INHERITANCE OF PATTERNS OF OXYGEN CONSUMPTION IN MICE

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Abstract

Oxygen consumptions were measured for males from three random-breeding mouse stocks, R70, Wild, and TNa, and for F_1 and F_2 offspring of R70 × Wild crosses and of R70 × TNa crosses. In each group consumptions were measured on two occasions, once when the animals were adjusted to their rearing temperature (21°C) and once after they had been acclimatized to 33°C for 2 weeks. On both occasions consumptions were measured at air temperatures of 26, 28, 30, 32, and 34°C.

Wild mice differed from R70 mice in having a higher rate of oxygen usage at all temperatures, in the rapidity of the increase in consumption at temperatures above thermal neutrality (30°C), and in showing no depression in consumption at temperatures above 30°C following acclimatization to 33°C. The consumptions of TNa mice also differed from those of R70 mice in the two latter characteristics.

The F_1 and F_2 offspring of the R70 × Wild cross resembled their R70 parents in their oxygen consumptions at 26, 28, and 30°C. They resembled their Wild parents in the rapid increase in consumption at temperatures above 30°C and in their lack of response to acclimatization. The F_1 and F_2 offspring of the R70 × TNa cross resembled the TNa stock, rather than the R70 stock, in the rapid increase in consumption at temperatures above 30°C, and in their response to acclimatization.

I. Introduction

Animals which consume oxygen at relatively low rates at high environmental temperatures are thought to be better adapted to life in such an environment than those with a high rate of consumption. Breeds with low consumptions have therefore been favoured in selecting livestock for tropical climates.

Relatively few experiments have been carried out on the inheritance of oxygen consumption patterns when unrelated stocks are crossed. In mice these have been confined to measurements of oxygen consumption of parental strains and F_1 hybrids at a limited number of environmental temperatures. Schlesinger and Mordkoff (1963) and Górecki and Krazonowska (1970) measured the consumption of inbred mouse strains and their F_1 hybrids at temperatures at and below thermal neutrality. They found that the oxygen uptakes of hybrids were intermediate between those of the parental strains. Pennycuik (1969) measured the consumptions, at temperatures above and below thermal neutrality, of a random-bred strain, two selection lines, and crosses between the random strain and both selection lines. The consumptions of the hybrids resembled the random parents in one cross and the selection-line parents in the second cross. This was true at all temperatures investigated. No one appears to have investigated the inheritance of the ability to lower consumption following acclimatization to high temperatures, or the pattern of consumption of F_2 hybrids.

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Since the inheritance of oxygen consumption patterns is of some interest to breeders of tropical livestock it was decided to repeat measurements on three of the stocks examined earlier in this laboratory (Pennycuik 1967), and to measure the consumptions of F_1 and F_2 crosses between two pairs of these stocks. The results of these investigations are reported below.

II. Materials and Methods

(a) *Animals*

The three random-breeding stocks examined were R70, TNa, and Wild. The R70 stock was formed by crossing a multiple recessive stock from Harwell with inbred strains 101, C_3H, and CBA, the TNa stock was formed by backcrossing random-breeding mice carrying the N gene to CBA (only ++ sibs were used in the present investigations), and the Wild stock was formed by crossing wild mice trapped near Sydney with a Brachy stock. In addition to animals from these base stocks oxygen consumption measurements were carried out on F_1 and F_2 descendants of two crosses, R70 × Wild, and R70 × TNa. All experimental animals were males.

(b) *Environmental Temperatures and Routine Used for Acclimatization*

All animals were kept in an animal room maintained at 21°C. Details of the room are given elsewhere (Pennycuik 1967).

Following oxygen-consumption measurements the animals were transferred to an incubator regulated to 33°C and allowed to acclimatize to the new temperature for 2 weeks before the oxygen-consumption measurements were repeated.

(c) *Oxygen-consumption Measurements*

Oxygen uptake was measured with a mouse spirometer (Aloe). In this apparatus uptake was measured from the change in volume of the oxygen store connected to the animal chamber. Soda lime was used to absorb CO_2 in the chamber and silica gel was used to absorb water vapour. Uptakes were measured at five air temperatures: 26, 28, 30, 32, and 34°C. These were achieved by circulating water round the sides of the animal chamber from a water-bath adjusted to the following temperatures: 25, 30, 33, 36, and 40°C. Animals were allowed to adapt to the experimental temperature for 15 min before measurements were carried out. Consumption was then measured each minute over the next 45 min. The smallest uptake over a 14-min period was taken as the resting oxygen consumption.

The mice were weighed before transfer to the animal chamber. They were not restrained in any way and they were given food and water.

III. Results

Oxygen Consumptions of the Three Base Stocks and their Crosses

(i) *R70 × Wild*

The oxygen consumption curves of the R70 and Wild stocks and the F_1 and F_2 animals produced when these two strains were crossed are shown in Table 1. Figure 1(*a*) illustrates the curves for the four groups when they were maintained at 21°C.

When the mice were maintained at 21°C, the Wild animals had greater oxygen consumptions than the R70 mice at all temperatures. They also showed a much sharper increase in consumption at temperatures above the thermoneutral point (30°C) than the R70 mice. The consumptions of the F_1 and F_2 animals were not significantly different from those of the R70 mice at temperatures between 26 and 30°C. At temperatures above 30°C the consumptions of the F_1 and F_2 animals rose sharply like those of their Wild ancestors, and the differences between the consumptions of the R70 mice and the F_1 and F_2 mice became significant. The consumptions of the F_1 and F_2 animals were not significantly different at any of the temperatures investigated and the F_2 variances were no greater than those of the F_1 animals.

When the R70 and Wild mice and their crosses were acclimatized to 33°C only the R70 stock showed a fall in oxygen consumptions at temperatures above 30°C. The consumption of the Wild mice and the F_1 and F_2 mice showed little change following acclimatization and, where changes did occur, consumptions tended to increase rather than decrease.

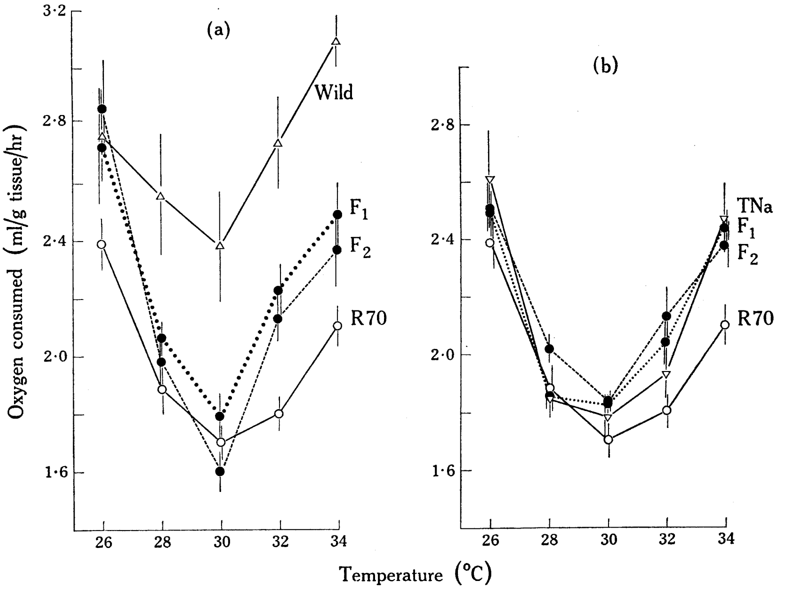

Fig. 1.—Resting oxygen consumptions of (*a*) R70 and Wild mice and the F_1 and F_2 offspring of the cross between the two; and (*b*) of R70 and TNa mice and the F_1 and F_2 offspring of the cross between the two. The animals were left at 21°C up to the time when measurements were carried out.

(ii) *R70×TNa*

The oxygen consumptions of R70 and TNa mice and of the F_1 and F_2 offspring of the cross between the two stocks are shown in Table 2. The values obtained when the mice were at 21°C are illustrated in Figure 1(*b*).

When the mice were at 21°C the differences between the consumptions of the two parent stocks were not significant at temperatures at and below 32°C, but were significant at 34°C. The differences above 32°C were due to the fact that consumption increased more rapidly in the TNa stock than in the R70 stock over this part of the temperature range. The consumptions of the F_1 and F_2 animals were not significantly different from those of the TNa stock but were significantly different from the R70 stock at 32 and 34°C. The consumptions of the F_1 and F_2 animals were not significantly different from one another and their variances were very similar.

TABLE 1

OXYGEN CONSUMPTIONS OF R70 AND WILD MICE AND THEIR F_1 AND F_2 HYBRIDS

The consumptions of each group were measured twice: once when they were at 21°C and once after acclimatization to 33°C. Consumptions were measured at temperatures between 26 and 34°C. Significances of F values were as follows: * $0 \cdot 05 > P > 0 \cdot 01$; ** $0 \cdot 01 > P > 0 \cdot 001$; *** $0 \cdot 001 > P$

Strain	Temp. of acclimatization (°C)	No. of mice	Body weight ± S.E. (g)	Oxygen consumption ± S.E. (ml/g tissue/hr)				
				26°C	28°C	30°C	32°C	34°C
R70	21	23	33·6±0·9	2·39±0·09	1·88±0·08	1·70±0·06	1·80±0·06	2·10±0·07
	33	23	33·7±0·8	2·38±0·07	1·93±0·09	1·81±0·08	1·62±0·07	1·75±0·09
Wild	21	14	28·1±1·2	2·77±0·16	2·56±0·21	2·38±0·19	2·74±0·16	3·09±0·09
	33	14	28·1±1·3	2·84±0·12	2·97±0·21	2·74±0·26	2·94±0·18	2·84±0·13
R70 × Wild								
F_1	21	10	32·7±0·6	2·73±0·20	2·06±0·06	1·79±0·08	2·23±0·09	2·49±0·11
	33	10	32·7±0·7	3·03±0·19	2·53±0·19	2·24±0·18	2·36±0·14	2·50±0·10
F_2	21	12	33·5±1·0	2·86±0·17	1·98±0·10	1·60±0·07	2·13±0·08	2·37±0·13
	33	12	33·7±1·2	2·75±0·22	2·11±0·18	1·80±0·24	2·00±0·18	2·23±0·14
F values:								
R70 (21), Wild (21)				4·85*	12·71**	16·40***	42·55***	69·97***
R70 (21), F_1 (21), F_2 (21)				3·72	1·05	1·37	11·73***	4·25*
Wild (21), F_1 (21), F_2 (21)				0·14	4·39*	8·97***	7·30**	13·27***
F_1 (21), F_2 (21)				0·06	0·41	3·29	0·75	0·46
R70 (21), R70 (33)				0·01	0·18	1·18	4·07	9·21**
Wild (21), Wild (33)				0·12	1·89	1·28	0·67	2·44
F_1 (21), F_1 (33)				1·23	5·46*	5·07*	0·60	0·01
F_2 (21), F_2 (33)				0·16	0·39	0·63	0·43	0·56

TABLE 2

OXYGEN CONSUMPTIONS OF R70 AND TNa MICE AND THEIR F_1 AND F_2 HYBRIDS

The consumptions of each group were measured twice: once when they were at 21°C and once after acclimatization to 33°C. Consumptions were measured at temperatures between 26 and 34°C. Significances of F values were as follows: * $0\cdot05 > P > 0\cdot01$; ** $0\cdot01 > P > 0\cdot001$; *** $0\cdot001 > P$

Strain	Temp. of acclimatization (°C)	No. of mice	Body weight ± S.E. (g)	Oxygen consumption ± S.E. (ml/g tissue/hr)				
				26°C	28°C	30°C	32°C	34°C
R70	21	23	33·6±0·9	2·39±0·09	1·88±0·08	1·70±0·06	1·80±0·06	2·10±0·07
	33	23	33·7±0·8	2·38±0·07	1·93±0·09	1·81±0·08	1·62±0·07	1·75±0·09
TNa	21	9	33·4±1·7	2·61±0·17	1·84±0·06	1·78±0·08	1·93±0·09	2·47±0·12
	33	9	35·1±1·5	3·01±0·23	2·16±0·22	1·79±0·13	1·97±0·09	2·21±0·13
R70 × TNa								
F_1	21	10	32·0±0·5	2·49±0·08	1·85±0·04	1·82±0·04	2·04±0·08	2·44±0·06
	33	10	33·4±0·7	2·71±0·15	2·27±0·17	1·94±0·15	2·25±0·13	2·34±0·05
F_2	21	12	32·5±0·4	2·51±0·09	2·02±0·05	1·83±0·04	2·13±0·10	2·38±0·08
	33	12	33·4±0·7	2·82±0·20	2·43±0·17	2·23±0·20	2·21±0·16	2·38±0·11
F values:								
R70 (21), TNa (21)				1·53	0·09	0·53	1·55	6·94*
R70 (21), F_1 (21), F_2 (21)				0·51	1·17	1·73	6·22**	5·62**
TNa (21), F_1 (21), F_2 (21)				0·29	4·55**	0·07	1·17	0·29
R70 (21), R70 (33)				0·01	0·18	1·18	4·07	9·21**
TNa (21), TNa (33)				1·95	1·91	0·00	0·09	2·22
F_1 (21), F_1 (33)				1·65	5·72*	0·61	1·86	1·54
F_2 (21), F_2 (33)				1·92	5·57*	3·91	0·18	0·00

Acclimatization to 33°C caused a fall in consumption at temperatures above 30°C in the R70 stock but the TNa mice and the F_1 and F_2 mice were unaffected by acclimatization.

IV. Discussion

The results of earlier experiments suggest that the oxygen-consumption curves of F_1 hybrids may be either intermediate between those of the parent stocks (Schlesinger and Mordkoff 1963; Górecki and Krazonowska 1970) or that they may resemble that of one of the parent stocks more closely than that of the other, over a range of temperatues (Pennycuik 1969). The curve of the F_1 progeny of the R70 × TNa cross conforms to the second pattern. The curve of the F_1 progeny of the R70 × Wild cross conforms to neither: although consumptions of F_1 mice were not significantly different from those of the R70 parents at temperatures at and below thermal neutrality, the two groups were significantly different at temperartues above this temperature. This appeared to be because the F_1 mice resembled their Wild parents in the sharp increase in consumption over the upper part of the temperature range investigated.

The inheritance of the ability to respond to acclimatization to high temperatures with a fall in oxygen consumptions at temperatures above 30°C does not appear to have been investigated before. In both the R70 × Wild cross and the R70 × TNa cross the F_1 mice resembled the parent which failed to respond to acclimatization rather than the R70 stock which showed a fall in consumption following exposure to 33°C. The fall in the oxygen consumption of hamsters which follows acclimatization to 34–35°C has been shown to be associated with a reduction in the mass of the heat-producing organs and to modification of the respiratory chain in the liver (Cassuto 1968; Cassuto, Chayoth, and Rabi 1970). Clark (1971) on the other hand observed that the improvement in body temperature control of rats at 42°C, following acclimatization to 40°C, was due to a reduction in locomotor activity. At present the cause of the reduction in the oxygen consumption of R70 mice at temperatures above 32°C following acclimatization is not known; nor is it known how the other stocks or the crosses differ from the R70 strain. These points will have to be investigated.

Little or nothing appears to be known about the genetic control of oxygen-consumption patterns. The results of the F_2 mice of both crosses suggest that control is due to a polygenic system and that no major genes are involved, for the variances of the consumptions of these animals at all temperatures were little different from those of F_1 hybrids. In the offspring of the R70 × Wild cross the level of oxygen consumption at temperatures between 26 and 30°C appeared to be inherited independently from consumptions at temperatures above 30°C and from the ability to respond to acclimatization. It is possible, therefore, that there is a shift in the complement of genes involved in determining consumption at the upper and the lower end of the range of environmental temperature investigated in these experiments.

V. Acknowledgments

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