# LINKAGE OF ALBINO ALLELOMORPHS IN RATS AND MICE[1]

HORACE W. FELDMAN
*Bussey Institution, Harvard University, Forest Hills, Boston, Massachusetts*

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Present concepts of some phenomena of inheritance, derived from experimental studies of unit characters, are definite enough to allow certain predictions to be made with considerable accuracy. Of the genetic linkage or partial coupling of characters there exist some remarkable examples. It has been established, for instance in Drosophila, that when two pairs of characters show a given degree of linkage, any allelomorph of either will show a similar linkage with the other pair. However, heretofore, no material has been available to enable us to know whether this generalization is tenable in mammals. It is important, therefore, to make use of the first opportunity to test this point.

In the Norway rat and house mouse the linkages have been determined between the characters, albinism and pink-eye with colored coat. These characters are similar in both forms. Both characters are recessive. Albinos in both rat and mouse are devoid of pigment in eye and coat, but pink-eyed individuals develop traces of black pigment in the eye and coat and the full amount of yellow pigment in the coat, so far as their constitution in other genes permits. Recently, two dilute (colored) allelomorphs of albinism have been described for the mouse by DETLEFSEN (1921) and FELDMAN (1922), and one for the rat by WHITING and KING (1918). These allelomorphs of albinism have parallels in the rabbit, guinea-pig, and probably other forms.

The most outstanding characteristic of the albino allelomorphs is a practical elimination of the yellow pigment from the coat. In addition, a progressive decrease in the intensity of black and brown is obvious, as one proceeds from the intense to the dilute members. The extremities of the animal, the ears, eyes, nose, and tail region, are affected less than the other regions. The effects produced by these allelomorphs persist when they are in conjunction with other dilution factors. For example, rats and mice homozygous for pink-eye as well as for an albino allelomorph,

[1] This work on mice was begun at the Genetics Laboratory of the UNIVERSITY OF ILLINOIS, and completed at the Bussey Institution of HARVARD UNIVERSITY. The work on rats was done entirely at the latter institution.

possess little or no pigment, much less than pink-eye alone would produce. Normal color is completely dominant over the other members of the albino series in the rat and mouse, and intermediate members are incompletely dominant over each other and over albinism.

This paper deals with the more intense allelomorph in the mouse described by the writer (FELDMAN 1922), and the one described for the rat by WHITING and KING (1918). For convenience these two factors will be spoken of as ruby-eyed dilution (from the effects produced on the pigment of the eye) and will be designated by $c^r$, indicating that they are allelomorphic to color, $C$, and complete albinism, $c$. The pink-eye factor will be designated by $p$; its allelomorph, dark-eye, by $P$.

The method of procedure in determining the occurrence and strength of linkage was essentially the same in both rats and mice. In the former, pink-eyed colored animals, $CCpp$, were mated with ruby-eyed dilute, $c^rc^rPP$. In mice the same cross was made; and in addition, ruby-eyed dilute ($c^rc^rPP$) animals were mated to albinos carrying the pink-eye factor, $ccpp$. In both cases the $F_1$ animals, heterozygous for the two factor-pairs concerned, were mated to homozygous double-recessives, $ccpp$. Briefly, from the first type of cross (repulsion), the $F_1$ animals may be expected to produce gametes of the classes, $Cp$, $c^rP$, $CP$ and $c^rp$. Of these, the last two are the crossovers. And from the second cross (coupling), we expect gametes from the $F_1$ mice as follows; $c^rP$, $cp$, $c^rp$ and $cP$. In this case, also, the last two are crossover classes.

By observing the progeny of the $F_1$ animals when mated with double-recessive animals, it was possible to determine the proportion of each of the four kinds of gametes produced by the $F_1$ individuals. An exception existed in the mouse cross involving albinism. In this case, only one class, the dark-eyed non-crossover ($c^rP$), is distinguishable from the others. It was necessary to calculate the percentage of crossover gametes by assuming that the indistinguishable non-crossover class, $cp$, tended to equal the observed non-crossover class, and therefore that the remaining gametes which functioned, composed the two crossover classes. Where the error of sampling is not large, this should not injure the reliability of the results.

As a means of increasing the tests on individual $F_1$ rats, their progeny were classified at birth and discarded. At that age one crossover class, namely, the double-dominant, dark-eyed animals, $CP$, can be easily distinguished from the others. It is reasonable to assume that the other crossover class, $c^rp$, will tend to be of equal size, and that the total crossing over may be obtained by doubling the observed. The use of this method

increases the probable error on crossover percentages considerably, as compared with the direct classification of all types.[2] Because of this fact, small samples of gametes, as individual tests, are discussed solely in terms of the known, dark-eyed class. However, there is justification for concluding that the observations on that class are valid in regard to the reciprocal class, and therefore to the total crossovers.

Table 1 gives a summary of my data with those of CASTLE and WACHTER (1924) from their comparable experiments in which the linkage between albinism and pink-eye was studied. They found the percentage of crossing over between albinism and pink-eye in the rat to be $19.66 \pm 0.26$, while

TABLE 1

*Summary of data on the linkage between pink-eye and ruby-eye (or its allelomorph, albinism) in rats and mice*

| GENES CONCERNED | SEX OF $F_1$ PARENT | GAMETES TESTED | CROSSOVER GAMETES | PERCENT CROSSOVERS | NATURE OF CROSS |
|---|---|---|---|---|---|
| Ruby-eye and pink-eye in rats | Female | 3,075 | 492 | $16.00 \pm 0.86$ | Repulsion |
| | Male | 2,742 | 508 | $18.52 \pm 0.91$ | Repulsion |
| Total | | 5,817 | 1000 | $17.18 \pm 0.62$ | |
| Albinism and pink-eye in rats | Female | 11,480 | 2,518 | $21.93 \pm 0.44$ | Repulsion |
| | Male | 21,255 | 3,920 | $18.39 \pm 0.32$ | Repulsion |
| Total | | 32,735 | 6,438 | $19.66 \pm 0.26$ | |
| Ruby-eye and pink-eye in mice | Female | 313 | 51 | $16.29 \pm 1.91$ | Repulsion |
| | Male | 275 | 32 | $11.64 \pm 2.03$ | Repulsion |
| | Female | 1,040 | 208 | $20.00 \pm 1.48$ | Coupling |
| | Male | 129 | 15 | $11.63 \pm 4.18$ | Coupling |
| Total | | 1,757 | 306 | $17.42 \pm 1.14$ | |
| Albinism and pink-eye in mice | Female | 3,345 | 550 | $16.44 \pm 0.82$ | Repulsion and coupling |
| | Male | 7,057 | 965 | $13.77 \pm 0.57$ | |
| Total | | 10,352 | 1,515 | $14.63 \pm 0.47$ | |

[2] The method of calculating probable errors used by CASTLE and WACHTER (1924) was applied by the author here. That is, $n$ represents one-half instead of the whole sample, and the values of P. E. have been taken from EMERSON'S tables.

I found the crossover percentage to be $17.18 \pm 0.62$ between ruby-eye and pink-eye. In the mouse experiments involving albinism, those workers found $14.63 \pm 0.47$ percent crossing over, and in the experiments involving ruby-eye I found the crossover percentage to be $17.42 \pm 1.14$. The numbers secured by CASTLE and WACHTER probably give an accurate idea of what the crossover percentage is, between the two genes in question. The same is true of my data concerning ruby-eye and pink-eye, with more reservation, however, because of the smaller numbers which I recorded. Further, the differences between our figures in either species are not statistically significant. The results obtained in these experiments warrant the conclusion, therefore, that the ruby-eye allelomorph of albinism has the same linkage strength with pink-eye that albinism has, in both the rat and mouse.

In their experiments dealing with linkage in rats and mice, CASTLE (1919), DUNN (1920), and CASTLE and WACHTER (1924) have secured results which indicate a significant difference between the crossover percentage exhibited by ova and that exhibited by spermatozoa in the same cross. Their data show in every instance, a higher percentage of crossing over among the gametes of $F_1$ females than among those of $F_1$ males. In order to learn what my data yield on this point, the sexes have been tabulated separately (see table 1). In both of my crosses in mice, crossing over was higher in females than in males, which agrees with the results obtained by CASTLE and others. However, in my work on rats, the opposite obtains; females yielded $16.00 \pm 0.86$ percent, while the males gave $18.52 \pm 0.91$ percent.

However, it does not appear safe to assume that an exception to the general situation has been found. The crossing over for the two sexes is not so widely different as to lead to the conclusion that the apparent reversal, which my rat data show, would persist, if the sample of gametes examined was increased sufficiently. The occurrence of a sample such as I secured, precludes the possibility, however, of a large general excess of crossing over in the female over that in the male.

Figure 1 shows the variation among individual $F_1$ rats in the percent of the dark-eyed class, *CP*, among their gametes. The range is from 0.0 to 28.6 percent. The mean variate is 8.9 percent of dark-eye; the standard deviation is 5.21 percent. The variation can be readily ascribed to chance sampling, since the average number of gametes per rat was only 41.26. It may be noted that the males (indicated by the broken line) have essentially the same distribution as the females, which are included with the males in the total shown by the unbroken line.

In addition to the above tabulation, the individual records have been arranged according to the parentage of the animals. This was undertaken in an effort to discover whether there was a tendency among any of the original parental rats, to produce $F_1$'s whose crossing over was outstandingly either high or low; for such a tendency would indicate at once the presence of genetic modifiers of crossing over. A careful examination of the data when they were thus arranged, failed, however, to disclose any evidence of the presence of such genetic factors.

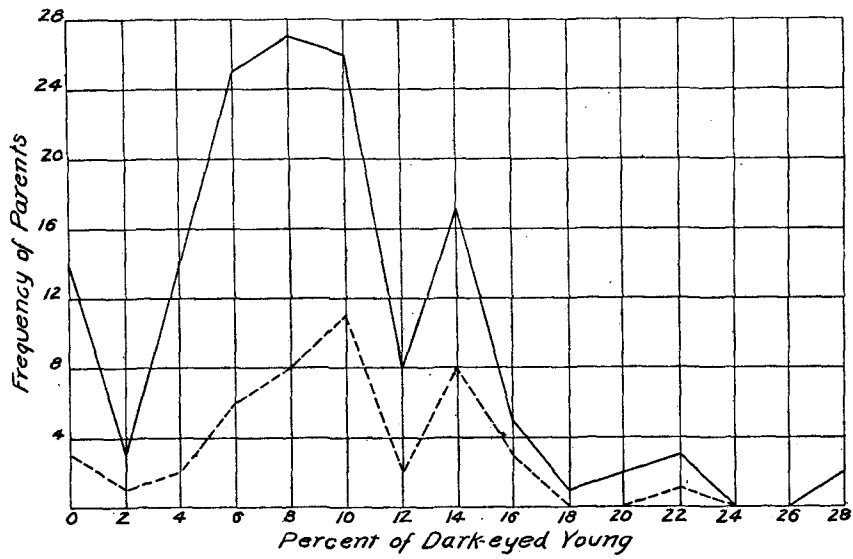


FIGURE 1.—Variation in percentage of the dark-eyed class, *CP*, among the gametes of individual $F_1$ rats. The unbroken line represents both females and males; the broken line, males only.

## SUMMARY

1. The albino allelomorphs in the rat and mouse have the same linkage relation with the character pink-eye, that albinism has.

2. There is probably a small but significant difference between the sexes in rats and mice in crossing over. It is higher in the female than in the male.

3. Rats have a normal frequency distribution as regards the amount of crossing over among their gametes.

4. Linkage in $F_1$ rats does not appear to be influenced by genetic factors received from their parents.

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