

Current Myths in Avian Genetics Nomenclature

by Linda S. Rubin
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Introduction

As aviculturists we should never underestimate the importance of avian genetics and, just as crucial, color mutation genetics, the latter often serving as an easy access route for companion bird owners and hobbyists to enter into the world of aviculture. The facts are indisputable. The number one and number two pet birds kept in over six million U.S. households are still the Budgerigar, and the Cockatiel, respectively (PIJAC 1995).

The enormous variety of color mutations in both species has clearly aided in their popularity and is a fundamental reason the companion bird owner/hobbyist first tries his hand at breeding, only later to be seduced into the hobby in the quest for "more colorful birds." Although some hobbyists continue on to breed larger, or additional new species (in effect swelling the ranks of aviculture), there remains a significant number of new breeders who become color specialists engrossed only with the challenge that color genetics uniquely provides.

Objective Observation

Yet, where does the curious color breeder turn for information? There are several avenues one can pursue to accumulate additional knowledge even beyond the usual avicultural books, such as textbooks, scientific articles or papers, and of course, the "lab," or aviary. Furthermore, descriptions from the aviary are usually contributed by aviculturists who work directly with the birds and who are intent on publishing and sharing their results.

However, part of the problem with relying on descriptions given by aviculturists, lies in our methods of reporting. A truly objective documentation of new or atypical color anomalies, from nest feather through to the adult molt, is seldom reported with an unbiased point of view and is frequently colored by our subjective interpretations. As aviculturists, we have yet to establish a scientific standard on the formal nomenclature on established (e.g., classified) color mutations.

However, putting such problems aside, the color breeder must still be able to decipher what is posited in the literature, or lecture, and that generally occurs only after some rudimentary knowledge has been accumulated. Unfortunately, the typical color breeder may not possess either the text book knowledge, or the curiosity to separate scientific fact from sophist rhetoric. In truth, many of us learn avian genetics, not through formal study, but from hands-on work "in the field" (i.e., the aviary), where the gradual absorption of facts contributes to the subtle and

News Release

The Blue-throated Macaw (*Ara glaucogularis*) has just become the latest of the world's most endangered species of wildlife to become the subject of an international studbook. A petition to extend the existing European regional studbook was made following the 1996 meeting of the Taxon Advisory Group for psittacines at the annual EAZA/EEP meeting which was held in France at the end of June.

Currently a regional studbook for Europe has been running as part of the EEP scheme for the Blue-throated Macaw which is coordinated by Loro Parque. The application for the international studbook was made by Roger Sweeney, the curator at Loro Parque, and by Alan Hesse, who is the biologist coordinating the current field conservation work for this species in Bolivia.

The application received official endorsement by both the IUCN/SSC and the IUSZG-WZOq by the end of 1996 so the work began in 1997 to encourage every aviculturist in the

world who works with this species to register their birds so that for the first time a clear idea of the true status of the Blue-throated Macaw in captivity can be realized. It is feared that the wild population may number only 100 birds or fewer. ➔

Notice

I am a veterinarian surgeon at the Parc de les aus, an avian zoological garden in Barcelona, Spain where we keep, among other species, a collection of toucans.

Here we are very interested in starting a toucan breeding program and would thus like to gain contact with toucan breeders in the United States. We should like to exchange experiences on incubation, hand-rearing and nutrition/feeding.

We will be very grateful to receive correspondence from American aviculturists who have experience with this family of birds. Please write:

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"There is enough information in this little volume to teach anyone the secrets of dealing with recessive, sex-linked and dominant mutations...from the simplest pairings to complex combinations...the book will give much pleasure and knowledge to all." Dr. Rainer R. Erhart, ACBM, Dec. 1993.

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seemingly effortless process of learning by "osmosis."

Clarifying Information

When deciphering information, one might assume it is the novice who suffers the most confusion. Oddly enough, it may be the advanced breeder who experiences the most disconcertion, since it is generally the seasoned breeder who yearns to add to his fundamental storehouse of knowledge.

Even worse, it is often the advanced breeder himself who, in all innocence, erroneously contributes, inappropriately endorses, or does not recognize such misinformation. Or, perhaps just as faulty, the aviculturist who does not wish to publicly embarrass or correct a peer. Yet, more often than not, the novice is still seeking basic information and his "cup is not yet full" with prior conceptions or material for comparison. Obviously, misinformation will set the novice on the wrong course and the resulting frustration may prevent further pursuit in this area.

In the author's opinion, when such a paradox arises it is the responsibility of the aviculturist to aid in the clarification of misinformation for the benefit of aviculture as a whole. However, such clarifications, or indeed any declaration of information needs to be backed by viable references such as those which the reader or listener will be able to confirm for themselves.

The listing of references meaningful only to the author does little to substantiate an article, body of work, or any plausible theory. Conversely, personal observations, opinions, and supposition, needs to be stated as such, as less blame is assigned when the material is merely an "offering," rather than presented solely as objective fact.

Although the myths outlined below focus on color mutations, it is well to keep in mind that such rules of genetics may be applicable to other areas of avian inheritance, once their inheritance mode is identified.

As more information becomes generally known, it will hopefully encourage scientists to apply such understanding of gene mapping to captive avian species outside of poultry and encourage breeders to establish viable lines (e.g., livestock breeding that is relevant to current times), and consistently produce healthy, long-lived, fertile offspring capable of successfully reproducing, for generations to come.

In the spirit of contributing a combination of facts and personal observations, the author wishes to aid in the clarification of some common misconceptions currently prevailing. Being experienced in teaching color genetic workshops to breeders over the years, the author has become familiar with common problem areas and the pitfalls which often prevail with novice and even seasoned aviculturists. And so, here then are 10 of the most common misconceptions, or myths, that immediately spring to mind.

Common Fallacies in Avian Genetics

Myth #1: Mutations are synonymous with hybrids.

There are still some aviculturists who are confused or

mystified by the science of genetics and do not understand the difference between breeding color mutations within a species, and producing hybrid offspring between two different species.

Mutations may be caused by a variety of factors but generally arise in aviculture as a sudden onset of a variation (e.g., a spontaneous mutation) which produces a new, anomalous color or pattern. Some spontaneous mutations, if not fully developed, may require a planned, selective breeding program requiring several generations to achieve the full mutation. Valid mutations are able to reproduce, as such genes are generally inherited in the progeny either as visuals, or carried as splits, depending upon the full genotype.

Producing hybrids, on the other hand, requires mating a bird of one species to a bird of a different species.

For example, breeding Plum-headed Parakeets to their close relative, the Blossom-headed Parakeet, would result in offspring which are neither 100% genetically Plum-headed Parakeets, *Psittacula cyanocephala* or 100% Blossom-headed Parakeets, *Psittacula roseata*.

On the other hand, breeding a Plum-headed Parakeet to a Lutino mutation Plum-headed Parakeet, would produce Plum-headed Parakeets. In other words, all resulting offspring, whether Normal colored Plum-headed Parakeets, or Lutino mutation Plum-headed Parakeets, would all be of the same species, 100% *Psittacula cyanocephala*.

Myth #2: Compared to the nominate species, color mutations are inherently weak.

Contrary to what some aviculturists might think, there are many mutations in aviculture which have proven hardy and long-lived.

Granted, there are a number of autosomal recessive mutations in aviculture that have had inherent difficulties. This is not entirely unusual in new mutations, although certainly not the rule. For example, in the original emergence of the (autosomal) Recessive Silver Cockatiel in Europe during the early 1960s, the mutation was reported to have produced chicks which were born blind. While first breeding Cockatiels in the mid-70s, the author became aware of Recessive Silvers imported from Europe, some few years later. These birds, however, did not have the inherent blindness or weakness of the earlier birds and were, in fact, quite healthy. Obviously, the lethal genes were either selectively bred out, or a new strain of Recessive Silvers was developed, one which did not carry any lethal factors.

The author occasionally hears tales of ino mutations (i.e., Lutino or Albino) in species such as Cockatiels, which have been labeled by some avian veterinarians as being defective in some way, e.g., weak, inferior, "poor doers," who inherit a multitude of problems from eyesight troubles to immune compromised defenses. While some birds may be affected, the converse is also true. The author has personally bred robust lines of long-lived mutations over the past 20 years, including inos, without experiencing any problems whatsoever.

Nor, have other Cockatiel breeders of the author's

acquaintance remarked upon any abnormalities, either personally, or in the literature (including such vehicles as the Cockatiel society journals from America, England, and Australia). In fact, there are quite a number of robust, healthy, inos repeatedly seen at bird shows, including many a winning "top bench" ino mutation, and champion pedigreed Lutinos who keep winning top awards year after year. While years ago it was commonplace to see a Normal Gray Cockatiel win best in show, today it is usually a color mutation which takes the top position over the original wild colored Normal Gray. Such healthy ino mutations are routinely kept in breeders' aviaries and continue to thrive.

Often, a greater population of sick individuals may be seen by avian veterinarians. In addition, the majority of Cockatiels commonly seen are typically the Normal Gray, or readily available mutations such as Lutinos, and to a lesser extent, Pieds, Pearls, Cinnamons, and their cross-mutations.

To further complicate the picture, new pet owners may not always select healthy birds from strong bloodlines, or be properly informed on how to provide adequate nutrition (malnutrition in birds is a frequent lament among many avian veterinarians).

Any bird, whether of the nominate wild coloration, or a color mutation, will only be as hardy as its genes and the breeding program from where it originated. If a bird originates from healthy, well bred stock, produced from proven bloodlines (which are not necessarily limited to show stock), then the result will be a more hardy bird.

Even show breeders know the old genetic adage, "like produces like." If you start off with problem birds (e.g. highly inbred, compromised stock, etc.), then that is what you will produce: weak, sickly birds. The laws of genetics apply to any bird, whether it is the nominate wild color or a variant color mutation.

Occasionally some new mutations, especially autosomal recessives (although not all), can be linked with lethal factors. However, the responsible breeder will work with the line establishing a viable, healthy strain, before ever attempting to let go of such stock.

As aviculturists, this is our responsibility. And such a responsibility is not merely limited to producing color mutations but includes any stock we work with, be it a family line, strain, or stud of birds; or be it one species, genus, or avian family of birds. The genetic modes of inheritance such as those employed with producing color mutations can theoretically be applied to the many valued traits in the establishment of all species, e.g. health, fertility, longevity, resistance to disease, and other important factors.

Myth #3: All chromosomes are alike.

Chromosomes (which contain the genes) travel in pairs and in most cases are identical, with the exception of the sex chromosomes. As most of the avicultural literature universally assigns sex-linkage in terms of "X" and "Y" chromosomes (rather than the Z - W notation used in most genetic literature), for the ease of the reader this article will

follow suit.

The sex chromosomes, which determine the sex of the offspring, are identical in the cock (XX), but differ in the hen (XY). Each offspring will inherit one sex chromosome from each parent. The cock will always donate an "X" from his "XX" sex chromosomes; the hen will donate either an "X" or a "Y" from her "XY" sex chromosomes (with an equal chance of donating either an "X" or a "Y"). If the cock's "X" sex chromosome unites with the hen's "X" sex chromosome to form "XX," the offspring produced will be male. If the cock's "X" sex chromosome unites with the hen's "Y" sex chromosome, the offspring produced will be female.

Therefore, in avian species (unlike mammals, including humans), it is the female who determines the sex of the offspring by whichever sex chromosome she donates to the union.

Autosomes are the names of all of the chromosomes except the sex chromosomes. Autosomes carry a multitude of genes, including genes for color mutations, which we refer to as autosomal.

This difference is important, since you shall soon see that while hens can never be heterozygous (split) to sex-linked colors or traits, hens may be heterozygous (split) to autosomal recessive colors and traits.

Myth #4: Hens may be heterozygous (split) to sex-linked traits.

At present, it is theorized in sex-linked avian mutations that only the "X" chromosome is sufficiently large enough to carry the genes for sex-linked recessive traits. The "Y" chromosome, being significantly smaller, has no locus (i.e., "address") sites available for such color alleles to reside. It becomes exceedingly clear when charting such inheritance why hens cannot carry sex-linked recessive colors in hidden form, as do their male counterparts (Table 1).

As the hens' "Y" chromosome is too small to carry locus sites for color alleles, and therefore is unable to cover or mask the color alleles on the "X" sex chromosome, the recessive genes on the "X" chromosome must show themselves. This is why hens (XY) show sex-linked recessive colors more frequently. They need only carry the mutation on their one "X" chromosome for the mutation to be visual. Therefore, whenever working with sex-linked colors in hens, the old adage, "what you see is what you get" could never be more true. If you can't see it, it's not there. However, this statement only applies to sex-linked recessive traits, as hens may certainly be heterozygous (split) for autosomal color mutations which work under different rules of inheritance.

Myth #5: Single and double quantities are synonymous with single and double factor inheritance.

Autosomal recessive color mutations are sometimes referred to as having single or double quantities. If a color mutation is carried on both autosomes, the bird is said to carry a double quantity and will therefore display the homozygous phenotype for the autosomal recessive trait. Put another way, the color mutation (or trait) must be car-

ried on both chromosomes in order for a bird to appear visual for the mutation.

However, if the color mutation is only carried in single quantity on one autosome, the bird is then heterozygous (split) for the trait, carrying the trait in hidden form. Therefore, if only one autosome is affected by a single quantity of the trait, the remaining autosome serves to mask the autosome which carries the recessive trait. A bird with a single quantity is called heterozygous, or in avicultural lingo, "split," denoted in writing as a slant sign (i.e., "/").

On the other hand, single and double factor color mutations refer mainly to autosomal mutations in one of the dominant modes of inheritance. Single and double factor birds may appear in two distinct color forms, expressed phenotypically in their outward appearance (Table 2). Although such dominant mutations may theoretically be charted alongside sex-linked or autosomal recessive color mutations (within the same individual or when charting a pair of birds), it functions as a co-dominant since the allelic gene present in a heterozygous state is expressed as a single factor phenotypic color form of the mutation. In other words, single factor birds will visually appear as one color; double factor birds will appear as a uniquely different and alternate color form of that mutation.

Common examples of co-dominant and intermediate dominant mutations include the Dominant Silver Cockatiel, the Yellowface Budgerigar, and the Gray-green Indian Ring-necked Parakeet, respectively. When such colors are bred with others, new and interesting cross-mutations may result e.g. Whiteface-Dominant Silver Cockatiels, Yellowface-Opaline-Clearwing ("Rainbow") Budgerigars; Yellowhead-Gray-green Indian Ring-necked Parakeets, etc. Such color combinations can require a great deal more work to chart compared to simple sex-linked recessive or autosomal recessive color mutations, especially when combined with additional existing mutations or modes of inheritance (Table 3).

The terms "single and double quantity" may appear deceptively similar to the terms "single and double factor." However, the breeder might find it easier to associate "quantity" differences with homozygous and heterozygous genotypes (i.e., visuals and splits) in recessive traits; while "factor" differences indicate fully expressed, distinctly different colored phenotypes (i.e., two distinct color forms) appearing in dominant mutations.

Myth #6: Single and double factor inheritance is synonymous with dark factor inheritance.

In many of the popular species in aviculture which have been bred for numerous years in captivity, mutations have further differentiated themselves by being affected by color modifiers. Some modifiers, such as dark factors, can change the appearance of a standard color mutation.

For example, dark factors are well known in the Budgerigar Fancy. In the nominate wild green Budgie, referred to as the Light Green, the appearance of dark factors work to modify the Light Green into the Dark Green (one dark factor), and Olive Green (two dark factors)

Note: Tables are based on Mendelian ratios for every 100 chicks produced, which over time, work out to the percentages shown below. The following legend is used for Tables 1 through 7:

P1 = Parental Generation
 F1 = First Filial Generation (or progeny produced)
 "/" (slant sign) = Heterozygous, or "split to" (e.g. carrying a gene in a hidden state).
 ♂ = Scientific notation for cock
 ♀ = Scientific notation for hen

TABLE 1. SEX-LINKED INHERITANCE			
Cock ♂	X	Hen ♀	Progeny
1. Sex-linked		Non-linked	= 50% Non-linked/Sex-linked ♂ 50% Sex-linked ♀
2. Sex-linked		Sex-linked	= 50% Sex-linked ♂ 50% Sex-linked ♀
3. Non-linked		Sex-linked	= 50% Non-linked/Sex-linked ♂ 50% Non-linked ♀
4. Non-linked/Sex-linked		Non-linked	= 25% Non-linked/Sex-linked ♂ 25% Non-linked ♂ 25% Sex-linked ♀ 25% Non-linked ♀
5. Non-linked/Sex-linked		Sex-linked	= 25% Non-linked/Sex-linked ♂ 25% Sex-linked ♂ 25% Sex-linked ♀ 25% Non-linked ♀

Key: Where "Non-linked" is Normal, or any other color that is not sex-linked. This table may be used to check the results of individual sex-linked mutations, one at a time. While the charts demonstrated in the workbook allow for graphing several sex-linked mutations together (with other colors or modes of inheritance) on the same chart, each sex-linked trait may be double-checked one at a time, by simply using the above table.

Example: Non-linked/Sex-linked cock ♂ x Non-linked hen ♀

P1	X ^L X	X Y	= Normal/Lutino ♂ (X ^L X)	Normal ♀ (XY), where L = Lutino:
F1	X ^L X	X ^L Y	= 25% Normal/Lutino ♂	25% Lutino ♀
	X X	X Y	= 25% Normal ♂	25% Normal ♀

Note: It is easier to understand why a hen can never be heterozygous (split) to a sex-linked trait when looking at a chart. As a hen's sex chromosomes (XY) have only one "X", the only possibility is to be visual for the trait (X^LY), or not (XY). This is because hens do not have a second "X" sex chromosome to cover or hide a recessive sex-linked trait on a companion "X" sex chromosome. Also, it is believed that the "Y" sex chromosome is too small to carry locus sights (addresses) for sex-linked color traits to reside.

TABLE 2. SINGLE AND DOUBLE FACTOR DOMINANT INHERITANCE	
1. Single Factor x No Factor	= 50% Single Factor 50% No Factor
2. Single Factor x Single Factor	= (produces a 1:2:1 ratio): 25% No Factor 50% Single Factor 25% Double Factor
3. Single Factor x Double Factor	= 50% Single Factor 50% Double Factor
4. Double Factor x No Factor	= 100% Single Factor
5. Double Factor x Double Factor	= 100% Double Factor

Key: "No Factor" represents a Normal, or any other mutation which is not governed by Single and Double Factor Dominant inheritance.

Example: Cockatiels: Single Factor x Single Factor = 1:2:1 ratio with equal chance of either gender.

P1	Single Factor Dominant Silver ♂ x Single Factor Dominant Silver ♀ =
F1	25% No Factor (e.g. unaffected) 50% Single Factor Dominant Silver 25% Double Factor Dominant Silver

TABLE 3. COMBINING AUTOSOMAL RECESSIVES WITH CO-DOMINANT TRAITS	
Example:	P1 Whiteface-Single Factor Dominant Silver ♂ x Whiteface Single Factor Dominant Silver ♀ =
	F1 wSwS = 25% Whiteface-D.F. Dominant Silvers wSw = 25% Whiteface-S.F. Dominant Silvers wwS = 25% Whiteface-S.F. Dominant Silvers ww = 25% Whiteface

Key: S.F. = Single Factor; D.F. = Double Factor; Equal opportunity of either gender.

Note: The above example can be checked with Table 2: Single & Double Factor Inheritance (i.e., #2, Single Factor x Single Factor = 1:2:1 ratio); and Table 5: Dominant and Recessive Matings (i.e. recessive x recessive = 100% recessive).

shades. In the blue series, dark factors appearing in the Sky Blue Budgerigar result in Cobalt (one dark factor), and Mauve (two dark factors). Dark factors also affect the Yellow series, Gray series, and other mutations in Budgerigars (Table 4).

Similarly, lovebirds and Indian Ringnecks have followed suit with dark factor modifiers, which have permeated their green and blue series and other various colors. Many Cockatiel breeders already argue that Gray Cockatiels show dark factors, ranging from Light, to Medium, to Dark Gray (somewhat akin to the Gray Budgerigar as mentioned above). We also see dark factors in other parrots, most recently the Cobalt Blue Lineolated Parakeet, which is an affected blue mutation showing one dark factor.

While single and double factor mutations (as discussed under Myth #5) generally operate by a dominant mode of inheritance affecting specific mutations (e.g., Yellowface Budgerigars, Dominant Silver Cockatiels, etc.); dark factor modifiers appear to exist in both dominant and recessive autosomes affecting a number of color forms (e.g., Dark Green, Olive, Cobalt, Mauve, Dark Yellow, Olive Yellow, Medium Gray, Dark Gray, etc.).

Myth #7: A bird may be a "dominant recessive" color mutation.

Unfortunately, this is becoming a common misconception and does not need to be. To the best of the author's knowledge, a gene cannot exist in both a dominant mode of inheritance and a recessive mode of inheritance, concurrently. It is either one or the other (Table 5). A gene may, however, interact with other genes or alleles in a variety of behaviors, depending upon their mode of inheritance. The confusion appears to stem from the lack of understanding that, while an autosomal recessive color is recessive in its mode of inheritance, it may behave in a dominant manner when interacting with a double recessive mutation.

For example, in Budgerigar genetics, while the autosomal recessive allele for body color Sky Blue is recessive to Normal Green, recessive Sky Blue will act as a dominant to the double recessive White (i.e., Blue x White = all Blue/White progeny). This relationship among recessives merely indicates their hierarchy. It does not justify labeling the allele Sky Blue "dominant" since genetically Sky Blue is an autosomal recessive. Rather, Sky Blue behaves in a dominant manner in the hierarchy of relationships with double recessives (e.g., White). However, as an autosomal recessive it would be genetically incorrect to label Sky Blue as a dominant gene (Table 6).

Similarly, the Pastelface Cockatiel is our first autosomal recessive Cockatiel mutation to interact in a dominant relationship to the double recessive, Whiteface. For example, one may say the autosomal recessive, Pastelface, is recessive to Normal Gray, but behaves as a dominant over Whiteface. To call the autosomal recessive Pastelface a "dominant" would be genetically incorrect. What Cockatiel, Ringneck, and other parrot breeders must learn to understand (as do Budgie and lovebird breeders who

TABLE 4.
DARK FACTOR INHERITANCE

- 1. No Dark Factor x No Dark Factor = 100% No Dark Factor
- 2. No Dark Factor x One Dark Factor = 50% No Dark Factor
50% One Dark Factor
- 3. No Dark Factor x 2 Dark Factors = 100% One Dark Factor
- 4. One Dark Factor x One Dark Factor = 25% No Dark Factor
50% One Dark Factor
25% Two Dark Factors
- 5. One Dark Factor x Two Dark Factors = 50% One Dark Factor
50% Two Dark Factors
- 6. Two Dark Factors x Two Dark Factors = 100% Two Dark Factors

Example: Budgerigars (applicable to psittacine species with equivalent psittacin color pigments).

Dark Factor:	Green series:	Blue series:
None	Light Green	Sky Blue
One D.F.	Dark Green	Cobalt Blue
Two D.F.	Olive Green	Mauve
None	Light Yellow	Light Gray
One D.F.	Mustard Yellow	Medium Gray
Two D.F.	Olive Yellow	Dark Gray

Key: D.F. = Dark Factor. "Families" of Yellow and Gray correspond with Light, Medium, and Dark shades.

Example 2: Cobalt Blue Lineolated Parakeet x Normal Green Lineolated Parakeet:

P1: One Dark Factor (Cobalt) x No Dark Factor (Normal Green) =
F1: 50% No Dark Factor: Normal Green/Blue
50% One Dark Factor: Dark Green/Cobalt

F1 Backcross: F1 x P1: Normal Green/Blue Lineolated Parakeet x Cobalt Lineolated Parakeet =

F2: Offspring: 25% Normal Green/Blue
25% Blue
25% Dark Green/Cobalt
25% Cobalt

TABLE 5.
DOMINANT X RECESSIVE MATINGS

P1	Cock	x	Hen	=	F1	Progeny
1.	Dominant	x	Dominant	=	100% Dominant	
2.	Dominant	x	Dominant/Recessive	=	50% Dominant 50% Dominant/Recessive	
3.	Dominant	x	Recessive	=	100% Dominant/Recessive	
4.	Dominant/Recessive	x	Dominant/Recessive	=	25% Dominant 50% Dominant/Recessive 25% Recessive	
5.	Dominant/Recessive	x	Recessive	=	50% Dominant/Recessive 50% Recessive	
6.	Recessive	x	Recessive	=	100% Recessive	

Example: Budgerigars:
where GG = Light Green; Gb = Light Green/Sky Blue; and bb = Sky Blue

Model: 1,2, 3,4 (High School Algebra "FOIL" method = First, Outer, Inner, Last).
1,3
1,4
2,3
2,4

1. GG GG	2. GG Gb	3. GG bb
GG	GG	Gb
GG	Gb	Gb
GG	GG	Gb
GG	Gb	Gb
4. Gb Gb	5. Gb bb	6. bb bb
GG	Gb	bb
Gb	Gb	bb
bG	bb	bb
bb	bb	bb

TABLE 6.
HIERARCHY OF RECESSIVES

Note: Table 6 demonstrates the hierarchy of autosomal recessive mutations and does not include sex-linked, co-dominant, or intermediate dominant mutations.

Color	Dominant to:	Recessive to:
BUDGIES/(and a general guide in parrots which produce similar psittacin pigments)		
Normal Green	All colors	None
Dilute Green (i.e., Graywing)	Blue in all suffusions	Normal Green
Pastel Green (i.e., Yellow)	Blue in all suffusions	Normal Green, Dilute Green
Normal Blue	All Blue Suffusions	All Green Suffusions
Dilute Blue (i.e., Graywing Blue)	Pastel Blue (i.e. White)*	All Green Suffusions, Normal Blue
Pastel Blue (i.e., White)*	None	All Green and Blue Suffusions
COCKATIELS:		
Normal Gray	All colors	None
Pasteface	Whiteface	Normal Gray
Recessive Silver	Unknown**	Normal Gray,
Whiteface	None	Normal Gray, Pasteface

Key: *White includes Whites of Suffusion (i.e. White Sky Blue, White Cobalts, and White Mauves) which act as double recessives.

**Unknown refers to not enough data has been reported by breeders, or colors do not yet exist.

routinely work with such colors), is that such recessive genes merely demonstrate a hierarchy of relationships among autosomal recessive color mutations; in particular, how such recessives are inherited when working with double recessive mutations.

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Myth #8: The Albino Cockatiel is a single mutation, therefore a hen may be heterozygous, or split, to Albino.

The Albino mutation in Cockatiels, unlike the majority of inos in other species, is not a singular spontaneous color mutation. The Albino Cockatiel is actually a cross-mutation between the sex-linked recessive Lutino mutation, and the autosomal recessive Whiteface mutation. When birds of the correct genotype are paired they produce the cross-mutation, Whiteface-Lutino, an all white bird with red eyes, depigmented beak and feet, that is void of all melanin and carotenoids, or psittacin pigment. Rather than call the cross-mutation by its genotypic name, Whiteface-Lutino, the phenotypic label, Albino, has caught on as the common avicultural lingo.

Since the Albino Cockatiel is the result of two distinct mutations, one of which is a sex-linked color, it is incorrect to state that a hen can be split to Albino. Hens, like cocks, can be split to autosomal recessives such as Whiteface, Pied, Recessive Silver, etc. Unlike cocks, hens cannot be split to sex-linked recessives such as Lutino (see myth #4, above). Therefore, when speaking of Albinos, a hen could only be heterozygous, or split, to Whiteface. This is also true of many other species where "ino" (i.e., Lutino or Albino) is sex-linked, although inos do exist in other modes of inheritance.

However, if you purchased a Cockatiel hen "guaranteed split to Lutino, or Albino," the bird was misrepresented (in other words, you got taken)! As you may recall from above, when working with sex-linked mutations in hens, "what you see, is what you get." Therefore, where concerning the production of the Albino mutation, a Cockatiel hen may only be visual for Albino, Lutino, or Whiteface; visual for Lutino and split to Whiteface; or Normal Gray split to Whiteface (Table 7).

TABLE 7.
WHITEFACE-LUTINO (ALBINO) COCKATIEL CROSS MUTATION
Possible genotypes used for producing the Albino cross-mutation in the F1 generation contingent upon the correct pairings

Phenotype	Heterozygous (split to)	Genotype
COCKS:		
Albino	---	Whiteface-Lutino
Lutino	Whiteface	Lutino split Whiteface
Whiteface	Lutino	Whiteface split Lutino
*Normal Gray	Whiteface & Lutino	Gray split Whiteface and Lutino
*Lutino-Cinnamon	Whiteface	Lutino-Cinnamon split Whiteface (or other Lutino/Whiteface cross).
*Whiteface-Cinnamon	Lutino	Whiteface-Cinnamon split Lutino (or other Whiteface/Lutino cross).
HENS:		
Albino	---	Whiteface-Lutino
Lutino	Whiteface	Lutino split Whiteface
Whiteface	---	Whiteface
*Normal Gray	Whiteface	Normal Gray split Whiteface
*Lutino-Cinnamon	Whiteface	Lutino-Cinnamon split Whiteface (or other Lutino/Whiteface cross)
*Whiteface-Cinnamon	---	Whiteface-Cinnamon (or other Whiteface cross).

Key: Phenotypes demonstrate how the bird appears visually; heterozygous traits show which color genes the bird is carrying, if any; and the genotype lists both visual and nonvisual traits. For example, a Lutino split Whiteface (i.e., Lutino/Whiteface) appears visually as a Lutino (phenotype), but is (heterozygous) split to Whiteface, so its full genotype is Lutino/Whiteface.

*May substitute other standard or rare varieties in single or multiple combinations: (e.g. Pearl, Pied, Fallow, Yellowface, Pasteface, Recessive Silver, Dominant Silver, etc.) in place of "Normal Gray" or "Cinnamon."

Photo by Herschel Burgin



The autosomal recessive Pastelface mutation in the sex-linked Lutino Cockatiel.

Photo by Linda S. Rubin



The autosomal recessive Cobalt mutation in the Lineolated Parakeet.



Photo by Herschel Burgin

Whiteface-Dominant Silver Cockatiel: a double recessive and co-dominant cross-mutation.

Myth #9: "Crossing over" occurrences can be predetermined or predicted.

Crossing over refers to a phenomenon in genetics where chromosome pairs swap segments of their chromosomes (i.e., chromatids) during meiosis, resulting in a recombination of linked genes. Such "crossovers," as termed in the Fancy, happen by chance occurrence and there is currently no way to predict when or where it will happen in avian color genetics. However, once crossing over does occur, it will result in some of the genes linking together to produce a new combination such as a cross, or double mutation. Without the original act of crossing over, (e.g., coupling, or recombinant forms) many double mutations would not exist today.

For example, when this author presented a genetics workshop to color breeders at the Boston Cockatiel Society in 1989, reference was made to a breeder/biologist



Autosomal recessive *ino* mutations: Lutino Princess of Wales Parakeet (above), Albino Princess of Wales Parakeet (below).

who observed a near 30% occurrence of crossing over between the Lutino and Pearl genes in a very small population of Cockatiels. Such a crossing over (from XLXP to XLPX) in a male Cockatiel (i.e., known as "coupling" or "cis linkage"), was originally responsible for producing a small percentage of the first (XLPY) Lutino-Pearl hen genotypes. Unfortunately, while the author has fully explained this example in both lectures, and workbooks, the information has been taken completely out of context and has appeared elsewhere as: "A crossover occurs about 30% of the time with a male Cockatiel's chromosomes." (NCS 1995).


Myth #10: Gene mapping in cage birds proves the current "mutation du jour."

To the best of the author's knowledge, there has yet to be any formal undertaking that has become available to aviculture in the science of gene mapping known color mutations in psittacine birds (and most likely, other families of birds outside of poultry). First, to fund such a venture can be costly. Second, there are very few scientists who (should they be interested in doing so in the first place) are qualified in the procedure while being well-versed in the multitude of mutations which now exist in aviculture, and possess the very limited scientific knowledge of color pigmentation and its chemistry.

While aviculturists can provide information, document their aviaries, and even demonstrate on paper how such mutations might be inherited, there still remains a wealth of information to uncover through scientific protocols and formal research methods that the aviculturist cannot undertake alone. It would then seem that a team of well versed aviculturists, and scientists who have the background and interest in gene mapping, might be the answer to satisfying such extraordinary mysteries which keep many aviculturists hooked in the constantly challenging and ever-changing world of aviculture. For without the many sides of aviculture uniting together in these hard times, doubtless fewer bird breeders would remain.

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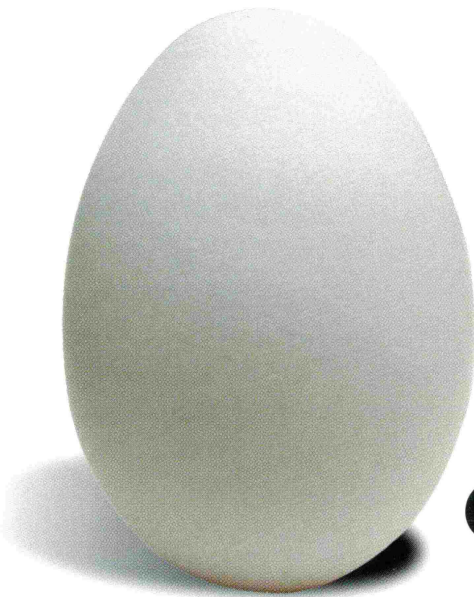


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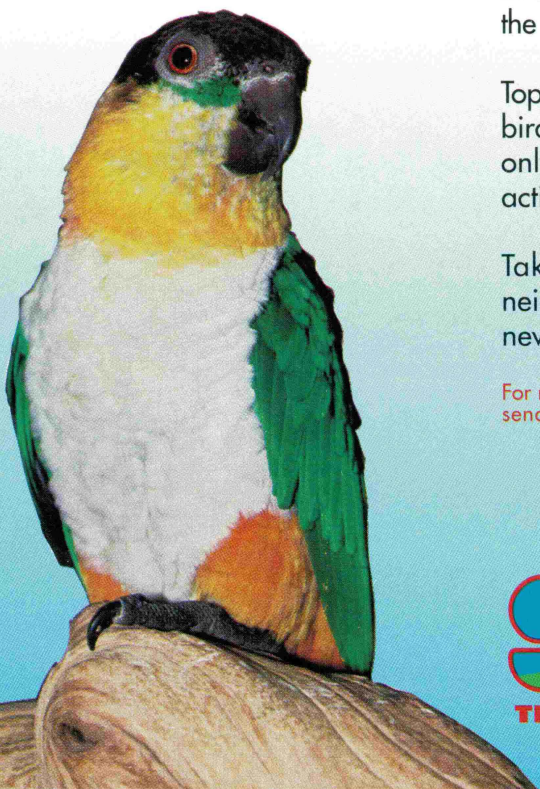


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