Heat tolerance and evaporative cooling in goats, cattle and buffalo under tropical conditions and during exercise

by

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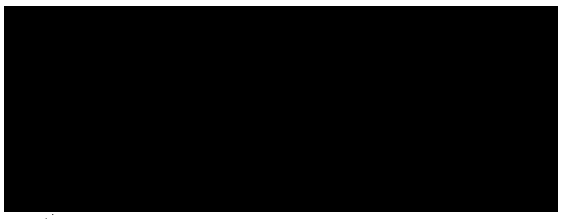
PREFACE

The work reported in this thesis was completed by the author while a student in the Department of Animal Science at the University of New England, under the supervision of Assoc. Prof. C. J. Thwaites.

I certify that the substance of this thesis is the original work of the author and has not been submitted for a degree at any other university.

I certify that any help received in the preparation of this thesis and all sources of information used have been duly acknowledged in the text.



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SUMMARY

In general, draught animal power (DAP) is provided by cattle, buffaloes, camels, donkeys and horses in many developing countries in Asia and Africa. In Bali (Indonesia), for example, Bali-cattle, buffaloes and horses are preferred: Bali-cattle for ploughing; buffaloes for both ploughing and carting, and horses for carting only. Little is known of the extent or causes of sex and breed differences in the heat stress experienced during exercise. This thesis attempts to rectify this deficiency, and reports studies on animals of different sexes and breeds (Bali-cattle and buffalo) involved in DAP in the field in Bali-Indonesia and on goats in the climate laboratory at UNE, Armidale, Australia.

A series of experiments was carried-out to examine the effects of ploughing and treadmill exercise on heat tolerance and evaporative cooling under tropical conditions. Physiological parameters, sex and breed responses and their possible causes, were investigated. Overall, it is concluded that the male was more stressed than the female, as evidenced by increases in RR, RT and ST with time, in every test condition. For example, in male and female Bali-cattle (Experiment 1) during ploughing in Bali the RR and RT in males and females averaged 66 vs 61/min ($P < 0.05$) and 39.4 vs 39.2°C ($P < 0.01$) respectively. With time, ST in males was significantly higher than in females ($P < 0.05$) at all intervals after 0.5 h exercise. There were significant differences in PCV between times ($P < 0.05$); after 2.5 hours of work the PCV decreased from 27.4 to 25.6 %, and this was taken to indicate acclimatisation.

Similar patterns were found when swamp buffalo worked in the field; the RR for males being higher than of females in both the hot/dry and cool/humid seasons (77.7 vs 67.4/minute compared to 30.1 vs 24.9/minute respectively; $P < 0.05$). With time, RR increased during the 2.5 h work period by a mean of 81/min ($P < 0.001$). RT in males was significantly higher than in females ($P < 0.01$) by a mean of 0.3°C, and RT was higher during the hot/dry season (mean values of 39.5°C) than in the cool/humid one (38.6°C). In males, ST was significantly higher than in females ($P < 0.05$) by a mean of 0.5°C. PCV decreased during work (25.6 vs 23.7 %; $P < 0.05$).

When experiments were conducted on a treadmill at 20°C in the laboratory, using goats of different sexes, body weights and feed intakes (Experiment 5), it was found that the RR and RT did not differ significantly ($P > 0.05$). It was concluded that 20°C was too low a temperature to induce stress under the conditions used. However, ST varied between the 3 sites studied: rump: 37.1 ± 0.0°C; loin: 36.9 ± 0.1°C and ear: 36.8 ± 0.1°C ($P < 0.05$). For RR and RT there were significant effects of time during exercise ($P < 0.01$), but the absolute increases were small (16/minute and 0.5°C respectively). Similarly, ST increased with time by less than 1.3°C ($P < 0.05$); final values ranged from 37.1 to 37.3°C. It was concluded that these increases at 20°C represented only a very marginal level of heat stress.

When goats were compared at similar body weights and when fed at maintenance (Experiment 6), mean RR after 120 minutes of exercise was 248 in males and 67/min in females. In that same time RT increased ($P < 0.001$) to reach an overall mean of 40.9°C. LST, RST and EST each increased progressively during exercise ($P < 0.001$), but although the sex differences were significant for both LST ($P < 0.001$) and RST ($P < 0.05$), values for males exceeded those of females by < 0.4°C.

In Experiment 7 goats of similar body weight but different feed intakes (400 and 1200 g/d) were compared, and once again males reacted more than females; after 1 hr RR averaged 163.5 and 115.5/min respectively. RR values were much lower at 400 g/d feed intake than at 1200 g/d (mean values of 38 vs 110/min respectively; $P < 0.001$). In RT, the males were higher than the females in both feeding regimes ($P < 0.05$): at the 1200 g/d feeding level RT in males and females averaged 40.0 and 39.7°C respectively. With time, RT increased progressively by a mean magnitude of 1.4°C after 1h exercise ($P < 0.001$). For both RST and LST there were interactions with feeding levels; values were higher for females than males at 400g/d (both N.S.), but at 1200g/d the reverse was true ($P < 0.05$).

EST for females was uniformly higher than for males ($P < 0.05$), but the difference was greatest before exercise. During the experiments a pattern of acclimation was evident, which is consistent with the ear being an important thermoregulatory

structure. For EST there were significant differences between feed intake levels, with values being much lower at 400 g/d intake than at 1200 g/d (34.4 vs 35.9°C respectively). With time, both RST and LST increased progressively ($P < 0.001$). Before and after 1h of exercise mean values for RST and LST were 36.1 and 37.7°C, and 36.2 and 37.6°C, respectively.

In Experiment 8, the effects of exercise in goats at 20, 30 and 40°C were investigated. After 30 minutes, RR in males (164/min) was higher than in females (103/min). RR increased progressively with increasing ambient temperature (means of 39, 62 and 90/min respectively; $P < 0.001$). As previously, RT increased progressively with time, and was higher for males than females (40.1 vs 39.7°C after 30 min., $P < 0.01$). Between ambient temperatures, RT gradually decreased from a mean of 39.4 at 20°C to 39.2°C at 40°C ($P < 0.05$) RML increased with time ($P < 0.001$), more so in males than females. By the end of 30 mins of exercise the respective values were 606.5 and 375.3 mg/min. RML increased gradually with rising ambient temperature: mean values of 263.9, 310.5 and 346.6 mg/min were recorded at 20, 30 and 40°C respectively ($P < 0.001$). PCV declined ($P < 0.01$) during 30 minutes of exercise from 35.9 to 31.8%.

In Experiment 13, in which the effects of treadmill exercise on the RML of different sexes were investigated, it was also found that an increase in RR was followed by rise in RML, the correlation between the two was 0.8 in both males and females. RML again increased ($P < 0.01$) with time during exercise, and values in males exceeded those in females by 334, 381 and 418 mg/min after 20, 40 and 60 min respectively. RML/breath decreased gradually with values of 6.1 and 3.4 mg/breath recorded in males and females after 60 mins of exercise ($P < 0.05$).

Experiment 15 investigated variation in SR during exercise, and revealed that values were uniformly higher in males than females. These differences were significant for RSR and ESR (both $P < 0.05$) but not for LSR. In all cases the SR of the goats studied reached peak values of only 60-70 g/m²/h, and the fact that both RSR and ESR declined towards the end of the exercise period is taken to indicate sweat gland fatique.

Clear breed differences in physiological responses to exercise were demonstrated. In Experiment 4 in the field, it was observed that albino swamp buffalo had consistently lower RR than black ones in all cases except for the final observation (210 min). Values in the cool/humid season were lower than in the hot/dry (21 and 69/minute; $P < 0.01$).

Albinos had consistently higher RT (by from 0.1 to 0.5°C; $P < 0.05$) than black buffalo on most days, and, as for RR, values in the cool/humid season were lower than in the hot/dry (38.6 and 39.1°C). ST in the cool/humid season was also lower than in the hot/dry (37.1 and 37.7°C; $P < 0.01$), and increased during work ($P < 0.01$) to reach an overall mean of 42.1°C after 2.5 hr. Black buffalo had higher ST (37.7 vs 37.2°C; $P < 0.01$) than albino ones. PCV decreased after 2.5 h exercise by 1.3 percentage points ($P < 0.05$).

Experiments were then conducted in the climate laboratory to confirm such differences under controlled conditions, by using different breeds of goats. In Experiment 9 the Saanen, Anglo Nubian and Toggenburg breeds were compared at different body weights and feed intakes, and it was found that RR was lower in Anglo Nubians than in Toggenburgs ($P < 0.01$) by from 81 to 115/min, while values for the Saanen were intermediate and did not to differ significantly from the other 2 breeds. With time, RR increased gradually in all breeds and differed significantly, and after 1h the respective values were 238, 221 and 303/min in the Saanen, Anglo Nubian and Toggenburg.

Significant differences in RT ($P < 0.01$) between the 3 breeds were found, with values averaging 40.5, 41.0 and 41.3°C in the Anglo Nubian, Saanen and Toggenburg respectively. With time, RT increased gradually in all breeds, and after 1h exercise mean values were 40.8, 41.3 and 40.7°C in the Saanen, Anglo Nubian and Toggenburg respectively. RST values differed significantly ($P < 0.01$) between Anglo Nubians and Toggenburgs (by from 0.3 to 0.6°C at different times), and increased gradually in Saanens, Anglo Nubians and Toggenburgs to reach mean values 38.4, 39.0 and 38.6°C respectively after 1h exercise.

Responses in Saanen, Anglo Nubian and Toggenburg goats of similar condition score and at the same feed intake in Experiment 10 revealed differences ($P < 0.01$) in RR between the respective breeds, with means of 288, 235 and 125/min after 60 mins. With time, RT increased gradually by 1.2, 1.9 and 1.4°C ($P < 0.01$) after 1h exercise in the Saanen, Anglo Nubian and Toggenburg respectively. With time during exercise, there were increases ($P < 0.001$) in each of RST, LST and EST, and after 1h exercise the increases were 1.8, 1.4 and 7.3°C respectively.

With similar condition scores but different feed intakes (500 and 1000 g/d; Experiment 11), significant differences in RR were found between breeds in RR, with values of 236, 168 and 297/min in Saanen, Anglo Nubian and Toggenburg respectively after 1h exercise. Feed intake had significant effects on RR ($P < 0.01$); values at 1000g/d feed intake were higher by 43/minute. After 1h exercise, RT averaged 39.7, 40.3 and 39.6°C in Saanen, Anglo Nubian and Toggenburg ($P < 0.001$). RT responses increased with feeding level; values were higher at 1000g/d than at 500g/d by 0.5, 0.4 and 0.3°C respectively in the Saanen, Anglo Nubian and Toggenburg. RST values were also uniformly higher ($P < 0.05$) in animals fed 1000g/d; the differences with the 500g/d treatment averaging 0.2, 0.4 and 0.5°C in Saanen, Anglo Nubian and Toggenburg respectively. There were highly significant differences in RST with time during exercise; the greatest increase (mean 0.5°C) was recorded during the first 15 minutes of exercise.

When experiments were conducted in Saanens and Toggenburgs at ambient temperatures of 20, 30 and 40°C (Experiment 12), the Toggenburgs recorded higher RR than Saanens ($P < 0.01$); the differences averaged 22, 34 and 55/min at 20, 30 and 40°C respectively. At different temperatures RT was also significantly different, but while RT increased progressively with increasing ET the overall difference was only 0.3°C. RT again varied significantly ($P < 0.01$) with breed, the Toggenburg was slightly lower than Saanen (39.4 vs 39.6°C respectively), presumably as a consequence of their higher RR. RT increased progressively with time during exercise ($P < 0.001$) by an increment of 1.3°C after 30 min. Between breeds, RML was higher in the Toggenburg

than the Saanen; at ambient temperatures of 20, 30 and 40°C the respective differences were 46, 76 and 194 mg/min respectively. RML also increased from 156.5 mg/min before exercise to 576.1 mg/min after it ($P < 0.001$). PCV increased during exercise from 32.7 to 35.2 % ($P < 0.05$).

Experiment 14 studied the effects of treadmill exercise on the RML of different breeds, and showed that RML/breath differ significantly ($P < 0.05$), and also decreased gradually by 4.0 and 6.5 mg/breath after 60 min exercise in Saanen and Toggenburg goats respectively. Correlations between RML and RR in Saanen and Toggenburg goats were 0.8 and 0.9 respectively. Both PCV and Hb declined significantly ($P < 0.05$) during exercise by an average of 5.5 percentage points and 1.5 g/dl respectively.

Results from Experiment 16 on the effects of treadmill exercise on cutaneous moisture loss, indicated that Toggenburgs responded most in terms of LSR; particularly in the first 20 minutes of exercise when values increased sharply to 80 g/m²/h. Then followed the Anglo Nubian and Saanen with respective values of 64 and 65 g/m²/h ($P < 0.01$). RSR did not differ significantly between breeds, but ESR did ($P < 0.05$), with the Saanen being most stressed (56.2 g/m²/h) compared to the Anglo Nubian and Toggenburg (55.0 and 50.3g/m²/h respectively). The absolute differences were, however, very small, and of doubtful thermoregulatory significance.

The above patterns recorded in the hotroom supported the field results, in which RR increased markedly during ploughing ($P < 0.01$) to reach overall means of 83 breaths/minute. In the field, values declined gradually during the recovery period to mean rates after 30 and 60 minutes of 63 and 48 breaths/minute. For RT, there was a consistent trend for values in Bali-cattle to exceed those of buffalo by a mean magnitude of from 0.3 to 0.7°C ($P < 0.05$) during the first 120 minutes, thereafter (150 minutes and recovery period) RT of buffalo exceeded that of cattle by from 0.1 (NS) to 0.3°C ($P < 0.05$). At different times, corresponding ST values increased markedly ($P < 0.01$) to reach overall means of 40.4°C before declining gradually during 30 and 60 minutes of recovery to values of 37.0 and 36.2°C.

A series of experiments was next carried-out to confirm the importance of sweating as a thermoregulatory mechanism during exercise (Experiments 17, 18 and 19). Artificial reduction in the evaporation of sweat by coating (Experiment 17) caused RR to increase gradually with time ($P < 0.05$), with coated animals being more stressed than controls by 5 (NS), 32 and 54/min after 10, 20 and 30 min of exercise. Between breeds, the Toggenburg was more stressed than the Saanen, with mean values of 61 vs 37/min respectively. RT also differed significantly between treatments, coated and control values being 39.2 and 39.0°C respectively ($P < 0.05$). Between times, RT increased by a mean of 1°C after 30 min exercise ($P < 0.001$).

RML differed significantly ($P < 0.001$) between treatments, coating led to higher values than in controls (313.8 vs 246.5 mg/min respectively), indicating that the goats had the capacity to increase RML in order to compensate for a (forced) reduction in SR. With breed, RML did differ ($P < 0.001$); the Toggenburg being more stressed than the Saanen (320.9 vs 239.4 mg/min respectively).

When goats were allowed to inhale air at 45 or 75% RH (Experiment 18), RR was higher ($P < 0.01$) at 75% than at 45% RH (97 and 59/minute after 30 min exercise). RT also differed significantly ($P < 0.05$), with animals being more stressed at 75% than at 45% RH (39.1 vs 38.7°C and 38.9 vs 38.7°C in Saanen and Toggenburg respectively). RML at 75% was higher than at 45% by magnitudes for Saanens of 81mg/min and for Toggenburgs of 138 mg/min ($P < 0.05$). While RML increased gradually, as observed previously, the rate of increase at 75% RH was higher than at 45% RH and after 30 min the respective means were 514 and 341 mg/min. SR at 75% RH was also higher than at 45% RH, although the respective values were only 31.7 and 26.5 g/m²/h ($P < 0.05$). This result indicates that while the goat has some ability to increase SR in response to a limitation placed on RML, that ability is small in absolute terms, and is consistent with the goat being a species with "low" sweating ability.

Sprinkling the skin of goats with water during exercise (Experiment 19) led to significantly lower RR and RT than in controls (both $P < 0.05$), a result which confirms the suggestion that the low natural SR of goats limits their thermoregulatory capacity.

RML was also lower ($P < 0.05$) in sprinkled animals than in controls (by a magnitude of 41.3 mg/min), a result which confirmed the earlier demonstration (Experiments 17 and 18) that in the goat compensation between evaporative cooling avenues does occur when for some reason one or other of them is defective, or blocked. Viewed overall, the major findings of these studies was that sprinkled animals were less stressed (lower RR, RT, RML and SR) than control ones. At the practical (field) level, that results suggests wallowing, or the application of mud or wet hessian to the body of working animals, as practices that would improve thermoregulation, and thus the performance, of draught animals.

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LIST OF ABBREVIATIONS

CS	=	Condition score
DAP	=	Draught animal power
DAs	=	Draught animals
ESR	=	Ear sweating rate
EST	=	Ear skin temperature
ET	=	Environmental temperature
Hb	=	Haemoglobin
LSR	=	Loin sweating rate
LST	=	Loin skin temperature
LW	=	Live weight
PCV	=	Packed cell volume
RML	=	Respiratory moisture loss
RR	=	Respiration rate
RSR	=	Rump sweating rate
RST	=	Rump skin temperature
RT	=	Rectal temperature
SR	=	Sweating rate
ST	=	Skin temperature