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Analysis of the genetic variation for adaptation to a short thermal stress on young « *Bos taurus* » cattle

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Summary

In the present work, an attempt was made to determine the adaptation to heat of some cattle breeds, especially French ones. A total of 582 young male and female cattle, about 14 months old and coming from 41 elementary genetic combinations analyzed in 5 different non bioclimatological experiments, were subjected to a heat stress for 8 hours during which the room temperature was increased from 18° to 38 °C.

The usual reaction were observed i.e. increase in the rectal temperature during the stress (+ 0,54 °C), increase in the respiratory rate (× 3), increase in the sweating rate, heart rate and skin temperature.

The statistical analyses were made at three stages of stress (beginning, middle, end). In all cases, a very strong environmental effect was noticed, ie effect of the year and of experimental errors in the management of the theoretical schedule involving temperature and relative hygrometry.

The data adjusted for environmental effects rather clearly show the genetic variability. However, a more accurate analysis shows that it is mainly proceeded from a between group variability when defining the groups according to « animal husbandry » parameters (dairy purpose, beef purpose, and local breed group). As a matter of fact, in most cases, there was no significant variability between the reactions of the genotypes belonging to the same group, whereas this variability existed between the groups. The satisfactory performance of the local breed group clearly appeared in comparison with the group including the improved dairy or beef breeds exhibiting only minor differences in the parameters analyzed.

In the discussion, emphasis in laid on the possible influence of thermogenesis on the results. Although our findings could have been affected by disturbing events such as emotional stress, they agree rather well with data obtained is practice on the behaviour of the local French breeds in some hot countries.

Introduction

Animal breeding improvement of milk and meat productions in tropical countries gives rise to problems depending on the practical conditions encountered in these countries (Payne, 1970; Mc Dowell, 1972; Halipre and Bibé, 1973; Mc Dowell, 1976). They are in connection with the direct effects of the climate, especially the temperature and its indirect effects : low average level and large variations in the quantity and quality of feed, parasitic attacks (Frisch, 1976).

The peculiarity of these conditions is so strong that the breeding methods used often take advantage of crossbreeding between *Bos taurus* and *Zebu* cattle, for milk production as well as meat production. Many experimental results show that in the present tropical conditions, there is an optimal proportion of « *Bos taurus* » genes (« productive » genes) between 50 and 70 p. 100, the remaining proportion corresponding to « resistance » genes necessary for expressing productive genes (Amble and Jain, 1965; Cundiff, 1970; Payne, 1970). These results are mostly derived from comparisons between a local zebu breed, a European breed and some corresponding crosses. However, it is not often possible to obtain a direct comparison between the European breeds, pure or crossbred, concerning their production abilities in tropical conditions and their components.

Most of the results of the comparison between lines or breeds of « Bos taurus » cattle were obtained in British breeds but the technical references on typically French breeds are scarce, although some of them are used in hot climates : the *Tarentaise* breed in North Africa, the *Norman breed* in South America and the *Charolais* and *Limousin* breeds all over the world.

Thus, between 1971 and 1975, an experiment was carried out in order to compare the resistance to a short thermal stress of various animals from the running experiments managed by the *Animal Breeding Department* of the Institute. Unfortunately, no Zebu « control », was introduced into the test nor were tested the same genetic combinations outside, in real hot conditions. However the range of the studied animals was very large, all the types of common « Bos Taurus » breed being represented.

The purpose of this paper is to give the final result and conclusions, after a rather long list of preliminary surveys written by scientists or students (Halipré, 1971, 1973; Guillard, 1971; Corbel, 1972; Vizine, 1973; Singh, 1976; Colleau, 1977).

Material and methods

A. — *The hot room*

The room used is closed and measures 4.7 × 4.2 × 2.2 m i.e. 43 m^3. Heating is performed by three electric radiators with a total capacity of 6 000 W.

Four animals may be recorded at the same time in the room. They are separated by bails and are not allowed to lie on the concrete floor. They have not access to feed and water during the thermal stress.

A direct radiative heat load is brought to the animals since they are fairly close to the radiators. Because of geometrical considerations, this radiative load is expected to differ slightly from bail to bail. However we never observed any

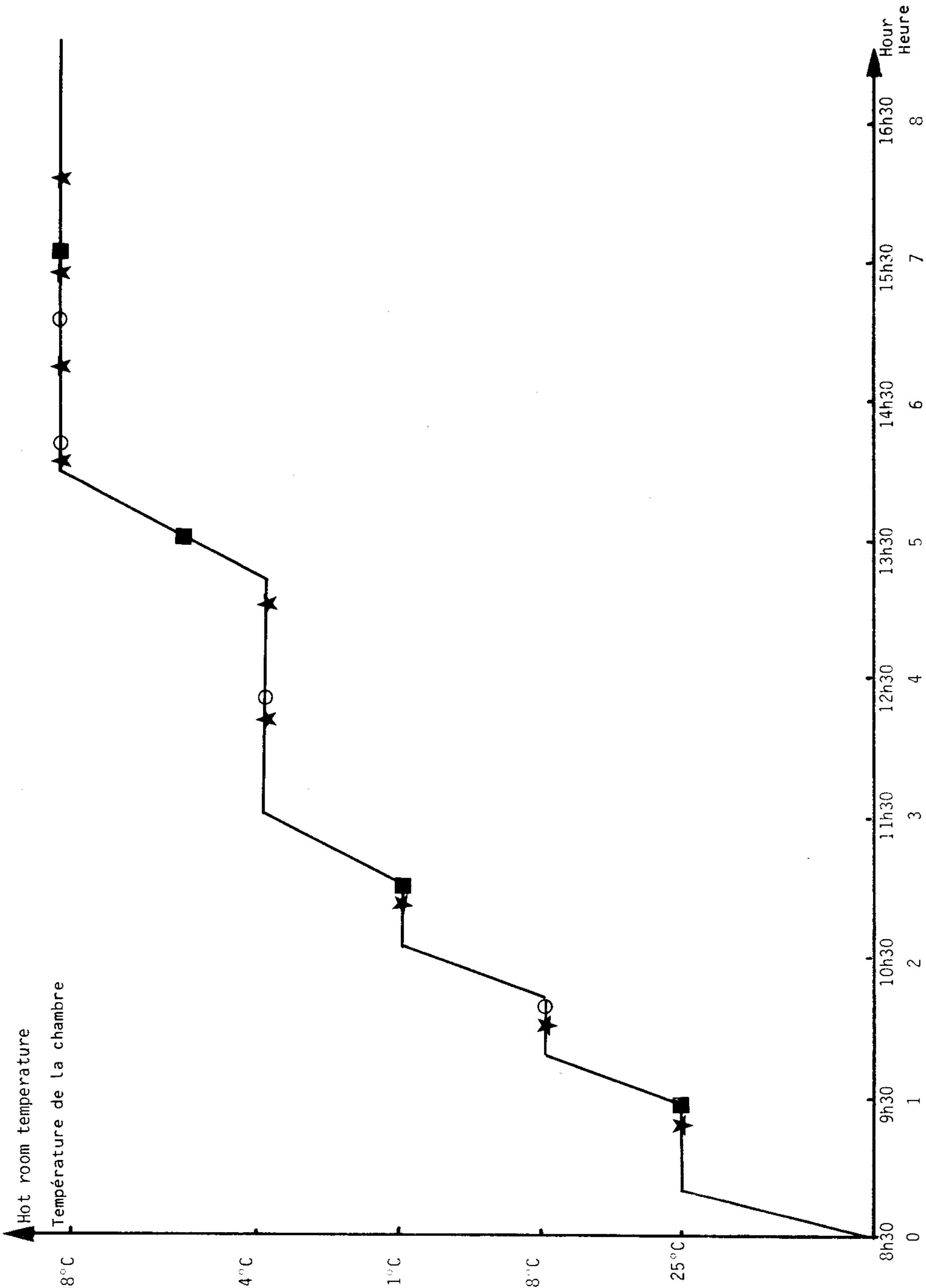

FIG. 1. — *Programmed external temperatures and records measured in the hot room according to time.*
Températures programmées et mesures effectuées dans la chambre chaude en fonction du temps.
★ Rectal temperature + respiratory rate (*Temperature rectale + rythme respiratoire*).
○ Sweating rate + skin temperature (*Taux de sudation + température de peau*).
■ Heart rate (*Rythme cardiaque*).

significant influence of the site (1 to 4) inside the hot room, on the studied variates, as reported subsequently.

The thermal programme applied during the test is transmitted to the radiators by means of the following method. It is drawn as a diagram on a paper disk, turning at a constant speed. The inner part of the diagram has been covered previously with graphit using a soft pencil. A conducting stylet is kept close against the disk and connected with a metallic serpentine pipe located in the room. The moves of the stylet are controlled by the dilatation of a gas inside the serpentine pipe. The dilatation is proportional to temperature. When the temperature of the room is higher than the programmed one, the stylet gets off the graphit area and the current in the radiators is switched off. The actual temperature in the room is recorded continuously on a second paper disk.

Relative humidity is continuously registred by means of a hair hygrograph. A device for regulating moisture, working according to the same principle and connected with a fan was used. A mobile button allows the releasing of the fan, extracting air when relative humidity is higher than a previously chosen threshold.

The ordinary ventilation in the hot room was static and obtained by means of a trap in the wall, opposite the door.

The thermal programme used is shown in figure 1. The animals are introduced into the hot room at 8.30 a.m. at room temperature (18 °C). The trial was finished at 16.30 p.m. when the programmed temperature was 38 °C. The increase is temperature is sharp till 12.00 a.m. Then a plateau was maintained at 34 °C for 2 hrs and at 38 °C for 3 hrs. This programme was intended to be applied under high humidity (70-80 p. 100) in order to enhance the thermal load.

Measurements

— Rectal temperature was recorded by a medical thermometer introduced into the rectum of the animal at constant deepness (13 cm), during 1.5 mn. The rectal temperature during normal conditions, when the animals were tied in the stall, was taken in the morning, 24 hours before the stress.

— Respiratory rate was evaluated visually from the number of beats during 30 seconds. This measurement was generally made two times consecutively.

— Heart rate was derived from the tracing of an electrocardiograph with 4 electrods, within 10 seconds. During the last two years, it was derived from the number of heart beats in the coccygean artery, during 1 minute.

— « Sweating rate » was evaluated from a small previously shaved area located on the hips, according to the method of SCHLEGER and BEAN (1971) : three pellets of dried chromatographic paper, previously moistered with a 20 p. 100 cobalt chloride solution were put on this area. For each pellet, the time to change thoroughly into pink was measured and then averaged over the three measurements. The more the animal sweated, the faster the paper turned from blue to pink.

— Skin temperature was evaluated by a thermocouple positioned in the area of the last ribs, on the side turned towards the middle of the room.

B. — *Variates*

The experiment lasted five years (1971-1975) but the previously described 4 variates were only measured the last 3 years. The first two years, only rectal temperature and respiratory rates were measured in all animals.

Because of the relatively large number of elementary measurements, all this information is reprocessed to describe three phases : beginning, middle and end of stress. The elementary measurements used for each phase are described in table 1.

TABLE I

Synthetical variates used for calculations
Variables synthétiques utilisées pour les calculs

— Above diagonal = number of elementary measurements.
Au-dessus de la diagonale : nombre de mesures élémentaires.
— Below diagonal = recording orders.
Au-dessous de la diagonale : n° des mesures.

Stress Variate (*Variable*)	**Beginning** (*Début*)	**Middle** (*Milieu*)	**End** (*Fin*)
Rectal temperature . . . . (*Température rectale*)	2 2; 3	2 5; 6	4 7; 8; 9; 10
Respiratory rate . . . . (*Rythme respiratoire*)	2 2; 3	2 5; 6	4 7; 8; 9; 10
Heart rate . . . . (*Rythme cardiaque*)	1 1	1 3	1 4
Sweating rate . . . . (*Taux de sudation*)	1 1	1 2	2 3; 4
Skin temperature . . . . (*Température de peau*)	1 1	1 2	2 3; 4

C. — *Animals*

The animals originated from the fattening cattle herd in *La Minière* near the *Research Centre* of Jouy-en-Josas. As hot room was constructed in the cattle shed, almost no transport of animals was required. Every young cattle fattened in this shed whatever the sex or the genotype entered the hot room at least once. The period of entering the hot room ranged from February to June, each year.

The animals actually come from five experiments :

— an experiment comparing three French meat breeds (*Charolais, Limousin, Maine-Anjou*) composed of purebreds and crossbreds, with a Hereford control sample;

— an experiment comparing local breeds (*Aubrac, Gasconne*) known as hardy breeds, purebred and crossbred with meat breeds such as *Charolais* and *Blond d'Aquitaine,*

— an experiment comparing a specialized dairy breed (*Holstein*), a dual-purpose breed (*Norman*), a specialized meat breed (*Charolais*) and several crosses between these breeds;

— an experiment comparing the effect of sex an type of sire (normal, double muscled) on *Charolais* × *French Friesian* crossbreds;

— a specific heat resistance experiment devoted to comparing three local French breeds (*Salers, Abondance* and *Tarentaise*) and a French dairy breed (*Montbéliarde*), all these breeds coming from mountainous regions in France.

D. — *Statistical methods*

All analyses were made according to linear models involving factors like genotype × sex combination, year and covariates.

The effect of years was introduced because of the changing of operators. The combinaison genotype × sex was introduced as a factor instead of two factors, because of the few genotypes in the females.

A possible « seasonal » effect was never tested, and that is perhaps a shortcoming, because of the already complex statistical model and mostly because of the problem of summing up efficiently the thermic « history » of each animal before the test, from the observations of temperature and hygrometry in the cow shed.

On the other hand, genotypes are in fact primary groups (small groupings) according to the following rules :

— no distinction between the reciprocal crossbreedings,

— backcrosses are considered as purebreds.

The interactions between year and genotype were never tested because of the high number of empty cells. Nor was tested the « experimental » factor because of the nearly total confusion between « experiment » and « genotype ». Despite the fact that each experiment had its own system of rearing before fattening, it appeared that the long stay in La Minière (approximately 5 months) before the test at the age of 14 months was large enough to cancel any expected experimental effect.

Within these defined linear models, the least square solutions, analysis of variance and residual correlations were obtained. Owing to a special computer programme, additional hypotheses were tested in reference to large secondary groups of genotype-sex combination (differences between and within groups). The group means were then calculated from the estimates of each member weighted according to the inverse of their sampling variance. That expression is only one approximation since the best estimation of the group means should be obtained by generalized least squares procedure (SEARLE, 1971), involving not only the sampling variance of the individual estimates of the j^{th} genotype of the i^{th} group but also their sampling covariance. The calculations were simplified because the off diagonals term of the variance-covariance matrix between the genotype effects of the same group were generally small in comparison to the diagonals terms, what is probably primarily due to the large overall number of genotypes.

Results

Since the measurements collected were not always the same, the results will be shown in two parts : the last three years (complete data) and the whole five year period for the variates collected all over these years (incomplete data). The genetic types and the number of animals involved are reported in table 2.

1. — *Analysis of the complete data*

a) *Overall range of the climatic room measurements*

Table 3 shows the averages and standard errors for five variates related to the animals and for two variates related to the hot room, at three phases : beginning, middle and end of stress.

Rectal temperature rose steadily, by 0.54 °C during the whole stress. At beginning of the stress, rectal temperature was already considerably higher than in the barn, 24 hours before : + 0.38 °C.

The rise in respiratory rate was drastic, i.e. nearly three times higher than normal. The rise in heart rate was low : from 88 to 90 pulses per min. The rise in the sweating rate was shown by a distinct drop (50 p. 100) of the turning time of the pellets. The rise in skin temperature was marked (+ 2 °C).

The high final temperature of the room (39 °C) and the regular fall in relative humidity (70 p. 100 at the end of the stress) can be noticed. Temperature and hygrometry curves obtained on different days are far from overlapping each others : the standard errors for temperature and hygrometry at a fixed hour are large, for example 0.7 °C for temperature at the end of the stress.

b) *Variation factors at a given time*

The results of the analysis of variance are given in table 4 and the estimates for the end of the stress only are shown in table 5.

Generally there exists significant differences between « genotype × sex » combinations. Further comments will be made about this factor.

It can be noticed that the « year » effect has always a large influence, probably due to the changes of operators from year to year.

Rectal temperature (R.T.) and respiratory rate (R.R.) at a given hour strongly depended on the actual temperatures and hygrometries. This is even more marked as the end of the stress is approaching. At that time, if the hot room is 1 °C warmer than planned, the rectal temperature is enhanced by 0.2 °C and the respiratory rate by 13 beats. Thus a higher hygrometry at constant temperature enhances the stress effect as expected. As far as R.T. is concerned, as increase of 8 p. 100 in relative humidity at a given temperature is equivalent to a 1 °C increase in room temperature. R.R. seems less sensitive to hygrometry, since an increase of 13 p. 100 in relative hygrometry has the same effect as a increase of 1 °C.

Skin temperature (S.T.) closely depends on external temperature : the final regression coefficient is even higher than calculated for rectal temperature. This is in agreement with what can be observed during the overall stress. Skin temperature increases more than rectal temperature (2 °C relatively to 0.5 °C).

TABLE 2

Repartition of the animals according to genotype-sex combination and type of record file

Répartition des animaux suivant le type génétique

File 1: Last three years: complete records ($n = 395$).
Fichier 1 : Trois années : résultats complets.

File 2: Five years: incomplete records ($n = 582$).
Fichier 2 : Cinq années : résultats incomplets.

Group	Mâles					Group	Females			
	Genetic type	File 1		File 2			Genetic type	File 1	File 2	
Beef (*Viande*)	CH + 3/4 CH 1/4 AU + 3/4 CH 1/4 GA	16	147	28	170	Beef (*Viande*)	3/4 BL 1/4 AU, BL, 3/4 BL 1/4 GA	0	9	25
	LI	10		10			CH + (3/4 CH 1/4 AU) 3/4 CH 1/4 GA	0	11	
	MA	14		14			CH × BL + BL × CH	0	5	
	HE	11		11						
	CH × LI + LI × CH	27		27						
	LI × MA + MA × LI	35		35						
	CH × MA + MA × CH	29		29						
	HE × LI + HE × MA	5		5						
	3/4 BL 1/4 AU + BL + 3/4 BL 1/4 GA	0		8						
	CH × BL + BL × CH	0		3						
Dairy (*Lait*)	NO	28	95	57	150	Dairy (*Lait*)	—	—	—	
	HF + FF + HF × FF + 3/4 HF 1/4 NO	51		66						
	HF × NO	9		18						

Local (*Local*)	SL . . . . AB . . . . TA	7 9 8	24	7 8 7	28	(*Local*)			
Beef × Dairy	HF × CH + CH × FF . . . CH × NO	66 0	66	66 6	72	Beef × Dairy	CH × FF	63	63
Local × Beef	BL × AU + CH × AU + CH(BL × AU) + BL(CH × AU) + BL × GA + CH × GA + CH(BL × GA) + BL(CH × GA)		0		39	Local × Beef	Idem males of the same group	0	29
Total . . .			332		459			63	123

AB = *Abondance*
AU = *Aubrac*
BL = *Blond d'Aquitaine*
CH = *Charolais*
FF = *French Friesian*

GA = *Gasconne*
HE = *Hereford*
HF = *Holstein*
LI = *Limousin*
MA = *Maine-Anjou*

MO = *Montbéliarde*
NO = *Normande*
SL = *Salers*
TA = *Tarentais*

TABLE 3

Average values (first line) and standard errors (second line) for the complete file (last three years)

Moyennes et écart-types pour le fichier complet

Variate / Time	Rectal temperature (°C) (*Température rectale*)	Respiratory rate (/mn) (*Rythme respiratoire*)	Heart rate (/mn) (*Rythme cardiaque*)	Sweating rate (sec.) (*Taux de sudation*)	Skin temperature (°C) (*Température de peau*)	Room temperature TE (°C) (*Température de la chambre*)	Room hygrometry HY (p. 100) (*Hygrométrie de la chambre*)
Cow-Shed (*Étable*)	38,70 0,21	— Age at control (months) — Average = 14,3 — Standard error = 0,8					
Beginning of stress (*Début de stress*)	39,08 0,23	49,0 13,0	87,7 8,9	504 205	36,38 0,61	27,67 1,18	80,3 6,8
Middle of stress (*Milieu de stress*)	39,26 0,35	99,0 29,6	87,2 9,2	359 152	37,49 0,49	35,72 0,78	74,9 8,0
End of stress (*Fin de stress*)	39,62 0,51	135,1 29,8	90,1 9,7	288 128	38,37 0,62	39,15 0,67	70,0 7,5

At a given time, sweating rate (S.R.) seems to depend on R.H. rather than on temperature.

Heart rate in practically independent on fluctuations when applying the programme and this is in agreement with the overall evolution of H.R. during the stress.

c) *Effect of the « genotype-sex » factor*

It is a combined factor that has no specific meaning. In fact, it groups 16 classes of males and one of females (*CH* × *FF*).

— Comparison between males and females.

Application of contrast analysis shows that females *CH* × *FF* are more resistant than males *CH* × *FF* to heat stress. Their R.T., R.R., S.R. and H.R. are lower.

— Overall comparison between males.

the differences observed are particulary large and significant for heart rate and sweating rate. The differences are also significant for rectal temperature. The results are however fluctuating for respiratory rate and skin temperature.

These males can be divided into four groups according to animal husbandry criteria :

— The « beef » group :

Charolais, Limousin, Maine-Anjou, Hereford,
Charolais × *Limousin* and reciprocals, *Charolais* × *Maine-Anjou* and reciprocals,
Limousin × *Maine-Anjou* and reciprocals,
Hereford × *Limousin, Hereford* × *Maine-Anjou.*

— The « dairy » group :

Holstein, Friesian, Holstein × *Friesian,* 3/4 *Holstein* 1/4 *Norman,*
Holstein × *Norman, Norman, Montbéliard.*
— The « beef × dairy » group
Holstein × *Charolais, Charolais* × *Friesian.*
— The « local » group
Abondance, Salers, Tarentais.

In these conditions, the between-male variation observed was also divided into between and within-group variation. The results of table 4 show that the variability observed at the end of the stress is located primarily at the group level, the within group variability being non significant. S.R. is an exception since the contrary is observed : non significant between-group variation and significant within-group variations. The details on the individual estimates for each genotype are shown in table 5.

Figure 2 to 6 allow to locate the between-group differences. When comparing the « dairy » and « beef » group, it appears that the differences are small (except for H.R. and S.T.) but all in the same direction. Beef animals seem to show a less favourable heat balance, although appealing to thermolytic mechanisms (stronger respiration and sweating). The heart rates are definitely different : all over the test, the number of pulses per minute was approximately 8 points higher for beef animals. At the beginning of the stress, a much lower skin temperature was observed in the « dairy » animals. The dairy × beef animals, when compared to the former groups are generally located at an intermediate level.

TABLE 4

Analysis of variance of the heat resistance variates for the complete file (values of F)
Analyse de variance des variables de thermotolérance (valeurs de F)

	Rectal temperature (*Température rectale*)			Respiratory rate (*Rythme respiratoire*)			Heart rate (*Rythme cardiaque*)			Sweating rate (*Taux de sudation*)			Skin temperature (*Température de peau*)		
	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E
Genetic type-sex factor	2,75 ***	1,66 *	2,48 ***	1,45	3,38 ***	6,13 ***	5,80 ***	6,95 ***	5,41 ***	5,13 ***	3,84 *	2,73 ***	3,25 ***	3,61 ***	1,79 *
Year factor (*Facteur année*)	5,86 **	23,34 ***	67,51 ***	39,54 ***	83,10 ***	142,89 ***	6,15 **	4,73 **	5,45 **	37,48 **	14,04 **	33,78 ***	41,03 ***	13,83 ***	8,50 **
Covariates (*Covariables*) TE	10,01 **	7,57 **	52,04 ***	12,78 ***	46,64 ***	61,02 ***	0,85	0,00	2,30	0,14	0,08	0,21	1,95	55,77 ***	58,39 ***
HY	7,42 **	8,06 **	28,89 ***	22,83 ***	19,47 ***	13,23 ***	0,18	1,20	2,81	1,00	4,81 *	3,88 *	9,01 **	21,44 ***	5,48 **
age	4,52 *	12,92 ***	2,49	8,54 **	4,41 *	0,57	3,65 *	2,72	2,20	1,15	1,73	3,96 *	1,32	0,57	0,14
Contrasts :															
— Males vs females	0,36	3,57	9,74 **	2,26	22,50 ***	33,90 ***	10,86 ***	0,15	4,95 *	3,37	4,30	2,38	2,85	6,69 **	8,14 **
— Between males (*Entre mâles*)	2,90 ***	1,53	1,56	1,39	1,41	2,11 **	4,89 ***	6,79 ***	4,67 ***	5,46 ***	3,95 ***	2,85 ***	3,00 ***	2,66 ***	0,82
— Between groups of males (*Entre groupes de mâles*)	5,66 ***	4,64 **	3,28 *	0,91	1,83	4,59 **	13,99 ***	26,19 ***	16,79 ***	3,68 *	1,69	1,25	4,38 **	5,05 **	1,02
— Within group of males (*Intra groupe de mâles*)	2,08 *	0,77	1,19	1,51	1,30	1,53	2,54 **	1,84 *	1,60	5,69 ***	4,48 ***	3,25 ***	2,65 **	2,06 *	0,75
Residual standard error	0,21	0,28	0,36	10,03	20,0	19,4	7,8	7,8	8,4	158	128	107	0,52	0,39	0,55
R^2 (p. 100) of the model.	16,2	38,8	53,4	40,9	56,9	59,7	26,7	31,3	28,9	43,9	32,7	28,7	31,1	37,5	23,9

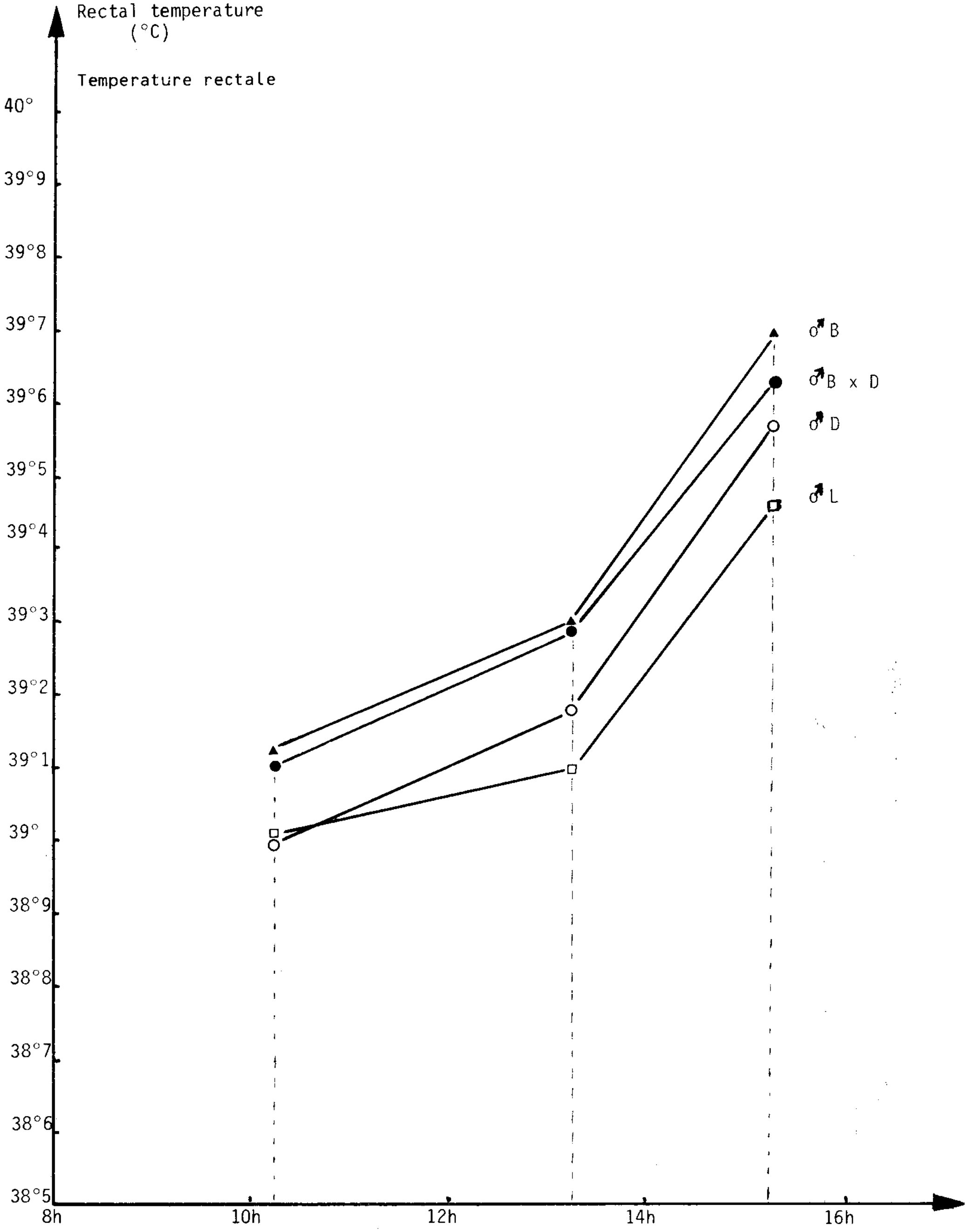

FIG. 2. — *Variation of group means for rectal temperature (years 3, 4, 5).*
Moyennes de groupe pour la température rectale (années 3, 4, 5).

▲———▲ ♂ Beef (*Viande*)
●———● ♂ Beef × Dairy (*Viande × lait*)
○———○ ♂ Dairy (*Lait*)
□———□ ♂ Local (*Local*)

TA

Estimates of least square
Estimées de moindres carrés pou

		Estimates	Number	Rectal temperature (*Température rectale*)			Respiratory (*Rythme respira*	
				B	M	E	B	M
		Least square means	397	39,10	39,24	39,61	49,39	99,84
Genotype-sex effect	♂ Beef	CH	16	0,00	— 0,04	— 0,02	— 1,29	— 3,64
		LI	10	0,06	0,10	0,15	— 2,25	12,41
		MA	14	0,07	0,08	0,21	2,18	— 0,49
		HE	11	0,01	— 0,04	— 0,11	1,58	11,35
		CH × LI + LI × CH .	28	0,04	0,05	0,02	— 0,90	7,08
		LI × MA + MA × LI .	35	— 0,01	0,06	0,05	0,30	—1,25
		CH × MA + MA × CH	29	0,02	0,10	0,17	2,57	3,96
		HE × LI + LI × HE .	5	0,04	0,23	0,31	3,16	14,56
	♂ Dairy	NO	28	— 0,13	— 0,02	— 0,02	— 2,07	0,16
		HF + FF + HF × FF + 3/4 HF 1/4 NO. . .	51	— 0,17	— 0,11	— 0,06	— 1,10	1,20
		HF × NO	9	— 0,02	— 0,03	— 0,04	— 2,72	— 13,86
		MO	9	0,13	0,00	— 0,08	— 1,28	2,24
	♂ Local	AB	8	— 0,17	— 0,19	— 0,24	— 3,75	— 10,72
		SL	8	— 0,02	— 0,18	— 0,25	12,44	— 4,14
		TA	7	0,12	— 0,06	0,05	— 5,27	— 3,25
	Beef × Dairy	HF × CH + CH × FF (♂)	66	0,01	0,08	0,04	0,56	0,60
		CH × FF (♀)	63	0,03	— 0,01	— 0,17	— 2,18	— 16,22
Year effects		Year 3	130	0,06	— 0,07	— 0,25	— 7,85	— 19,32
		Year 4	151	— 0,04	0,17	0,32	2,56	15,87
		Year 5	116	— 0,02	— 0,10	0,07	5,28	3,45
Covariates		Partial regression coefficients on:						
		Room TE (°C)		— 0,03	0,06	0,21	1,79	10,68
		Room HY (p. 100)		— 0,01	0,01	0,03	0,53	0,89
		Age at control (months) . .		0,04	0,09	0,05	2,63	3,67

LE 5

or the hot room variates
es variables de thermotolérance

ate *oire*)	Heart rate (*Rythme cardiaque*)			Sweating rate (*Taux de sudation*)			Skin temperature (*Température de peau*)		
E	B	M	E	B	M	E	B	M	E
137,08	88,04	87,85	91,16	513,27	357,30	286,78	36,43	37,55	38,39
— 0,03	— 0,55	1,72	2,03	9,60	— 7,27	— 22,81	0,09	0,12	— 0,02
17,36	11,32	10,19	7,42	63,08	90,14	82,55	0,28	0,34	0,10
0,68	1,94	3,46	3,03	26,63	40,97	31,32	0,22	0,11	0,15
9,03	— 1,89	— 1,90	— 0,89	2,41	42,93	48,75	— 0,21	— 0,30	— 0,08
9,92	1,97	3,47	2,30	37,01	— 44,86	— 32,90	0,04	0,05	0,01
— 1,06	4,30	3,86	2,12	24,85	1,90	11,74	0,00	0,10	— 0,02
1,36	3,55	6,39	4,98	4,28	7,41	14,32	0,17	0,05	0,18
10,63	7,28	5,87	9,06	85,48	— 24,66	— 42,53	0,08	0,24	0,21
— 2,09	— 6,08	— 6,91	— 7,49	221,03	135,96	76,03	— 0,20	— 0,03	— 0,09
— 1,55	— 2,62	— 4,25	— 4,36	— 7,50	0,18	10,05	— 0,18	— 0,16	0,10
— 10,14	— 7,16	— 2,63	— 6,07	— 22,99	— 33,11	— 39,93	— 0,11	— 0,14	0,29
4,04	— 1,26	— 0,87	0,93	— 168,38	— 118,97	— 63,51	0,14	— 0,15	— 0,06
— 10,98	— 6,03	— 4,60	— 2,02	117,09	37,84	49,88	— 0,66	— 0,16	— 0,22
— 16,94	0,65	— 3,58	— 5,19	— 13,96	6,58	— 9,09	0,52	0,33	— 0,17
7,81	— 2,06	— 4,13	1,04	— 60,24	— 140,25	— 118,71	0,38	0,07	— 0,02
— 6,36	0,59	— 2,78	— 1,74	— 62,33	— 20,94	— 12,63	— 0,06	— 0,08	— 0,04
— 26,91	— 3,97	— 3,31	— 5,15	— 11,06	26,17	17,46	— 0,22	— 0,26	— 0,33
— 18,95	1,68	1,01	0,78	— 43,11	— 5,28	17,64	0,40	0,16	0,17
25,16	0,91	1,81	2,07	— 94,82	— 60,71	— 70,08	— 0,08	— 0,13	0,13
— 6,21	— 2,58	— 2,82	— 2,85	137,93	65,99	52,45	0,31	— 0,03	— 0,31
12,54	— 0,35	— 0,02	1,06	2,9	— 2,8	4,0	0,03	0,23	0,35
1,02	0,04	0,09	0,20	— 1,7	— 2,8	— 3,0	0,02	0,02	— 0,02
— 1,30	— 1,31	— 1,13	— 1,10	14,8	14,7	18,8	— 0,05	— 0,03	— 0,02

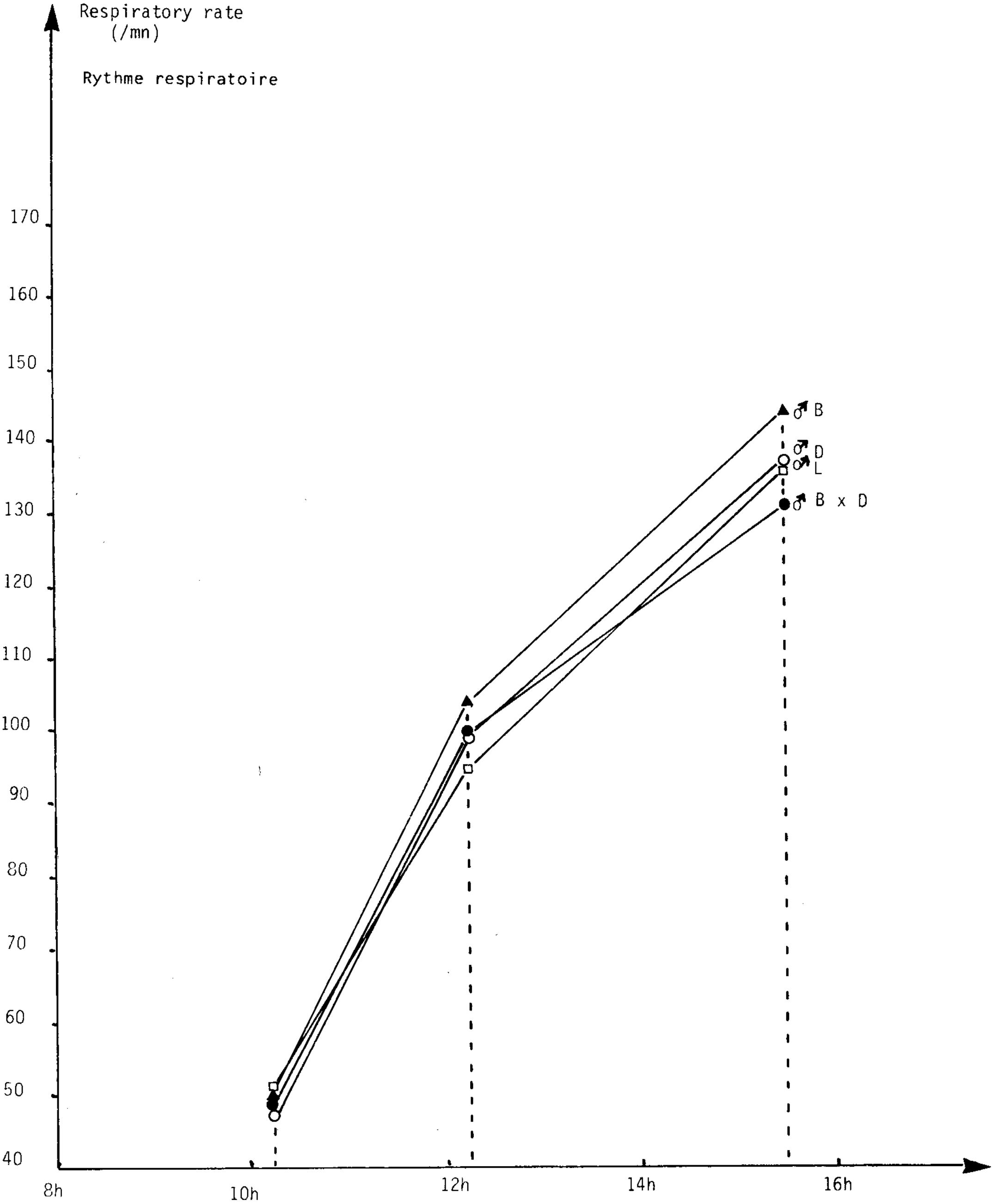

FIG. 3. — *Variation of group means for respiratory rate (years 3, 4, 5).*
Moyennes de groupe pour le rythme respiratoire (années 3, 4, 5).

▲———▲ ♂ Beef (*Viande*)
●———● ♂ Beef × Dairy (*Viande × lait*)
○———○ ♂ Dairy (*Lait*)
□———□ ♂ Local (*Local*)

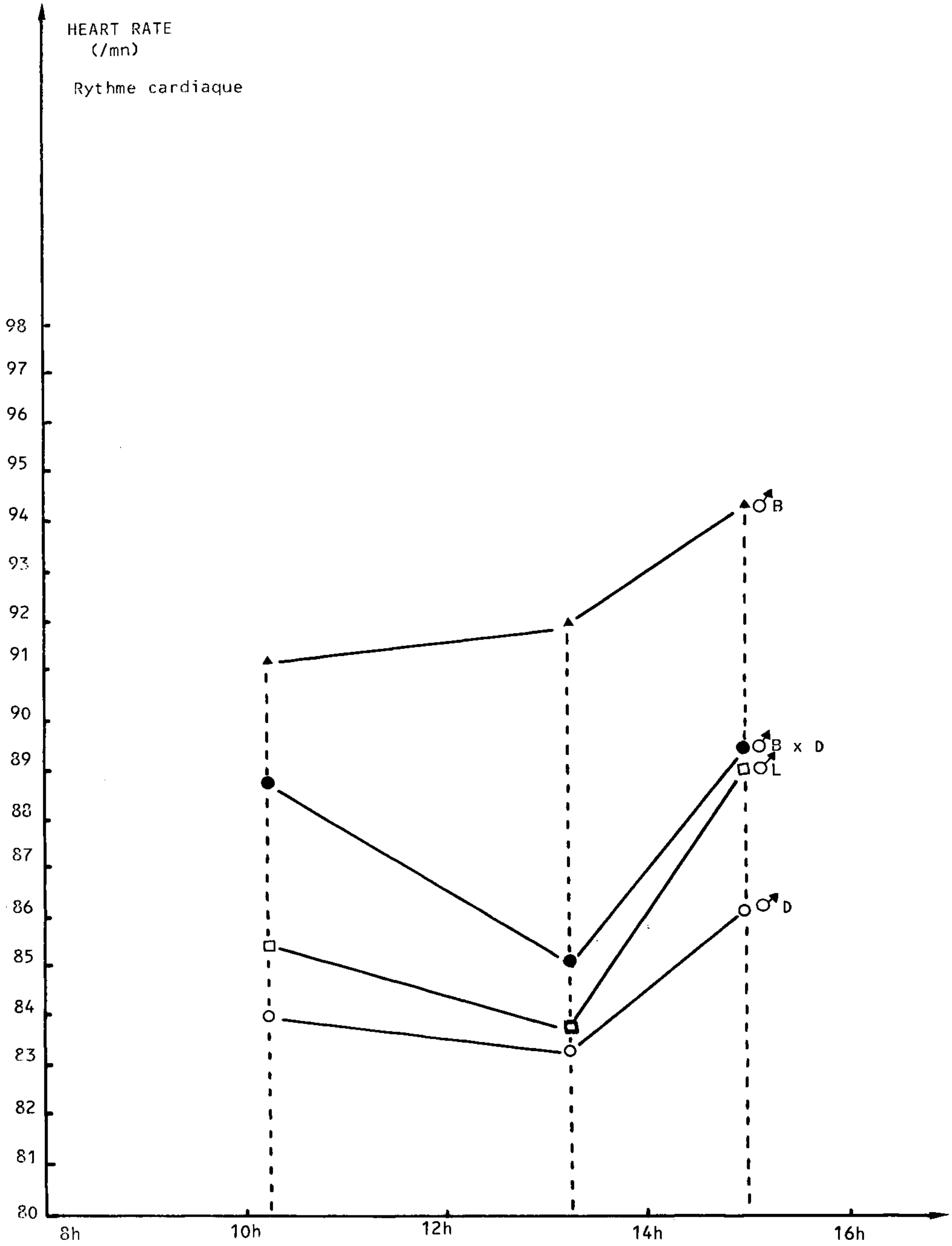

FIG. 4. — *Variation of group means for heart rate (years 3, 4, 5).*
Moyennes de groupe pour le rythme cardiaque (années 3, 4, 5).

▲———▲ ♂ Beef (*Viande*)
●———● ♂ Beef × Dairy (*Viande × lait*)
○———○ ♂ Dairy (*Lait*)
□———□ ♂ Local (*Local*)

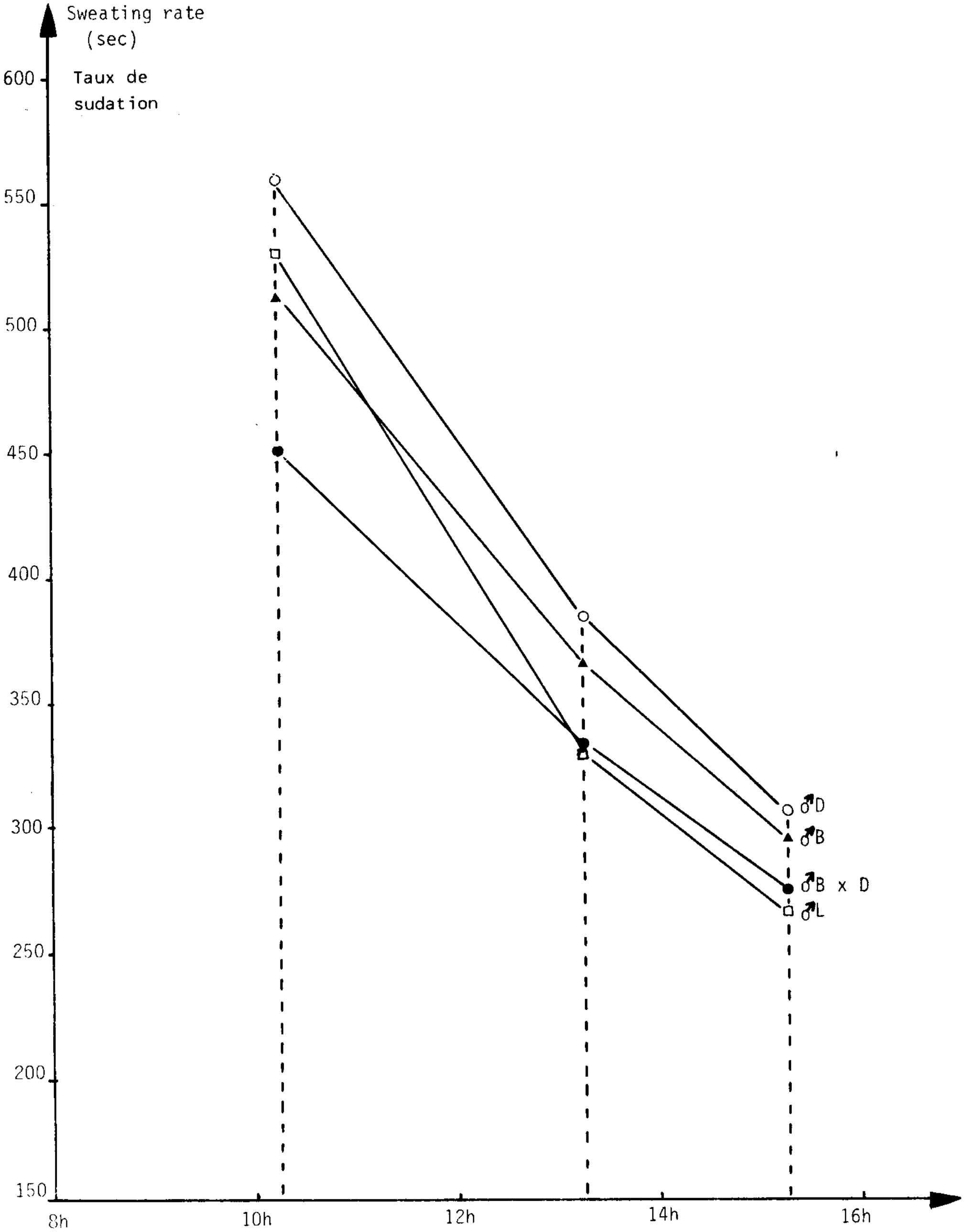

FIG. 5. — *Variation of group means for sweating rate (years 3, 4, 5).*
Moyennes de groupe pour le taux de sudation (années 3, 4, 5).

▲———▲ ♂ Beef (*Viande*)
●———● ♂ Beef × Dairy (*Viande × lait*)
○———○ ♂ Dairy (*Lait*)
□———□ ♂ Local (*Local*)

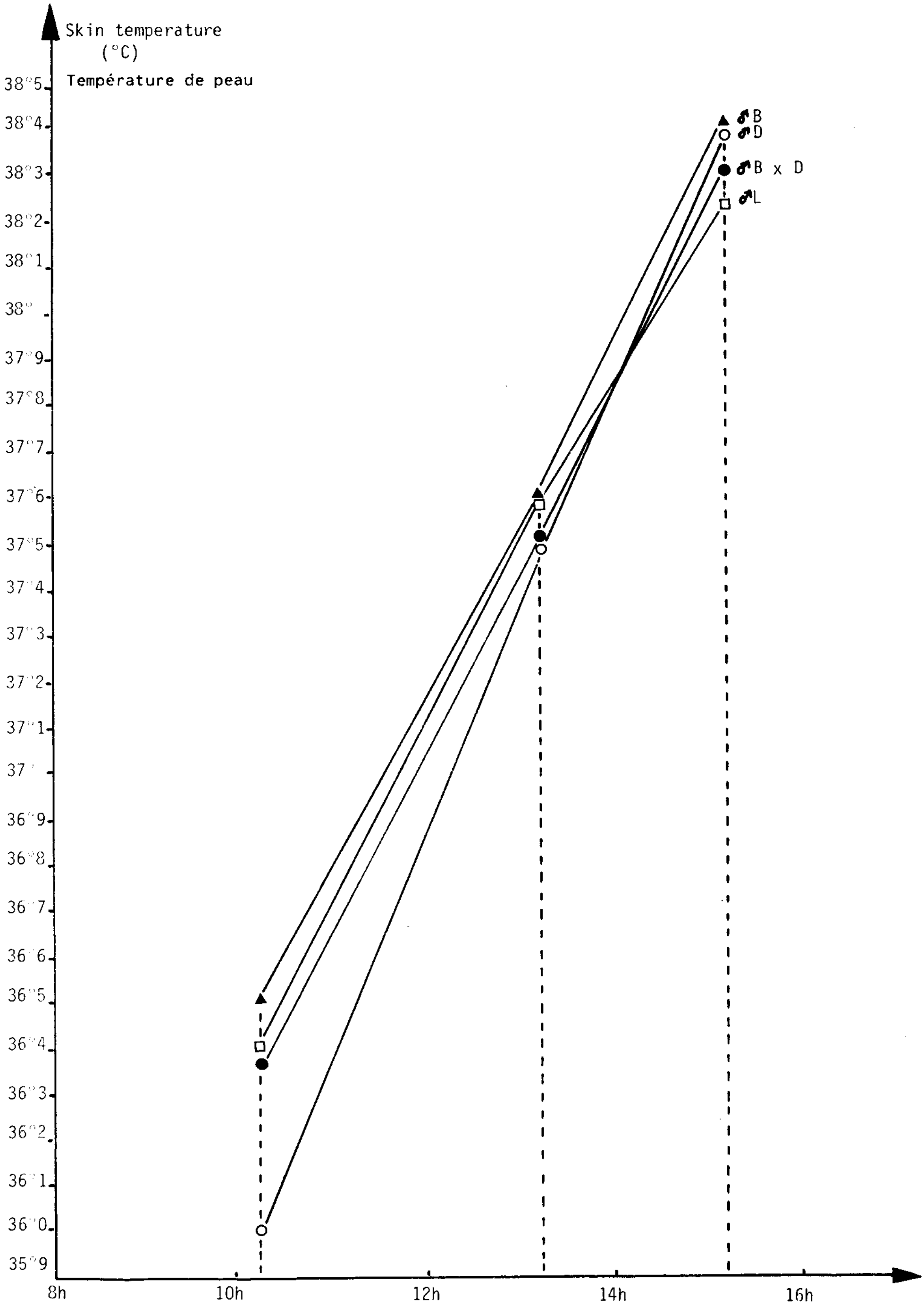

FIG. 6. — *Variation of group means for skin temperature (years 3, 4, 5).*
Moyennes de groupe pour la température de peau (années 3, 4, 5).

▲———▲ ♂ Beef (*Viande*)
●———● ♂ Beef × Dairy (*Viande × lait*)
○———○ ♂ Dairy (*Lait*)
□———□ ♂ Local (*Local*)

TABLE 6

Repeatability coefficients after correction for temperature and hygrometry variations in the hot room
Coefficients de répétabilité après correction pour les variations de température et d'hygrométrie dans la chambre chaude

Variate	Rn of average measurements (n = 1 to 4) (*Répétabilité des mesures synthétiques*)	r of basic measurements (*Répétabilité des mesures élémentaires*)
Rectal temperature : (*Temperature rectale*)		
Cow-shed (*Étable*)	0,37	0,37
Beginning of stress (*Début de stress*)	0,58 (0,56)	0,41
Middle of stress (*Milieu de stress*)	0,45 (0,48)	0,29
End of stress (*Fin de stress*)	0,37 (0,39)	0,13
Respiratory rate: (*Rythme respiratoire*)		
Beginning of stress (*Début de stress*)	0,35 (0,33)	0,21
Middle of stress (*Milieu de stress*)	0,47 (0,44)	0,31
End of stress (*Fin de stress*)	0,66 (0,48)	0,33
Sweating rate: (*Taux de sudation*)		
Beginning of stress (*Début de stress*)	0,36 (0,27)	0,36
Middle of stress (*Milieu de stress*)	0,41 (0,45)	0,41
End of stress (*Fin de stress*)	0,53 (0,55)	0,36

( ) Values before correction (*Valeurs avant correction*).

The local group exhibited the best heat resistance measured by R.T. However, as regards the other variates, it does not differ very much from the « dairy » group except for sweating rate.

d) *Repeatabilities*

This kind of measurement was not made during the first four years. They were carried out in 1975 in animals of experiment 5, (38 animals recorded two times at 1 month interval). But that year, incomplete data for H.R. and S.T. were obtained. So the repeatability was not calculated for these criteria.

Table 6 shows the within breed, between-months, within-year repeatability values, before and after correcting for temperature and relative hygrometry in the room. This correction does not seem to affect very much the repeatability values. They are fairly good and range between 0.35 and 0.66 according to time and trait. At the end of the stress, the R.R. seems to be the most repeatable (0.66), followed by the sweating rate (0.53) and the rectal temperature (0.37). But it must be kept in mind that all these values are derived from means of elementary measurements. The repeatability r for one measurement can be extracted from the repeatability Rn for a mean of n measurements :

$$r = \frac{\mathrm{R}n}{n - (n - 1)\mathrm{R}n}$$

According to this, r is almost constant for RR and S.R. whereas it decreases for R.T. as stress rises (from 0.41 to 0.13).

e) *Correlations between variates obtained in the hot room*

Within genotypes, the variates R.T., R.R., H.R., S.T. are positively correlated (0.2-0.4) especially the first two ones (table 7). It can be therefore assumed that the unfitness to stress is described by an overall increase of these variates. The sweating rate seems to be a specific variate independent of the others. Considering that it is somewhat subjective, it might be associated with a bad repeatability. However, the results of table 8 show that the S.R. is as repeatable on the same day as R.T. or R.R. This lack of correlation with the other variates describing the heat stress is surprizing since the impact of thermolysis by evaporation is recognized to be very important at high environmental temperatures.

The between genotype analysis does not differ very much from the forementionned results. Once more, S.R. does not seem to be seriously bound to any other variate. The positive correlations between all these other variates are found again, at a somewhat higher level than for the within-genotypic analyses (r = 0.4 - 0.8).

f) *Correlations between the final rectal temperature and other variates not measured in the hot room*

In order to understand better the origin of the variations between and within genotypes, some parameters were investigated : live weight before test, some body measurements before slaughter, feed intake before test, consumption drop after test and carcass composition. The general means for these variates are shown in table 9 as well as the weighted group effects (their sum is not necessarily zero), the values of the F tests for differences between and within group.

As expected, at the moment of the test when the animals were approximately 14 months old, the males of the « beef » group were the heaviest followed by the crossbred « Beef × Dairy » males, the « Dairy » males, the « local » males and finally the « Beef × Dairy » females. The males of the « Beef » group were the widest but not the tallest. The differences in body conformation were obvious from these

TABLE 7

Correlation coefficients for thermoresistance variates after correction for hot room conditions and age
Coefficients de corrélation entre les variables de thermotolérance après correction pour les conditions de la chambre et l'âge

— Above diagonal = Between genotypes.
Au-dessus de la diagonale : entre génotypes.
— Below diagonal = Within genotype.
Au-dessous de la diagonale : intragénotype.

	Rectal temperature	Respiratory rate	Heart rate	Sweating rate	Skin temperature
Rectal temperature (*Température rectale*)	B M E	0,35 0,54 0,67	0,57 0,80 0,83	— 0,36 — 0,05 0,01	0,58 0,61 0,69
Respiratory rate (*Rythme respiratoire*)	0,35 0,37 0,35	B M E	0,57 0,47 0,68	— 0,28 — 0,02 — 0,11	0,70 0,58 0,62
Heart rate (*Rythme cardiaque*)	0,32 0,23 0,21	0,29 0,21 0,27	B M E	— 0,27 — 0,17 — 0,23	0,67 0,62 0,52
Sweating rate (*Taux de sudation*)	— 0,07 0,04 0,08	0,01 0,02 0,09	— 0,11 — 0,07 0,01	B M E	— 0,25 0,02 — 0,13
Skin temperature (*Température de peau*)	0,21 0,36 0,16	0,17 0,30 0,25	0,07 0,27 0,16	— 0,02 0,04 0,27	B M E

TABLE 8

Values of the within genotype correlations between the same variates at different times of the stress (after correction for the hot room conditions)
Valeurs des coefficients de corrélation intragénotype entre les mêmes variables à différents moments du stress

	Beginning-Middle of stress (*Début-Milieu de stress*)	Middle-End of stress (*Milieu-Fin de stress*)	Beginning-End of stress (*Début-Fin de stress*)
Rectal temperature (*Température rectale*)	0,69	0,86	0,56
Respiratory rate (*Rythme respiratoire*)	0,44	0,72	0,32
Heart rate (*Rythme cardiaque*)	0,59	0,65	0,54
Sweating rate (*Taux de sudation*)	0,71	0,82	0,58
Skin temperature (*Température de peau*)	0,45	0,37	0,08

TABLE 9

Least square means and tests of significance between groups for variates not in hot room
Moyennes de moindres carrés et test de signification entre groupes pour variables hors chambre chaude

Variate / Group	Live weight before test (kg) (*Poids vif avant test*)	Height at withers before slaughter (cm) (*Hauteur au garrot avant abattage*)	Width at schoulders before slaughter (cm) (*Largeur épaules avant abattage*)	Age at slaughter (months) (*Age à l'abattage*)	Feed intake before test (1) (kg /day) (*Consommation avant test*)	Feed intake decrease after test (2) (kg /day) (*Chute de consommation après test*)	p. 100 fat (3) (*p. 100 gras*)	p. 100 muscle (3) (*p. 100 muscle*)
Least square mean	486,70	123,66	56,56	16,01	11,48	1,42	20,22	63,92
Males :								
Beef	19,9	0,00	4,50	0,26	0,00	— 0,05	— 2,96	2,63
Beef × Dairy	2,7	— 1,22	0,96	— 0,12	— 0,24	— 0,40	— 2,65	2,42
Dairy	— 3,2	3,52	— 4,89	— 0,35	0,13	0,06	3,00	— 3,60
Local	— 7,0	1,43	— 4,83	— 0,11	0,29	0,54	0,18	0,12
Females :								
Beef × Dairy	— 68,6	— 5,90	— 5,72	— 0,36	— 1,22	— 0,01	6,74	— 5,60
Values of F between groups								
Between groups of ♂. . . .	29,21***	15,28***	77,89***	4,22**	5,41**	1,53	44,20***	32,12***
Within group	9,62***	8,93***	75,64***	4,45**	2,67*	1,94	26,75***	23,50***
	7,80***	10,12***	5,08***	9,30	5,69***	1,59	7,50***	7,00***

(1) During the week before test (*Pendant la semaine avant le test*).
(2) Feed intake before test — Average feed intake for the first 3 days after test (*Consommation avant test* — *Consommation après test* (3 *jours*)).
(3) 11th rib (11e côte).

figures. Compacity was maximum for « Beef » and « Beef × Dairy » animals and minimum for « Dairy » and « Local » animals. The body measurements were collected just before slaughter, they were somewhat biased by the differences in age at slaughter, which were significant between groups because of the differences in fattening procedures. However the maximum difference ranged around 0.5 months. Measurements of the feed intake show that despite their heavier weight, the « Beef » or « Beef × Dairy » males ate less than the other males, the lowest consumption being of course found in the females. As the animals generally reduced their consumption after the test, this drop was calculated and estimated as approximately 12 p. 100 of the initial consumption, when measures were made three days after the test. The differences between groups in this respect seemed to be somewhat large but they were not significant. The figures concerning carcass composition were classical, except perhaps for the « Local » males, which seemed to be intermediate between the « Beef » and the « Dairy » group.

Before going further, it must be stressed that the so-called « groups » are obviously not homogenous for these « zootechnical » variates, contrary to the « hot room » variates, despite the fact that the groups were precisely based on animal husbandry considerations. This is the reason why we did not try to correlate the differences between groups for resistance to heat to any other between-group differences but rather to calculate the correlation directly at the genotype level. The results of the corresponding calculations are shown in table 10, together with the calculations at the within-genotype level. The highest correlation coefficients between genotypes and the final rectal temperature were obtained with weight and body composition criteria. From a statistical point of view, the less resistant the genotypes are to heat, the bigger, the compacter, the leaner they are. The correlations with compacity may be evaluated from the correlation between final rectal temperature and height at withers at a given weight (— 0.50) or between rectal-temperature and width at schoulders on the same basis (0.71). The positive statistical association between rectal temperature and weight or compacity is found again at the within genotypic level, though considerally lower. From an energetical point of view, the concept of metabolic weight is more pertinent than that of weight. However, that transformation is not expected to have affected significantly the result, since within the range of the observed weights, the metabolic weight is a practically linear function of the actual weight. As far as body composition is concerned, the between and within genotypic results do not agree, as no relationship between rectal temperature and body composition was found within genotype. Good agreement at the two levels was obtained for the association between rectal temperature and consumption : it seems to be clear that the more the animals eat, the less resistant they are to heat. The association is moderate ($r = 0.30$), but it is to be mentioned that the within genotype variation coefficient for the before test consumption is important (12 p. 100).

2. — *Analysis of the incomplete data (five years period)*

The only variates regularly measured during these years were rectal temperature and respiratory rate. Table 2 shows that working over a period of five years instead of three introduces supplementary groups (males « beef × local », females « beef », females « local » × « beef ») and supplementary genotypes in the groups already present such as Blonde d'Aquitaine for the group « male beef » or such as Charolais × Norman crosses for the group « male beef × dairy ».

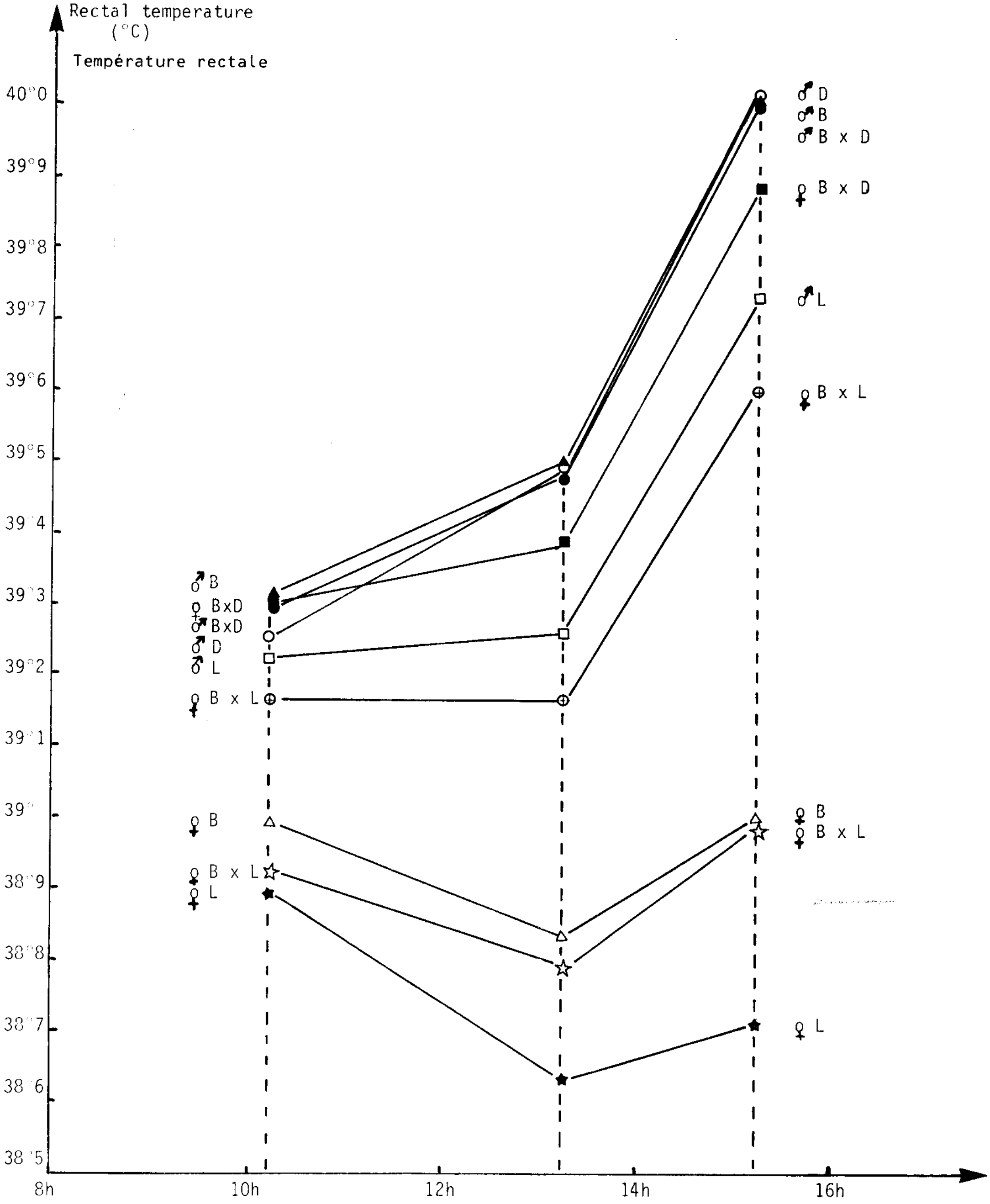

FIG. 7. — *Variation of group means for rectal temperature (years 1 to 5).*
Moyennes de groupe pour la température rectale (années 1 à 5).

▲ ♂ Beef (*Viande*)
● ♂ Beef × Dairy (*Viande × lait*)
○ ♂ Dairy (*Lait*)
□ ♂ Local (*Local*)
⊕ ♂ Beef × Local (*Viande × local*)
△ ♀ Beef (*Viande*)
■ ♀ Beef × Dairy (*Viande × lait*)
♀ Beef × Local (*Viande × local*)
★ ♀ Local (*Local*)

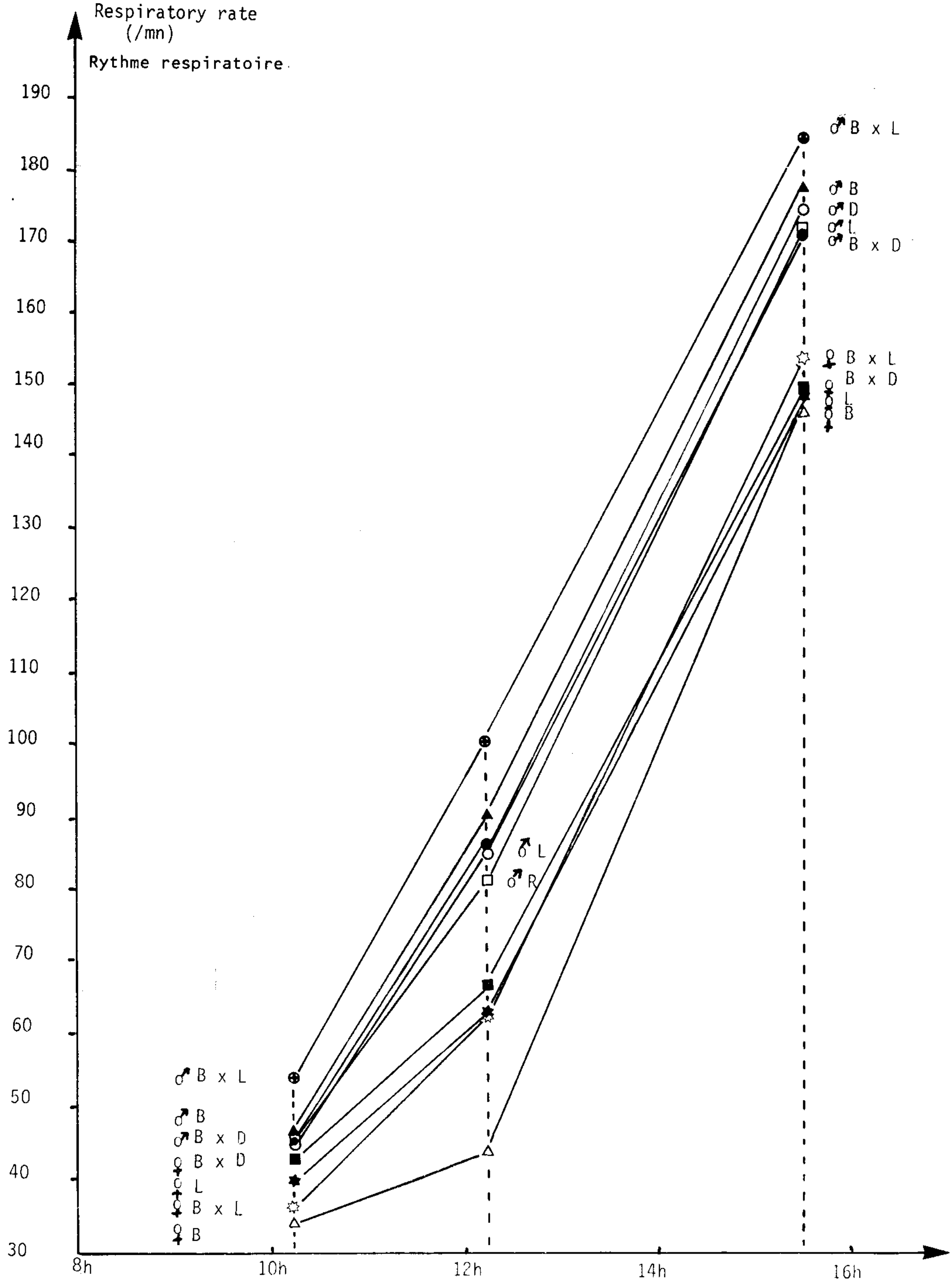

FIG. 8. — *Variation of group means for respiratory rate (years 1 to 5).*
Moyennes de groupe pour le rythme respiratoire (années 1 à 5).

▲ ♂ Beef (*Viande*)
● ♂ Beef × Dairy (*Viande × lait*)
○ ♂ Dairy (*Lait*)
□ ♂ Local (*Local*)
○ ♂ Beef × Local (*Viande × local*)

△ ♀ Beef (*Viande*)
■ ♀ Beef × Dairy (*Viande × lait*)
♀ Beef × Local (*Viande × local*)
★ ♀ Local (*Local*)

The results of the analysis of variance are shown in table 11. Although the data were not adjusted for variations in external temperature and relative hygrometry, the significance results of the previously analyzed factors do not vary very much. Besides it has to be noticed that there was never any significant influence of the site (1 to 4) inside the hot room.

Analysis of the incidence of genotype-sex factor shows again that there are significant differences between males and females, between males from different genotypes and between females from different genotypes. Between groups of males (« dairy », « beef × dairy », « beef × local », « local ») differences are mostly significant. Within the group of males, differences are significant for rectal temperature. This results differs from that obtained during the last three years, but is has to be recalled that the data are not corrected for temperature and hygrometry variations on the hot room. Between groups of females, differences are significantly for rectal temperature. The differences within group for the females have a fluctuating significance level.

In figure 7, comparison between groups of males for rectal temperature shows that the groups « dairy », « beef », « dairy × beef » differ little. The « local » and « beef × local » groups differ clearly with a lower rectal temperature. Figure 8 confirms that the differences between « dairy », « beef », « beef × dairy » groups for respiratory rate are not very large.

As to the females, the between-group differences are very large for rectal temperatures. A very high difference can be noticed between the « beef × dairy » and « beef » females while that is not true for the corresponding males. This proceeds probably from the fact that 56 p. 100 of these « beef » females have at least 50 p. 100 Blond d'Aquitaine blood, since the results for pure Blond d'Aquitaine animals are better. The « local » females have a lower rectal temperature than that of the « beef » females, what agrees with the results obtained on males.

Discussion

A. — *Interpretation of the variates*

In order to evaluate the possible correlation between measurements taken in a hot room and the same measurements in current hot conditions, it would be useful to gather some information about the physiological mechanisms involved in the overall control of the variates as well as about their variability.

It is well known that at high ambient temperatures, the processes of heat loss by conduction and convection are somewhat reduced, because of a decrease in the gradient skin to air temperature when the air temperature increases (KIBLER and BRODY, 1952; Mc LEAN, 1963; MONTEITH, 1973; BERBIGIER, 1978). As a consequence, only a small direct effect of variates related to conduction and convection processes can be expected in relation to the thermal equilibrium measured by rectal temperature. In our opinion, these direct effects can safely be measured from the variability occurring within genotypes as they can be confounded with other effects reasoning on a between-genotypic level. Conduction processes as predicted by the percentage of highly insulating tissues (fat) in the carcass are obviously unrelated to rectal temperature (table 10) but one estimator of the

TABLE 10

Values of correlation coefficients between and within genotype for final rectal temperature and other variates (17 genotypes - 3 years)

— Above diagonal = Between genotypes.
— Below diagonal = Within genotype.

Valeur des coefficients de corrélation entre et intra génotype pour la température rectale finale et les autres variables (17 génotypes - 3 années)

— *Au-dessus de la diagonale : entre génotypes.*
— *Au-dessous de la diagonale : entre génotype.*

Variate	1	2	3	4	5	6	7	8
1 Final rectal temperature . . . . (*Température rectale finale*)		0,63	0,14	0,83	0,33	— 0,21	— 0,62	0,58
2 Live weight before test . . . . (*Poids vif avant test*)	0,19		0,68	0,78	0,74	— 0,04	— 0,65	0,54
3 Height at withers . . . . (*Hauteur au garrot*)	— 0,03	0,46		0,15	0,73	— 0,30	— 0,20	0,09
4 Width at schoulders . . . . . (*Largeur aux épaules*)	0,25	0,39	0,23		0,33	0,27	— 0,77	0,72
5 Feed intake before test. . . . . (*Consommation avant test*)	0,28	0,51	0,15	0,37		— 0,30	— 0,21	0,12
6 Feed intake decrease after test (*Chute de consommation après test*)	0,21	— 0,15	0,06	— 0,06	— 0,32		— 0,06	0,04
7 p. 100 fat. . . . . (*p. 100 gras*)	0,00	0,14	0,15	0,08	0,24	— 0,08		— 0,98
8 p. 100 muscle . . . . (*p. 100 muscle*)	0,02	— 0,07	— 0,15	— 0,06	— 0,13	0,07	— 0,92	

subcutaneous fat would have been by for more pertinent (BIANCA, 1965). The convection processes may be accelerated by a high $\frac{\text{surface}}{\text{weight}}$ ratio, estimated for example by the $\frac{\text{height at withers}}{\text{weight}}$ ratio if it is assumed that surfaces primarily depend on the size of skeleton at least at a within-breed level.

Table 10 shows an estimation of — 0.13 for the correlation coefficient between this ratio and final rectal temperature. Thus, our results seem to confirm a small influence of conduction and convection processes on rectal temperature.

Contrary to sensible heat losses, latent heat losses are expected to increase at high environmental temperatures, especially by sweating and panting (KIBLER and BRODY, 1952; BIANCA, 1965). Present results show that these phenomena considerably increase from the beginning to the end of the stress and that, at a given hour of the stress, variations of hygrometries influenced the R.T. by affecting the S.R., a high hygrometry being associated with a high S.R. These overall results are in accordance with those found in the literature (SCHRODE *and al.*, 1960; KIBLER 1964; BIANCA, 1965). However, the wide variability of the S.R., within breed and within hour, is never related to the variability in rectal temperature.

This lack of relation cannot be attributed to the lack of accuracy in S.R. measurements as they are highly repeatable from one hour to another. This apparently surprising result may most likely be related to the high hygrometries in the hot room which in addition to high external temperatures involved a high water vapour pressure of 35 mm Hg approximately. In this respect, results of Mc LEAN (1963) clearly show that an increase of the water vapour pressure (from 8 mm Hg to 35 mm Hg) induces a significant drop (from 150 to 60 gm/m^2/h) in the sweating rate of calves. This physical limitation to evaporation may have adjusted between animal variability of true evaporation.

The heat production processes have also to be considered. They might be at the origin of the clearly positive within genotype correlation on the one hand between final rectal temperature and weight, and between final rectal temperature and feed consumption before test on the other. A high weight should theoretically be associated with a high rectal temperature since the surface/weight ratio and the thermolysis processes relatively to thermogenesis tend to decrease (BIANCA, 1968). The fact that this relation is found to be positive (0.63) within and between genotypes demonstrates the incidence of thermogenesis on variability of the results of heat balance. As expected, even more obvious is the influence of the level of feed consumption, demonstrated by the statistical relationship between feed consumption and weight i.e. the level of maintenance needs for energy, and by the direct effect of the amount of feed consumed, through the processes of digestion and absorption of nutrients (I.N.R.A., 1978). All these figures show the incidence of thermogenesis on the individual variability of heat balance but they are probably underestimated as thermogenesis also depends on other factors than weight and feed consumption.

It has been shown that heat production during a short heat stress may be considerably increased by the stress of adaptation (KIBLER and BRODY, 1952; BIANCA, 1965; Mc LEAN, 1963), contrary to long term heat stress where heat production slows down (BIANCA, 1965; BOND and Mc DOWELL, 1972; SINGH and NEWTON, 1978) mostly through feed intake decrease (BIANCA, 1965; ALLEN and DONEGAN, 1974). This phenomenon might have affected our mean results since at the beginning of the stress, the rise in R.T. is nearly as high as during the whole stress. Another indication of that is that for every group of animals (except for the « beef » group) the H.R. decreases during the first part of the experiment resulting in a calming effect, before increasing because of the real heat stress. The share of thermogenesis in stress effects in the individual variability is difficult to establish, but it can be assumed that it is somewhat large as experimental conditions are disturbing enough for aspects other that heat: transfer from the shed to the hot room, lack of feed and water and tiredness due to the standing position. This could explain the better correlation between final R.T. and initial H.R. (0.30) rather than final (0.18), the initial H.R. being probably influenced by the stress.

TABLE II

Analysis of variance of the heat resistance variates for the pooled data (F values)
Analyse de variance pour les variables de thermotolérance sur l'ensemble des observations

	Rectal temperature cow-shed (*Température rectale à l'étable*)	Rectal temperature (*Température rectale*)			Respiratory rate (*Rythme respiratoire*)		
		B	M	E	B	M	E
Genetic type-sex factor	1,27	2,97***	6,33***	7,90***	2,00***	5,34***	5,28***
Year factor		5,13***	46,90***	74,60***	38,26***	60,05***	79,36***
Site factor		0,22	0,62	0,92	2,33	0,22	0,13
Contrasts :							
Males vs females	2,20*	3,58**	5,16***	8,45***	5,85***	11,73***	11,09***
Between males	1,37	2,04**	2,87***	3,06***	0,91	1,36	1,67*
Between groups of males	2,29	2,47	9,75***	10,08***	2,21	2,72	3,60**
Within group of males	1,13	2,02*	1,80*	1,85*	0,60	1,40	1,31
Between females	0,25	7,60***	12,32***	14,85***	3,90**	3,48**	0,72
Between groups of females	0,35	9,04***	13,21***	15,73***	1,02	2,42	0,23
Within group of females	0,93	5,33***	1,14	1,43	8,76***	7,90***	1,41
R^2 (p. 100) of the model		40,1	39,4	48,5	34,5	43,5	51,7
Residual standard error	3,86	0,23	0,30	0,41	12,60	24,15	22,10

B. — *The between breed differences*

The most striking result of our studies is that between genotypes the within-group differences (dairy, beef or local breeds) are generally non significant (except for S.R.) whereas the between-group differences are significant.

As emphasized for the thermogenesis, such a result has first to be examined in the light of the « animal husbandry » differences like weight and feed consumption. In a first approach, the differences in rectal temperature between the three main groups may be explained by a corresponding difference in weight, the ranking being the same. But this is probably not so easy since the position of the dairy group with respect to R.T. is clearly half way between the beef group and the local group, while it is closer to the local group with respect to weight and feed intake. It is difficult to speculate on this. Two hypotheses, not exclusive, can be forward. First, it has been established that in normal heat conditions and at the same weight, the heat production of the dairy breeds is higher than that of beef breeds (VERMOREL, 1976; COLLEAU, 1978; I.N.R.A., 1978). Secondly, the beef group could have been more stressed in addition of the heat stress as it is clear that their R.T. differs from that of the other two groups from the beginning of the experiment. In this experiment, the local breeds are characterized by a low weight and a high S.R. This second factor had probably a minor incidence on the heat balance as shown by the previous figures. Thus, a first approximation suggested that the good resistance of the French local breeds to heat as indicated by a low final R.T. is related to their low weight that reduced the thermogenesis. Contrary to the dairy breeds in the North, it may be objected that these local breeds originate from the central and southern parts of the country, where climate is somewhat hotter in summer, and this might have led to some natural selection. In our opinion, the effect of these hot climates of Southern France must be not be exagerated and it must be recalled that the local breeds are mainly located in hilly and mountainous areas: altitude may cancel the effect of latitude.

C. — *Possibility of extrapolation to normal hot conditions*

First of all, the present results cannot be extrapolated to any type of cattle production. When we are speaking of dairy breeds, it is for systems (fattening of males, rearing of females) where the animals are not expressing milk production, because at the onset of milk secretion, production of heat is highly increased (I.N.R.A., 1978) and therefore the body core temperature (WOLFF and MONTY, 1974; MONTY and GARBARENO, 1978).

The intensity and shortness of our test are characteristics that must be stressed upon. It is most likely that factors such as emotive stress have affected some animals, especially those from the beef group. The mechanisms usually developed for long-term adaptation such as the control of feed intake could not be evaluated at all. Some information can be drawn from the decrease in feed intake observed after the test: it is rather confusing that the group resisting the best to stress (the local group) showed the largest decrease, in absolute and relative values, as if it was beginning to adapt its feed consumption to hot conditions. However, this observation could not be proved statistically.

The between-group differences are large enough to be maintained in normal hot conditions, especially the good position of the local group. The real ranking of the beef group relative to the dairy group is somewhat more questionable as shown in our previous discussions.

As already mentioned, no significant within group differences between breeds could be found showing that there is no effects of heterosis either, according to the rather large fraction of crossbred animals studied. Such an observation can probably be made in actual hot conditions. If not, it may be due to differences in S.R. for the groups are not homogenous in this respect and these differences did not have any efficient impact in our experimental conditions.

Conclusion

It appears from the current analyse that in our experimental conditions some French local breeds may be resistant to heat, that is to say maintain their core temperature at a lower level. This supports frequent observations made in that field. Improved breeds for either milk or beef production seem to have difficulties in keeping constant their mid body temperature, what is usually considered as a bad adaptation to heat. Another very important result of the present study is that within each large group (improved for dairy or beef and local) neither between breed variability nor heterotic effects seem to occur, at least within our system of testing and the statistical efficiency of our data analysis. Though the test might be largely improved by using for example a pre-experimental in the non heated room, long enough to prevent any emotional stress, the general pattern of our results, between group speaking, could well be observed in practice because in our conditions the heat balance variability was primarily related to the variability in heat production. That factor was really demonstrated to be predominant for explaining some differences in heat tolerance in actual conditions, for example between *Bos Taurus* and *Zebus* (JOHNSTON *and al.*, 1956; FRISCH and VERCOE, 1977). However, our test is probably too inaccurate to discriminate possible heat resistant genetic types from other contemporary types from the same group.

Unfortunately French local breeds are generally small and less productive than the commonly used European cattle breeds and their poor production ability must be considered together with their ability to resist to heat. Furthermore, the capacities of an animal to maintain low core temperature under hot conditions are usually considered as criteria of heat tolerance but they are not necessarily criteria of economic profitability under hot conditions. Thus, the local breeds have to demonstrate their overall economic superiority, which may be the case at least for some peculiar cases, as shown for example by CASU *and al.* (1975). These authors reported that the crossbreds between *Charolais* and *Sardinian* breed (a local Italian breed) could be superior to pure *Charolais*. In very hot and dry conditions, it is likely that the European local breeds should have to be compared not with the improved European breeds, but with some special genetic combination, « *Bos taurus* × *Zebu* » for example. If they do not lead to better results, it is not even sure that they would be valuable in these genetic combinations, as FRISCH (1977) showed that the ranking of European breeds in hot conditions might vary according that they are pure or crossed with *Zebu* cattle.

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Résumé

Analyse des variations génétiques d'adaptation de jeunes bovins « Bos Taurus » *à un stress thermique court*

Le but de ce travail est d'essayer de caractériser l'adaptation à la chaleur d'un certain nombre de races bovines, notamment françaises. Pour cela, 582 jeunes bovins, mâles et femelles, d'environ 14 mois et issus de 41 combinaisons génétiques élémentaires analysées dans 5 expérimentations différentes, à objectif non bioclimatologique, sont soumis en chambre chaude, à un stress thermique de 8 heures pendant lequel la température externe a été portée de 18 °C à 38 °C.

Les réactions classiques sont observées : augmentation de la température rectale au cours du stress (+ 0,54 °C), augmentation du rythme respiratoire (× 3), augmentation du taux de sudation, du rythme cardiaque, de la température de la peau.

Les analyses statistiques sont effectuées à trois stades du stress (début, milieu, fin). Dans tous les cas, on note de très forts effets dûs au milieu : effet de l'année et des erreurs expérimentales dans la conduite du protocole théorique, concernant la température et l'hygrométrie relative.

Sur les données ajustées pour les effets de milieu, la variabilité génétique apparaît assez clairement. Cependant une analyse plus fine montre qu'elle provient essentiellement d'une variabilité inter groupe en définissant le groupe d'après des critères « zootechniques » ou « fonctionnels » (groupe à vocation laitière, groupe à vocation bouchère, groupe des races locales). En effet, dans la grande majorité des cas, il n'apparaît pas de variabilité significative entre les réactions des génotypes rangés dans le même groupe, alors qu'elle existe entre les groupes. La bonne performance du groupe des races locales apparaît en comparaison des groupes mettant en œuvre les races améliorées, laitières ou bouchères, qui diffèrent peu entre eux pour les critères analysés.

Dans la discussion, l'accent est mis sur l'incidence probable sur les résultats des phénomènes de thermogénèse. Si nos résultats ont pu être affectés par des phénomènes parasites, notamment ceux de stress émotionnel, il n'en reste pas moins qu'ils concordent assez bien avec l'expérience pratique acquise sur le comportement des races locales françaises dans certains pays chauds.

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