Rocks and the Smyth Brown line. If there is a difference between the alleles it is in the regulation of the gene and not in the coding sequence. There may be linked genes that affect the expression of the E locus too."

Further research by Dr Okimoto (quote from <u>Classroom @ The Coop: Blue & E/ or ER/</u>, posted May 02, 2006)

Some of us speculated that Andalusian blue used E^R instead of E because E^R would be more amenable to secondary pattern genes like Pg. I recently tested some Andalusian Blues from McMurray. I had a mixed batch of chicks so I could only tell the gray ones as blues the blacks could have been something else. There were three gray chicks that produced gray chick feathers. Two were homozygous $E^R E^R$ and the Poultry Genetics -Mutations

third was heterozygous E E^R. My guess is that E probably causes the dark birds and that the show quality birds are probably E^{R} .

I had ordered 5 birchin Cochin bantams, but I may have gotten black Cochins by mistake because all 5 feather footed black chicks were homozygous for E and not E^R . I couldn't tell if there had been a mix up because we couldn't raise the chicks longer than two weeks in the isolation facilities. I found two weird alleles in McMurray Buff Rocks. I was looking for recessive wheaten, and it may be in those stocks. One allele has the dominant wheaten mutation, but it is coupled with the Fayoumi birchin mutation. You can speculate and infer that it might produce more black melanin than dominant wheaten.

There is another allele that has the e^b attenuating His/Pro mutation that turns the extended black allele to a brown allele, but the attenuating mutation is in the E^R sequence. My guess is that this allele produces less black than the e^b allele, how much less is anyones guess. Someone would have to cross these Buff birds out to Brown Leghorns and backcross them to Leghorns while tracking the E locus alleles and getting rid of the columbian restrictors.

In summary, there have been 7 E locus alleles sequenced:

- e⁺ (no mutations)
- E^R Leghorn (Glu92Lys) {one mutation}
- E (Glu92Lys and Met71Thr) {two mutations, sharing 1 with E^R}
- e^b (Glu92Lys, Met71Thr and His/Pro) {three mutations, sharing 2 with E}
- E^R Fayoumi (Leu133Gln)
- e^{Wh} (? -dominant wheaten mutation)

plus the following 2 alleles found in McMurray Buff Rocks:

- 1st allele: E^R Fayoumi/e^{Wh} mutations (Leu133Gln & dominant wheaten mutation)
- 2nd allele: e^b on E^R allele (His/Pro and ER mutation*)

* note, I wasn't sure if Ron meant the E^R-Leghorn mutation or the Fayoumi mutation, for the last allele.

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Eumelanin enhancers (extending black areas, MI, Cha)

* Images used in the following photos are from <u>Feathersite</u>, and the <u>OEGBCA</u> website.

These eumelanin enhancing genes are responsible for extending the typical black areas of the wild type in to the pheomelanin areas. The Brassy Back variety is a good example:



* Brassy Back variety (e+ wild type plus eumelanin enhancer)

They are also responsible for extending eumelanin in the Quail and Vorwerk varieties: both Buff Columbian based varieties:



* Quail variety (e+ wild type, Co Columbian, plus eumelanin enhancer(s))



* Vorwerk variety (e^b Brown, Co Columbian, plus eumelanin enhancer(s))

Obviously there are differing eumelanin enhancing genes/genotypes in the Quail and Vorwerk varieties, as both varieties can be produced with the base genes: e^b Brown, Co Columbian plus eumelanin enhancer(s).

Research by Campo & Oronzco indicated that the synthetic variety "Melanised Prat" (Quail phenotype) has the genotype of eWh Co Ml. Smyth segregated a possibly new dominant eumelaniser (ie not Ml, possibly Cha) from OEGB Brassy Backs. Jeffrey segregated a recessive eumelaniser in OEG Brassy Backs & Quails.

Smyth produced a Lakenvelder phenotype from an e^b line, which segregated Co and Ml, plus additional eumelanin enhancers. Once the Columbian gene was removed, he segregated e^b solid black birds. Yet e+ Quail lines usually segregate Brassy Back phenotype when the Columbian gene is removed. It also needs to be determined why Vorwerk/Lakenvelder hens have no quail-like hen markings (ie no eumelanised & laced back/wings), eg, is there another eumelanin restrictor present

in Vorwerk hens, or is the difference due to the eumelanisers present?

Eumelanin enhancing genes are also found in E solid black based varieties. The Ml gene is found in the secondary pattern varieties: Spangled & Doubled Laced and Single Laced.

Melanotic allele: MI (1971):

First described by Moore and Smyth (1971), after extracting it from a randombreeding recessive white population previously described by Jeffrey (1947). Ml is incompletely dominant autosomal mutation that extends eumelanin into the normally red areas of pyle-zoned fowl, while having little effect on the chick down colour. Heterozygotes on wild-type (e+) or brown (eb) backgrounds are distinctly darker, particularly in the hackle and head; however, Ml/ml+ has little effect on eWh/eWh females. Homozygotes approach self blackness, but the salmon pigment of the wildtype and wheaten females remain evident.

- • Ml found in the Quail pattern (Campo and Oronzco, 1986)
- • The Melanotic gene by itself does not make a wild-type bird black.

MI (Melanotic) is sex influenced, autosomal incompletely dominant gene. This means that heterozygote hens with only one dose of the black enhancer (MI/mI+) show very little pheomelanin (gold or silver) on ER (birchen) base (ie acts like a dominant gene). Whereas, heterozygote roosters with only one dose of MI (MI/mI+) show more gold on the hackles, wing bows, etc, when ER (i.e, acts like an incompletely dominant gene). MI homozygous (MI/MI) & on its own doesn't cover all pheomelanin areas on e+ & ER male birds (although covers a lot), & doesn't cover salmon areas of e + (eg, as in Brassy Backs) & eWh hens. Therefore, other eumelanin enhancers are needed to change the gold/silver areas to black (eumelanin). MI isn't expressed in day-old chick down, unless in combination with other mutations, eg eWh Co MI produces a heavily melanised chick down - research by Campo & Oronzco - Melanised Prat. Campo & Oronzco (1986) (and Campo, 1991) also noted that two doses of MI is needed to produce the dark chick down, & quail pattern in adult eWh Co birds.

Unsuccessful efforts to determine the genetic basis for certain "recessive black" lines (Punnett, 1957, Smyth, 1976) suggest the existence of more than one eumelanin intensifying mutation.

References:

Crawford, R.D (ed.)(1990). Poultry Breeding and Genetics. Elsevier, Amsterdam.

Campo, J.L. and Orozco, F. (1986) *Genetic basis of the melanotic Prat phenotype*. British Poultry Science. 27:361-367.

Campo, J.L. (1991) Use of the sex-linked barring (B) gene for chick sexing on an eumelanotic columbian background. Poultry Science. 1991 Jul;70(7):1469-73.

Jeffrey, F.P. (1947). *Plumage color genes in White Plymouth Rocks and White Wyandottes*. Poultry Sci. 26:526-528.

Moore, J.W. and Smyth, J.R. (1971). *Melanotic, key to a phenotypic enigma of the fowl*. J.Hered. 62:214-219.

Crawford (1986)- eumelanising gene 0.3 cM to Peacomb locus:

Crawford segregated a eumelanising gene, closely linked with the P (pea comb) locus, only 0.3 map units apart (from "Poultry Breeding & Genetics, 1990).

Carefoot (1990)- Linkages of MI with Peacomb locus:

Carefoot, 1990 tested linkages again of Ml (Melanotic) with P (peacomb) loci, and found the loci to be 46 map units apart. It was suggested from this evidence that two eumelanising genes were in existance, ie Crawford's eumelanising gene was different to Ml - Melanotic. Therefore, Charcoal (cha) was suggested by Dr Crawford for the recessive gene linked with P by 0.3% (Carefoot, 1990).

Smyth (1994)- Charcoal:

Smyth listed the Charcoal gene with the dominant symbol - Cha (Smyth, 1994).

Carefoot (2001)- Black Hackle of the Indian Game:

Carefoot crossed Indian Games (pea-comed, black hackled) with Barnevelders (single-combed, partially black striped hackled), to determine the genetics of the neck hackle eumelanising gene found in Indian Games. He found the black hackled eumelanising gene to be closely linked with the P (pea comb) locus, and to be a dominant gene. Therefore, Carefoot suggested the eumelaniser appearred to be allelic to, if not a further manifestation of the Charcoal gene.

*note: Carefoot mentioned in the above report that Smyth (pers. com.) investigated in Brassy Back OEGB a potentially new eumelanin extension that had a dominant charcoal effect on wild type.

References:

Carefoot, W.C. (1990) *Test for linkage between the eumelanin dilution blue (B1), the extended black (E) allele at the E-locus and the linked pea comb (P) and eumelanin extension (M1) genes in the domestic fowl.* British Poultry Science. 1990 Sep;31(3):465-72.

Carefoot, W.C. (2001) *Inheritance of the Black Hackle of the Indian Game bantam*. British Poultry Science. 2001 May;42(2):274-5.

Crawford, R.D. (1986) *Linkage between pea comb and melanotic plumage loci in chickens*. Poultry Science 65:1859-1862.

Crawford, R.D (ed.)(1990). Poultry Breeding and Genetics. Elsevier, Amsterdam.

Smyth, J.R. Jr. (1994) *Melanin Pigmentation: Its Biological Roles, Inheritance and Expression in the Chicken.* University of Massachusetts, Amherst.

Cote (1976) - Self Black Plumage:

Many examples of self black breeds, but similarity is more phenotypic than genotypic. Most are based on E or ER, but not all. Eumelanin enhancing genes found in E & ER based self blacks. Cote (1976) studied nine self black & one birchen male (1976), all carrying eumelanising modifiers. MI found in only 5 out of 9 (ie not in birchen, Black P.Rock, Blue Frizzle & Black OEG). It was linked with the black lacing gene (ie Pg) except in a Mottled Ancona that was homozygous for MI & nonlacing (pg+). Other eumelanin intensifiers were also present, even in the birchen, but they were not identified individually. None of the E heterozygotes developed solid black plumage in the absence of eumelanising modifiers. Eight of the nine males also carried eumelanin restrictors, but only 2 of these carried Co. No birds were carrying Db (tested with Db/Db and Co/Co tester lines)(ed. Crawford, 1990).

Cote's research birds.....

- 1 Mottled Ancona (EE Ml-pg+/Ml-pg+ co+/co+ Id w/w)
- 2 Exhibition Barred Plymouth Rock (EE Ml-Pg/ml+-pg+ Co/co+ Id w/w)
- 3 Meat type Barred Plymouth Rock (E/eb Ml-Pg Co/co+ Id w/w)
- 4 Blue Frizzle Cochin (EE ml+/ml+ co+/co+ Id w/w)
- 5 Meat type Blue (EE Ml-Pg co+/co+ Id W+/W+)
- 6 Black Wyandotte (EE Ml-Pg co+/co+ Id w/w)
- 7 Solid Black Plymouth Rock (E/eb ml+ Co/co+ id+/id+ w/w)
- 8 Black Old English Game (E/e+ ml+-pg+/ml+-pg+ co+/co+ id+/id+ W+/W+) (plus eumelanisers)
- 9 Birchen Modern Game (EE ml+/ml+ co+/co+ id+/id+ W+/W+)(plus one eumelanin

intensifier)

* References to Cote's research:

Cote, R.S. (1976). A genetic analysis of self black plumage color in the domestic fowl. M.S. Thesis, University of Massachusetts, Amherst.

Crawford, R.D (ed.)(1990). Poultry Breeding and Genetics. Elsevier, Amsterdam.

Jeffrey, F.P. (1976) Bantam Chickens, ABA .

Smyth, J.R. Jr. (1976) *Genetic Control of Melanin Pigmentation in the Fowl*. University of Massachusetts, Amherst.

Smyth's eb Massachusetts Recessive Black line:

Totally black, breeds true. Dark Brown down (e^b) and white undercolour in the adult males. Shanks and beaks are non-black (Smyth 1976). When crossed to e^+/e^+ and e^b/e^b , its net effect is "incomplete dominance". Three and possibly four genes are hypothesised as contributing to the non-E self black plumage (ed. Crawford, 1990).

* References: Crawford, R.D (ed.)(1990). *Poultry Breeding and Genetics*. Elsevier, Amsterdam.

Smyth, J.R. Jr. (1976) *Genetic Control of Melanin Pigmentation in the Fowl*. Proc. 25th Poultry Breeder's Roundtable (Kansas City), 69-86.

Fred Jeffrey - Old English Games & eumelanisers:

Jeffrey, 1988 – Brassy Back & Quail OEG are e^+e^+ , plus autosomal recessive eumelanin enhancer (the Quails also with Co). This eumelanin enhancer darkens the chick down significantly, and produces a purplish-black hue in the down. The Ml gene (on its own) does not change the chick down. Jefrrey produced solid black male birds with this eumelanin enhancer & wheaten, but hens were black with gold lacing.

Fred Jeffrey used the term "hypothetical ebonies" for unknown eumelanin enhancers. Other genes

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have been suggested, eg sg (eg, listed by Dr Hollander on his <u>chicken color genetics chart</u> - but used sg as a replacement for Ml)) & mi, but mi later believed by Smyth not a new gene, but the effects of Db (Smth & Malone, 1979). Db (Dark Brown, Columbian-like restrictor) is another sex-influenced autosomal gene, but this time, acts dominant in E^R males (ie, only one dose needed for expression-Db/db⁺) and recessive in females (2 doses needed for expression). You can see how this could be misinterpreted as a recessive eumelanin enhancer.

References:

Crawford, R.D (ed.)(1990). Poultry Breeding and Genetics. Elsevier, Amsterdam.

Jeffrey, F.P. (1976) Bantam Chickens, ABA .

Jeffrey, F.P. (1988) *Crow wing and recessive black in Old English Game bantams*. ABA Yearbook, Amherst, MA.

Jeffrey, F.P. & Richardson, W. (1995) *Old English Game Bantams as Bred and Shown in the United States*. ABA.

Smyth, J.R., Jr and G.W. Malone, (1979). *Evidence that plumage color genes mi and Db are identical*. Poultry Sci. 58:1108-1109 (Abstract).

Washburn, K.W., & J.R. Smyth Jr., (1967). *A gene for partial feather achromatosis in the fowl.* J. Hered. 58:130-134.

It can be difficult determining new eumelanin enhancers. Both Melanotic & Charcoal genes were identified as different, by using linkage relationships. They are both on the same chromosome, but different distances to other known loci (eg P) on the same chromosome. The Massachusetts Recessive Black line (e^b based, not E or E^R) has 3, or possibly 4 genes contributing to the all black plumage. So there are obviously more eumelanin enhancers that have not been formally described by scientists. Cote found other eumelanin enhancers, other than Ml in his studies (including in a Birchen Modern Game). E black lines usually have eumelanin enhancers also.

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Eumelanin restrictors (Columbian restrictors, restricting black

areas) (Co, Db, Mh, Di)

* Images used in the following photos are from Feathersite, and the OEGBCA website.

All these genes not only extend pheomelanin into typical eumelanin areas (Columbian restrictors), but also change the shade of pheomelanin- dilute or darken the gold at various levels.



Co -Columbian



Db - Dark Brown

The Db gene is unusual in that when homozygous, it is a very good columbian restrictor in males, yet only a partial columbian restrictor in females. The Db/Db male phenotype is black-tailed red (black-tailed silver if S/S), with e+, eb, ER, etc alleles. There is a European breed, Villafranquina (eb/eb Db/Db), which has the Black-tailed Red male & secondary patterned female phenotype. The Db gene has little effect on salmon colouring in e+ & eWh hens, diluting the colour slightly (Smyth) (Dr Okimoto's personal experience is that Db slightly intensifies the salmon shade).

The Db gene (when homozygous) significantly changes chick down pattern/colour, in all E locus alleles, except for e^{Wh} . This gene was named after its trait of modifying E^R - black down to brown shades (in some genotypes, the brown may be restricted to the head region- i.e. black body unchanged). With e⁺ and e^b, the Db gene modifies pheomelanin shade to very pale gold-brown to cream/white, & modifies dorsal striping pattern on the back & head - widens light stripes on the back, & may reduce/fade "arrow-head" stripe on the head. Juvenile pheomelanin feathers of e⁺/e⁺ Db/Db may appear at first quite pale on the body & wings, contrasting with salmon-red shades on the breast (for both males & females). In juveniles, a poor autosomal barring pattern may be observed on the top/wings, this generally fading with adult plumage (unless modifiers are present, eg Pg). The following link is of an <u>e[±]/e[±] Db/? rooster</u>, from dayold through to adulthood (note, this rooster also has other eumelanin modifiers present). Db is linked to MI - 12cM (approx 22cM to Pg & 32cM to P), i.e., the linkages in order along the

chromosome are P-32-Db-12-Ml-10-Pg.

*Note, heterozygous e⁺/e⁺ Co/co⁺ hens may appear similar in phenotype to e⁺/e⁺ Db/Db hens, ie appear similar to Ginger Red phenotype.



Mh - Mahogany

* note, the above Welsumers have characteristics similar to Mh traits, but I don't know if it has been substantiated whether this is due to the Mh gene.



Di - Dilute (& possibly eWh Co Db Mh) * note, a solid buff/red phenotype may be produced various ways. The above birds may or may not have Di (or Db), although both Mh & Di were extracted from a solid Buff Minorca bird by Brumbaugh & Hollander. This Buff Minorca bird's genotype was determined to be: e^yor e^{bc}/? Di/Di Co/Co Mh/Mh db⁺/db⁺, plus possibly Cb.

Undercolour: (by Dr Okimoto)

Wheaten has a cream feather undercolor. e+ and eb have a gray feather undercolor even in the presence of Co. eWhe+ Coco+ heterozygotes have the gray feather undercolor and birds that I have that are eWheb CoCo (I crossed a New Hamp to a Columbian Wyandotte) also have the gray feather undercolor, but it is lighter and looks more silvery than gray. If you find that your birds are eWheb and they have a white or cream feather undercolor they may have melanotic. Birds with melanotic often have a white feather undercolor, but this may be an interaction with some other genes because I don't think that they all have a white undercolor.

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Secondary Pattern Genes

(Pg, Ml, Db, mo, B, B^{Sd}, Co, Db, Erminette (Er))

Secondary Patterns based on:

Pg- Pattern gene, Ml- Melanotic, Co- Columbian, Db - Dark Brown

* Images used in the following photos are from Feathersite, and the OEGBCA website.

* Note, the following are only base genotypes. Both Smyth & Carefoot have indicated that their proposed genotypes of secondary patterned varieties (with Pg, etc) are the BASE genotypes for these varieties. They have noted what genes have segregated from test breeding (including linkage testing), but admit freely that there are other modifiers needed to produce exhibition quality birds.

Photo	Hen Phenotype	Genotype	Added mutation from previous variety
	e ^b - Brown based - stippling	e ^b e ^b	e ^b - Brown
	Concentric Pencilling	e ^b e ^b PgPg	Pg - pattern gene

	Double Lacing	e ^b e ^b PgPg MlMl	Ml - Melanotic
	Single Lacing	e ^b e ^b PgPg MlMl CoCo	Co - Columbian
	E ^R - Birchen based	ERER	E ^R - Birchen
	Autosomal Barring	E ^R E ^R PgPg DbDb	Pg, Db - Dark Brown,
SPA	Spangled	E ^R E ^R PgPg DbDb MIMI	Ml - Melanotic
	Single-laced	E ^R E ^R PgPg DbDb MIMI CoCo	Co - Columbian



The following table lists the most common secondary pattern genotypes:

* click the images to enlarge

* Images used in the following photos are from <u>Feathersite</u>, the <u>OEGBCA</u> website & Dr Corti's <u>website</u> (Erminette image).

Phene	otype	Pattern	Genotype	Breed/ Variety	Comments
e ^b (Brown) ba	sed varieties:				
		eb hens, stippling on back & body.	e ^b - plus red enhancer(s)	Dark Brown Leghorn	- plus red enhancer(s)
		Concentric Pencilling	e ^b Pg	Partridge Wyandotte Brahmas, Cochin, etc	-
		Double- laced	1: e ^b Pg Ml 2: e ^{Wh} Pg Ml Cha* 3: e ^y Pg Ml Cha*	1: Barnevelder- Dark 2 & 3: Indian Games - Dark	-both Smyth & Carefoot segregated e ^{Wh} in Indian Games/ Cornish lines, but other alleles have been noted (e ^y - Morejohn, plus wildtype & dark brown downs) *Indian Games have an extra neck eumelaniser, possibly Cha.

		Buff Columbian	e ^b Co	Buff Columbian Wyandotte, Brahma, etc	-
		Single Laced	e ^b Pg Ml Co	Gold Laced Wyandotte, Cochin, etc	-
		Melanised Co- Quail	e ^b Ml Co	Quail Belgian Barbu Bantams	also: e ⁺ Ml Co, e ^{Wh} Ml Co, or another eumelanin enhancer
		Melanised Co- Vorwerk	e ^b Co + eumelanin enhancer(s)	Vorwerk or Golden Lakenvelder	? Charcoal ? Melanotic
	Test	Black Tailed Red male- stippled hen	e ^b Db	Villafranquina	similar to Ginger Red variety (e ⁺ Db) - photos are Ginger Reds -e ⁺
The second se		Black Tailed Red male- autosomal barred hen	e ^b Pg Db	Gold Pencilled Hamburg	-

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	Black- Tailed Red male- buttercup hen	e ^{bc} or e ^b Pg Db	Silician Buttercup	Recent DNA sequencing has indicated that this variety may not be e ^{bc} , but e ^b with other modifiers
	Black Tailed Red	1: e ^{Wh} Db Co ? * possibly Mh 2: e ^y Co Mh 3: e ^{Wh} Co Mh	Black Tailed Red 1: Old English Game 2: Rhode Island Red 3: New Hampshire	This variety can be developed without Db - eg Rhode.I.Reds - red enhancers
	Mottled Buff Columbian	e ^b Co mo	Millefleur Belgian Barbu Bantams, Dutch Booted, Pekins, Speckled Sussex	-may also be e ^{Wh} , e ⁺ based

E^R Birchen based varieties:

		Brown Red	ER	Brown Red Marans	-not necessarily with gold breast lacing, as the genetics of the lacing is not known
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	Black Tailed Red male- autosomal barred hen	E ^R Fayoumi Pg Db * Smyth believed these had Co. * Carefoot found no Co in his stock (ie co +).	Fayoumi	- note, the photos are of sex-linked silver versions, not gold.
	Autosomal barred, both genders	E ^R Pg Db Hf	Campine	- henny- feathered
	Gold Spangled- both genders	E ^R Pg Ml Db	Gold Spangled Hamburg	-sometimes henny feathered - Hf
	Single Laced -both genders	E ^R Pg Ml Db Co Hf	Gold Laced Sebright -possibly Polish Laced varieties	- henny feathered
Race	Black Mottled	E ^R mo + eumelanin extenders (eg Ml)	Black Mottled Ancona	- may also be E - Extended Black based

		Laced Blue (Blue Andalusian)	E ^R Bl/bl+ Pg Ml (Co) + eumelanin extenders	Blue Andalusion	- may also be E - Extended Black based -Carefoot found Co, but Campo et. al. found co ⁺
		Non-laced Blue	E ^R Bl/bl+ + eumelanin extenders (eg Ml)	UK Blue Leghorn, UK Blue Wyandotte, Spanish Blue Andalusian, etc.	- may also be E - Extended Black based *note, this is not lav - Lavender
	N/	Sex-linked Dilution	E ^R B ^{Sd} + eumelanin extenders (eg Ml)	Californa Grey	- may also be E - homozygous B ^{Sd} /B ^{Sd} males are white.
		Sex-linked Barred	E ^R B + eumelanin extenders (eg Ml)	Cuckoo	- may also be E - Extended Black based
e+ wild type b	ased varieties:				
		Barred wild type	e ⁺ B	Crele Old English Game	-
		Mottled wild type	e+ mo	Spangled Old English Game, Mottled Brown Leghorn, etc	- Spangled also with pheomelanin enhancers

Poultry Genetics -Mutations

		Melanised wild type	e+ Ml	Brassy Back Old English Game	- may also be other eumelanin enhancers, eg Cha, etc.
Miscellaneous	s varieties:				
		Buff	eWh Co Mh Di	Buff Orpington Buff Minorca	-may also be other E locus alleles, plus Db, Cb.
		Erminette	E Er	Erminette	-Incomplete Dominant. -Er/Er are white.

Heterozygous Pg and MI on eb Co base:

Moore & Smyth (1972) found that **by itself the pattern gene caused an incomplete lace – restricted to the distal tip of the feather.** Melanotic (Ml) was required to complete the lace, with the two genes functioning dose dependently. The following diagram is based on a drawing from the following article by Smyth: *Genetic Control of Melanin Pigmentation in the Fowl* (1976).

This is what they segregated from test breeding Silver Laced Wyandottes (from memory, to an eb test line?): The following are eb Co based:



Eumelanin diluters (BI, Iav, I, I^D, I^S, choc, c)

These genes alter the eumelanin- black areas of the wild type. Some genes change both eumelanin & pheomelanin pigment (eg Lavender, Recessive White, etc).

* Images used in the following table are from <u>Feathersite</u>, and the <u>OEGBCA</u> website, except the Smoky image (from Dr Ron Okimoto), Lavender OEGB image from Al Zwick, photo also found at <u>Yahoo</u> <u>Poultry Genetics</u> website, and the sex-linked Chocolate image (breeder: Dr WC Carefoot, photo supplied

by Dr Corti, at the following <u>website</u>).

Photo	Name	Gene	Inheritance Mode	Comments
	Blue/ Splash	Bl	Autosomal Incomplete Dominant	Heterozygous- Blue Homozygous- Splash
	Lavender	lav	Autosomal Recessive	Also dilutes pheomelanin
	Dominant White	Ι	Autosomal Incomplete Dominant	Fades pheomelanin when homozygous, but not with one dose.
	Dun	ID	Autosomal Incomplete Dominant	One dose darker than two doses. Allelic to I

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	Sex- linked Chocolate	choc	Sex-Linked, recessive	Changes black- eumelanin to a chocolate-brown shade
	Recessive White	c	Autosomal recessive	Changes both pheomelanin & eumelanin to white

Miscellanous Eumelanin inhibitors/diluters:

Recessive White Locus:

Recessive White (c) relates to Tyrosinase in chickens.

There are a few alleles on the c locus, eg c, c^{re}, c^a

- Recessive White (c),
- Recessive White -Red Eyed (c^{re}),
- Albinism (c^a)

The c^{re} have very dark red eyes, usually only noticable by shining light into the eyes. The typical

recessive whites - c have dark eyes.

Sex-Linked Silver Locus (sal mutations):

There is also a sex-linked imperfect albinism (s^{al}) mutation, proposed to be on the S (silver) locus. This one changes eye pigment to pinkish- through to red. E birds, both down & adult plumage, are changed to "light greyish tan", while red columbian birds -down is changed to "creamy", with adults "tinge with red". Order of dominance on the S locus is: S, s⁺, s^{al}, i.e. s^{al} is recessive to the wild type sex-linked gold gene. Silversides & Crawford (1991) also noted another allele, a mutation that occurred at the University of Saskatchewan, i.e sex-linked imperfect albinism: S^{al-s}

Both c^a and s^{al} albinos have health associated problems (eg, eyesight problems, higher embryo mortality rates, etc).

References:

Crawford, R.D (ed.)(1990). Poultry Breeding and Genetics. Elsevier, Amsterdam.

Silversides F.G, Crawford R.D. (1991). *Phenotypic, embryonic, and neonatal effects of a gene for sexlinked imperfect albinism* (*Sal-s*) *in chickens.* Poult Sci. 1991 Jun;70(6):1306-13.

Pink Eye (pk):

An autosomal recessive gene. Eye colour appears pink and the plumage colour appeared blue in the birds studied by Warren (1940). The mutation was first found in White Plymouth Rocks by Warren, and later found in another flock of White Plymouth Rocks by Roberts et. al., in 1952. The mutation doesn't appear to modify pheomelanin.

References:

Crawford, R.D (ed.)(1990). *Poultry Breeding and Genetics*. Elsevier, Amsterdam. Hutt, F (1949) *Genetics of the Fowl*".

Grey:

The following description from "Poultry Breeding & Genetics".

"Grey: - autosomal recessive, dilutes black to light to dark brownish-grey. In older birds, the colour bleached to a dirty yellow."

Reference:

Erasmus, J.E., & Liebenberg, C.R. (1958). A New Mutant in Feather Colour of the South African Black Australorp. S. Afr. J. Agric. Sci. 1:227-230.

The mutation occurred in South Africa.

Dun (I^D) and Sex-linked Chocolate (choc):

There are at least two different genes that give a chocolate phenotype, ie Dun (I^D) and Chocolate (choc). Here is a little history on Carefoot's Chocolate Orpingtons.. * translated from Italian -Dr Corti's website Vol 3 -V 12. Cioccolato quote:

The change chocolate in the chicken was observed for the first time in 1994, and precisely from Clive Carefoot in its breeding - - -. In 1996 Carefoot it confided an its large disappointment: although had wanted to put itself repeatedly in contact with an Australian breeder than perhaps had observant in the chicken the same change, not ever some ricevette reply. The disappointment was had to to the fact that Carefoot did not want absolutely to attribute itself the fatherhood of a verification already done from other.

So the chocolate gene is a relatively new mutation, first observed by Carefoot in 1994. As the chocolate gene is sex-linked recessive, it will breed true to type. Yet the Dun gene (I^D) is similar to Blue (Bl), ie incompletely dominant, where heterozygotes (I^D/i^+) produce a darker Dun colour, yet the homozygotes (I^D/I^D) produce a much paler Dun colour. The Dun genetics are explained at <u>MSN Polish Chickens</u> website:

The difference in Dun expression are shown in the OEGB varieties: <u>OEGB: Fawn (Dun homozygote I^D/I^D)</u> Fawn Silver Duckwing (Dun heterozygote I^D/i[±])

Dan has written an article at S.P.P.A, explaining the differences between Dun & Blue: <u>http://groups.msn.com/SPPA/dunvsblue101.msnw</u>

Dun seems to have variation in expression, from bluish-dun to a hint of chocolate in others. The following Fawn Breasted Red OEGB appears more blue than chocolate, yet another example of heterozygous I^D. Fawn Breasted Red OEGB (Heterozygous ID/i+)

* Dr Okimoto has mentioned in the past that red enhancers may modify Dun expression.

The Dun gene is an allele of the Dominant White (I) locus. The Dun gene (I^D) is found in various breeds in the US, but unfortunately given several different variety names, eg "Fawn" in OEGB, "Chocolate & Khaki" in Polish, "Dun" in Wyandottes, etc. So the reference to "Chocolate" in Dun Polish, etc may cause some confusion in the future, if/once the sex-linked Chocolate (choc) stock becomes available for distribution (I'm not aware if Dr Carefoot has released stock to date). Going by the photos I've seen of Chocolate Orpingtons & Dun birds, the Chocolates (choc) seem to have a glossy sheen to them & a richer chocolate colour (no slate-dun shades, as found in I^D). * P.S. I'm not aware of what chocolate-like birds in Australia that were referred to by Carefoot. There are brown breasted birds, eg "Brown Breasted Brown Reds", "Brown Breasted Birchen Duckwings" etc, that are a dull mustard brown shade. But I haven't been able to find out their genetics. It doesn't appear like the colour of Carefoot's Chocolate Orpingtons. I've also seen brown laced gold birds in Australian Pit Game Bantams, I imagine the same brown breasted gene(s) involved. The following is a Brown-breasted Brown Red (?) Australian Pit Game Bantam:



Pheomelanin Intensifiers and Diluters

* Images used in the following examples are from <u>Feathersite</u>, and the <u>OEGBCA</u> website.

The following groups influence the ground colour (pheomelanin), at various levels:

- S locus (Sex-linked Gold or Sex-linked Silver),
- Pheomelanin Diluters (eg. Cream, Dilute, Champagne Blonde, etc)
- Red Intensifiers (eg. Mahogany, Dk, Dk1, etc)
- Eumelanin Restrictors (eg. Columbian, Dark Brown, Dilute, Mahogany, etc)
- Eumelanin diluters (eg. Dominant White, Lavender, Blue)
- Slow feathering genes (K is believed to intensify red)
- E locus (eg, Wheaten alleles tend to be intensified more than other alleles when in combination

with Mh)

• Hormonal influences (eg, females darken as they age, & in some instances remain darker than roosters)



* Left: Black, Middle: Blue- Bl, Right: Lavender- lav

I've noticed the blue gene seems to dilute the pheomelanin ground colour some, but not to the extreme of homozygous Dominant White or Lavender. Heterozygous Dominant White (I/i+) doesn't change pheomelanin, but homozygous Dominant White fades the expression of pheomelanin. Lavender (lav/lav) dilutes the expression of pheomelanin dramatically to a straw-cream shade.

Columbian Restrictors :



One other point is the influence of columbian restrictors on gold. The Columbian gene lightens the red of the wild type (eg Black Red- partridge, or Black Breasted Red) to an orangy colour. Yet the Dark Brown gene tends to keep the pheomelanin a richer burnt orange-red colour.

Red Intensifiers:

Mh (Mahogany) characteristics;



- -incompletely dominant
- -a partial eumelanin restriction, especially in back, breast & wing plumage (male homozygote resembling the spangling pattern on breast),
- -down colour not effected (eg, pheomelanin not darkened in chicks),
- -1st isolated from Buff Minorcas.

Dk, Dk1 characteristics (proposed by Kimball, 1955, but not substantiated):



- An allelemorphic series (ie, all alleles on the same locus)
- -Dominant
- Dk present in Spangled Game, Partridge varieties & Dark Cornish (Indian Games)
- Dk1 present in Dark Brown Leghorns

Gold Diluters:

Sex-linked Silver:



* Sex-linked Silver on e⁺ wild type

The Sex-linked Silver gene (S) changes most of the pheomelanin (gold-red) of the wild type phenotype to silver-white, except for the salmon breast of the hens. This gene is incompletely dominant in the males.

Di (Dilute) characteristics;



*note, the above pheonotype is an accumulation of columbian-like restrictors (eg, Co, & other possibilities such as Di, etc)

- -incompletely dominant
- -dilution of pheomelanin in adult plumage (gold-red)
- -dilution of chicken down (in pheomelanin),
- -reduction of lateral stripes on wild type down (stripes remained in the head & eye area),
- -dilution of dermal pigment (id+), &
- -a partial eumelanin restrictor.

Cb (Champagne Blonde) characteristics;

- -dominant
- -might have a close linkage with Columbian,
- -not supposed to dilute down (pheomelanin) &
- -no change to down pattern.

* It appears there was a mix up at one stage, as both Carefoot & Jeffrey printed the gene as recessive, yet it is believed to be dominant by the researchers who segregated Cb.

ig (Inhibitor of Gold - Cream) characteristics;



- -recessive,
- -no effect on eumelanin
- -generally males show a greater dilution of pheomelanin than females
- - Smyth has noted that it doesn't dilute down (pheomelanin)

* The British Poultry Standards of the Cream Legbar chicken down (says to refer to the Silver Legbars for description), suggests the down is diluted dramatically. So it would be interesting to read Punnett's & Taylor's research, to see if a description is given for ig chick down.

*A gold diluted phenotype in my d'Uccles, looks very similar to the cream (ig) phenotype in European d'Uccles (ie, Lemon/Citron Millefleur), although the roosters have adult plumage similar shade of gold to the hens (ig males are lighter silvery/gold phenotype to the gold females). But in my d'Uccles the chick down (pheomelanin only) is diluted dramatically (appearing very similar to silver).



The first feathers appear silvery/very light-gold but darken into patches of gold (see below) at about 3 months on - and into a more even shade of lemon (similar to European Citron Millefleur) at adulthood.



The gold diluter has no effect on id+ slate/blue leg colour, and appears to be a recessive gene.

Kimball (1955) reported another recessive gold diluter (isolated from lemon-buff & pale gold-laced Wyandottes) that is believed different to ig.

Poultry Mutations Sub-Menu 2

..... Leg Colour :
..... Eye Colour & Ear lobe Colour:
..... Feather types- Frizzle, Silkie, Hard feather:
..... Foot Feathers, Stubs, Vulture Hocks:
..... Crest, Ear Tufts, Muff/Beard, Naked Neck:
..... Slow/Late Feathering, Tardy:
..... Long tail, Rumpless, 8-main tail, Henny:
..... Comb Types:
..... Toes & Spur Mutations:
..... Short-legged Genes:
..... Dwarfism Mutations:

URL: http://home.ezweb.com.au/~kazballea/genetics/mutations2_print.html Last updated: 29 May, 2007

* Most of the photos on this website originated from "Feathersite",
and "Old English Bantam Club of America" websites, and have been given with permission by the website administrators.
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This section became quite large, so I've divided the mutation section into three pages: Mutations: <<<u>Page 1</u>>><<<u>Page2</u>>><<<u>Page3</u>>>

- Page 1: Feather Colour/Pattern mutations
- Page2: Leg/Skin, Eye and Ear-Lobe Colour, plus Physical Mutations
- Page 3: Genes Tables

Leg Colour Genetics

The gene responsible for white skin is "W⁺". It is a dominant gene. The gene "w" is the yellow skin gene, recessive to white. These gene alleles affect the "epidermal-outer layer", therefore influence shank/sole colour. The "dermal-under layer" influence to shank colour is determined by the gene alleles "Id" (no pigment) & "id⁺" (dermal-black pigment). The dermal genes are sex-linked.

The combination of both dermal & white/yellow skin genes alone can produce the following :

Shank colour	Dermis	Epidermis
White	none (Id/Id)	white (W ⁺ /W ⁺)
Yellow	none (Id/Id)	yellow (w/w)
Green (Willow)	black (id+/id+)	yellow (w/w)
Slate/Blue	black (id+/id+)	white (W^+/W^+)
Black	black (id+/id+)	white (W^+/W^+)

* I have modified the above table from Jeffrey, F. (1977) "Bantam Breeding & Genetics" book.

Another influence to shank colour is the gene Fm (Fibromelanosis). This dominant gene is responsible for the dark flesh colour of the Silkie fowl.



This is a very simple explanation on the genetics. Unfortunately, there is much more, as "plumage colour genes" can influence shank colour significantly. Another major influence on epidermal pigment shank colour is the E (Extended Black) gene, and to a lessor degree - ER (Birchen). These genes enhance black extension on to the epidermal layer.

Plumage Colour Influence:

Diluters of black shank colour: Blue (Bl/bl), Splash (Bl/Bl), Recessive White (c/c), Mottling (mo/mo), Dominant White (I/I), Gold Dilute (Di/Di), Barring (B/B)

Enhancers of black shank colour: Extended Black (E/E), Birchen (ER/ER)

Enhancers of horn shank colour: Red/gold plumage



* Above: Recessive White, Blue & Black birds, all E^R (birchen) & White skinned (W⁺/W⁺).

I'll give a few examples:

Shank colour	Dermis	Epidermis	Plumage colour
White	black (id/id)	white (W/W)	cuckoo (B/B), D. White (I/I)
Yellow	none (Id/Id)	yellow (w/w)	some ER- birchen/black *
Green (Willow)	none (Id/Id)	yellow (w/w)	black (E or ER)
Blue	black (id/id)	white (W/W)	blue (Bl/bl), splash (Bl/Bl), R.white (c/ c), heavily mottled (mo/mo),
Slate	none (Id/Id)	white (W/W)	black (E or ER) + lavender (lav/lav)
Black	none (Id/Id)	white (W/W)	black (E or ER)
Horn	none (Id/Id)	yellow (w/w)	red



The above are:

- 1 Top left: Willow (e⁺/e⁺ wildtype, id⁺/- dermal pigment & w/w yellow skin),
- 2: Top right: Slate (e⁺/e⁺ wildtype, id⁺/id⁺ dermal pigment, mo/mo & W⁺/W⁺ white skin) &
- 3: Bottom left: Yellow (e^{Wh}, e^b or e^y?, Id/- no dermal pigment & w/w yellow skin)
- - 4: Bottom right: White (e^{Wh}/e^{Wh} wheaten, Id/- no dermal pigment & W⁺/W⁺ white skin)

* it is not clearly understood why some ER (eg solid black plumage) breeds/varieties may have yellow shanks, whereas others have black shanks, regardless of the dermal gene allele. That is, an ER, Id/Id (no dermal pigment) bird may be either yellow or black (or willow) shanked. For example, Black: Pekins, Japanese Bantams, Leghorns, etc have yellow shanks. Other examples are Birchen Grey, Brown Red varieties with yellow legs. Sometimes epidermal pigment is sex-influenced with ER, ie more prominent pigment with hens than roosters, eg in some lines the ER roosters are clean yellow legged, yet the hens have epidermal pigment. There is a relationship between white feather undercolour in Blacks & no shank pigment, suggesting a plumage melanotic gene is involved in some lines.



The above are all E^R (birchen) at e locus:

- 1 Top left: Willow (E^R birchen, Id- no dermal pigment & w/w yellow skin),
- 2: Top right: Slate (E^R birchen, I/i⁺ dominant white & W/w⁺ white skin, carrying yellow),
- 3: Bottom left: Yellow (E^R birchen, Id- no dermal pigment & w/w yellow skin),
- 4: Bottom right: White (E^R birchen, id⁺/id⁺ dermal pigment, B/b⁺ Barring, carrying non-barring & W ⁺/W⁺ white skin)

The level of influence varies greatly from the list above, eg Barring/Cuckoo (B/B) can dilute black dermal colour to white, whereas Blue (Bl/bl⁺) or RecessiveWhite may only dilute colour to Blue, & exhibition Belgian mottled birds have slate/blue legs.

Shank colour may change from day-old to adult hood. For example, W+ (White skin) and id+ (dermal pigment) is not usually expressed in day-old chicks.

Id Locus Alleles (Id, id^a, id^c, id^M, id⁺⁾

There are multiple mutations on this locus, eg:

- Id Inhibitor of Dermal Melanin,
- id^a Ancona (mottled pigment),
- id^c Cornell Randombred White Leghorn line (plumage & beak pigment present in dominant

whites),

• id^M - Massachusetts line (pigment expressed on day-old chicks (E, ER, e+ or c/c), but not expressed with I, except I E chicks - expressed later at approx 10 -12 weeks of age),

- plus id+ wild type (dermal melanin, not expressed on day-old chicks)

Sex-linked Recessive White Skin (y)

There is a sex-linked recessive white skin mutation - \mathbf{y} , but this gene would not normally occur in exhibition flocks. The mutation not only reduces carotenoid pigments to skin/shanks (& egg yolks), but has other deleterious effects to bird health, including significantly reducing growth rates and feed consumption. This sex-linked recessive white-skin (y) allele is expressed in day-old chick shanks (ie, white skin), whereas the autosomal W+ white skin gene is not usually expressed in day-old chick shanks (usually takes approx. 10 weeks for expression of W+).

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Eye Colour & Ear Lobe Colour: (Eye: Sex- linked Brown, Pearl)

(Ear lobe: turquoise, white, Spanish, red)

* Images used in the following examples are from the Feathersite website.

Eye Colour:



* Pearl Eye-colour

From Dr Okimoto.....

There is a gene for brown eye, but I can't remember to much about it. I'll have to look it up. Eye color is also associated with the E locus alleles (black produces darker eyes) and genes like dominant white will dilute the eye color. I would expect blue and lavendar to do this too.

I had a Blue splash Ameraucana rooster that had bright orange eyes with red streaks in them. I bred him for two generations (the second one back to his daughters) because I like the eye color, but I never got anymore like him. Eye color is pretty much a genetic mystery for chickens.

Smyth in Poultry Breeding and Genetics, 1990 Crawford, ed. Cites a Sex-linked brown eye phenotype (Br). The normal color is called bay. Brown eyed birds are also seen in association with dark shanks and the id^M sex-linked dermal melanin allele. The dominant E allele is associated with brown eye too.

Pearl eye is thought to be recessive to bay eye. I'd think that there were at least two genes involved, but the genetics aren't known. Something inhibits carotinoid deposition and also melanin deposition in these eyes. White skin is known to inhibit carotinoid deposition in the skin, but Smyth claims that it isn't involved in pearl because yellow skinned Cornish can have pearl eyes.

The color I had in my Ameraucana was not the normal bay color it was a bright orange eye with blood red streaks in it. It was pretty striking and could not be confused with the normal bay.

The red color may be carotinoids (the pigment left in fall leaves and can be seen in vegetables like carrots and red peppers).
Ear lobe colour:



* Spanish - white faced



* Left: White Ear-lobes

*Right: Red Ear-lobes



* Turquoise Ear-lobes



Feather types: Frizzle (& mf- modifier frizzle), Silkie, Soft feather- Hard feather

* Images used in the following examples are from Feathersite, and the OEGBCA website.

The Frizzle gene (F) is incompletely dominant, with exhibition quality Frizzles usually with one dose only of the Frizzle gene (F/f+).

But there is a frizzle modifying gene (mf) which is recessive. The mf gene when homozygous (two doses) is a strong modifier of the frizzle trait. Birds with one dose of the frizzle gene (F/f+) & two doses of the modifying gene (mf/mf) may appear predominantly smooth, & may be mistaken for non-frizzle (& not of exhibition quality). Frizzle birds homozygous for both F & mf (F/F mf/mf) may be mistaken for heterozygous F/f+ (one dose of Frizzle gene) with no modifiers (Mf+/Mf+). It is mentioned in the Hutt book that this mf gene is very common in non-frizzled breeds.



* Frizzle (F) autosomal incomplete dominant



* Silkie- hookless (h) autosomal recessive



* Hard feathered (Ha) autosomal incomplete dominant



* Soft Feathered (ha⁺ plus other modifiers)

The following mutations diminish feather quality (eg, feathers prone to breakages, etc). (source: Poultry Breeding & Genetics).

- 1. Fray (fr) autosomal recessive (affects mostly wing flights & tail feathers)
- 2. Flightless (F1) autosomal dominant (affects mostly wing flights & tail feathers)
- 3. Alopecia autosomal recessive (affects mostly remiges & rectrices)
- 4. Dysplastiv remiges (dr) (affects remiges & rectrices, -extreme cases wing coverts)

5. Hypoplasia of tail feathers (Hy) - autosomal dominant (affects tail feathers, resembles rumplessness, but vertebrae normal) Found in Ingie Fowl.

- 6. Matted Down polygenic trait
- 7. Ragged Wing (rw) autosomal recessive (affects wing flights)
- 8. Porcupine (pc) autosomal recessive (spiny quills)

9. Ropy (**ropy**) - autosomal recessive (sticky down, adults - large wing feathers, sometimes body feathers - roughness)

10. Stringy (st) - recessive (down feathers stringy, very high mortality rate)

11. String-2 (**st-2**) - autosomal recessive (down sticky, adults - most barbules were absent from wing & tail feathers)

12. Sunsuit (sn) - autosomal recessive (down wiry & sticky, adults - extremities bare of feathers, body better covered)

13. Wiry (wi) - autosomal recessive (down sticky & lacked barbs on distal halves. Adults - mostly wiry barbs of wing flights & tail feathers).

14. Wooly (wo) - autosomal recessive (shortened down- semi-naked, slick shiny feet. Adults - feathers abnormal in structure, rough & incomplete).

15. Wing Patch - expression limited to males, may possibly be linked to the lavender locus.



Feather Mutations: Foot Feathers- Ptilopody & Stubs, Vulture Hocks (Pti-1B, Pti-1L: Ptilopody 1-Brahma, Ptilopody 1-Langshan) (Pti-2, Ptilopody 2) (pti-3, Pti-1L: Ptilopody 3 (Pavloff)) (sb-1 - recessive stubs, Sb-2 - dominant stubs) (v - vulture hocks)

* Images used in the following examples are from the Feathersite website.



Ptilopody

In "Poultry Breeding & Genetics" (Crawford, 1990), 3 ptilopody loci were noted, eg:

- Pti-1
- Pti-2
- pti-3

2 dominants, 1 recessive

I checked PubMed, found the following on

Identifying the ptilopody (feathered shank) loci of the chicken. by Somes (1992)

Somes went a step further, identifying 2 alleles on the Pti-1 locus, ie **Pti-1B** & **Pti-1L**, the B dominant to L, eg:



B = allele found in Brahma



L = allele found in Langshans

- Pti-1B, Pti-1L (& pti-1⁺ -> wild type)
- Pti-2 (& pti-2⁺ -> wild type)
- pti-3 (& Pti-3⁺ -> wild type)

Stubs

Ht (Heel tuft feathering)sb-1

sb-2

The last two genes came from a study on Rhode Island Reds (Crawford, 1990). It was mentioned that these stub genes may be partially sex-limited, as stubs expression was more prominent in males. Other studies indicated a polygenic basis for the stubs trait (ie, multiple genes involved, acumulative effect on expression).

Vulture Hocks (v)



* Vulture Hocks- autosomal recessive (v)



Feather Placement Mutations: Crest, Ear tufts, Muff/Beard, Naked Neck, Nakedness

* Images used in the following examples are from the <u>Feathersite</u> website.



* Crest (Cr) autosomal incomplete dominant



*Muff Beard (Mb) autosomal incomplete dominant



*Ear Tufts (Et) autosomal, semi-lethal, incomplete dominant



* Both Ear-tufted & Muff/Bearded (Et / Mb)



* Left- heterozygous Naked Neck (Na/na+),

Right - homozygous Naked Neck (Na/Na)

* Na -autosomal, incompletely dominant

There are quite a lot of plumage mutations discussed in "Poultry Breeding and Genetics" eg,

Apterylosis (autosomal nakedness) Ap gene –studied by Sturkie, 1942, condition found in a Rhode Island Red flock

Scaleless (sc)- autosomal recessive gene. Studied by Abbott & Asmundson, 1957, condition found in a New Hampshire flock. Birds are without scales on shanks. Males do not develop spurs.

Sex-linked Naked (n). Studied by Hutt & Sturkie 1938, condition found in a White Leghorn flock.

Ottawa Naked (nk) autosomal recessive (variable expressivity). Trait first observed in 1956

Abnormal feathering (af) autosomal recessive. Studied by Bulfied. Very variable expression, with extreme cases completely naked

Congenital Baldness (ba). Newly hatched chicks with bald areas on the top of their heads. Hutt, 1932 suggested the trait was a simple recessive, but other researchers found variability in inheritance, with Somes believing it was partly a sex-linked recessive trait (although some heterozygous males expressed the trait).

Edema (thigh patch) (ed-1, ed-2), studied by Savage et. al. 1986. Two autosomal recessive genes, at two

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separate loci.

There are many other mutations listed that effect feather quality (eg, tardy, etc), but the above are the main "naked" genes.

The book only has photos of the scaleless (chicks & rooster), of the naked genes. There are some photos of the sex-linked slow feathering trait- **Kn**. These have very poor feathering, little coverage (even as adults).



Feather rate of growth (late/slow feathering alleles, tardy/retarded alleles)

Kⁿ, K^s, K, t, t^s

Kⁿ, K^s, K are sex-linked dominant alleles from the Late/Slow Feathering locus.

t, t^s (Tardy & Retarded) are autosomal recessive alleles from the Tardy locus.

Slow feathering modifier(s) are believed to exist, these modifying expression of the Slow-feathering K alleles.



Tail, Flight & Saddle Mutations: Rumpless (Rp, rp-2),

Long tail (Gt -continual growth), Non-moulting (mt), 8 main tail feathers (ext), Wry tail, Henny feather (Hf), Surplus Flight Primaries (Sf1, Sf2), Long filoplumes (Lf)

* Images used in the following examples are from the Feathersite website.



* Rumpless



* Long tailed



* Henny Feathered - Hf autosomal incomplete dominant



Comb types: single, pea, rose, buttercup, breda, duplex, rough, sprigs

* Images used in the following examples are from the Feathersite website.

Comb Types:

Photo	Comb Type	Genotype
*	Single Comb	p+p+ r+r+ d+d+ Bd +Bd+
	Rose Comb	p+p+ RR d+d+ Bd +Bd+

	Pea Comb	PP r+r+ d+d+ Bd +Bd+
	Duplex- Cup Shaped	p+p+ r+r+ DcDc Bd +Bd+
	Duplex- V Shaped	p ⁺ p ⁺ r ⁺ r ⁺ D ^v D ^v Bd ⁺ Bd ⁺
(P	Walnut (Pea & Rose combed)	PP RR d+d+ Bd +Bd+
	Breda - combless	p+p+ r+r+ DvDv bdbd



* Modified Rose Combed - Trifid (R, p^+/p^+) & smooth comb, possibly- he^l



* Redcap - modified Rosecomb (R p^+/p^+)

"single comb is recessive to all other comb types except....Breda."

Different loci, recessives, so a good example of "Epistasis", ie where one gene interferes with the expression of another (<u>epistasis</u>).

For example, d/d,r/r,p/p,bd/bd is genetically combless, suppressing single comb. A d/d,r/r,P/P,bd/bd bird is still combless, but suppressing pea comb, & so on.... That is, the Breda combless gene (bd), when homozygous, suppresses all other comb types, regardless of d, r & p loci. Similar to recessive white gene (c/ c) suppressing all colour in plumage, regardless of all colour/pattern genes present.

* In Hutt, Genetics of the Fowl:

-"Strictly speaking, pea & rose are not dominant to single comb but epistatic to it. Single comb is "Hypostatic" to these two but epistatic to the combless type of the Breda (Hutt, p88)"

-" In Breda males, two small papillae on each side of the median line back from the upper beak indicate the duplex condition, although the birds appear practically combless (p87)"

In Crawford, p194: D^v allele is dominant to the D^c allele. The wide cavernous nostrils are expressed with homozygosity for D^v allele but not D^v/d^+ . Also expressed with D^v/D^c , but only in association with D^v allele.

The Breda breed has the wide-open nostril trait (chickenbreeds website-Breda fowl)

The P gene: pea comb & breast ridge/reduced feather characteristics is a good example of "Pleiotropy" ie the effect of a single gene on more than one characteristic (<u>Pleiotropy</u>)

In Poultry Breeding & Genetics:

Page 192

Poor fertility is associated with R/R males in at least several breeds. Fertility of R/r⁺ and r⁺/r⁺ males & of all 3 genotypes of females is perfectly normal. Sperm cells from R/R males have some fertilizing capability, but they cannot compete with sperm cells from R/r⁺ males in multiple sire matings. This can explain persistance of the single comb allele in rose-combed populations.

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A large single gene effect is the poor fertility of males homozygous for the rose comb gene. Mating frequency is lower and duration of fertility after a single insemination is shorter for R/R males. The motility of their spermatozoa after storage is inferior and certain enzymatic activities differ. The He locus which modifies the appearance of rose comb may also be associated with a difference in male fertility.

Comb Modifiers:

There are two "Rough/Smooth" comb alleles listed, that modify comb texture (especially noticable in rosecombs), eg:

- He⁺ (Rough, also produces more spikes in single comb) &
- hel (Smooth)

* notice the first is considered the wild type.

A modifier described by Warren is "Spike Blade Comb" - **sb**. This one modifies the single comb by ending the comb in a single spike instead of the usual broad oblong blade. It is generally expressed as an autosomal recessive gene, but with variable penetrance (small percentage of heterozygotes express the trait, & a small percentage of homozygotes suppressed, no expression).

Other comb modifiers have been studied, but without genes formally named. For example:

- Trifid three-pronged (rosecomb modifier, eg found in Silkies, deWatermael)
- Side sprigs (single comb modifier)
- Multiplex (single comb modifier multiple combs)



Spurs & Toes (multiple spurs, hen spurs, 5-toes, Brachydactyl)

Brachydactyly

Sevebrovsky noted with the ptilopody birds he studied, that all with the "tip-type" phenotype (feathers on the outer toes, little on middle toe) were brachydactylous of the outer toe. Because of this & other studies it was hypothesised that the Brachydactyly trait may actually be due to a ptilopody (feathered shank) gene (Crawford, 1990). The problem is, within Danforth's studies, birds with brachydactyly & no foot feathers were noted in his research (see Hutt, p56).



The shorter outer toe trait has been given the mutation name: **Brachydactyly** - **By** gene (autosomal incomplete dominant). There is a strong correlation with foot feathering - **ptilopody** (feathered shank) & the brachydactyly trait. So some researchers believe the Brachydactyly trait is not a separate gene, but one of the ptilopody genes. The problem is, some brachydactyly, clean-legged birds have segregated from test crosses.



* In Crawford, it is mentioned that birds homozygous for foot feathers, have higher occurrence of brachydactyly (& more pronounced features), but as you can see above, birds with poor foot feathers may also be brachydactylous.

Leg Length (Creeper gene, Cornish Gene)

* Images used in the following examples are from the Feathersite website.

There is some very good information & references on the Creeper gene in both Crawford (pp 223-224) & Hutt (pp 58-63) books. It seems Cp has been a favourite topic for W. Landuaer, with decades of study on the subject. There are many articles published by him over the years. Some other interesting genes are Cl (short-legged Cornish lethal) & Mp (Ametapodia). These 2 have similar traits to Cp, with reduction to leg length & lethal when homozygous. Mp is found on the same chromosome as Creeper, but not as closely linked to Rosecomb gene as Cp is. It is a more debilitating gene, with heterozygotes (Mp/mp) badly deformed. There is another semi-lethal gene affecting leg length shl (Shankless).

The chapters on the short-legged Cornish (Cl) gene are a very good read. Studies have found that more than one gene was responsible for the short-legged phenotype in Cornish. Intermediate leg lengths were produced in F1 crosses with Leghorns, but offspring in the 2nd generation (F2) ranged from short-legged to some that were longer-legged than the parent (P1) leghorns.

References: Crawford, R.D. (1990). Poultry Breeding & Genetics. Elsvier, N.Y. Hutt, F.B. (1949). Genetics of the Fowl". McGraw-Hill, N.Y.



* Creeper Cp - shortlegged, - autosomal semi-lethal incomplete dominant



* Cornish Lethal - Cl, shortlegged, - autosomal semi-lethal incomplete dominant

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Size Mutations (Sex-Linked Dwarfism, Recessive Dwarfism, Bantam Genes, etc)

* Images used in the following examples are from the Feathersite website.

The following information is mostly from the book "Poultry Breeding and Genetics"



Dwarfing Genes:

There have been four loci identified with dwarfing mutations, one locus with multiple mutation alleles:

- Z
- rg
- adw
- dw, dw^M, dw^B

* Z "Dominant Sex-linked Dwarfism"– found in Golden Sebrights (Maw 1935, crossed Light Brahma with Gold Sebrights).

* rg "Recessive Sex-linked Dwarfism"– Black Rosecomb Bantams (Godfrey 1953, crossed Barred Plymouth Rock with Black Rosecomb bantams)

* adw "Autosomal Dwarfism"- mutation occurred in Cornell K strain White Leghorns (Cole 1973)

* dw, dw^M, dw^B "Sex-linked Dwarfism"- closely linked to silver-gold & slow-rapid feathering loci.

⁻ dw Mutation appeared in a New Hampshire flock (Hutt 1959)

⁻ dw^B found in Golden Sebright (Custodio & Jaap 1973) (dw^B dominant over dw)

 dw^M found in a meat-type line (Hsu et al 1975). (inheritance relationship with other locus alleles not determined).

Generally large & bantam crosses produced F1 offspring intermediate in size (sometimes closer to bantam size). F2 offspring had the greatest variation in size. An exception was found in a study by Danforth (1929). There was variation between bantam breeds when he crossed a Millefleur Belgian d'Uccle Bantam male with Sebright females. Some F1 progeny were larger than the parents, & in later generations birds both larger and smaller than the parental types were obtained.

I haven't crossed Standard size to bantams, but there is a lot of difference in size between various bantam breeds I have crossed, and sometimes there is obvious variation in sizes within a breed, between lines. Usually the first crosses are intermediate in size, but I've had results similar to Danforth, where F1 offspring were larger than both parent birds (eg Orpington Bantam X Indian Game Bantam, resulting F1 were close to commercial layer size, and unrelated d'Uccle X d'Uccle, some F1 offspring larger than parents, etc). Something that I thought was amiss in "Poultry Breeding and Genetics" was that there was little mention in the chapter of mutations that INCREASE size. Crosses were made between bantam breeds to large Standard size breeds, these much larger than the Red Jungle Fowl –wild type. Obviously mutations that increase size would need to be taken into consideration when determining dwarfing genes.

There is another chapter in the book, dealing with studies on the dw gene, for possible commercial use. Usually these dwarfing genes have little in the way of deleterious effects to general health (sometimes heath gains), but of course there are few production issues, eg reduced egg size, body weights, etc (tend to be more efficient with feed consumption to production outputs though).



-End of Page 2 (of 3) Poultry Mutations-

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Poultry Mutations Sub-Menu 3

..... Poultry Mutations- Colour/Pattern Genes Table: Poultry Mutations- Physical Genes Table:

> URL: http://home.ezweb.com.au/~kazballea/genetics/mutations3_print.html Last updated: 29 May, 2007

* Most of the photos on this website originated from "<u>Feathersite</u>",
and "<u>Old English Bantam Club of America</u>" websites, and have been given with permission by the website administrators.
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This section became quite large, so I've divided the mutation section into three pages: Mutations:

<<<u>Page 1</u>>><<<u>Page2</u>>><<<u>Page3</u>>>

Page 1: Feather Colour/Pattern mutations

Page2: Leg/Skin, Eye and Ear-Lobe Colour, plus Physical Mutations

Page 3: Genes Tables



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Poultry Genetics -Mutations3
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Locus	Alleles	Name	Inheritance Mode		
	Plumage Colour/Pattern Genes				
В	B ^{Sd} , B, b ⁺	Sex-linked Dilute, Sex-linked Barred	Sex-L. Inc. Dom		
B1	Bl, bl+	Blue	Inc. Dom		
с	C ⁺ c, c ^{re} , c ^a	Recessive White, Recessive White-Red Eyed, Albinism	Rec		
Cb	Cb, cb+	Champagne Blond	Dom		
Cha	Cha, cha+,	Charcoal	Dom		
choc	Choc ⁺ , choc	Sex-linked Chocolate	Sex-L. Rec		
Со	Co, co+	Columbian	Dom		
Db	Db, db+	Dark Brown	Inc. Dom, Sex- Infl.		
Di	Di, di+	Gold Dilute	Inc. Dom		
Dk	Dk1, Dk2, dk+	Dark	Inc. Dom		
E	E, E ^R , E ^R - Fay, e ^{Wh} , e ⁺ , e ^b , e ^s , e ^{bc} , e ^y , e ^q	Extended Black, Birchen, Fayoumi Birchen, Dominant Wheaten, wild type, Brown, Speckled, Buttercup, Recessive Wheaten, Queen Silvia	Dom		
Er	Er, er ⁺	Erminette	Inc. Dom		
I	I ^S , I, I ^D , i+	Smoky, Dominant White, Dun	Inc. Dom (Smoky- Rec- adult plumage to i ⁺ , Dom- chick down to i ⁺) (I ^S dominant to I), I dominant to I ^D		

ig	Ig+, ig	Recessive Cream (Inhibitor of Gold)	Rec
ko	Ko+, ko	Sex-linked Head streak	Sex-L. Rec
lav	Lav+, lav	Lavender	Rec
Li	Li, li+	Sex-linked Light Down	Sex-L. Dom
Mh	Mh, mh ⁺	Mahogany	Dom
Ml	Ml, ml+	Melanotic	Inc. Dom , Sex- Infl.
mo	Mo+ mo	Mottled	Rec
Pg	Pg, pg ⁺	Pattern Gene	Dom
rs	Rs ⁺ , rs	Red Splash	Rec
S	S, S ^{al-s} , s ⁺ , s ^{al}	Sex-linked Silver, Sex-linked Imperfect Albinism (Saskatchewan), wild type (sex-linked gold), Sex- linked Imperfect Albinism	Sex-L. Inc. Dom
SW	Sw+, sw	Snow White down	Rec
wh	Wh+, wh	Dorking White	Rec
		Grey (found in Australorps in South Africa)	Rec
		Eye Colour	
br	Br+, br	Sex-linked Brown Eye	Sex-L. Rec
pk	Pk+, pk	Pink Eye (dilutes eumelanin plumage also)	Rec
?		Pearl	
		Leg- Skin Colour	
Fm	Fm, fm ⁺	Fibromelanosis	Dom
g	G+, g	Yellow Head	Rec

Id	Id, id ^a , id ^c , id ^M , id ⁺	Sex-linked Inhibitor of Dermal Melanin, id ^a - re Ancona, id ^c - re Cornell line, id ^M -re Massachusetts line, wild type (dermal melanin)	Sex-L. Dom
w	W+, w	Yellow skin, wild type (white skin)	Rec
У	Y ⁺ y	Sex-linked white skin	Sex-L. Rec
		Egg Shell Colour	
0	O, o+	Blue Egg-shell (Olive)	Dom
pr	Pr+, pr	Inhibitor of Brown Egg-Shell	Sex-L. Rec



Poultry Mutations- Physical Genes Table (alphabetical order)

Locus	Alleles	Name	Inheritance Mode
	categories	feather type, amount of feather, comb, size,	
?		Abnormal tibia metatarsal joints	
?		Crippling Abnormalilty (in Dark Cornish)	
?		Crooked Keel	Dom
?		Crossed Beaked - multiple genes	

?		Syndacytly (toe webbing- fused toes)	? not Sex-L.
?		Side Sprigs- 2 genes	Dom
?		Moulting Spurs	
?		Spurs in Females	
?		Trifid	Dom
?		Wing Patch (in Lavender birds)	?
?		Multiplex Combs	
adw	Adw+, adw	Autosomal Dwarf	Rec
af	Af+, af	Abnormal Feathering	Rec
Ap	Ap, ap ⁺	Apterylosis (Autosomal Nakedness)	Dom
As	As, as ⁺	Auxillary Spur	Dom
ba	Ba+, ba	Congenital Baldness	Rec
bd	bd, Bd ⁺	Breda Combless, wild type S	Rec
bf	Bf+, bf	Blistered Foot Lethal	Leth. Rec
By	By, by ⁺	Brachydactyly, wild type	Inc. Dom
Cl	Cl, cl ⁺	Short-Legged Cornish, wild type	Semi-Leth. Inc. Dom
Ср	Cp, cp ⁺	Creeper, wild type	Semi-Leth. Inc. Dom
Cr	Cr, cr ⁺	Crest, wild type	Inc. Dom
crt	Crt+, crt	Congenital Crooked Toes	Rec
D	D ^v , D ^c . d ⁺	Duplex Comb V-shaped, Cup -shaped	Dom
dac	Dac ⁺ , dac	Dactylolysis	Rec

dgp	Dgp+, dgp	Double Oil Gland Papillae	Rec
dr	Dr+, dr	Dysplastic Remiges (feathering)	Rec
ds	Ds+, ds	Double Spur	Inc. Rec
dw	Dw ⁺ dw ^B , dw ^M , dw	Sex-linked Dwarfism- Bantam, Sex-linked Dwarfism-MacDonald, Sex-linked Dwarfism, wild type	Sex-L. Rec
ed-1	Ed-1+, ed- 1	Edema 1 (Thigh Patch)	Rec
ed-2	Ed-2+, ed- 2	Edema 2 (Thigh Patch)	Rec
Et	Et, et ⁺	Ear Tufts	Semi-Leth. Inc. Dom
ext	Ext ⁺ , ext	Eight Tail Feathers	Inc. Rec
F	F, f +	Frizzle, wild type	Inc. Dom
Fl	Fl, fl+	Flightless	Semi-Leth. Inc. Dom
fr	Fr+, fr	Fray	Rec
Gt	Gt, gt ⁺	Long Tail & saddle feathers, wild type	Dom
h	H +, h	Silkie (Hookless) , wild type	Rec
На	Ha, ha+	Feather Texture- Hardness	Dom
hel	He+, he ^l	Smooth Comb, Fewer Spike Numbers, wildtype (rough comb)	Rec
Hf	Hf, hf +	Hen-Feathering, wild type	Inc. Dom

Ht	Ht, ht ⁺	Heel Tuft Stubs	Dom
Ну	Hy, hy+	Hypoplasma of Tail Feathers	Dom
K	K ⁿ , K ^s , K, k ⁺	Sex-linked Slow Feathering	Sex-L. Inc. Dom
Lf	Lf, lf+	Long Filoplumes	Dom
М	M, m ⁺	Multiple spurs, wild type	Inc. Dom
Mb	Mb, mb ⁺	Muff Beard, wild type	Inc. Dom
mf	Mf ⁺ , mf	Frizzle Modifier, wild type	Rec
Мр	Mp, mp ⁺	Ametapodia (extreme reduced legs)	Semi-Leth. Inc. Dom
mt	Mt ⁺ , mt	Non- moulting, wild type	Rec
n	N+, n	Sex-Linked Naked	Sex-L. Rec
Na	Na, na ⁺	Naked Neck, wild type	Inc. Dom
nk	Nk+, nk	Ottawa Nakedness	Rec
Р	P, p +	Pea comb, wild type	Inc. Dom
pc	Pc ⁺ , pc	Porcupine	Rec
pe	Pe ⁺ , pe	Genetics Perosis	Rec
Ро	Po, Po ^d , po +	Polydactyly	Inc. Dom
po-2	Po-2+, po-2	Recessive Polydactyly	Semi-Leth. Rec
psp	Psp+, psp	Multiple trait Semi- Lethal (Ptilopody & Syndactyly)	Semi-L. Rec
Pti-1	Pti-1B, Pti- 1L, pti-1 ⁺	Ptilopody 1 Brahma, Langshan	Inc. Dom
Pti-2	Pti-2, pti-2 ⁺	Ptilopody 2	Inc. Dom
pti-3	pti-3, Pti-3+	Ptilopody 3 (Pavloff)	Rec

R	R, r ⁺	Rose comb, wild type	Dom
rg	Rg ⁺ , rg	Recessive Sex-Linked Dwarfism	Sex-L. Rec
ropy	Ropy, ropy +	Ropy	Rec
Rp	Rp, rp ⁺	Dominant Rumpless, wild type	Semi-Leth. Inc. Dom
rp-2	Rp-2+, rp-2	Recessive Rumpless, wild type	Rec
rw	Rw ⁺ , rw	Ragged Wing	Rec
sb	Sb+, sb	Spile Blade Comb (extra spike-end)	Inc. Rec
sb-1	Sb-1+, sb-1	Recessive Stubs	Rec
Sb-2	Sb-2, sb-2+	Dominant Stubs	Dom
SC	Sc, sc ⁺	Scaleless	Rec
se	Se+, se	Sleepy Eyes	Rec
Sf1	Sf1, sf1+	Surplus Primaries 1	Dom
Sf2	Sf2, sf2+	Surplus Primaries 2	Dom
shl	Shl+, shl	Shankless	Lethal Inc. Rec
sl	Sl+, sl	Spurlessness, wild type	Rec
sn	Sn, sn ⁺	Sunsuit	Rec
st	St, st ⁺	Stringy	Rec
st-2	st-2, St-2+	Stringy 2	Rec
t	T+, t ^s , t	Tardy- Retarded Feathering, Tardy- Secondary Flights	Rec
U	U, u ⁺	Uropygial Gland	Inc. Dom
U-2	U-2, u-2+	Cleft and Double Papillae	Dom

V	V+, v	Vulture Hocks	Rec
wi	Wi+, wi	Wiry	Rec
wo	Wo+, wo	Wooly, wild type	Rec
wp	Wp ⁺ , wp	Wooly	Rec
Z	Z, z+	Dominant Sex-Linked Dwarfism	Sex-L. Dom

Inheritance Mode

Dom = Autosomal Dominant, Rec = Autosomal Recessive,

•

Semi-Leth. Inc. Dom = Semi-lethal Incompletely Dominant, Leth. Rec = Lethal Recessive, Semi-Leth. Rec = Semi-Lethal Recessive

Sex-L. Rec = Sex-Linked Recessive, Sex-L. Dom = Sex-Linked Dominant, Sex-L. Inc. Dom = Sex-Linked Incompletely Dominant,

Inc. Rec = Incompletely Recessive, Inc. Dom = Autosomal Incomplete Dominant, Co-Dom = Autosomal Co-Dominant.



-End of Page 3 (of 3) Poultry Mutations-

<<<u>Page 1</u>>><<<u>Page2</u>>><<<u>Page3</u>>>

Page 1: Feather Colour/Pattern mutations

Page2: Leg/Skin, Eye and Ear-Lobe Colour, plus Physical Mutations

Page 3: Genes Tables

Chromosome Linkages Sub-Menu

..... Introduction: Chromosome Linkages Table:

> URL: http://home.ezweb.com.au/~kazballea/genetics/linkages_print.html Last updated: 9 Nov, 2008

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and "<u>Old English Bantam Club of America</u>" websites, and have been given with permission by the website administrators.
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Linkages

Introduction on linkages

Linkages tables, categorised into chromosome groups

Map units

Chromosome Linkages Table

The following linkage map table is based on the following books:

1. Crawford (ed.) (1990) Poultry Breeding and Genetics.

2. Stevens, L. (1991) Genetics and Evolution of the Domestic Fowl.

3. Muir and Aggrey (ed.) (2003) *Poultry Genetics, Breeding and Biotechnology*, CABI Publishing.

All hashed data is from the last book (Muir & Aggrey), & is based on the following quote from this book (page 499):

The classical linkage groups I, IV and Z correspond to chromosomes 1, 2 and Z, and linkage group II to linkage group E22C19W28. These results also clearly show that several of the linkages reported in the past are incorrect. For example, naked neck and blood group P are located not on chromosome 1 (linkage group 1) but on chromosome 3 and extension of eumelanin (MC1R) is not located on chromosome 1 but located on microchromosome 11 (Takeuchi et al., 1996; Sazanov et al., 1998; Kerje et al., 2003, unpublished).

-Note, the recessive white locus (Tyrosinase) map reference is from Dr Ron Okimoto (pers. comm.)

*Recent sequencing of the yellow skin allele:

Eriksson J, Larson G, Gunnarsson U, Bed'hom B, Tixier-Boichard M, et al. (2008) *Identification of the Yellow Skin Gene Reveals a Hybrid Origin of the Domestic Chicken*. PLoS Genet 4(2): e1000010. doi:10.1371/journal. pgen.1000010

Quotes from the above article:

....yellow skin was previously assigned to chromosome 24. An examination of this chromosomal region revealed an obvious candidate gene for yellow skin, BCDO2 located at position 6.26–6.29 Mbp.

Due to the above information, I've included w locus on Microchromosome 24 () in the table below. It is obvious from growing discrepancies in data below that the old Linkage Maps in Crawford, etc (which most of the table below is based on) are outdated and need significant revision.

Locus	Map Unit Distance	Locus Description	Comments
Gro	up I : (# Chr	romosome 1- new)	
Ср		Creeper	
	0.4		
R		Rose Comb	

	30				
U		Uropygial	linkage not given to lav		
the below not linear					
lav	32.5	Lavender	lav 32.5 map units to R		
	?		linkage not given between lav & Mp		
Мр	16		Mp 16 map units to R		
the above not linear					
Group II	Group II (# linkage group E22C19W28- new)				
fr		Fray			
	46				
Cr		Crest			
	12.5				
I, I ^D , I ^S		Dominant White, Dun, Smoky			
	17				
F		Frizzle			
Group III: (# Chromosome 1- old)					
W		Yellow Skin	*sequenced on Microchromosome 24		
	22				
Ea-H		Blood Group H			

	21		
se		Sleepy Eye	se is 45 map units from P
	3		
Ea-J		Blood Group J	
р	36		
О		Blue Egg-Shell	
	4		
Cha		Charcoal	
	0.3		
Р		Pea Comb	*Carefoot believed E locus linked to P -43 cM, this later determined incorrect.
	32		
Db		Dark Brown	Db is 32 Map units from P
	12		
Ml		Melanotic	Ml is 45 + map units from P
	10		
Pg		Pattern	
	?		
Т		Tardy	
	?		
Ea-P		Blood Group P	(#Chromosome 3 - new)
	28		
Na		Naked Neck	(#Chromosome 3 - new)
q	43		
---------------------------------	-------------	---------------------------	----------------------------------------
h		Hookless - Silkiness	
	11		
Fl		Flightless	
	?		
с		Recessive White	Tyrosinase (#Chromosome 1 - new)
Gro	up IV (#Chr	comosome 2 -new)	
D ^V , D ^C		Duplex Comb	
	27		
М		Multiple Spurs	
	33		
Po, Po ^d		Polydactyly, Duplicate	
Group V:	(Z Chromos	some -sex chromos	ome)
ro		Restricted Ovulator	
	3		
sh		Shaker	
p	14		
n		Naked	
	7		
рх		Paroxysm	
	1.9		
ln		Liver Necrosis	

n

	3.1		
dw ^B , dw ^M , dw		Dwarf	
	3.4		
wl		Wingless	
	0.6		
pn		Prenatal Lethal	
	3		
K ⁿ , K ^s , K		Slow Feathering	
	1.1		
S, S ^{al-s} , s ^{al}		Silver, Imperfect Albinism	
	4		
lk	1	Lady Killer	
	12		
Li	1	Light Down	
	7		
У		Recessive White Skin	
	13		
br		Brown Eye	
	27		
Id, id ^a , id ^c ,id ^M		Dermal Melanin Inhibitor	
	14		
B ^{Sd} , B		Sex-linked Dilution, Barring	
	13		
ko		Head Streak	
Group VI · (W C)	hromosome	-ser chromosome. fem	ales only)

C	Group VII (Chromosome 6)	
the below not linear			
Gc, Alb			
Ade-A			
Pgm-2			
the above not linear			
G	roup VIII (Chromosome 7)	
Ade-B			adenine synthesis B
Gro	up X (Micr	ochromosome 17)	
р			
B-G			
Ea-B			
	0.4		
B-F		MHC	
R-Rs 1			
B-L			
lr-GAT			
NOR		Nucleolar organiser region	
q			
Ea-B			

Poultry Genetics - Chromosome Linkages

#Microchromosome 11				
E, E ^R , E ^R - Fay, e ^{Wh} , e +, e ^b , e ^s , e ^{bc} , e ^y , e ^q E Series				
*Microchromosome 24				
w Yellow skin *see ref. above				



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Chicken Variety Genotypes Sub-Menu

..... Poultry Breeds/Varieties Base Genotypes

URL: http://home.ezweb.com.au/~kazballea/genetics/genotypes_print.html Last updated: 29 May, 2007

* Most of the photos on this website originated from "Feathersite",
 and "Old English Bantam Club of America" websites, and have been given with permission by the website administrators.
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Poultry Breeds/Varieties Base Genotypes

* Note, genotypes can vary from line to line. The following are only base genotypes.

* Images used in the following examples are from the <u>Feathersite</u> website.

Photo	Variety	Genotype	Phenotype	Comments
		Ancona		
Se	Black Mottled	E/E Ml/Ml mo/mo w/w p ⁺ /p ⁺ r ⁺ /r $^+$	Black Mottled, yellow skin, single comb	
	Red Mottled (e ⁺ based)	$e^+ e^+ s^+/s^+ mo/mo w/w p^+/p^+ r^+/r$	Black Breasted Red rooster- salmon breasted hens, mottled, yellow skin , single comb	

Ś	Red Mottled (E ^R based)	$E^R/E^R s^+/s^+$ mo/mo w/w p^+/p^+ r^+/r^+	Brown Red, mottled, yellow skin, single comb	
		Andalusian		
	Black	E/E Ml/Ml bl+/bl+ Pg/Pg Co/Co W+/W+ p+/p+ r+/r+	Solid Black, white skin, black legs, single comb	- may have id ⁺ dermal melanin - Can be E or ER
S.	Blue	E/E Ml/Ml Bl/bl+Pg/Pg Co/Co W +/W+p+/p+ r+/r+	Blue Laced Blue, white skin, slate legs, single comb	- may have id+ dermal melanin - Can be E or ER
	Splash	E/E Ml/Ml Bl/Bl Pg/Pg Co/Co W $^{+}/W^{+} p^{+}/p^{+} r^{+}/r^{+}$	Pale Splashed Blue, white skin, slate legs, single comb	- may have id ⁺ dermal melanin - Can be E or ER
		Aseel		
	Wheaten	e ^{Wh} /e ^{Wh} s ⁺ /s ⁺ w/w P/P R/R	Black Breasted Red, wheaten hens, yellow skin , Strawberry (walnut) comb	
			Solid Black, yellow	

E/E Ml/Ml w/w P/P R/R

Australorp

skin , Strawberry (walnut) comb

Black

Poultry Genetics -Variety Genotypes

Ś	Black	E/E Ml/Ml bl+/bl+ W+/W+ p+/p+ r +/r+	Solid Black, white skin, slate legs, single comb	may have id ⁺ dermal melanin
	Blue	E/E Ml/Ml Bl/bl+ Pg/Pg W+/W+ $p^+/p^+ r^+/r^+$	Blue Laced Blue, white skin, slate legs, single comb	may have id+ dermal melanin
	Splash	E/E Ml/Ml Bl/Bl Pg/Pg W ⁺ /W ⁺ p $^{+}/p^{+} r^{+}/r^{+}$	Blue Splash, white skin, slate legs, single comb	may have id+ dermal melanin
	White	E/E Ml/Ml c/c W+/W+ p+/p+ r+/r+	Solid White (Recessive White), white skin, slate legs, single comb	may have id+ dermal melanin

	Barnevelder		
Dark	e ^b /e ^b Pg/Pg Ml/Ml w/w Id/Id p ⁺ /p $+ r^+/r^+$	Double laced hens, melanised B.B.Red males, yellow skin & legs, single comb	plus red enhancers



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 and "<u>Old English Bantam Club of America</u>" websites, and have been given with permission by the website administrators.
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Poultry Genetics Books:

Here are some poultry genetics books:

1. Crawford (1990) *Poultry Breeding and Genetics*. Elsevier, Amsterdam. (recent reprint, now available for sale.)

2. Carefoot, W.C. (1986) *Creative Poultry Breeding*. (recent reprint 2005, now available for sale. Published by Veronica Mayhew)

3. Jeffrey, F.P. & Richardson, W. (1995) Old English Game Bantams as Bred and Shown in the United States.

^{4.} Jeffrey, F.P. (1976) Bantam Chickens, ABA.

* the second edition (British publication) of the same book is called "*Bantam Breeding and Genetics*" (1977), Spur publishing, England .

5. Hollander, W.F. (1989) ABC's of Poultry Genetics.

6. Hutt, F (1949) Genetics of the Fowl"

All of the above book is available online: <u>http://chla.library.cornell.edu</u>

The book has been reprinted, now available for sale at: http://www.plamondon.com/genetics_of_the_fowl.html

The first three books are mostly up-to-date, but there were some changes in secondary pattern genes, etc after books 4, 5 & 6 were published.

Some of the out-of-date genes listed in Dr Hollander's book are:

I is listed as "Pyle", but generally called "Dominant White" today,

Gr (Ginger) = Columbian (Co) today,

Nigrum = Extended Black (E) today.

Ab, Lg & Sp are now obsolete (genes Pg, Ml & Db are used instead).

Not all of the E locus alleles are in these books (especially the Hutt book).

So it's best the read the most recent books first (ie 1, 2 & 3), &/or compare to the genes table at the Sellers Website. There is still plenty of good information in the old books though

There is a recently published poultry genetics book:

Muir and Aggrey (ed) (2003) *Poultry Genetics, Breeding and Biotechnology* CABI Publishing. but this one doesn't have a chapter on plumage colour/pattern genetics. There is information on genetics resistance breeding, etc.

Hartl, Daniel L. *A Primer of Population Genetics* ISBN: 0878933018 (not information on poultry colour/pattern genetics)

(1991) Genetics and Evolution of the Domestic Fowl by Lewis Stevens

* very little information on colour/pattern genetics

Dr H.S. Gankema, *VERERVING VAN VEERKLEUR BIJ HOENDERS (Inheritance of Feather Color in Chickens)*. - in Dutch

Morley A & Jull (1932). Poultry Breeding.

Poultry Genetics Journals:

- British Poultry Science

- Poultry Science

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----Poultry Genetics Discussion Groups/Forums----

The Classroom @ The Coop New Board (Poultry Breeding/Genetics): http://www.the-coop.org/cgi-bin/UBB/ultimatebb.cgi?ubb=forum;f=3

The Coop (Old Board archives - not for posting) http://www.the-coop.org/wwwboard/discus/messages/board-topics.html

> yahoo group: http://groups.yahoo.com/group/poultrygenetics/

msn group: http://groups.msn.com/PoultryGenetics

OEGBCA forum: http://bantychicken.com/OEGBCA/cgi-bin/index.cgi?action=forum&board= Here are a couple more boards, with genetics forum:

Feather Genetics: http://chickenfeathers.proboards25.com/index.cgi

The Poultry Link: <u>http://forums.thepoultrylink.com/</u>

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----- Poultry Genetics Websites (not forums)-----

There is a whole Poultry Genetics (& poultry evolution) book online, but all in Italian. It is more recent information than "Poultry Breeding & Genetics". Here is the website: <u>http://www.summagallicana.it/</u>

- Volume 1: Origin of the domestic fowl (including a chapter on Araucanas)
- Volume 2: Genetics theory, etc (including a large section on population genetics)
- Volume 3: Alot of information on colour/pattern genes (plus plenty more topics).

*The genetics information is in volume 3 (includes links to photos)

Free language translation website: <u>http://www.freetranslation.com/</u>

The sellers website has a good table of poultry genes: http://marsa_sellers.tripod.com/geneticspages/page3.html

Dr Wilmer: http://www.concannon.net/wilmer/Wilmer's%20WebPage/SILKYCHI.htm

-----Poultry Genetics Journals-----

Poultry genetics journal abstracts at the PubMed website: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?CMD=search&DB=pubmed

> Genetics.Org http://www.genetics.org/

Highwire Press http://highwire.stanford.edu/

Poultry Science http://www.poultryscience.org

-----Poultry Breed Websites (with genetics)-----

Polish Chickens: http://groups.msn.com/PolishChickens/yourwebpage5.msnw

Rosecomb Website: http://www.rosecomb.com/federation/articles/articles.html

Dutch Bantam Website: http://www.dutchbantamclub.com/articles.html

The Bantam Roost: http://www.geocities.com/heartland/plains/4175/genes.html

> SPPA: http://groups.msn.com/SPPA/



-----Chicken Genome Websites-----

ARKdb Chicken genetics database: http://iowa.thearkdb.org/browser?species=chicken&objtype=locus

Chicken Genome Resources: http://www.ncbi.nlm.nih.gov/genome/guide/chicken/

Chicken Genome (Entrez Genomes website): http://www.ncbi.nlm.nih.gov/mapview/map_search.cgi?taxid=9031

-----Poultry Genetics Nomenclature-----

Nomenclature to be used in poultry genome publications and databases: <u>http://poultry.mph.msu.edu/about/NOME1195.html</u>

ArkDB-Notes on Nomenclature: http://iowa.thearkdb.org/nomenclature.html

Dr Wilmer & Dr Hollander: http://www.ringneckdove.com/Wilmer's%20WebPage/BioSience/bioscience.htm

-----Genetics Theory (not on poultry)-----

Avian Genetics - BirdTracker website: http://www.cabinsoftware.biz/Genetics_Tutorial/Part1.htm

Biology glossary website. Often helps with genetics terms: http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookgloss.html

Table of Contents, on biology information: http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookTOC.html

-with the following on genetics:

<u>http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookgenintro.html</u> <u>http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookgeninteract.html</u> The following is a good website on genetics theory in general (not on poultry). It is an online genetics course, with course material/lectures: <u>http://www.ucl.ac.uk/~ucbhjow/bmsi/bmsi-lectures.html</u>

