

THE FOLLOWING PAPER IS BY
Anthony Olszewski

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MUTATIONS IN AVICULTURE

Mutation has been defined as "a heritable change in the base sequence sequence of a cistron." These disrupted base sequences are caused by mistakes in DNA replication. Due to the structure of the DNA molecule, and due to proofreading by repair enzymes, such errors are very rare. Mutation may occur at a universal rate of 1×10^{-7} per base pair per generation under normal conditions. Certain chemicals, radiation, and even high temperatures, can contribute to an increase in the probability of such mistakes.

At the chromosome level, little is known concerning the mechanics of mutation with respect to cage birds. For the avian practitioner, such knowledge would be desirable but is not needed. Mutations of the feather colors and the feather structure can be classified into a relatively small number of categories. An understanding of the different types of mutations will allow the discerning eye to judge whether a true breeding strain can be developed from an unusual individual. This understanding of mutation will also enable the avian practitioner to separate birds with pathological metabolic disorders and "artificial mutations" from actual mutations.

As in any form of domestication, mutations are of central importance to aviculture. Even initial captive breedings may be as much a matter of the selection of suitable pairs as of husbandry. As soon as such a first breeding has been accomplished, the aviculturist strives to produce superior or novel strains. Superior may mean freer breeding, steadier, resistant to disease, or able to withstand extremes of climactic conditions. Novelties are selected most often on the basis of size, feather color, and feather structure.

Mutations are also valuable in the monetary sense. About ten years ago years ago a lutino Peach Faced Love Bird (*Agapornis roseicollis*) sold for one thousand dollars. Such examples of high prices could be listed for any of the early mutations of exotic birds. Such mutations create, albeit temporarily, a gold rush atmosphere. The price of even the most drab and common colors goes up, since interest in and market consumption of the species increases. Many more people start to keep and breed birds of all types. Thus it can be seen that mutations serve both to create, improve, and vary captive strains and to promote aviculture.

The genetics of the mutations in aviculture are relatively simple. A review of basic genetics will now be given. The patterns of inheritance that are most important to the production of cage birds will of course be stressed.

Simple, autosomal, recessives are the largest class of mutations of exotic birds. It is possible for such recessive traits to be present in a proportion of the wild population as heterozygotes. Such heterozygotes exhibit the normal phenotype. The mutant phenotype of autosomal recessives manifests itself only in the homozygote. Any regime of inbreeding will quickly bring such mutations to the surface. As soon as any species becomes established in captivity, such factors are discovered.

This is the most likely explanation behind the phenomenon noted by Darwin that domestication seems to induce variation. Domestication does not increase the rate of mutation, but it does increase the probability of the production of homozygotes. Also such mutant phenotypes that might be culled by natural selection will be favored by artificial selection.

The autosomal recessive traits are denoted by lower case symbols. The corresponding normal, wild gene is given by a plus sign, +.

As a practical matter such mutations may be discovered by inbreeding. This system is exploited by Dutch breeders of Australian Parakeets. These clever fanciers seem to turn out mutations on an assembly line basis.

Dominant autosomal mutations are less common in aviculture. If the dominant mutated individual appears in captivity from normal parents, the mutation must have occurred in the germ cells of the parents. The extremely low rate of mutation explains the paucity of such traits.

Dominant genes are of two types: complete and incomplete. Complete dominance allows heterozygotes to express the full mutant phenotype. With incomplete dominance, heterozygotes show a compromise between the normal and the mutant phenotypes.

The manifestation of the dominant genes is affected by the phenomena of penetrance and expressivity. Penetrance is defined as "The percentage of individuals that, carrying a gene in proper combination for its expression, actually express that genes phenotype." Expressivity is defined as "the manner in which phenotype is expressed." These terms clearly describe two aspects of the same situation. Penetrance refers to the clear cut, discrete, cases where a given trait is or is not expressed. Expressivity refers to the full range, continuous cases, of intermediate examples.

Another way of looking at this would to be consider the dominant trait as not fully suppressing the recessive trait. This may be noted in the clear dominant white mutation of the canary (*Serinus canarius*). Rarely this mutation shows only the faintest hints of lipochrome in the wings. More often they will have well defined bars of lipochrome color. At the other end of the spectrum, some show a red or yellow suffusion throughout the entire plumage.

Expressivity is almost certainly due to the action of modifiers. Without controlled experiments we are not able to simply discount environmental influences. Modifiers are secondary genes that mold the phenotype. "Even when only one principal gene is involved, its expression is influenced by some extent by countless other genes with individual effects often so slight that they are very difficult to localize and analyze." Thus modifiers are by definition a multiple allele phenomena.

Even though multiple alleles may not be analyzed by simple Punnet squares, we, as aviculturists, can still control them. Simply and drastically, we can cull out any bird that we deem undesirable. More subtly we can utilize as stock birds specimens that are extreme examples of the expression of a trait. By blending these together, we hope to take a middle path and so obtain a few outstanding birds.

The symbol for dominant genes is a capital letter. The corresponding wild, normal allele is again given by a plus sign.

Sex linkage is a very important pattern of inheritance in aviculture. The sex chromosomes are of two types: X and Y. The X chromosome is relatively large and contains many genes. The Y chromosome is much smaller and, in the case of cage birds, no traits are known to be located on it. Male birds have X chromosomes in pairs. In females, the sex chromosome pair consists of one X and one Y. The X chromosome is sometimes designated as Z and the Y as W. The Z-W notation is used in most genetic literature to signify the difference between birds and mammals. The sex linkage system in mammals is the inverse of that in birds. Avicultural literature universally uses the X-Y notation.

All sex linked mutations so far described in exotic cage birds are recessive. One reason for this, as for autosomal recessives, such sex linked recessives can build up hidden in the wild gene pool. Dominant sex linked traits are certainly possible, in fact, Levi describes many common ones in the domestic Pigeon (*Columba livia domestica*).

For the male bird to exhibit a sex linked recessive phenotype, he must possess two such factors, be homozygous for the mutant gene. A hen will exhibit the mutant gene with only one factor. This is explained by the fact that the X chromosome has no corresponding allele on the Y chromosome to dominate the normally recessive mutation. Such hens are called hemizygous. Some traits seem to act differently in the homozygous and the hemizygous configurations. Two examples are the Pearl mutation in the Cockatiel (*Nymphicus hollandicus*) and the Pastel mutation in the Canary (*Serinus canarius*). More research is needed to confirm these observations. An alternate explanation is a different phenotype is due to hormonal differences.

In some organisms a few genes are located on the Y Chromosome. None have been described for cage birds.

Crossing over and linkage must be taken into consideration when any traits that are to be combined are located on the same chromosome pairs. This is obviously the case for any double mutations involving sex linked traits. This is also true for autosomal chromosome pairs. An example is the traits for blue, *s*, and the dark factor, *D*, in the budgerigar (*Melopsittacus undulatus*). The breeder attempting to get a combination of the dark and blue mutations is in for a surprise if he starts by mating an olive, a two factor green bird, with a sky blue. This mating will produce all one dark factor green birds that are heterozygous with respect to, split for, blue. Realizing that blue and the dark factor are autosomal, not sex linked, he computes the expected frequencies of the progeny. Mating a green carrier of blue to a blue bird yields 50% blue and 50% green carriers of blue. Pairing a dark factor bird to a no dark factor bird gives 50% one dark factor birds and 50% normal, no dark factor, birds. By simple multiplication (50% blue X 50% one dark factor), this fancier expects 25% of the young to be cobalts, one dark factor blue birds.

If only a few pairs are being used it is very likely that no cobalts will result. If he manages to breed one hundred young from this sort of pairing, on the average, only seven cobalts will be obtained.

Why is there this gap between theory and practice?

Our fancier assumed segregation of the traits. These genes do not follow Mendel's law of independent assortment because they are not independent. Both traits, blue and the dark factor, are located on the same chromosome. Genes located on the same chromosome are said to be linked or in linkage.

During prophase 1 of meiosis homologous chromosomes, chromosome pairs, are situated in close proximity to each other. Sometimes points of contact and breakage are formed. These discrete points are visible under magnification and are called chiasma, plural chiasmata. At these points, single strands, chromatids, of each chromosome may break and switch chromosomes. This whole process is known as crossing over. It is through crossing over that linked factors may undergo recombination.

There are two basic plans by which linked traits may become involved in crossing over: in coupling and in repulsion. Genes are linked in coupling when mutant traits are located on the same chromosome. They are linked in repulsion when mutant genes are located on opposing chromosomes. See figures 1 and 2.

Figure 1 $s+ / +D$

Figure 2 sD/++

Figure 1 symbolizes traits linked in repulsion. In figure two they are in coupling. Linkage in coupling is also known as cis linkage. Linkage in repulsion is also known as trans linkage.

Most avicultural literature, in particular budgerigar literature, refers to linkage in repulsion as type 1 linkage, type 2 designating linkage in coupling. This is an undesirable terminology for several reasons. Firstly, no genetic text books ever use these terms. Secondly, some authors switch type 1 with type 2. They designate type 1 for coupling and type 2 for repulsion. This leads to confusion. Also some authors use type 1 and type 2 to label a host of unrelated concepts: homozygous versus heterozygous, separate forms of the yellow face factor in the budgerigar, and various genotypes of specific phenotype, e.g. the fallow phenotype in the budgerigar. Thus we should follow the example of the geneticists.

The concepts of coupling and of repulsion are of both practical and of theoretical importance. The percentages of the genotypes and the phenotypes produced are most often different, since the percentages of young produced from crossing over is most often different.

This difference may be best observed by the frequencies of young produced from the cross of a one dark factor green budgerigar that is split for blue with a sky blue bird. Both blue and green are autosomal, non sex linked traits. These factors are located on the same chromosome and are thus linked.

The first example will be for in repulsion

D - dark factor
s - blue

olive green + D /+D X s+ /s+ sky blue
The young will all be: + D /s+ Dark green/blue

The symbols graphically represent how the traits, both mutant and normal, are located opposite to each other on the chromosome.

This bird will produce the following gametes: +D, s+, ++, and sD. The last two gametes are due to crossing over. Pairing this bird with a sky blue will give the young described in the accompanying chart. Percentages are according to Hart.

+ D/s+ X s+/s+

+ D /s+ 43% dark green/blue
s+/s+ 43% sky blue
sD/s+ 7% cobalt
+ +/ s+ 7% light green/blue

An alternate method to get a dark green carrier of blue is to mate a mauve, a two dark factor blue budgerigar, with a light green.

mauve sD/sD X + + /+++ light green
The young will all have the phenotype of ++/sD

. This is an example of traits in coupling. Though of the same phenotype as the preceding example, the genotype differs by the arrangement of the factors on the chromosomes. The

mutant genes are on one chromosome and the normal genes are on the other chromosome of the homologous pair. Pairing this bird with a sky blue gives the same genotypes and phenotypes as the case in repulsion, but the frequencies are modified.

+ + /sD X + s /+s

+ + /+s 43% light green/blue
sD/+s 43% cobalt
s+ /s+ 7% sky blue
+D/s+ 7% dark green/blue

Percentages are again according to Hart.

Thus the position of the genes determines the manner in which crossing over occurs. In the first example, linkage in repulsion, the gametes ++ and sD are only obtained through a crossover. This is the explanation for the low frequencies of cobalt and light green/blue young. In the second case, the example of linkage in coupling, the gametes +s and +D are obtained by means of the process of crossing over. Therefore the sky blue and the dark green/blue young are of the lowest frequencies.

The probability of crossing over and the implied frequencies of the progeny may only be inferred from breeding results. The closer the two linked traits are located to each other, the less likely is the chance of breakage and the subsequent crossing over. Genes located at a great distance from each other have a much greater probability of crossing over. This probability is expressed as a percentage and varies from 0% to 50%. At the rate of 0% there is, for all practical purposes, no chance of crossing over. The percentage of 50% implies that, since the chance of breakage and recombination is so high, in practice, the traits may be considered as independent. The probability of crossing over for any two specific traits, as it is a function of the location of the gene locus, is nearly constant. To calculate this probability, the percentage of crossing over may be expressed by the following formula:

PERCENTAGE OF CROSSING OVER = (NUMBER OF CROSSING OVER INDIVIDUALS / TOTAL NUMBER OF YOUNG) X 100

No complete chromosome maps have been constructed for any exotic birds. There are many problems concerning the formulation of such maps in birds. All birds have microchromosomes. These microchromosomes are extremely small, less than one micron in diameter. Even under magnification these are very small, in fact dot like, and hard to distinguish. Because of the difficulty of viewing these structures, the exact counts of even the well researched species is not known. The accepted counts of the domestic pigeon (*Columba livia domestica*), the budgerigar (*Melopsittacus undulatus*), and the canary (*Serinus canarius*) are +_80, +_58, and +_80 respectively. The plus or minus notation is used to stress that the exact count is not known. For the majority of cage birds, no attempt at a karyotype has been made. Very few traits have been documented in ornamental birds. Once we possess a more comprehensive understanding of the genetics of avicultural subjects, we will be in a position to deductively construct chromosome maps.

We all learned as children that the whole equals the sum of the parts. This very basic mathematical concept is so obvious that we accept it as common sense. Common sense does not carry much weight in genetics. Here the whole, the phenotype, might be more or less than the sum of the parts, the genotype.

The most important form of genetic interaction is epistasis. Epistasis is defined as "the suppression of the expression of a gene or genes by other genes not allelic to the genes suppressed. Similar to dominance but involving the interaction of non-allelic genes." Epistasis is

sometimes referred to as genetic masking for it may disguise or camouflage the genotype. Epistasis implies hypostasis in the same way that dominant implies recessive. The gene that is doing the masking is said to be epistatic to the other trait. The trait that is being masked is said to be hypostatic to the first factor.

Related to the concept of epistasis is the phenomenon of complementary genes. With complementary genes two or more traits must all be present, in the proper dosages, for a given phenotype to be expressed. The crest factor in the budgerigar is a perfect example.

Lethal traits so disrupt the metabolism that they cause the death of the individual. Dominant lethals are clearly self deleting. Recessive and incomplete dominant genes are perpetuated. In cage birds, very few lethal traits have been posited: the crest, hard feather, and dominant white traits in the canary. These traits are all incomplete dominants. In one factor, in the heterozygous state, these genes produce an unusual phenotype, desirable to the fancier. In two factors, in the homozygous configuration, they cause death. Penetrance and expressivity may also come into play.

Mutations, though often of an essentially simple genetic nature, tend to become confused in aviculture. Unusual specimens fetch high prices and bring prestige to their owners. This fact generates one of two responses from the person lucky enough to spot something different in the nest or in a consignment of wild caught birds. The egotistical fancier informs all that he possesses a new variety. The aviculturist more noted for business acumen will keep his new type a secret and build up his stock. In this way the market is cornered and a handsome profit may be realized at the time of sale of the novelties. All give poetical and fanciful names to mutations.

On occasion the same mutation arises in two or more locations at about the same time and greatly confuses the issue. Most every country regulates the import and export of birds. In Australia, an important country both ornithologically and aviculturally, trafficking in birds is all but outlawed. It may be years before the proper test matings are performed to determine the true nature of the new mutations. Without test matings, only comparisons from photographs or, even less reliably, from memory can be used. These comparisons, even if perfect pictures are available, are only the roughest of guides. The same mutation may be drastically affected by modifiers or by environmental factors.

Conversely, identical phenotypes may be expressed by completely different mutant genes. For example, there were originally both a sex linked recessive and an autosomal recessive ino factor in the budgerigar. Sadly, the latter has been lost.

The term sport is sometimes used with a wide range of meanings. The broadest definition is of any different and unusual appearance. This would include extremes of phenotype caused by both genetic and non genetic factors. We here restrict the definition to include only oddities that owe their unusual appearance to environmental or to pathological factors. Of course, such phenotypes will not be passed on the future generations.

Sports are not unknown in birds. Many unusual colors are caused by metabolic disorders or by injury to the skin or growing feather. Some very striking color combinations, half siders and other mosaics, though of a genetic nature, are also not inheritable.

Hybrids, inter-specific crosses, are common in aviculture. Mule breeding, the production of mostly sterile hybrids involving the canary and various finches is very popular in Europe. The society finch (*Lonchura domestica*) is possible a free breeding blend of several Mannikin species. With species of waterfowl, it takes real effort to not get hybrids.

Hybrids are very interesting genetic subjects. Mutant genes have been transferred to the canary and some love birds from closely related species by means of hybrids.

Unfortunately, the haphazard production of hybrids has often become a liability in aviculture. For example, it took many years for the American stocks of Love Birds to become sorted out after various species had become mixed up. Sometimes a hybrid might be mistaken for a new species or for a mutation.

At best, the heredity of birds is not easy to study. The shortest generations are several months. Many birds take years to mature. Some species insist on choosing their own mates. Others are difficult to keep alive in captivity, let alone rear. For the altricial species, some are poor parents. In these cases, the breeder must attempt to foster or to hand raise the young. This is not a perfect solution, for imprinting and other unnatural forms of socialization complicate further breeding. Even relatively simple mutations may be lost. The London fancy color variety of the canary was lost through ignorance. At the turn of the century this simple recessive melanin diluting gene was confused with variegation. Through pairings with variegated birds, the rare recessive was lost. We are very lucky that any mutations have been established for the more temperamental species.

The great majority of mutations in aviculture affect the color of the plumage. A basic knowledge of the mechanics of feather color is needed. The appearance of color in the feather is due to two mechanisms: chemical coloration and structural coloration. Biochromes, compounds actually present in the feather, cause chemical coloration. Structural coloration, on the other hand, produces an optical illusion by means of anatomical elements in the feather. These elements might manage to give the appearance of a blend of chemical colors. Orange, red, and yellow are most often caused by carotenoids being deposited in the feather. These compounds are called lipochromes in the avicultural literature. These chemicals are metabolized from plant and animal matter. They are not synthesized by the bird.

Species that possess carotenoid colors will often exhibit variation in color due to changes in the diet. The red of the male Virginia Cardinal (*Richmondena cardinalis*) fades in the North East United States during the Winter when fruits, berries, greens, insects, and other small animals that are part of the bird's diet become scarce. The Venezuelan Black Hooded Red Siskin (*Carduelis cucullata*) will lose its natural red color, turning yellow, if not offered a source of carotenoids.

Yellow ground birds can obtain a sufficient supply of carotenoids from a diet of seed. This is not true for red or orange ground birds. In captivity the most common practice is to supply these birds with a source of synthetic carotenoids. The most commonly used substances are beta-carotene, apo-carotenol, and canthaxanthin. Canthaxanthin gives the brightest scarlet red. Beta-carotene and apo-carotenol allow the birds to develop golden, orange shades. Beta-carotene is of limited usefulness for much is metabolized as vitamin A, which lacks color, according to Doctor Adams, technical director of Hoffman La Roche. All these chemicals may be used together, for their action is complimentary.

In parrot type birds orange, red, and yellow are probably not caused by carotenoids. George Smith has posited a new class of chemical compounds. He has named these substances psittacins. In parrot types, color is not clearly a function of the diet. Ramon Noegel states that birds raised in captivity do show a greater extent of red and orange color. He believes that this increased degree of color is related to a diet rich in carotenoids. It must be noted that an improperly fed scarlet macaw or chattering lory, or any other scarlet parrot, might be near death from malnutrition, but still have fire engine red plumage.

. Unique to touracos, musophagiformes, is green caused by the deposition of a biochrome, turacin, in the feathers. Since there are, to my knowledge, no mutations of touracos in aviculture, all cases of green plumage may be considered as structural colors.

The blacks, browns, and grey colors are from melanin pigments in the feather. These pigments are synthesized by the birds from amino acids. The exact color and shade is due to the size, density, and shape of the melanin granules. Mutations that affect melanin coloration most often affect either the size or density of the granules.

White is a structural color. Here all micro structures in the feather are transparent, including the covering cuticle. Since the whole spectrum of light passes through, our eyes register the color as white. This is seen, literally, in any color less chemical. An single sugar granule is transparent. A teaspoon of sugar is white.

Slate blue, as in the canary, is given by a combination of a transparent cuticle and underlying melanin cells. The transparent cuticle is called white ground in aviculture. The bright blue, as in the blue jay (*Cyanocitta cristata*) is due to a refractive layer of polyhedral cells situated between a transparent cuticle and a refractive melanin base. A green effect occurs when yellow carotenoids or psittacins are spread through the cuticle. Avicultural writers call this yellow ground. If the carotenoids or psittacins of the cuticle are primarily of a red nature, a red ground bird is the result. If no melanins are present, a red or orange hue is here observed. Red biochromes do not readily interact with melanins to form structural colors. Red is most often obscured by melanin.

Iridescence is given by spectral colors due to light interference. This interference is caused by twisted and broadened, melanin containing, barbules or by spherical granules of melanin in close proximity to the cuticle.

Since feather color is governed by only two phenomena, all color mutations may be divided into two classes: mutations of the biochromes or of the micro structure of the feather.

The most common mutations are of the chemical colors that affect the melanin granules: inos, cinnamons, fallows, pieds, and yellows.

The inos are the most distinctive colors. All the melanin is deleted from the entire bird. Here the ability to synthesize melanin is completely disrupted. A pinkish color is seen in the eyes, beak, skin, and nails. This is actually the red blood circulating below the transparent tissues. Carotenoids or psittacins are not affected. Thus an ino love bird is yellow with red-orange markings. A bird that is of a predominantly white ground is an albino. A yellow one is a lutino. A red orange ground bird is called a rosino. Unfortunately, the term rosino is often misused. The rose bourkes neophema (*Neophema bourkii*) and the rosino canary are not inos. These mutations do not delete all the melanin. The canary does have a true ino mutation, possibly transferred from the European Greenfinch (*Chloris chloris*), the satinette variety.

Cinnamon-inos are special cases. Ino mutations do not completely delete brown melanin. Daniels has shown that it is not unusual for birds of this genotype to evince a laced phenotype. This is seen in the brown satinette canary and in one form of the lacewing budgerigar. Similar cinnamon-ino colors are being researched in peach face love birds and the cockatiel.

Many species have patches of different ground colors. The most notable example is the cockatiel. These patches are almost completely hidden by melanin in the normal bird. Once the melanin is removed, the previously hidden psittacin is revealed.

In pieds the melanin mutation is removed in patches. These sections may be almost completely random, like the variegation in the canary, or may be very definite, as is the European clear flight

mutation in the budgerigar. Most peds are neither completely restricted to certain areas, nor are they random. The Australian banded pied mutation in the budgerigar affects mostly the feathers of the lower wings, belly, and tail, often giving a circle or band of clear feathers about the waist. The harlequin mutation of the budgerigar affects mostly the head, upper wings, and chest. The exact delineation of the areas from which melanin will be deleted is random.

Birds may be completely pied. In budgerigars such examples are called black eyed clears. I will use this term for all species. Here all melanin is removed from the skin, nails, beak, and feathers. Melanin is retained in the eyes. Black eyed clears may be obtained from selective breeding of a single pied mutation. For example, in the American pied peach faced love bird light strains exist. These are extremely pied birds that produce a percentage of black eyed clears. Variable penetrance is very common among pied mutations.

Black eyed clears may also result from a combination of distinct pied mutations. The black eyed clear budgerigar is derived from a cross of the European clearflight and the recessive pied. In the canary black eyed clears, most often called simply clears or lipochrome birds, are birds that possess two factors for an incomplete dominant, V, the variegation gene. Individuals of the genotype $+/+$ are the normal melanin forming birds. Those of the genotype $V/+$ are variegated, pied.

Cinnamon(brown) and fallow mutations change the shape and size of the melanin granules. The melanin is changed from black to brown and the size of the granules may also be reduced. Cinnamons often have red or plum colored eyes as nestlings and juveniles. In fallows this red eye is retained in the adults.

Strangely enough, despite the profusion of melanin diluting and restricting mutations, traits that increase melanin distribution are very rare in aviculture, at least in the exotic species. The only one is the black breasted zebra finch(*Poephila eastanotis*). All other black forms have so far proven to be sports.

Yellows result from genes that affect the quantity and distribution of melanin granules. Yellow mutations reduce the amount of melanin in the feather. A lighter, diluted, but not clear appearance is the result. Yellow might not change all the feathers. The clearwing mutation of the budgerigar most effectively reduces the melanin in the wing, but does not reduce the body striations. Yellow type genes can also restrict the melanin distribution to certain parts of the feather or body. The lizard mutation in the canary deletes the melanin only from the edge of the feather, but does not change the granules elsewhere. The terminology yellow is most descriptive in yellow ground birds. In white ground birds the term white may be used, as it is for a budgerigar mutation. It is important to keep in mind that here we are discussing a whole class of melanin affecting mutations.

A few categories of mutations affect the ground colors. As has been explained, the ground colors are due to the presence or absence of carotenoids or psittacins in the plumage. The only true mutations of ground colors are those that reduce or delete the pigment, producing a white ground or, like the ivory factor in the canary, reducing the deep original shade of the ground color.

The deletion of carotenoids or psittacins from the feather is very common. This is seen in the blue canary and the blue budgerigar. The phenotype is blue for the melanins are unaffected by this group of mutations. The combination of this sort of mutation and an ino factor, thus deleting all biochromes, is an albino. Albino double mutations have been produced in the canary, budgerigar, and cockatiel.

At this point a brief digression concerning feather anatomy is appropriate. The central shaft or quill of the feather is called the rachis. The visible rays of the feather that run perpendicular to the

rachis are called barbs. Very small, but just visible to the naked eye, are structures called barbules that run perpendicular to the barb. Under magnification, hooklets, or barbicels, may be observed. These hooklets catch adjoining barbules, holding the feather in a continuous sheet. The importance of these hooklets to mutations will soon become apparent.

The ivory factor in the canary is somewhat more interesting and also more complicated. This sex linked recessive manifests itself in a ground color one shade lighter than normal. Yellow ground ivory canaries have the light yellow bone ivory color of old piano keys. Red ground ivories appear rose or pink. This pale ground color occurs because carotenoids are deleted only from the hooklets. The pigmentation in the other parts of the feather is unchanged.

The other traits that are thought to affect the ground color are actually mutations of the structure of the feather.

The most commonly noted change in the feather structure is soft feather or buff. This is seen particularly in canaries, but also in budgerigars. Soft feather birds have defective hooklets on the barbules. The feathers are in this way all slightly raised. With the canary, a white frosting from the defective hooklets may be observed without magnification. This sort of plumage gives the bird a larger appearance. Soft feather reduces the intensity of all colors.

In the budgerigar, the feather duster, an abnormally long feathered bird, thus the name, is said to be a genetic aberration - analogous to Down's syndrome in the human. Feather dusters generally die soon after leaving the nest.

The dark factor of the budgerigar is due to changes in the feather structure. This gene reduces the layer of cells on the barbs that scatter and reflect light. Due to this less efficient structure, a dark factor budgerigar is of a deeper color. Because the reflecting layer is thinner, more color escapes. This trait reduces the layer of cells by about one third for each dose of the gene present. In a dark green the layer is about two-thirds of normal. In an olive, a two dark factor budgerigar, the layer is about one-third of normal. Similar acting dark factors are seen in the peach faced love bird and in the Indian ringneck parakeet.

The only remaining types of mutations are the long flight in the budgerigar, the frill in the canary, and the crest in the canary, budgerigar, society, and zebra finch. All other mutations of exotic and ornamental birds may be classified according to the previous discussion.

Modifiers are very important in all domesticated species. The very changed size, shape, plumage, and posture of the Norwich, Belgian, Yorkshire, and Scotch Fancy canaries are due to modifiers. Fanciers, through slow, selective breeding and the artful combining of breeds, derived these varieties.

Distinctive strains of many other species exist in aviculture. Some lines of Lady Gouldian finches (*Poephila gouldia*) are very free breeding but require foster parents to rear the young. The most commonly used foster parents are society finches. Other strains of Gouldians are known to be good parents. Some American fanciers are consistently rearing Lady Gouldians about fifty percent larger than usual, thus creating a modified phenotype. Families of pied peach faced love birds and pied cockatiels that are very light also exist. Primrose, extremely yellow, cockatiels also are available as distinctive strains.

Splashed or variegated birds are the most common sports. These are relatively common in Indian ringneck parakeets (*Psittacula krameri manillensis*) and budgerigars. Other parrot types sometimes spontaneously develop maroon patches. Some lutino cockatiels suddenly get a deeper yellow color. Black canaries have been produced but have never been reproduced.

No bird should be dismissed as a sport without careful test matings. Any individual that was born with a normal phenotype but develops an unusual color must be suspect. A careful examination by a qualified veterinarian is certainly in order.

Half siders are birds that have a dual phenotype. The plumage, size, color, sometimes even the gender, differs from the left and right sides. It seems as if two halves of different birds have been glued together, which is not far from the truth. Half siders are one facet of the larger phenomenon of mosaicism. Mosaics are organisms of patchwork phenotype and/or genotype. In aviculture, half siders are most frequently encountered in budgerigars, though they have been reported in canaries and Lady Gouldians.

Hollander has discussed half siders in many species of birds. Though of a genetic origin, half siders can not be intentionally bred. Half siders are the result of cytological accidents and are the inverse of twins. The half sider phenotype is not inheritable. A strain of half siders can not be developed.

Hybridization can be a valuable technique in aviculture. Fanciers have always delighted in the production of novel forms. The progressive aviculturist uses hybrids to achieve specific results. The red factor canary was produced by a cross of the Venezuelan red hooded siskin (*Carduelis cucullata*) and the canary. The satinette in the canary, actually an ino factor, as described above, might have been the result of a cross of the canary with the lutino European green finch (*Chloris chloris* var.) the yellow gene was transferred to the Fischer's love bird (*Agapornis fischerii*) from the masked (*Agapornis personata*).

The haphazard production of hybrids must be desisted. The clumsy breeding of mules and intergrades can not be tolerated. All birds used in a hybrid breeding scheme must be closed banded. Closed bands are seamless metal rings. They can only be placed on a young bird within about two weeks after hatching. These bands are coded and allow positive identification. Any birds that can not be identified should be destroyed.

Frauds are not unknown in aviculture. South American Indians have many techniques for treating the growing feathers of parrots to get bizarre and beautiful colors. Dyed finches are seen in quarantine stations. The most common fraud is the "double yellow head" conure. The cheap green conure becomes an expensive peroxide blond and is passed off the unsuspecting Yankee tourist as a juvenile Mexican double yellow head Amazon parrot. Similar combinations of dyes and bleaches must always be looked out for upon the announcement of any new and high priced mutation.

A more subtle form of deception also takes place. Many mutations in aviculture are sex linked recessives. Clearly, hens can not be split for these traits. Sometimes the developer of such a trait reports the mutation to be an autosomal recessive. This way he can sell normal hens as high priced splits. This occurred with the rosy variety of the Bourke's neophema.

IN CONCLUSION

This paper shows that the overwhelming majority of mutations in aviculture can be broken down into a limited number of patterns, in all species of birds. The underlying genetic phenomena show an amazing degree of similarity.

All bird breeders must be extremely selective. In all probability, many species will soon become extinct as viable wild populations. The only hope for these birds is aviculture. We must decide what sort of population or populations that we want to maintain. If the hope is for eventual re-introduction, the wild type, both in appearance and in behavior must be used as a model and as an ideal. Some feel that the wild type is superior on strictly aesthetic grounds. I hope that the

normal type of most captive birds will not be lost. I see no reason why different breeds, as have been produced in all domestic plants and animals, should not be developed. Selection can not be held in abeyance. It can be either used to improve and vary a species, or ignored with penalty.

Most every country regulates the import and export of birds. This will greatly affect the ability of aviculturists to work with wild species. It will also become increasingly difficult to make test matings between mutations occurring in different parts of the world and to thus determine if two birds of similar description are the same or different mutations.

We pontificate concerning the uninformed and poverty stricken third world peoples that catch and sell wild birds. The Western aviculturist is noted for his pious sermons of "saving from extinction." Unfortunately all too few breeders of the larger parrots deserve to be called aviculturists. Instead of developing any captive strains - despite their knowledge of the reality of rain forest destruction and their relative degree of financial comfort - they sell all the young parrots produced as pets. I hope that there is a special place in hell for these hypocrites. Perhaps a waste land that was once a rain forest?