EFFECTS OF HIGH TEMPERATURE ON THE BIOLOGICAL PERFORMANCE OF GROWING PIGS

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Summary

The physiological response by pigs to high temperature and the effects of plane of nutrition on the thermoneutral zone are discussed. Growth rate and food utilization are both influenced in the heat by age and feed intake, and less clearly by protein concentration in the diet.

Maintenance energy requirement is increased and efficiency of utilization of metabolizable energy is reduced in the heat. Carcass length is increased but eye-muscle appears to decline and therefore carcass quality at high temperatures. There is however very little data to show what dietary manipulations could be undertaken to improve biological performance in a hot environment.

I. INTRODUCTION

Investigations into the nutrition of the pig in Australia have occurred only in recent years largely due to a lack of financial support. Because of the wide fluctuation in ambient temperature and its influence on biological performance, many of these studies may be of only limited value. It is rather strange that more attention has not been paid to pig performance particularly at very high temperatures. Although attempts are generally made to modify fluctuations in shed temperature there are occasions when pigs are exposed to temperatures such that some degree of stress is imposed. This is an area of research which must command high priority in this country. As will be seen later very little research has been undertaken in any country in this area, and much of the results from the few published studies is conflicting.

II. PHYSIOLOGICAL CONSIDERATIONS

The pig does not enjoy living in a warm environment. Heat lost through moisture evaporation from the skin is much less than for any domestic species so far measured (Ingram 1974) largely because it does not have sweat glands. Under conditions of high humidity and high temperature there may be a net gain of water by the skin. It is for this reason that pigs allowed outdoors wallow in water, or preferably in mud, to dissipate body heat at high temperatures. At temperatures of 35°C and above, the pig, like other species, relies almost entirely on respiratory evaporation of moisture to lose body heat (Holmes & Close 1977) by changing liquid water into vapour using 2.5 kJ/g of water. Furthermore the pig compared with other species such as the sheep can change its minute volume only to a limited extent, thus heat lost by evaporative means is restricted. The partition of heat loss into evaporative and sensible means is given in Table 1 (Holmes. & Close 1977).

When exposed for long periods to high temperature anatomical changes often occur; these probably help pigs to lose heat by sensible means. Fuller (1965) noted that pigs raised in a hot environment had

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TABLE I. The partition of total heat loss from a pig pen into sensible and evaporative components (Holmes & Close 1977).

Temperature (°C)	% of Total	
	Sensible	Evaporative
5	85	15
10	84	16
15	80	20
20	71	29
25	58	42
30	43	57
35	20	80

less hair, large ears (see also Straub et al. 1975) and longer limbs than controls raised in the cold. Subcutaneous back-fat is of considerable importance; it reduces rate of heat transfer from the body "core" to the environment. As pigs age they tend to fatten and consequently become less tolerant of heat. Overall thermal conductance by the skin and coat of pigs of various liveweights is given in Table 2. Comparisons are made with sheep and cattle. Clearly the young pig requires warmth, but rapidly acquires a thick skin which is somewhat deceptive in its capacity to transfer heat.

TABLE 2. Overall thermal conductance of various domestic animals (Fuller 1969).

Pig	Species & breed	Weight (kg)	Overall conductance	Coat type
	Large white	1.5	133	Normal
	Large white	4 to 10	100	
	Landrace	23	48	
	Large white	150	36	
Sheep	Merino	5	58	Fine
	Merino	5	43	Coarse
	Down	45	81	Clipped
	Down	45	31	5 cm

In Australia ambient temperature within pig houses is frequently above that which is considered comfortable for growing pigs. Although insulation of buildings, use of exhaust fans and in some cases installation of evaporative coolers will reduce, significantly, shed temperature, cost of these installations may be considerable and constant-temperature houses may be uneconomical.

The upper critical temperature may be defined as that temperature above which the pig shows signs of stress. This may be the point at which metabolic rate, rectal temperature or evaporative heat loss as a percent of the total, starts to increase. Upper critical temperature is influenced by the plane of nutrition, age or weight of pig, and the number of pigs in a group. Since feeding level may be unrestricted for pigs up to about 40 kg, and thereafter at a controlled rate, upper critical temperature may increase during the latter phase of growth. Normally, however, this effect of feeding is nullified by the increasing deposition of subcutaneous fat. Holmes & Close (1977) calculated the thermoneutral zone of pigs at various liveweights. These data are shown in Table 3, and are theoretical values for individually-housed animals.

TABLE 3. Thermoneutral zone (°C) of individual pigs of different liveweights and fed at maintenance (M), 2M and 3M (Holmes & Close 1977)

Liveweight (kg)	Metabolizable energy intake		
	M	2M	3M
2	31-33	27-32	27-31
20	26-33	21-31	17-30
60	24-32	20-30	16-29
100	23-32	17-30	14-28

The number of pigs in a group will obviously change these temperatures (Mount 1975). Effect of daily variation in temperature on biological performance of pigs is virtually unknown. But one would suppose that such variation would modify responses and may not necessarily be the summation of performances predicted from the mean temperature.

Verstegen et al. (1978) summarised data from several experiments in Table 4 to show the effects of temperature on various performance parameters of pigs during the fattening period taking 15°C as the "standard" temperature. It would seem that for feed-intake and feed conversion ratio maximum values occur at temperatures above 20°C. Although under conditions of a draughty, uninsulated house with wet floors, the critical temperature may be as high as 29°C (Mount 1975).

TABLE 4. Performance of fattening pigs summarised by Verstegen et al. (1978), taking 15°C as the "standard" temperature.

	Ambient temperature °C		
	15	20	25
Intake %	100	96.1	94.7
Rate of gain			
40-70 kg	100	105.4	105.4
70-100 kg	100	103.4	96.2
Feed conversion	100	95.8	94.4

III. GROWTH RATE AND FEED UTILIZATION

As indicated in Table 4, feed intake declines as house-temperature increases above 15°C, while rate of gain increases and feed conversion also improves. But clearly 15°C is below the critical temperature of growing pigs except perhaps at 70 to 100 kg where rate of gain at 25°C declined (Table 4). Much of the information presented here is drawn from the work of Holmes carried out in New Zealand (Holmes 1971, 1973, 1974) where the upper experimental temperature was 32 to 34°C. Difficulty frequently arises in that the feeding scale adopted, although appropriate for pigs housed in a warm environment, may result in feed refusals at high temperatures particularly when pigs exceed about 50 kg in liveweight (Holmes 1971). Data drawn from various studies are shown in Table 5. In some of the studies feeding level was often ad libitum which clearly imposed a greater stress on pigs in the warmth compared with controlled feeding. In the work of Tonks et al. (1972), although carried out at a high relative humidity, showed that pigs at the lower liveweight fed on a restricted basis gave similar performance irrespective of house temperature. Holmes (1974) made a similar observation

TABLE 5. Effect of temperature on performance at different levels of feeding.

	Feed regimen				Source and comments
	Restricted		Ad libitum		
Temperature ($^{\circ}$C)	21	29	21	29	
Liveweight (kg)		Gain (g/d)			
23 to 45	486	477	682	527	Tonks et al. (1972)
45 to 68	627	609	741	600	Mixed sexes, group
68 to 91	650	591	795	691	pens, high humidity
23 to 91	572	440	736	582	
Feed conversion ratio					
(23-91 kg)	3.55	3.72	3.33	3.43	
Temperature ($^{\circ}$C)			23	33	Sughara et al.(1970)
Liveweight (kg)					Humidity 50%, cast-
9 to 31			610	400	rates, housed in
Feed conversion ratio			2.2	2.3	pairs
Experiment	I		II		Holmes (1974)
Temperature ($^{\circ}$C)	23	34	24	33	Individually-housed,
Liveweight (kg)					castrates
42 to 77	660	620			
60 to 77			720	540	
Feed conversion ratio					
42 to 77 kg	3.07	3.10			
			3.07	3.61	
Plane of feeding	Low		High		Holmes (1973)
Temperature ($^{\circ}$C)	24	34	24	34	Individually-housed,
Liveweight (kg)					castrates
20 to 70 kg	335	356	487	433	
Feed conversion ratio	3.46	3.30	3.28	3.73	

when feeding pigs (31 to 78 kg) at two different planes of nutrition when there was an interaction of temperature x level of feeding. The hot temperature (33°C) decreased growth rate by 14% at the high level of feeding but increased, it by 24% at the lower level of feeding. Feed conversion ratio tended to follow the same pattern although at *ad libitum* intake there was little difference in feed conversion at the two temperatures (Table 5). But clearly the effect of high temperature on performance is modified by the reduced plane of feeding and is accentuated as pigs approach slaughter weight.

The data of Fuller (1965) determined with pigs grown from 15 to 72 days, fed *ad libitum* and housed in individual cages are illustrated in Fig. 1. In many respects the response by pigs for the three parameters measured from 10 to 30°C summarises much of the information presented in Table 5.

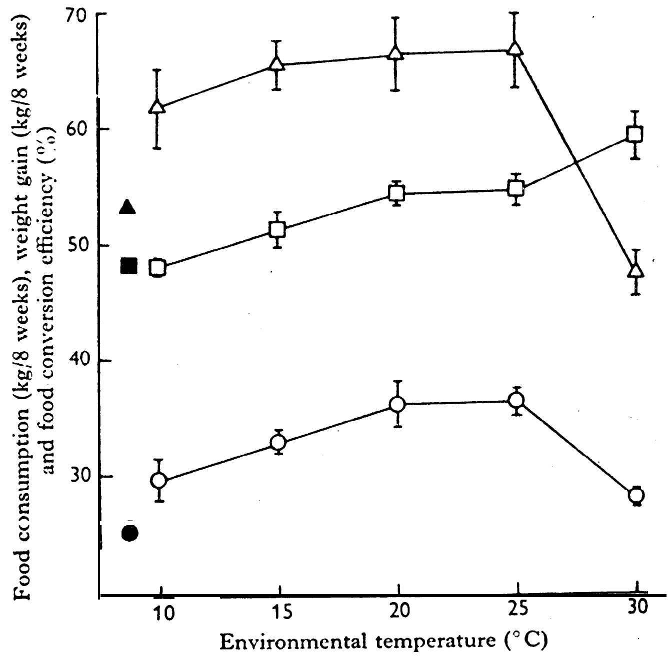

Fig. 1. Total food consumption per pig (△, ▲), weight gain per pig (○, ●) and overall food conversion efficiency (□, ■) of four pigs at each temperature with low air movement (open symbols) and of two pigs at 10° with high air movement (closed symbols). The values are the means with standard errors shown as vertical bars. Fuller (1965)

IV. DIETARY PROTEIN LEVEL

Few experiments have set out to study the effect of manipulation of nutrients in order to modify the effect of high temperature on pig performance. Seymour *et al.* (1964) fed *ad libitum* two diets containing 20% and 16% crude protein at 16° and 32°C. Results are shown in Table 6.

Although there was a response to additional crude protein in the diet at both temperatures, there was no indication from growth data that the high-protein diet was any more advantageous at the high than at the low temperature. However, feed conversion at the high temperature was better on the high protein diet by a greater percentage than when the same comparison is made at the lower temperature from 7 to 57 kg only. Overall feed conversion was similar at the two different temperatures when comparisons were made at the same dietary protein level. In many ways this experiment is unconvincing; a diet of 16% crude protein was insufficient to maximise performance. There should have been no difference in growth rate or feed conversion at 16°C on the two diets had both diets contained optimum nutrient concentrations.

TABLE 6. The effects of diets of high (20%) and low (16%) crude protein on growth and feed conversion when fed _ad libitum_ to pigs housed at 16 and 32°C. Relative advantage (%) is given in parentheses (Seymour _et al._ 1964)

	Temperature (°C)			
	16		32	
Protein level	High	Low	High	Low
Liveweight (kg) 7 to 57				
Weight gain (g/d)	636* (18%)	541	572 (20%)	477
Feed conversion ratio	2.55* (11%)	2.84	2.40 (17%)	2.81
Liveweight (kg) 7 to 89				
Weight gain (g/d)	736* (24%)	595	686 (20%)	573
Feed conversion ratio	3.15* (19%)	3.76	3.05 (21%)	3.68

*Difference between high and low protein significant ($P<0.05$)

V. ENERGY AND NITROGEN METABOLISM AND HIGH TEMPERATURES

Although there is evidence to the contrary (Holmes 1973) it appears that digestible energy of pig diets increases with increasing ambient temperature. Fuller & Boyne (1972) noted that for the same pig diet an increase of 0.12% increase per 1°C in temperature from 5°C to 23°C. Fuller & Cadenhead (1969) summarised data to support this observation not only for pigs but for some other species.

A logical place to start in any discussion of the interrelationship between ambient temperature and energy requirement is at maintenance. Data are given in Table 7. It is evident that there is an increase in maintenance energy requirement of growing pigs at 30 and 34°C compared with 25°C. Close & Mount (1976a,b) showed that for pigs between 20 and 50 kg maintenance energy requirement at 20°C was 5% higher than at 25°C, which in turn was 14.5% lower than at 30°C (Table 7).

Also shown in Table 7 is the net efficiency of utilization of metabolizable energy determined at various centres. The efficiency normally reported is in the range 68 to 72% (Thorbek 1975). Thus the value of 68% obtained by Close & Mount (1970a) at temperatures between 20 and 25°C is acceptable. While the coefficients of Holmes (1973, 1974) are doubtful value.

Close & Mount (1976a,b) calculated partial efficiencies of formation

TABLE 7. Maintenance energy requirements of pigs and net efficiency of utilization of metabolizable energy (ME) of growing pigs at warm (25°C) and hot temperatures (34°C). Values (%) in parentheses are the relative increments.

Liveweight (kg)	Environment	Maintenance energy requirement ($kJ/kg^{0.75}$)	Energy retention (% ME)	Reference
37 to 45	Hot	410 (7%)	65.7)	Holmes (1973)
	Warm	383	63.5)	
59 to 64	Hot	433 (23%)	61.8)	
	Warm	353	67.7)	
31 to 78	Hot	523 (9%)	75.1)	Holmes (1974)
	Warm	481	82.5)	
20 to 50	20°C	442 (5%))	68.0	Close & Mount (1976a,b)
	25°C	420)		
	30°C	481 (15%))		

of protein and fat of 63 and 70%. respectively at temperatures between 20 and 25°C. These efficiencies declined to 60 and 65% at 30°C. When pigs are stressed by high temperature not only is maintenance energy requirement ($kJ/kg^{0.75}$) increased but the energy required to effect protein and fat synthesis is also increased.

Nitrogen retention will vary with the quantity and quality of the protein in the diet, as well as level of feeding and the liveweight of the pig. It is evident from data in Table 8 that nitrogen retention (%) declines at high temperatures compared with a thermoneutral environment (20 to 25°C). Level of feeding appears to have a more pronounced effect at a high temperature (Holmes 1973, 1974).

VI. CARCASS CHARACTERISTICS

High temperature usually increases the length of the pig carcass compared with that at lower temperatures (Straub et al. 1976). There is less certainty as to the effect' of high temperature on the degree of fatness. Increased fatness (Houghton et al. 1964; Holmes 1971, 1973, 1974), to either no effect (Tonks et al. 1972), or tending towards a leaner carcass in a hot environment (Fuller 1965; Sughara et al. 1970) may be associated with differences in feeding level, sex and age of pig at slaughter. The recent work of Straub et al. (1975) with pigs (70 to 110 kg) fed ad libitum showed a significant effect of high temperature in reducing back-fat thickness and eye muscle area (Tonks et al. 1972). This might suggest an inferior carcass although this is difficult to assess objectively.

Holmes (1974) observed that at the high level of feeding the ratio of energy retained as fat to protein was 3.72 at the warm temperature and 3.16 in the hot. In a previous experiment (Holmes 1973)

TABLE 8. Nitrogen (N) retained by growing pigs measured at different environmental temperatures.

Liveweight (kg)	Temperature (°C)	Nitrogen retention (% dietary N)	Level of feeding	Reference
4 to 40	20	50	*Ad libitum*)	Fuller (1965)
	25	51	)	
	30	46	)	
20 to 65	25	36	High)	Holmes (1974)
		35	Low)	
	34	27	High)	
		36	Low)	
25 to 65	25	37	High)	Holmes (1973)
		36	Low)	
	34	24	High)	
		29	Low)	
25 to 50	20	46	Four	Close & Mount
	25	46	levels	(1976a, b)
	30	39		

the comparable ratios were 3.10 and 2 .07 respectively, indicating that more fat was deposited in the hot than in the warm environment. At the lower levels of feeding differences associated with temperature were less clear.

VII. OTHER NUTRIENTS

Water intake of pigs in a thermoneutral environment is normally two parts to one part of feed dry matter. Temperature increases water consumption to a ratio of 5:1 at 34°C (Mount *et al.* 1971). Some of the apparent increase in water consumption was due to spillage by pigs to cool themselves (Straub *et al.* 1976); this is an important means of increasing heat loss (Ingram 1974).

It has been suggested that thiamin requirement may increase for pigs at high temperatures, but the evidence is unconvincing (Peng & Huitman 1974). Potassium and calcium rates of excretion were increased in the urine of pigs exposed to a high temperature (Holmes & Grace 1975). Frequently these pigs showed some degree of lameness which may have influenced these high excretions.

VIII. CONCLUDING REMARKS

It is unsatisfactory to end a review such as this one with the statement that there are insufficient data to delineate the actual influence of temperature 'on many aspects of biological performance. However, there are no published studies designed to examine the effect of increasing the concentration of dietary energy, particularly through the incorporation of dietary fat, on performance in a hot environment. This may reduce the heat increment of the diet and thus allow pigs to become more tolerant to the heat. Frequency of feeding, the effect of variation in daily temperature, and the significance of time of feeding in relation to variation in temperature must provide scope to improve biological performance of pigs in the warmth. The effects of protein concentration in the diet at various temperatures has been tested in an unconvincing study (Seymour et al. 1964) and requires further examination.

One thing is abundantly clear, as pigs age they become less tolerant of high temperature, and as pigs increase their intake at any given age they become less tolerant of high temperature. Maintenance energy requirement increases and net efficiency of utilization of metabolizable energy for gain declines in the hot climate. Modification of these responses present a challenge to researchers and form a basis for future investigations.

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