HYBRID DYSGENESIS IN *DROSOPHILA MELANOGASTER*: STERILITY RESULTING FROM GONADAL DYSGENESIS IN THE *P-M* SYSTEM[1]

MARGARET G. KIDWELL AND JILL B. NOVY

Division of Biology and Medicine, Brown University, Providence, Rhode Island 02912

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ABSTRACT

Crosses between two types of strains, called *P* and *M*, characteristically give high frequencies of F_1 sterility and other aberrant traits. Previous studies indicated that, in addition to the direction of the parental cross, many factors influence the manifestation of this phenomenon known as "hybrid dysgenesis."——The present study is concerned with the characteristics of *GD* (gonadal dysgenesis) sterility associated with the *P-M* system and its temperature dependence. Female sterility is accompanied by a complete absence of egg-laying, and this is not attributable to an inability to mate. Thus, it seems likely that sterility results from a defect in gametogenesis of hybrid individuals. This conclusion is supported by the morphological and cytological observations presented in an accompanying paper (SCHAEFER, KIDWELL and FAUSTO-STERLING 1979).——A narrow, critical, developmental temperature range was found in which both female and male sterility rose sharply from a low level to a high maximum. The critical range was 27 to 29° for males, slightly higher than the range of 24 to 26° for females. Two other dysgenic traits, male recombination and transmission ratio distortion, were affected by developmental temperature, but temperature response curves were quite different from those for sterility. The temperature-sensitive stage for female sterility occurs during embryonic and early larval development.——*GD* sterility is compared and contrasted with *SF* sterility, another specific type of non-Mendelian sterility resulting from a different interstrain dysgenic interaction.

IT is now well established that many pairs of strains of *Drosophila melanogaster* may interact, usually nonreciprocally, to produce a variety of aberrant traits in their F_1 progeny (THOMPSON and WOODRUFF 1978; BREGLIANO *et al.* in preparation). This phenomenon, named "hybrid dysgenesis" (SVED 1976; KIDWELL and KIDWELL 1976), includes at least two systems, the *P-M* system (KIDWELL, KIDWELL and SVED 1977) and the *I-R* system (PICARD *et al.* 1978). In both systems, dysgenesis is mainly a hybrid phenomenon, but only one of the two interacting types of strains predominates in present-day wild populations. Thus, the induction of hybrid dysgenesis usually, but not always, involves the participation of a laboratory stock. The rules of inheritance in the two systems have strong similarities and consist of an unusual blend of Mendelian and non-

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Mendelian inheritance (PICARD 1976; BUCHETON and PICARD 1978; ENGELS 1979a).

The sterility characteristically associated with the *I-R* system (*SF* sterility) has been described in detail by PICARD *et al.* (1977). It is restricted to females and results from the failure of eggs to hatch. In contrast, the sterility associated with the *P-M* system is not restricted to females (KIDWELL, KIDWELL and SVED 1977). Moreover, the female sterility most commonly encountered in interacting crosses between *P* and *M* strains in the United States and Great Britain also differs markedly from *SF* sterility, in that no eggs are laid (KIDWELL 1979). Preliminary experiments have demonstrated a high degree of dependence of sterility and associated dysgenic traits on F_1 developmental temperature (KIDWELL, KIDWELL and SVED 1977). The purpose of this paper is to describe more detailed studies of the eggless type of sterility associated with the *P-M* system, with particular emphasis on the temperature effect. Complementary morphological and cytological studies are described in an accompanying paper (SCHAEFER. KIDWELL and FAUSTO-STERLING 1979).

MATERIALS AND METHODS

Strains used: (1.) *P* strains. Harwich—a strain established from two females collected in the wild in Harwich, Massachusetts, in 1967. Cranston—a strain established from several females collected in the wild in Cranston, Rhode Island, in 1964. (2.) *M strains.* Canton-S—a standard, wild-type laboratory stock. *rucuca*—a standard laboratory stock carrying the following recessive visible markers: roughoid, *ru* (3–0.0); hairy, *h* (3–26.5); thread, *th* (3–43.2); scarlet, *st* (3–44.0); curled, *cu* (3–50.0); stripe, *sr* (3–62.0); ebony-sooty, e^s (3–70.7); claret, *ca* (3–100.7).

Designation of parental reciprocal crosses: Consistent with previous usage, the following convention is adopted:

Cross A	*Cross B*
M strain ♀ × *P* strain ♂	*P* strain ♀ × *M* strain ♂

Cross A produces dysgenic F_1 progeny, whereas the progeny of Cross B are expected to be normal.

Method of testing for female sterility: Parental hybrid matings were made in mass cultures and immediately placed at 29° until the eclosion of F_1 progeny. F_1 females to be tested were first allowed to mate with their brothers for two to three days. They were then placed in individual vials at 25° with two males from a known fertile strain. After four days, vials were scored for the presence of eggs, and after ten days, they were checked for the presence of adult progeny.

Method of testing for egg hatchability: Groups of ten three-day-old females were mass mated with males from a known fertile strain. Eggs were collected on cardboard bottle caps to which approximately 1 cc of a grape-juice-agar medium, seeded with live yeast, had been applied. Caps were changed every 24 hr and placed in petri dishes on moistened filter paper. Hatchability was scored after a further 48 hr at 20°.

Characterization of female sterility in the P-M system: Nonreciprocal sterility, in both sexes, associated with male recombination was first reported by KIDWELL and KIDWELL (1975). In preliminary studies of this sterility, KIDWELL, KIDWELL and SVED (1977), noted that, in females, sterility sometimes resulted from an absence of egg-laying; at other times, eggs were laid but failed to hatch. Further study has revealed that dysgenic females from certain strain crosses invariably show the eggless type of sterility, whereas other crosses produce a mixture of the two types and a third group manifests only defective hatchability. A possible reason for this variability is given in the DISCUSSION. The present study is restricted to crosses exhibiting only the *P–M* interaction and displaying only the eggless type of sterility.

RESULTS

Tests of mating ability: Originally we considered that defective mating ability might be a cause of the absence of egg production, even though unmated females can produce some eggs. This was tested by observation of mating in female progeny of F_1 A and F_1 B reciprocal crosses between the strains Canton-S and Harwich and in control females of the two parental strains. Three- to four-day-old virgin females were mated individually with two males, of the same age, from either the Canton-S or the Harwich strains (equal numbers of females were mated with each of the two types of males). Flies were aspirated into the mating vials without etherization. The time that elapsed until copulation was recorded for all females mating within three hours. All vials were retained at 25° and their fertility or sterility was recorded.

The results are presented in Table 1. The number of F_1 A females that mated within periods of one and three hours was not markedly reduced from that of any of the other three groups. Moreover, 41 of a total of 46 F_1 A females that subsequently proved to be sterile were actually observed to mate. This was in contrast to the group of 11 out of 12 sterile Harwich females that, inexplicably, were not observed to mate or subsequently to produce offspring. Clearly, lack of mating was not a major cause of F_1 A sterility. The high frequency of sterility observed in the Harwich females was peculiar to this experiment. In other tests, females produced from intrastrain Harwich matings have not been unusually infertile (*e.g.*, KIDWELL, KIDWELL and SVED 1977; SCHAEFER, KIDWELL and FAUSTO-STERLING 1979).

There were no differences in mean mating speed among the four groups, calculated after one hour of observation. However, calculated after three hours of observation, Harwich and F_1 A females took about twice as long to mate as did Canton-S and F_1 B females. The data (mean mating times) were not distributed normally; therefore, the nonparametric Wilcoxan two-sample test was applied. The mating speed of F_1 A females was significantly slower than that of the re-

TABLE 1

Numbers of females observed to mate, classified according to their eventual fertility and mean female mating speeds

	Strain or cross of female							
	Harwich		Canton-S		F_1 A		F_1 B	
	F*	S	F	S	F	S	F	S
No. mating 0–1 hr	39	0	49	0	13	33	51	1
No. mating 0–3 hr	45	1	52	0	13	41	54	1
No. not mating within 3 hr	3	11	7	1	1	5	1	2
Total females observed	48	12	59	1	14	46	55	3
Percent of total observed	80	20	98.3	1.7	23.3	76.7	94.8	5.2
Mean no. min to mate								
Observed for 1 hr	10.7		11.5		11.2		10.4	
Observed for 3 hr	23.7		17.2		29.7		16.6	

* F = fertile; S = sterile.

ciprocal F_1 B females that were of identical genotype ($p < 0.05$). This may be an indication that mating behavior is slightly impaired in dysgenic females, but further investigation is required to clear up this issue. In any case, mating speed differences cannot account for the high frequencies of sterility observed in F_1 A females.

Sterility resulting from gonadal dysgenesis: With the exclusion of defective mating ability as a major cause of eggless sterility, it follows that the blockage occurs during oogenesis of dysgenic females or that it results from a gonadal structural defect. This conclusion is confirmed in the accompanying paper by SCHAEFER, KIDWELL and FAUSTO-STERLING (1979), who describe morphological and cytological studies of oogenesis in dysgenic females and controls. They find that sterility is attributable to the inability of ovaries to develop normally. The blockage occurs at an early stage of ovarian development and typically results in either unilateral or, more commonly, bilateral rudimentary ovaries in adult females raised at high temperatures.

Effect of a range of temperatures on female sterility: Preliminary studies have clearly established that the manifestation of sterility associated with the *P-M* system is highly dependent on F_1 developmental temperature (KIDWELL, KIDWELL and SVED 1977; ENGELS and PRESTON 1979). In order to obtain more precise information about the temperature-response curve over a broad range of temperatures, a series of reciprocal crosses between Harwich (*P* strain) and Canton-S (*M* strain) were set up. Mass matings were made in bottles and placed in incubators kept at temperatures ranging from 18 to 29° until eclosion of the F_1 progeny. At least 60 F_1 females from each treatment group were individually tested for sterility.

The results are presented graphically in Figure 1. The Cross A curve shows that most of the increase in sterility accompanying the change from permissive to restrictive temperature occurs over a narrow temperature range of 24 to 26°. Below this temperature, F_1 A sterility is no higher than that of the control reciprocal cross, F_1 B. Above the critical temperature range, sterility frequencies level off at 100%. F_1 B sterility frequencies were at a low level at all temperatures tested. Additional tests with other strain crosses showing *P-M* sterility, including those with sterility maxima below 100% (KIDWELL 1979, and unpublished results), have indicated a similar critical temperature range to that shown in Figure 1.

The relationship between temperature and male dysgenic traits: It was earlier observed (KIDWELL and KIDWELL 1975) that both male and female sterility, as well as male recombination, occurred in many dysgenic crosses, but that frequencies of female sterility usually exceeded those of male sterility. Other authors (*e.g*, SVED 1976), however, have claimed a complete absence of male sterility in association with male recombination. We have suspected that variable developmental temperature may be the reason for some of these conflicting results. It was, therefore, of interest to compare the temperature response curves for sterility in the two sexes and for different dysgenic traits produced simultaneously in the same males.

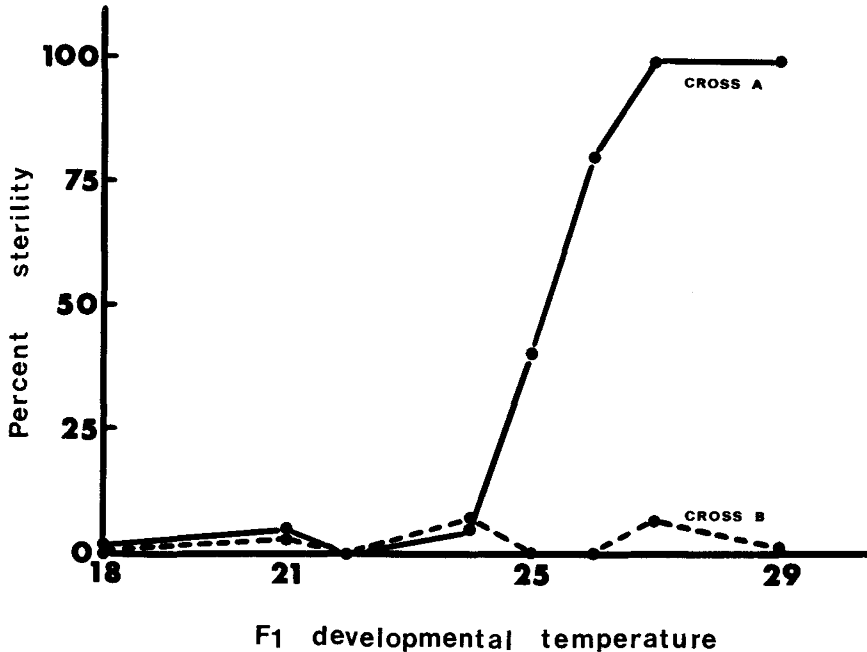


FIGURE 1.—Percent female sterility in the progeny of reciprocal crosses A and B between Canton-S and Harwich raised at a range of developmental temperatures.

Mass A crosses between *rucuca* (*M* strain) females and Cranston (*P* strain) males were made in bottles. This choice of strains allowed the simultaneous construction of temperature-response curves for male sterility, transmission ratio distortion and male recombination. Testing temperatures ranged from 15 to 29° and were again applied for the full F_1 developmental period. F_1 male progeny were individually backcrossed to four virgin *rucuca* females, and the F_2 were allowed to develop at 25°. Approximately 50 F_1 males were scored for sterility within each temperature group after eight days. The progeny of fertile F_1 males were scored for male recombination in the third chromosome, and k values were computed as the ratio of wild-type nonrecombinant progeny to total nonrecombinant progeny (HIRAIZUMI 1971). [Note that $k = 0.5$ if segregation is strictly Mendelian and there are no viability effects.] Approximately 3000 progeny were scored for each temperature, except for the 28° and 29° groups, in which about half this number were observed. A preliminary experiment indicated that no appreciable frequencies of male sterility were induced in the reciprocal F_1 B cross at any of the tested temperatures.

The effects of F_1 developmental temperature on Cross A male sterility and transmission ratio distortion are shown in Figure 2a and b, respectively. Comparing 2a with Figure 1, it is seen that there are general similarities in pattern between the two sexes in the effect of a range of temperatures on sterility; both show a steep rise in sterility over a narrow range of temperature increase. However, the critical range of precipitous sterility increase seems to occur at a rather

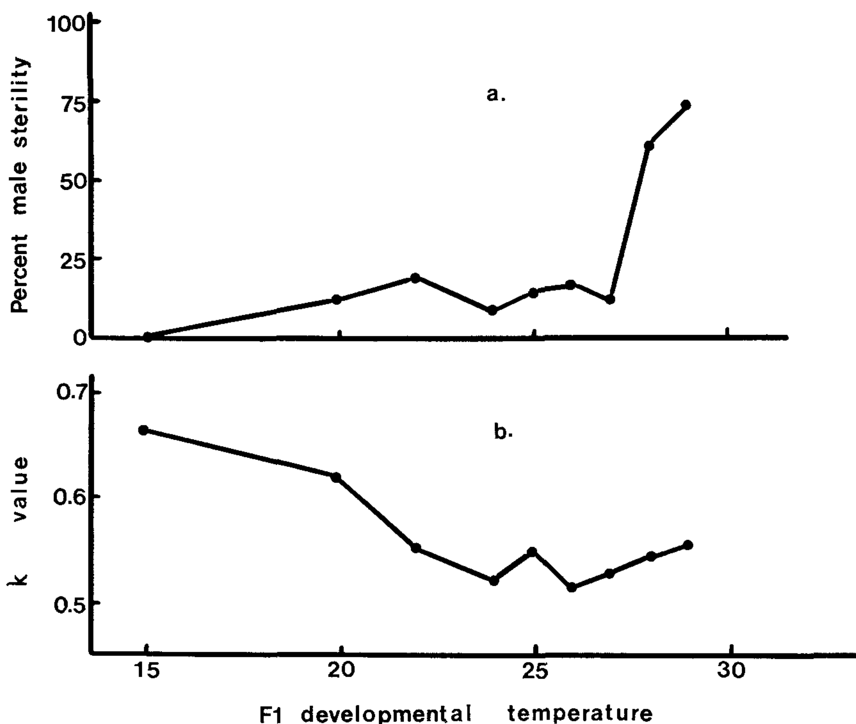


FIGURE 2.—(a) Percent male sterility and (b) k values in the progeny of crosses between *rucuca* females and Cranston males raised at a range of developmental temperatures.

higher temperature range in males than in females. This conclusion is strengthened by data obtained from F_1 A females from *rucuca* female × Cranston male crosses, raised at 25°. Forty-one of 66 (61.6%) females were sterile, compared with 12.0% male sterility at the same temperature (Figure 2a). This result is consistent with the low sterility observed in many male recombination tests at 25° (KIDWELL and KIDWELL 1975). Also, such a sex difference in the temperature threshold may provide an explanation for the absence of nonreciprocal male sterility in some dysgenic crosses (*e.g.*, WOODRUFF and THOMPSON 1977). From the present results, it is expected that, in general, a developmental temperature of 25° will produce moderate levels of sterility in some dysgenic females, but not usually in males from the same cross. However, evidence is accumulating (M. G. KIDWELL, unpublished results) that not all crosses yielding male recombination also produce F_1 sterility in either females or males, even after development at restrictive temperatures.

Figures 2b and 3 show that temperature affects k values and male recombination in a manner quite different from its effect on sterility (Figure 1 and 2a). Apart from the amplifying effect of a very few large clusters of male crossovers at high temperatures (top graph of Figure 3), there was no evidence in either trait for the critical temperature threshold observed for male and female sterility. Male recombination and transmission ratio distortion were observed over a very

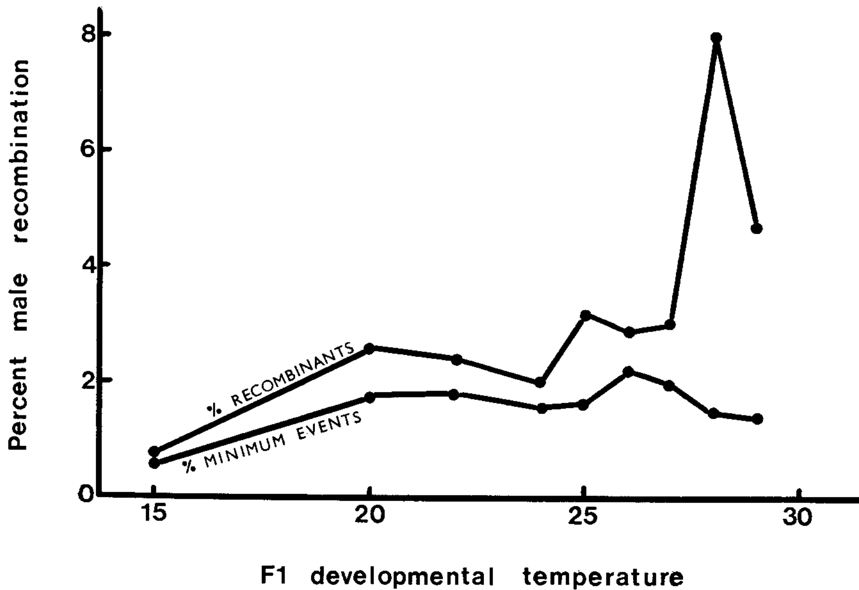


FIGURE 3.—Percent male recombination in the progeny of crosses between *rucuca* females and Cranston males raised at a range of developmental temperatures.

broad temperature range. Preliminary results (KIDWELL, KIDWELL and SVED 1977) had suggested that maximum male recombination occurred at 25°. KENDALL's tau, a nonparametric correlation measure (KENDALL 1955) was therefore calculated for (a) data in all temperature groups, (b) data from temperatures below 25°, (c) data from temperatures above 25°. The values of tau, together with their respective probabilities are summarized in Table 2. Using all the data, no significant temperature effect was observed for either trait. However, analysis of the two temperature range data subsets indicated a positive correlation between temperature and the two dysgenic traits up to 25° and a negative correlation above 25°. These data are consistent with our earlier observation of a 25° maximum for male recombination. They are in agreement with those of ENGELS (1979b), but differ from those of YANNOPOULOS and PELECANOS (1977), who observed a 29° maximum for male recombination.

Determination of temperature-sensitive period: In order to determine the

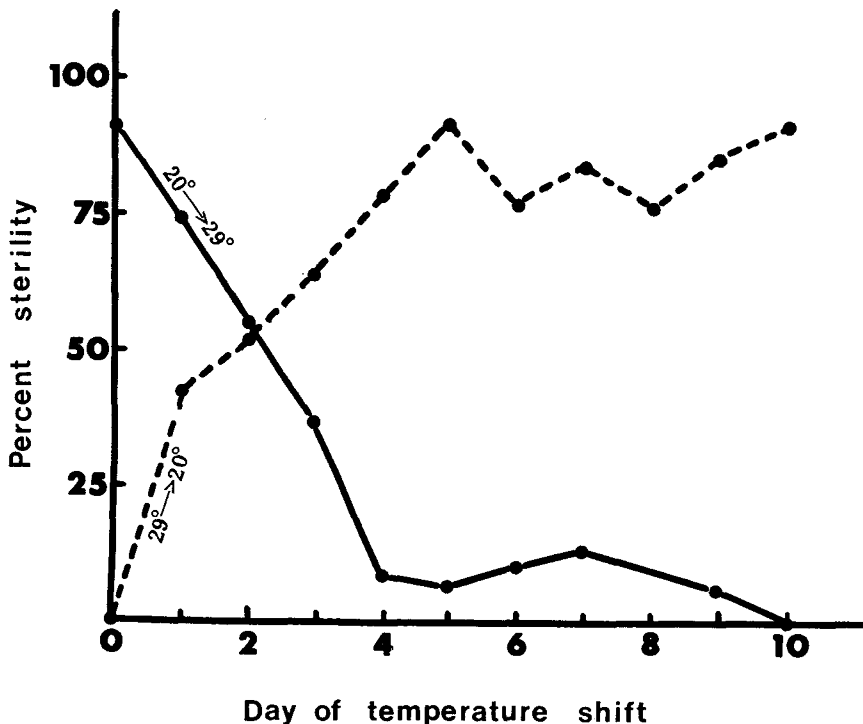
TABLE 2

Correlation coefficients (Kendall's tau) of k *values and minimum male recombination frequencies with temperature*

Temperature	k value	Minimum male recombination
15–29°	0.3 ($p = 0.1$)	0 ($p = 0.5$)
≤25°	—0.8 ($p = 0.04$)	0.2 ($p = 0.41$)
>25°	1.0 ($p = 0.04$)	—1.0 ($p = 0.04$)

stages of development that are sensitive to high temperature treatment, developing progeny of a potentially dysgenic cross were switched at different times from restrictive to permissive temperatures, and *vice versa*. Parental A crosses between 40 Canton-S virgin females and 25 Harwich males were used throughout the experiment. The females were allowed to deposit eggs for two hours at the permissive temperature of 21° and then immediately placed at the allocated starting temperature. Half the number of cultures were started at 29°, and after successively longer periods of development, individual cultures were "switched down" to 20° to complete their development. (On the assumption that temperature has a linear effect on developmental time, each time increment was calculated to be equivalent to 24 hours at 25°.) The remaining cultures were started at 20° and "switched up" to 29° in a similar way. About 60 F_1 females in each treatment class were tested for sterility.

The results are presented in Figure 4. It seems that a temperature-sensitive period exists during the first three to four days of development. The frequency of sterility appears to change approximately linearly with time up to four days, suggesting an additive effect of temperature during early development, rather than a short specific temperature-sensitive stage. This latter result differs from



FIGURES 4.—Percent female sterility in the progeny of crosses between Canton-S females and Harwich males subjected to a shift from restrictive (29°) to permissive (20°) temperatures, and *vice versa*. The indicated day of temperature shift was adjusted to the equivalent day of 25° in order to equate stages of development.

that of ENGELS and PRESTON (1979), who found that maximum sterility was achieved after approximately 24 hours at the restrictive temperature. This varying time to reach maximum sterility may reflect differences in techniques or differences in the parental strains employed.

In a second "shift down" experiment, using the same matings as before but the protocol of ENGELS and PRESTON (1979), we sought to determine more precisely the onset of the temperature-sensitive period within the first 24 hours of development. Eggs were collected at 29° over a one-hour period, and individual samples were successively switched down hourly to 20°. Of 69 Cross A eggs switched down between one and five hours, none produced sterile females. Twelve out of 106 (11.3%) switched down between six and nine hours, 15 out of 63 (23.8%) switched down between ten and 13 hours and 24 out of 61 (39.3%) switched down between 14 and 17 hours gave sterile females. Thus, the temperature-sensitive period clearly does not start before the sixth hour of development. It appears to begin at about the seventh hour (29°), a result which is in close agreement with that of ENGELS and PRESTON (1979).

Determination of egg hatchability: From the result reported above, the manifestation of sterility is clearly conditional on high developmental temperatures. Under permissive conditions, eggs are usually laid by dysgenic females. In order to cover all possible reasons for sterility, we now inquire whether such eggs have normal or reduced hatchability. The effects of aging and a seven-day thermal treatment of 29° on egg laying F_1 females were determined.

The results are shown graphically in Figure 5. There is an indication of lower hatchability in the A cross than in the B cross during the first week of production, but the difference is small. There is no evidence for the gross reduction of

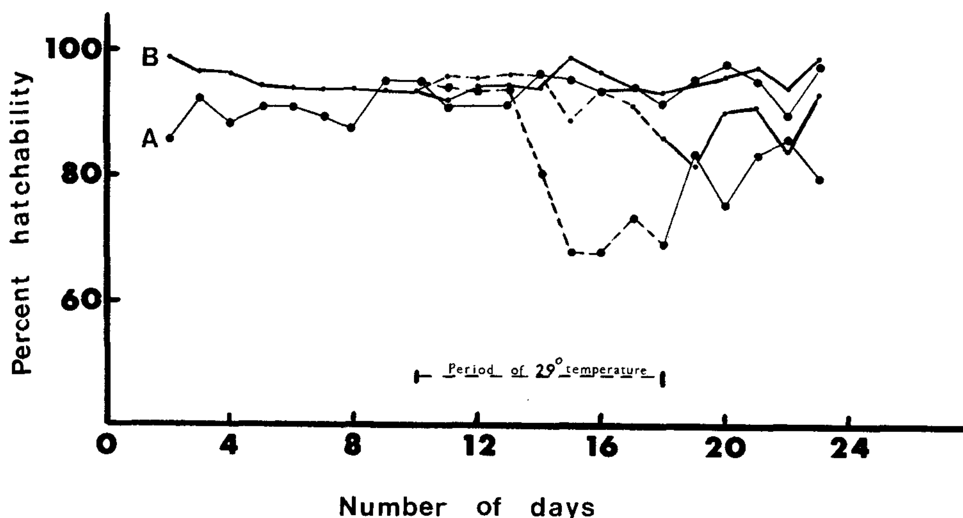


FIGURE 5.—Percent hatchability of eggs laid by F_1 progeny of reciprocal crosses between Canton-S and Harwich strains. Egg-laying females were kept at 20° except during the period of heat treatment (indicated by dashed lines).

hatchability typical of *SF* sterility in young hybrid females (PICARD *et al.* 1977). F_1 A hatchability was rather more sensitive to reduction by 29° temperature than F_1 B hatchability, but this response was in the opposite direction to the response of *SF* females at high temperatures.

DISCUSSION

The observations described in this paper, together with those of SCHAEFER, KIDWELL and FAUSTO-STERLING (1979), provide evidence for a quite specific type of sterility associated with *P* and *M* strain interaction. The results are in very close agreement with those of ENGELS and PRESTON (1979), who also observed eggless female sterility. The main characteristics of this type of sterility are as follows:

Sterility is the result of defective development of gonads (gonadal dysgenesis) in F_1 individuals. For convenience this type of sterility is therefore referred to as *GD* sterility.

All other aspects of development of dysgenic hybrids appear to be normal, as is their ability to mate. There is a possibility that mating speed may be retarded in dysgenic females, but not sufficiently to be a cause of sterility.

Sterility is dependent on high temperature during mid to late embryonic and early larval development, and the effect is irreversible once the temperature sensitive stage has passed.

The change from permissive to restrictive temperature occurs over a narrow range of two to three degrees. This critical temperature range appears to be somewhat higher for male sterility than for female sterility, but parental strain differences may also lead to some variability in the temperature threshold. The pattern of this temperature-response curve is very different from those of other dysgenic traits, such as male recombination and transmission ratio distortion, which increase over a much broader temperature range with intermediate rather than high temperature maxima.

Eggs laid by dysgenic females, raised under permissive temperature conditions, do not show any marked reduction in hatchability. The effect of high temperature, applied to egg-laying dysgenic females, is a modest reduction in hatchability.

These characteristics of sterility associated with the *P-M* interaction are in marked contrast to those of *SF* sterility, which is associated with the *I-R* interaction (PICARD *et al.* 1977). *SF* sterility results from the failure to hatch of the eggs laid by hybrid females. The blockage occurs at a very specific stage, namely late cleavage. Temperature is an important factor in the manifestation of both types of sterility, but it is effective in very different ways in the two systems. Acting on the *P-M* system, high temperatures are restrictive and low temperatures are permissive; applied to the *I-R* system the opposite is true, low temperatures are restrictive and high temperatures are permissive. Furthermore, the temperature-sensitive phase is also quite different; in the *P-M* system it occurs at early developmental stages of the F_1 but in the *I-R* system it occurs during a

period of one to two days prior to egg laying of F_1 (*SF*) females, probably coinciding with vitellogenesis (PICARD *et al* 1977). There is, however, evidence for some similarity between the two systems in that at an earlier temperature-sensitive period, increased temperatures have a diminishing effect on hatchability of eggs laid by *SF* females.

The two systems also differ in that the temperature effect on sterility in the *I-R* system is reversible, whereas it is not in the *P-M* system. Also, sterility is reversible by aging of females in the *I-R* system, but there is no evidence for such an effect in the *P-M* system.

In view of the rather unusual similarities between the *I-R* and the *P-M* systems in terms of general characteristics, distribution and mode of inheritance (KIDWELL 1979), the distinctive differences between the two types of sterility produced and their interaction with environmental factors are intriguing.

It was earlier mentioned that in certain *P-M* crosses some sterile dysgenic females have been observed to lay eggs, whereas most produce none at all. This observation has led to some confusion and has impeded the characterization of the sterility associated with the *P-M* system. Recent developments have provided at least a partial explanation. KIDWELL (1979) has shown that the *GD* and *SF* types of sterility are caused by two distinct types of interstrain interaction that are not mutually exclusive. It follows, and has been demonsrated, that female progeny of dysgenic crosses involving both *P-M* and *I-R* interactions may exhibit both *GD* and *SF* sterilities, providing the requisite temperatures are appropriately applied. Thus, the mixture of egg-laying and nonegg-laying hybrid females that has been occasionally observed may be readily explained by the presence of both types of interaction. It is thus of some importance to know the designation of strains within both the *P-M* and *I-R* systems in order to predict their interaction potential for hybrid dysgenesis.

HENDERSON, WOODRUFF and THOMPSON (1978) claim that chromosomal breakage and fragmentation leading to male recombination and other dysgenic traits occur predominantly at meiosis. Clearly, sterility resulting from the type of gonadal dysgenesis found in *P-M* hybrids must be an exception to this generalization because gonadal development, at least in females, is arrested long before the time of meiosis. Furthermore, ENGELS and PRESTON (1979) have discussed the difficulties of evoking chromosomal breakage to explain the complete failure of the germ line that results in sterility.

Although there seems to be a general tendency for dysgenic traits to be affected by developmental temperature, the marked differences in pattern among traits is somewhat unexpected. With respect to sterility in both sexes, there appears to be a temperature threshold above which extremely high frequencies of sterility are manifested. For male recombination and transmission ratio distortion, the relationship with temperature is clearly not of this threshold variety and intermediate rather than high temperatures produce maximum frequencies.

It can be argued that sterility is the most extreme of all the dysgenic traits. It is the result of the complete failure of the germ line of an individual. Other traits can be considered to be the result of aberrations in the germ line of a lower order

of magnitude; they are in fact observable only if some part of the germ line survives to produce viable gametes. Two main stages of susceptibility to developmental arrest are postulated to explain the observations. The first would occur during mid to late embryonic and early larval development and the changes at this stage may or may not be attributable to chromosome breakage. This stage is postulated to be highly sensitive to temperature. At restrictive temperatures, induced aberrations frequently are so drastic as to produce complete sterility. Cell lines that do survive may show a tendency for a low frequency of clusters of other aberrations such as mutations and crossovers, suggesting their very early origin. [Occasionally, single male dysgenic hybrids have been observed to produce progeny all belonging to one large cluster of recombinants with no nonrecombinant types (KIDWELL, unpublished results)]. The second susceptible stage would occur at meiosis, with chromosome breakage giving rise to second-order dysgenic traits such as male recombination and transmission ratio distortion. This stage is postulated not to be temperature sensitive. Thus, low frequencies of second-order traits can occur at all temperatures, but they could have some limited dependence on high temperatures for an increase in the frequency of clusters induced premeiotically at the first susceptible stage.

Sterility resulting from the *P-M* interaction is, on the average, more frequent in females than in males (KIDWELL, KIDWELL and SVED 1977). This is an exception to Haldane's rule, from which it would be predicted that the male, being the heterogametic sex, would display the higher sterility. A possible reason for the observed direction of inequality may lie in the mode of inheritance of hybrid dysgenesis. KIDWELL and KIDWELL (1976) suggested that two distinct components, chromosomal and cytoplasmic, were involved in the dysgenic interaction. ENGEL's (1979a) results indicate that the chromosomal component consists of polygenic, Mendelian factors found on all major chromosomes of *P* strains, which act nearly independently of one another. In a dysgenic cross, a *P* strain male contributes *P* chromosomes *Y*, *2*, *3* and *4* to his hybrid sons and *P* chromosomes, *X*, *2*, *3* and *4* to his hybrid daughters. Assuming that *Y* chromosomes do not carry sterility factors similar to those of the *X* chromosome, the observed sex difference in sterility may be explained simply by the fact that female hybrids carry one more *P* chromosome bearing sterility factor than do their brothers. However, such an explanation cannot account for the restriction of *SF* sterility to females only. In inducer stocks, *I* factors may be linked to any of the four chromosomes (PICARD, 1976) and inducer chromosomes seem to act nonadditively in determining the frequency of *SF* sterility.

The parallels of hybrid dysgenesis, and particularly its associated sterility, with earlier documented cases of hybrid sterility are becoming increasingly more apparent. The sterility observed in hybrids between *D. melanogaster* and *D. simulans* associated with reduced size of gonads (KERKIS 1933) bears strong similarities to *P-M* sterility. That described by Dobzhansky between interrracial crosses of *D. pseudoobscura* (later classified as two sibling species) has a strong resemblance to *SF* sterility in that it results from low egg hatchability. It is particularly interesting to note DOBZHANSKY's (1941, p. 319) tentative conclusions on

this type of sterility: "The sterility of the hybrids in question is due to interactions between the chromosomal constitution of the hybrid itself and the properties of the cytoplasm of the egg from which it develops, always keeping in mind that the properties of the latter are determined by the chromosomal constitution of the mother." Such a conclusion fits very nicely our most recent knowledge on the inheritance of the *I-R* system (BUCHETON and PICARD 1978) and that of the *P-M* system (ENGELS 1979a). Perhaps, in hybrid dysgenesis, we are seeing the first steps in the process of speciation that have eluded us for so long.

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