HETEROSIS AND THE INTEGRATION OF THE GENOTYPE IN GEOGRAPHIC POPULATIONS OF DROSOPHILA PSEUDOOBSCURA [1]

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THE work on the heterotic state of natural populations of *Drosophila pseudoobscura* has shown that the genotypes of these populations are integrated systems of genes (DOBZHANSKY 1949, 1951; DOBZHANSKY and PAVLOVSKY 1953 and unpublished data). This can be demonstrated most readily when the populations are variable with respect to the gene arrangement in their chromosomes. Inversion heterozygotes which carry two chromosomes derived from any one natural population usually exhibit heterosis, i.e., an adaptive superiority to the corresponding homozygotes. But when the chromosomes are derived from populations of remote localities, the situation becomes considerably more complex. Heterozygotes may or may not show heterosis. In some experiments, in which representatives of geographically different populations are crossed, heterosis is absent at the beginning, but develops gradually in the course of time. This is due to the gene recombination in the offspring of race hybrids producing a great variety of genotypes, some of which possess superior fitness in heterozygous condition. Natural selection acts to perpetuate such superior gene patterns.

The superior fitness, heterosis, of the inversion heterozygotes in any one natural population may be understood on a similar basis. A long-continued process of natural selection has resulted in coadaptation, fitting together, of the gene complexes in the chromosomes which occur in the same local population. The heterosis is a result of an adaptive integration of the population genotype through the action of natural selection.

In the above experiments, the chromosomal inversions have been used as convenient identification tags marking the presence of certain gene complexes in the natural or experimental populations studied. But it seems probable that the fitting together of the gene complexes present in the gene pool of any one population may occur also in the absence of inversions. The phenomenon of adaptive integration of the gene pools of populations may be of quite general occurrence, at least in the higher organisms. The experiments described in the present article represent an attempt to demonstrate the existence of such genotypic integration in the absence of variations in the gene arrangement.

The initial material consisted of approximately a dozen strains of *Drosophila pseudoobscura* from each of the following localities: Mather, Sierra Nevada, California; Mono Lake, close to the California-Nevada boundary; Lehman Caves National Monument, Nevada; Bryce Canyon National Park, Utah; Ferron, Utah; and Black Canyon of the Gunnison National Monument, Colorado. Each strain descended from a single fertilized female collected in the respective localities by PROFESSOR TH. DOBZHANSKY in summer of 1950. All the strains were known to be homozygous for the Arrowhead gene arrangement in the third chromosomes. Thus the chromosomal variation was completely eliminated from consideration in the experiments to be described. It must however be noted that while in the natural populations of Mono, Lehman, Bryce, Ferron and Gunnison, the Arrowhead homozygotes are the most frequent chromosomal type, they are a minority at Mather (DOBZHANSKY and EPLING 1944; DOBZHANSKY 1948).

The only laboratory strain used in the experiments was one having the dominant marker genes Blade wing (*Bl*) and Scute bristles (*Sc*) in the third chromosome.

All the cultures which served for making counts of the flies hatching in them were kept in incubators at 25°C, except that the oviposition took place at room temperatures. Ten females and ten males were mated per culture; the females were allowed to oviposit for 2 days in each bottle, whereupon they were transferred to fresh cultures. Consequently several bottles with eggs deposited in them by the same group of flies were obtained. Only bottles in which between 60 and 300 flies hatched were considered, and the underpopulated and strongly overpopulated bottles were discarded.

The *Bl Sc* strain was outcrossed to flies from the Mather and Gunnison stocks. In each case, several *Bl Sc* males were selected from the offspring, and crossed back to the respective geographical strains. Such outcrossings were repeated for 15 generations. As a result, cultures were obtained in which the *Bl Sc* chromosomes were present on the geographic backgrounds of Mather and of Gunnison origin respectively. It should be noted that different strains from Mather and Gunnison were used in the different backcross generations, so that the resulting *Bl Sc* strains carried a variety of modifiers, derived however from a definite geographic population.

Next, several females from various Mather, Mono, Lehman, Bryce, Ferron and Gunnison strains were outcrossed to *Bl Sc* males with the Mather genetic background. A similar series of crosses were made to *Bl Sc* males with the Gunnison genetic background. In the next generation, small groups of *Bl Sc* females and males were selected from each culture and inbred. Wild-type females were taken in the progeny and crossed again to *Bl Sc* males with the Mather background in one series, and with the Gunnison background in the

other. *Bl Sc* females and males were again picked and inbred. This procedure was repeated eight times. As a result, cultures were obtained which carried third chromosomes from Mather, Mono, Lehman, Bryce, Ferron and Gunnison, but which had other chromosomes replaced by those from the Mather strains in one series, and by those from the Gunnison strains in the other series. The possibility of preservation of an admixture of genes from the original stocks is, of course, not excluded, but it is safe to assume that in the main the genotypes of the strains used were as indicated above.

The crosses just described were carried out with great care and patience by MR. BORIS SPASSKY during 1950, 1951 and 1952. The writer profoundly appreciates the generosity of MR. SPASSKY who has permitted the use of the strains prepared by him for the experiments described in the present article.

HETEROSIS PRODUCED BY FOREIGN CHROMOSOMES

Six parallel series of crosses were arranged as follows (fig. 1). In one series, females of pure Mather origin were outcrossed to males with Mather genetic background, but carrying also one *Bl Sc* third chromosome and one third
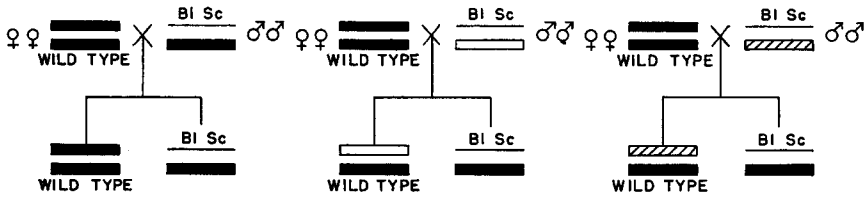

FIGURE 1.—Comparison of the viability of wild-type flies with two third chromosomes of the same geographic origin, with flies heterozygous for two chromosomes of different origins.

chromosome from Mather, or Mono, or Lehman, or Bryce, or Ferron, or Gunnison respectively. The results are shown in the upper part of table 1.

In the second series, females homozygous for Gunnison third chromosomes, but otherwise having Mather genetic background, were crossed to males also with Mather genetic background but carrying *Bl Sc* third chromosomes and third chromosomes from the various populations studied. The results are reported in the middle part of table 1.

The third series was like the second, except that the females carried two third chromosomes of Bryce, instead of Gunnison origin. The data appear in the lower part of table 1.

The fourth, fifth and sixth series of crosses were analogous to the first, second and third respectively, except that all the flies had the genetic background originating from the Gunnison locality. The results are summarized in table 2.

The different crosses of each series are comparable to each other, the only difference between them being the geographic source of the third chromosomes in the male parents. If neither the *Bl Sc* chromosome nor the geographic origin of the other third chromosomes would modify the viability of the flies which

TABLE 1

Results of crosses with the Mather genetic background.

Crosses	Total flies	Percent Wild type	Chi square	P
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Mather}}$	2146	50.37	....	...
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Mono}}$	3131	52.31	1.96	0.17
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Lehman}}$	2139	52.59	2.24	0.14
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Bryce}}$	2195	53.25	3.54	0.06
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Ferron}}$	2837	53.08	3.57	0.06
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Gunnison}}$	2237	49.54	0.29	0.65
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Gunnison}}$	4084	56.02	....	....
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Mather}}$	3549	55.33	0.28	0.72
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Mono}}$	2028	53.40	3.86	0.05
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Lehman}}$	2092	60.70	12.50	< 0.001
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Bryce}}$	3071	58.35	3.92	0.05
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Ferron}}$	2051	57.28	0.86	0.35
$\dfrac{\text{Bryce}}{\text{Bryce}} \times \dfrac{Bl\,Sc}{\text{Bryce}}$	2065	51.52	....	....
$\dfrac{\text{Bryce}}{\text{Bryce}} \times \dfrac{Bl\,Sc}{\text{Mather}}$	1734	54.90	4.36	0.04
$\dfrac{\text{Bryce}}{\text{Bryce}} \times \dfrac{Bl\,Sc}{\text{Gunnison}}$	2708	61.98	51.10	> 0.001

carry them, the progeny of all the crosses would consist of 50 percent $Bl\,Sc$ and 50 percent wild-type flies. This is however not the case, since the $Bl\,Sc$ chromosome tends to reduce the viability of its carriers, while the wild chromosomes increase the viability to different extents.

In the first series of crosses, the replacement of the Mather chromosomes by geographically foreign chromosomes seems to increase the viability in four cases (Mono, Lehman, Bryce, and Ferron), and to decrease it in one case (Gunnison). The differences do not, however, reach the conventional level of

TABLE 2

Results of crosses with the Gunnison genetic background.

Crosses	Total flies	Percent Wild type	Chi square	P
$\frac{\text{Gunnison}}{\text{Gunnison}} \times \frac{Bl\,Sc}{\text{Gunnison}}$	2311	48.72	....	....
$\frac{\text{Gunnison}}{\text{Gunnison}} \times \frac{Bl\,Sc}{\text{Mather}}$	2526	52.57	7.01	0.008
$\frac{\text{Gunnison}}{\text{Gunnison}} \times \frac{Bl\,Sc}{\text{Mono}}$	2363	52.18	5.47	0.02
$\frac{\text{Gunnison}}{\text{Gunnison}} \times \frac{Bl\,Sc}{\text{Lehman}}$	2176	54.87	17.01	< 0.001
$\frac{\text{Gunnison}}{\text{Gunnison}} \times \frac{Bl\,Sc}{\text{Bryce}}$	2280	54.82	17.09	< 0.001
$\frac{\text{Gunnison}}{\text{Gunnison}} \times \frac{Bl\,Sc}{\text{Ferron}}$	2255	53.03	8.41	0.003
$\frac{\text{Mather}}{\text{Mather}} \times \frac{Bl\,Sc}{\text{Mather}}$	2876	48.64	....	....
$\frac{\text{Mather}}{\text{Mather}} \times \frac{Bl\,Sc}{\text{Mono}}$	2132	49.39	0.26	0.70
$\frac{\text{Mather}}{\text{Mather}} \times \frac{Bl\,Sc}{\text{Lehman}}$	2010	54.57	16.57	< 0.001
$\frac{\text{Mather}}{\text{Mather}} \times \frac{Bl\,Sc}{\text{Bryce}}$	2682	51.08	3.35	0.07
$\frac{\text{Mather}}{\text{Mather}} \times \frac{Bl\,Sc}{\text{Ferron}}$	2284	51.40	3.87	0.05
$\frac{\text{Mather}}{\text{Mather}} \times \frac{Bl\,Sc}{\text{Gunnison}}$	2917	56.53	35.50	< 0.001
$\frac{\text{Bryce}}{\text{Bryce}} \times \frac{Bl\,Sc}{\text{Bryce}}$	2480	50.24	....	....
$\frac{\text{Bryce}}{\text{Bryce}} \times \frac{Bl\,Sc}{\text{Mather}}$	2206	53.49	4.95	0.025
$\frac{\text{Bryce}}{\text{Bryce}} \times \frac{Bl\,Sc}{\text{Gunnison}}$	2598	55.42	13.77	< 0.001

statistical significance, although they approach it in the cases of Bryce and Ferron (table 1). In the second series, making the two third chromosomes of different geographic origin gives a significant improvement of the viability in one case (Lehman), an improvement which does not reach the significant level in two cases (Bryce and Ferron), and a nonsignificant deterioration in two cases (Mono and Mather). In the third series, making the two third chromosomes different in geographic origin improves the viability quite significantly in the two cases tried (Mather and Gunnison) (table 1).

The experiments with the Gunnison genetic background, i.e., the fourth to sixth series (table 2), show an improvement of the viability in every one of the twelve crosses in which the two third chromosomes which the flies carried were made different in geographic origin. This improvement is statistically quite significant in ten cases, and close to the borderline of significance in one.

It should be noted that the results show no trace of a tendency towards improvement of the viability when the third chromosomes agree in geographic origin with the remainder of the genotype. Such an effect would not be unexpected, since the abnormalities in the spermatogenesis of *Drosophila pseudoobscura* × *Drosophila persimilis* hybrid males are the greater the more mixed are the chromosomes in their karyotype (DOBZHANSKY 1951). In reality, the flies which have only Mather chromosomes (the top of table 1), or only
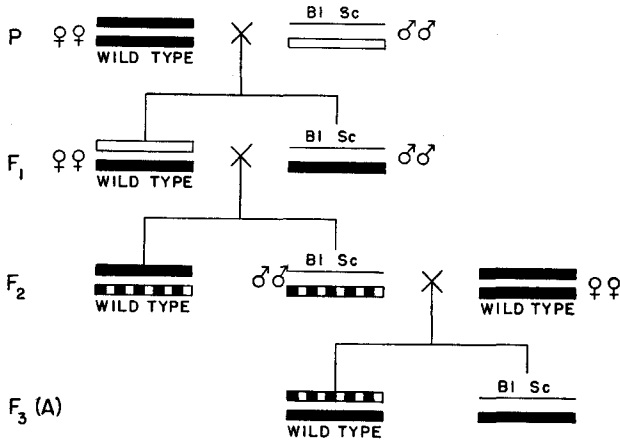

FIGURE 2.—Experiments designed to test the effects of crossing-over between chromosomes of different geographic origin (shown in black and white) on the viability. Flies with entire third chromosomes from different populations (F_1) are compared with flies that carry one chromosome resulting from crossing over with ($F_3(A)$).

Gunnison chromosomes (the top of table 2), are close to the bottom of the viability scale recorded in these experiments.

THE EFFECTS OF CROSSING OVER BETWEEN CHROMOSOMES
OF DIFFERENT GEOGRAPHIC ORIGIN

In the experiments described so far, the chromosomes of various geographic origins were treated as units. Crossing over between chromosomes of different origins was prevented by using male heterozygotes, in which crossing over is absent or very rare. The experiments now to be dealt with involve, on the contrary, the break-up of the gene complexes of various geographic origins.

The type of experiments represented schematically in figures 2 and 3, consists in crossing females homozygous for third chromosomes of a given geographic locality to males which carry a *Bl Sc* chromosome, and another chromosome of a different geographic origin. This is, consequently, the repetition

of the type of cross shown in figure 1. However, in the offspring, wild-type females which carried chromosomes of different geographic origins were selected and outcrossed to males heterozygous for the $Bl Sc$ and another third chromosome of the same locality as in the mother (figs. 2 and 3). The F_2 generation consists, then, of wild-type flies which carry one chromosome which may be a product of crossing over, and another chromosome which is of definite geographic origin. The $Bl Sc$ flies in this generation have a $Bl Sc$ chromosome, and a chromosome which may be a result of recombination. The $Bl Sc$ males from the F_2 generation are now outcrossed in two ways. In the experiments referred to as "A-type" (fig. 2), they are mated to females which have two third chromosomes of the same origin. The offspring consists, then, of wild-type flies which have one third chromosome of geographically pure
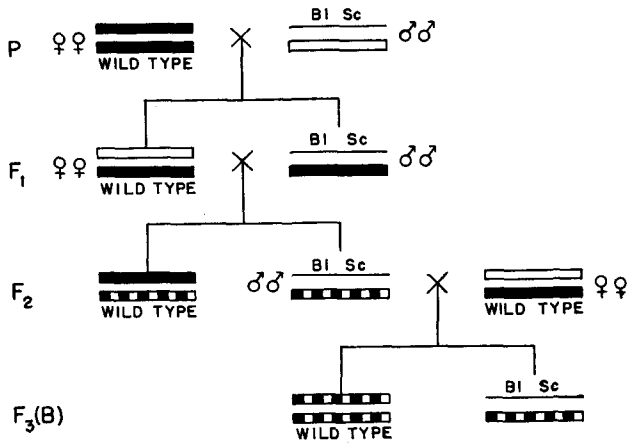

FIGURE 3.—Experiments designed to test the effect of crossing over between chromosomes of different geographic origin (shown in black and white) on the viability. Flies with two chromosomes of a pair resulting from crossing over (F_3(B)) are compared with flies having only one such chromosome (F_2).

and another of geographically mixed origin, and of $Bl Sc$ flies which carry a $Bl Sc$ and a geographically pure third chromosome. In the experiments of "B-type" (fig. 3), the $Bl Sc$ males from the F_2 generation are crossed to females having two third chromosomes of different geographic origin. The offspring, then, consists of wild-type flies which carry two third chromosomes both of which may be crossover products, and of $Bl Sc$ flies which carry a $Bl Sc$ and a crossover third chromosome.

The results of the A and B types of crosses are summarized in table 3 (flies with chromosomes other than the third of Mather origin) and in table 4 (individuals with the genetic background of Gunnison origin). The data permit a number of instructive comparisons. First, the proportions of the wild-type class in the F_1 generation is compared with those obtained in control experiments in which the wild-type flies carried both third chromosomes of the same geographic origin. There are twelve such comparisons in tables 3 and 4, and

TABLE 3

Comparative viability of wild type flies in P, F_1, F_2, $F_3(A)$ and $F_3(B)$ in crosses with the Mather genetic background.

Crosses		Total flies	Percent Wild type	Chi square between the homozygotes and F_1 and $F_3(A)$	Chi square between F_1 and $F_3(A)$ and F_2 and $F_3(B)$
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Mather}}$		1667	48.89		
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Bryce}}$	F_1	1560	52.94	5.40 (P = 0.02)	
	$F_3(A)$	1018	44.99	3.96 (P = 0.05)	15.58 (P = <0.001)
	F_2	1273	45.87		
	$F_3(B)$	1601	44.28		0.68 (P = 0.50)
$\dfrac{\text{Mather}}{\text{Mather}} \times \dfrac{Bl\,Sc}{\text{Gunnison}}$	F_1	1381	50.61	0.89 (P = 0.35)	
	$F_3(A)$	1243	47.54	0.56 (P = 0.50)	2.44 (P = 0.12)
	F_2	1310	47.70		
	$F_3(B)$	1540	46.29		0.56 (P = 0.50)
$\dfrac{\text{Bryce}}{\text{Bryce}} \times \dfrac{Bl\,Sc}{\text{Bryce}}$		1688	48.63		
$\dfrac{\text{Bryce}}{\text{Bryce}} \times \dfrac{Bl\,Sc}{\text{Mather}}$	F_1	1273	54.67	10.89 (P = <0.001)	
	$F_3(A)$	1095	46.57	1.17 (P = 0.30)	15.66 (P = <0.001)
	F_2	1295	49.11		
	$F_3(B)$	1377	42.70		11.15 (P = <0.001)
$\dfrac{\text{Bryce}}{\text{Bryce}} \times \dfrac{Bl\,Sc}{\text{Gunnison}}$	F_1	1606	51.93	3.54 (P = 0.06)	
	$F_3(A)$	1049	47.47	0.39 (P = 0.55)	4.94 (P = 0.03)
	F_2	1254	48.24		
	$F_3(B)$	1234	46.59		0.64 (P = 0.50)
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Gunnison}}$		1723	49.44		
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Mather}}$	F_1	1602	50.81	0.58 (P = 0.50)	
	$F_3(A)$	1421	49.26	0.002 (P = 0.95)	0.76 (P = 0.45)
	F_2	1412	50.21		
	$F_3(B)$	1522	50.98		0.19 (P = 0.70)
$\dfrac{\text{Gunnison}}{\text{Gunnison}} \times \dfrac{Bl\,Sc}{\text{Bryce}}$	F_1	1774	55.01	11.01 (P = <0.001)	
	$F_3(A)$	1441	49.82	0.04 (P = 0.90)	8.47 (P = 0.003)
	F_2	1381	46.12		
	$F_3(B)$	1404	47.01		0.20 (P = 0.70)

in every case the viability of the flies having two third chromosomes of different geographic origin is superior to that of the F_1 flies with the two chromosomes of the same origin. In eight of the twelve cases the differences are statistically significant. This agrees with the results of the experiments reported above (tables 1 and 2).

Another comparison is between the wild-type flies obtained in the F_3 of the A-type crosses and the control wild-type, which carries two chromosomes of the same origin. There are twelve comparisons of this kind in tables 3 and 4. In no case do the two kinds of wild-type flies show a significant difference in viability. The conclusion is quite different, however, if the wild-type flies of the F_3 (A) class are compared with those obtained in the F_1 generation (fig. 2). Among the twelve comparisons of this kind in tables 3 and 4, we have a lower viability in the F_3 flies in every instance, and in six of these comparisons the deterioration is statistically fully significant. The conclusion that fol-

lows is that the flies which carry two whole third chromosomes of different geographic origin are more viable than those in which one of the chromosomes is a mixture of parts of different geographic origin. This is confirmed by the fourth class of comparisons. These involve the wild-type flies from the F_3 (B) crosses and their wild-type parents from the F_2 (fig. 3). Here the F_3 (B) flies have two third chromosomes geographically mixed in origin, while the F_2 flies

TABLE 4

Comparative viability of wild type flies in P, F_1, F_2, $F_3(A)$ and $F_3(B)$
in crosses with the Gunnison genetic background.

Crosses		Total flies	Percent Wild type	Chi square between the homozygotes and F_1 and $F_3(A)$	Chi square between F_1 and $F_3(A)$ and F_2 and $F_3(B)$
$\frac{Gunnison}{Gunnison} \times \frac{Bl\,Sc}{Gunnison}$		1616	47.95		
$\frac{Gunnison}{Gunnison} \times \frac{Bl\,Sc}{Mather}$	F_1	1323	52.08	4.98 (P = 0.02)	
	$F_3(A)$	1361	51.35	3.38 (P = 0.07)	0.14 (P = 0.70)
	F_2	1137	50.74		
	$F_3(B)$	1239	47.37		2.69 (P = 0.10)
$\frac{Gunnison}{Gunnison} \times \frac{Bl\,Sc}{Bryce}$	F_1	1525	52.19	5.55 (P = 0.02)	
	$F_3(A)$	1382	48.69	0.93 (P = 0.35)	3.44 (P = 0.06)
	F_2	1033	44.43		
	$F_3(B)$	1407	42.64		0.82 (P = 0.45)
$\frac{Mather}{Mather} \times \frac{Bl\,Sc}{Mather}$		1314	48.70		
$\frac{Mather}{Mather} \times \frac{Bl\,Sc}{Bryce}$	F_1	1523	52.59	4.13 (P = 0.04)	
	$F_3(A)$	1473	49.08	0.05 (P = 0.85)	3.61 (P = 0.06)
	F_2	1141	48.81		
	$F_3(B)$	1320	46.13		1.67 (P = 0.20)
$\frac{Mather}{Mather} \times \frac{Bl\,Sc}{Gunnison}$	F_1	1404	54.05	7.64 (P = 0.006)	
	$F_3(A)$	1254	46.33	1.40 (P = 0.25)	15.70 (P = <0.001)
	F_2	1721	49.68		
	$F_3(B)$	1235	41.94		17.53 (P = <0.001)
$\frac{Bryce}{Bryce} \times \frac{Bl\,Sc}{Bryce}$		1492	49.66		
$\frac{Bryce}{Bryce} \times \frac{Bl\,Sc}{Mather}$	F_1	1554	55.34	9.74 (P = 0.002)	
	$F_3(A)$	1271	46.65	2.57 (P = 0.15)	21.30 (P = <0.001)
	F_2	1340	49.40		
	$F_3(B)$	1327	45.21		4.71 (P = 0.03)
$\frac{Bryce}{Bryce} \times \frac{Bl\,Sc}{Gunnison}$	F_1	1389	51.97	1.60 (P = 0.20)	
	$F_3(A)$	1584	48.98	0.13 (P = 0.70)	2.61 (P = 0.10)
	F_2	1495	50.16		
	$F_3(B)$	1514	44.25		10.32 (P = <0.001)

have only one such chromosome. Of the twelve such comparisons in tables 3 and 4, four show significant losses of the viability in the F_3 (B) flies, six show losses which do not reach the conventional level of significance, and two show insignificant increases.

I should also be pointed out that the flies having two crossover chromosomes, the F_3 (B) wild-type class, seem to be the least viable class in ten out of twelve series of the crosses recorded in tables 3 and 4.

Recent genetic work has shown that several distinct phenomena are confused under the common name of " heterosis." Populations of Drosophila and other sexually reproducing organisms carry in the heterozygous condition numerous recessive mutants and gene combinations which are deleterious, or even lethal, when homozygous. Inbreeding renders these deleterious genes homozygous, while crossing the inbred lines restores the dominance of the " normal " alleles tested by natural selection (mutational heterosis). On the other hand, as pointed out particularly by CROW (1948, 1952), heterosis may arise through interaction of alleles, or gene complexes, all of which are deleterious in homozygous condition. Natural selection maintains such alleles and gene complexes in populations, leading to the state of balanced polymorphism. The greater the variety of such heterotic genes the smaller the proportion of individuals homozygous for them in the population. Inbreeding increases the frequency of homozygosis, crossing the inbred lines restores the " normal " reproductive biology (the balance heterosis). By far the best evidence of the prevalence of balanced polymorphism in natural populations comes from observations and experiments on the chromosomal polymorphism in *Drosophila pseudoobscura* and other species (DOBZHANSKY 1951).

A still different type of heterosis is indicated by the results of VETUKHIV (1953), who worked with the strains of *Drosophila pseudoobscura* from the same localities which were used in the experiments described in the present paper. VETUKHIV observed that crossing of different geographic populations leads to an increase of the viability in the F_1 hybrids. Since the populations crossed are not inbred, they must be presumed to possess their normal heterotic state. This being the case, the further increase of the viability in F_1 hybrids suggests that heterozygosis may, up to a certain point, enhance the viability of the heterozygotes.

The results reported in the present article confirm and extend those of VETUKHIV. It is clear from the data in tables 1–4, that the presence of a single chromosome transferred from another geographic population of the same species increases the vigor of its carriers. Since such heterozygotes do not occur in natural populations, except perhaps very rarely, one can hardly suppose that the gene complexes in the chromosomes which occur in one geographic race are coadapted by natural selection to produce superior vigor in combinations with chromosomes of other races. A more direct effect of heterozygosity seems to be an assumption necessitated by the data.

The increased vigor in the F_1 hybrids contrasts, however, with a breakdown of the vigor as a result of gene recombination in the F_2 generation. VETUKHIV (1953) has observed such a breakdown in the F_2 hybrids from his crosses. The data reported in the present paper again confirm and extend his results. When a chromosome transferred from a foreign population is broken up by crossing over with chromosomes of different geographic origin, the resulting crossover products do not give a superior vigor to their carriers. In fact, the

F_2 and F_3 hybrids are inferior not only to the F_1, but in most cases even to the parental strains themselves (tables 3 and 4). The favorable effects of the presence of many heterozygous loci are more than offset by the disintegration of the internally balanced combinations of genes carried in the chromosomes of every population.

The existence of such internally balanced gene systems in the chromosomes in natural and certain experimental populations has been postulated by many authors (MATHER 1943; MATHER and HARRISON 1949; DOBZHANSKY 1949; DOBZHANSKY and PAVLOVSKY 1953; WALLACE 1952; WALLACE et al. 1953a, 1953b). Specialized chromosomal mechanisms, such as inversions found in many natural populations, have as their biological function the preservation of such balanced gene systems. The integrity of the gene system in a chromosome is easily lost by crossing over with chromosomes from foreign populations. It may be pointed out in this connection that the gene complex carried in chromosomes with the Arrowhead gene arrangement in the Mather population have become established in nature because of the high adaptive value of the heterozygotes formed with other chromosomes in the same population. At Mono, Lehman, Bryce and Ferron most of the flies are homozygous for Arrowhead chromosomes, while at Gunnison, the chromosomes with the Pikes Peak gene arrangement become common (DOBZHANSKY 1951). The " viability stimulus " found in the F_1 hybrids between different populations is definitely lost in the later generations. The lowest viability is encountered in individuals in which both chromosomes of a pair are crossover products, as in the F_3 (B) flies shown in figure 3 and in tables 3 and 4.

SUMMARY

The purpose of the experiments reported in the present article has been to study the integration of the genotype of local natural populations of *Drosophila pseudoobscura* in the absence of variations in the gene arrangements (inversions). The material used consisted of strains of *D. pseudoobscura* from several localities in California, Nevada, Utah and Colorado. All strains were homozygous for the Arrowhead gene arrangement in the third chromosomes. By means of a series of crosses, executed by MR. B. SPASSKY, third chromosomes from these various localities have been transferred to the genotypic backgrounds characteristic of the Mather, California, and of Gunnison, Colorado local populations.

F_1 hybrids, which carry two third chromosomes of different geographic origin are more viable than the flies with two third chromosomes from the same geographic locality. In F_2 and F_3, a breakdown of the viability is observed, and in most cases the viability is inferior to that in the original parents.

In the later experiments it has been possible to demonstrate that this breakdown of heterosis in F_2 and F_3 is an effect of the recombination by crossing over between the chromosomes derived from different populations. The lowest viability has been found in individuals in which both chromosomes of a pair are crossover products.

The general conclusion is that an internally balanced gene complex is maintained in every geographic population by natural selection. These complexes suffer disintegration owing to recombination and crossing over in the progeny of the hybrids.

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