

Influence of environmental temperature on prolificacy of pigs

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Summary. Exposure of male and female pigs to elevated ambient temperatures can result in reduced reproductive efficiency. When boars and gilts are exposed to heat stress, respiratory rates increase to enhance evaporative cooling because minimal sweating occurs.

During early pregnancy, gilts are especially susceptible to heat stress. Decreased conception rates and reduced litter size occur when gilts are exposed to elevated ambient temperature during Days 0 to 16 after mating. Concentrations of progesterone in peripheral plasma were reduced during Days 13–19 after mating and luteal function was extended to Day 25 in heat-stressed gilts that did not conceive. Increased concentrations of oestradiol during Day 10 to 12 of heat stress may interfere with normal maternal recognition of pregnancy. Heat stress reduced the amount of embryonic tissue present at Day 16 of pregnancy but the protein synthetic activity of the tissue was not altered. Thus some embryos may be lost and a reduction in litter size may occur. The production of oestrogen by the conceptus and uterus is not altered on Day 16, after exposure to heat stress for the previous 8 days. These studies suggest that heat stress during early pregnancy can alter the reproductive endocrine system, especially the control of luteal function. In addition, heat stress may have a direct effect on embryo or conceptus development.

Exposure of boars to elevated ambient temperatures causes reductions in semen quality, sperm output and fertility. About 5 weeks are required for boars to recover from the detrimental effects of heat stress and to produce semen with potential for maximal fertility. Increased temperature has an inhibitory effect on spermatid maturation and on testicular androgen biosynthesis. Improvements in reproductive performance can be achieved by increasing evaporative cooling of boars.

Introduction

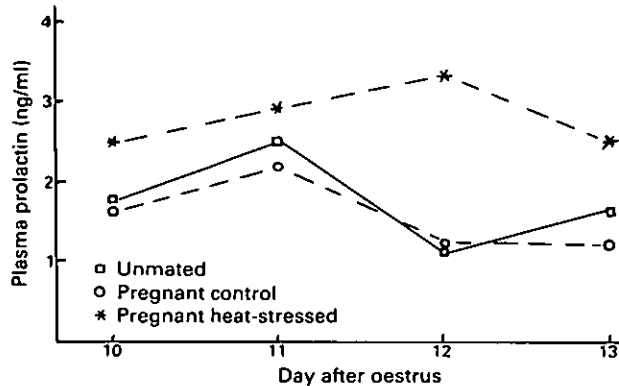
In most mammalian species, exposure of breeding animals to elevated ambient temperatures markedly reduces reproductive performance. This detrimental effect of heat stress is especially critical in subtropical and tropical areas of the world where temperatures are elevated during several months of the year. The reduced reproductive efficiency associated with heat stress may be due to a direct effect of increased temperature on gametes, embryos or uterine function, or heat stress may have an indirect effect by alterations of the endocrine system. Transport of gametes and embryos in the reproductive tract, uterine secretions or conceptus development could be influenced by altered endocrine secretions.

Decreased conception rates and increased embryonic mortality after exposure of females to elevated ambient temperatures have been observed in rats (Fernandez-Cano, 1958), ewes (Alliston, Egli & Ulberg, 1961; Dutt, 1963), cows (Stott & Williams, 1962; Dunlap & Vincent, 1971; Thatcher, 1974; Ingraham, Gilette & Wagner, 1974) and gilts (Warnick *et al.*, 1965; Tompkins, Heidenreich &

longer than 60 days (pseudopregnancy) only occurred when oestradiol benzoate was given daily on Days 11–15. In addition, sows are more resistant to the detrimental effects of exogenous oestradiol on embryonic survival when given on Days 12 and 13 after mating than on Days 9 and 10 (Pope & First, 1985). An alteration in the time of the oestradiol increase in heat-stressed gilts may therefore be related to increased embryonic losses.

Luteal function may be altered by heat stress of gilts during recognition of pregnancy. Since prostaglandins are luteolytic in pigs (Hallford, Wettemann, Turman & Omtvedt, 1975; Moeljono *et al.*, 1977), 13,14-dihydro-15-keto-prostaglandin F (PGFM) was measured in control unmated, control pregnant and heat-stressed pregnant gilts during 12–16 days after oestrus. The maximum concentration of PGFM was greater in control unmated gilts (2042 pg/ml) than in the control pregnant (1111 pg/ml) or heat-stressed pregnant (1227 pg/ml) gilts during Days 13–16 after oestrus. Average concentrations of PGFM were slightly greater ($P > 0.10$) in control unmated gilts (726 pg/ml) and heat-stressed pregnant gilts (646 pg/ml) than in control pregnant gilts (424 pg/ml). Concentrations of PGFM were > 1 ng/ml on at least 1 day between Days 13 and 16 after oestrus in 20% of the control pregnant gilts, 60% of the heat-stressed pregnant gilts and all of the control unmated gilts. These results suggest that recognition of pregnancy may be altered by heat stress and PGF is released from the uterus into the venous circulation.

Concentrations of prolactin in the serum of cattle are correlated with ambient temperature (Wettemann & Tucker, 1974). When gilts were exposed to 32°C during Days 8–16 after mating, concentrations of prolactin in plasma were increased compared with concentrations in pregnant and unmated gilts exposed to 21°C (Fig. 2). Whether this alteration in prolactin is related to reproductive function is unclear.



Text-fig. 2. Concentrations of prolactin in the saphenous artery of pregnant control, unmated control and pregnant gilts exposed to heat stress during Days 8 to 16 after oestrus.

Embryonic degeneration after implantation in rats may be induced by hypoxia (Fernandez-Cano, 1958). The composition of blood gases during exposure of gilts to elevated temperatures may be altered since heat-stressed gilts have greatly increased respiratory rates. Heat stress of gilts during Days 8–16 after mating resulted in increased rectal temperatures but the partial pressures of O_2 and CO_2 in the saphenous vein, saphenous artery and uterine-ovarian vein were not influenced by treatment. Pigs do not shift to a second phase of respiration in response to heat stress, as do cattle and sheep (Curtis, 1983). Thus, alveolar ventilation rate is not altered, so less CO_2 is lost through the lungs and dramatic changes in CO_2 in blood do not occur. Although the partial pressures of blood gases were not altered by heat stress, arterial blood pH was increased in the heat-stressed gilts during the period from 9 to 13 days after mating. This increase in pH may be an

indicator of non-respiratory alkalosis. The lack of a change in blood gases, and the minor transient changes in blood pH during heat stress of gilts indicate that these are not major factors related to embryonic mortality.

Heat stress may influence embryonic survival by altering uterine blood flow. Ford & Christenson (1979) observed uterine blood flow during Days 12 and 13 of pregnancy. Blood flow was measured with an electromagnetic transducer on Days 8–14 after oestrus in the uterine artery of control unmated, control pregnant and heat-stressed pregnant gilts (Table 1). There was a treatment \times day effect on blood flow ($P < 0.06$). Flow was increased in control pregnant and heat-stressed pregnant gilts on Days 11 and 12 compared with the rate on Day 8. However, blood flow in unmated gilts on Days 11 and 12 was slightly less than on Day 8. During Days 8–14, uterine blood flow was not significantly different between control pregnant and heat-stressed pregnant gilts. These results suggest that altered blood flow to the uterus is not a major cause of embryonic mortality in heat-stressed gilts during recognition of pregnancy.

Table 1. Influence of heat stress and pregnancy on the percentage change* in uterine arterial blood flow of gilts†

Day after oestrus	Treatment		
	Unmated	Pregnant, control	Pregnant, heat-stressed
9	72	111	104
10	104	148	92
11	82	158	148
12	96	174	260
13	155	132	236
14	188	216	155

* Percentage change in blood flow from Day 8 after oestrus.

† Treatment \times day effect ($P < 0.06$); 4 gilts per treatment.

Uterine and embryonic responses to heat stress

Exposure of gilts to elevated ambient temperatures during Days 8–16 after oestrus affected embryonic tissue. Wet weight of the embryonic tissue from heat-stressed gilts on Day 16 of pregnancy was reduced compared with the tissue recovered from control gilts (Table 2). Percentage dry weight of the embryonic tissue was not influenced by heat stress, but the amount of [^3H]leucine incorporated into macromolecules during a 24-h incubation of the embryonic tissue recovered from one horn was reduced for the heat-stressed gilts compared with control gilts. This suggests that heat stress of gilts between Days 8 and 16 after oestrus reduced the amount of embryonic tissue present at Day 16 but the protein synthetic ability of the tissue was not altered. Heat stress during blastocyst elongation and recognition of pregnancy usually has a minimal effect on pregnancy rate but embryonic mortality is increased (Omtvedt *et al.*, 1971).

Pregnant gilts that were exposed to heat stress (Days 8–16) had a similar amount of protein and prostaglandin F in uterine flushes on Day 16 as did control pregnant gilts (Table 2). Similar to other reports (Zavy, Bazer, Thatcher & Wilcox, 1980), protein and prostaglandin F content of uterine flushes of pregnant gilts was greater than that of unmated gilts on Day 16.

Uterine endometrium at Day 16 of pregnancy was not influenced by heat stress during Days 8–16 after oestrus. Percentage dry weight of the tissue and the incorporation of [^3H]leucine into macromolecules by uterine explants during 24 h were similar for control and heat-stressed pregnant gilts. Qualitative and quantitative analyses of media by two-dimensional polyacrylamide gel

Table 2. Characteristics of uterine flushings and embryos at day 16 after oestrus from control and heat-stressed pregnant gilts and from unmated gilts

	Pregnant		
	Control	Heat-stressed	Unmated
No. of gilts	5	5	5
Flushings			
Total volume (ml)	58.5 ± 4.0	61.9 ± 3.8	59.9 ± 2.4
Total protein (mg)	206 ± 12	210 ± 24	106 ± 16
Total prostaglandin F (ng)	2485 ± 335	2891 ± 672	189 ± 75
Embryo			
Wet weight—one horn (mg)	336 ± 75	233 ± 66	—
³ H]Leucine incorporated (c.p.m. × 10 ⁶)	1.18 ± 0.24	0.55 ± 0.21	—
³ H]Leucine incorporated (c.p.m. × 10 ³ /mg dry wt)	39.8 ± 7.6	38.6 ± 12.8	—

electrophoresis, after incubation of embryos and endometrial tissue from control and heat-stressed gilts for 24 h, revealed no effect of heat stress on protein synthesis. If heat stress alters uterine function in gilts, more sensitive techniques are needed to identify the effects.

Oestrogens in uterine flushings on Day 16 after oestrus should indicate if functions of the embryos and uteri are altered by heat stress. Total oestrone, oestradiol and oestrone sulphate were similar for pregnant control and heat-stressed (Days 8–16) gilts. These results indicate that the embryos and uteri from heat-stressed gilts have steroidogenic abilities similar to those of normal pregnant gilts.

Heat stress during mid- and late gestation

Exposure of gilts to elevated ambient temperatures during Days 53 to 61 after mating did not influence conception rate, litter size, piglet birth weights or survival rates (Omtvedt *et al.*, 1971). Although growth rate of the fetus is not very rapid at this time (about 8 g per day; Ullrey, Sprague, Becker & Miller, 1965; Knight, Bazer, Thatcher, Franke & Wallace, 1977), uterine weight and amniotic and allantoic fluid volumes are increasing rapidly (Knight *et al.*, 1977). Peripheral concentrations of progesterone are constant at this time and amounts of oestrogens produced by the fetal-placental unit are minimal compared with amounts in late gestation (Knight *et al.*, 1977). At this period when the fetus is only about 10% of birth weight and placental steroidogenic function is minimal, heat stress of pregnant gilts is not detrimental to normal development.

Heat stress of gilts during later gestation increases fetal mortality. Exposure of gilts to heat stress during 102–110 days of gestation increased the number of dead pigs in litters from 4 to 46% (Omtvedt *et al.*, 1971). Piglet weights at birth and at 21 days of age were not significantly influenced by treatment, but pigs from heat-stressed gilts tended to be lighter. During this time period, pigs gain about 25 g per day (Ullrey *et al.*, 1965; Knight *et al.*, 1977) and production of oestrogens by the fetal-placental unit is increasing. Requirements of the fetus for nutrients and gaseous exchange are maximal and deficiencies may result in abnormal development or fetal death. Pregnant females during late gestation are also more susceptible to exhaustion and death after exposure to elevated ambient temperatures (Omtvedt *et al.*, 1971).

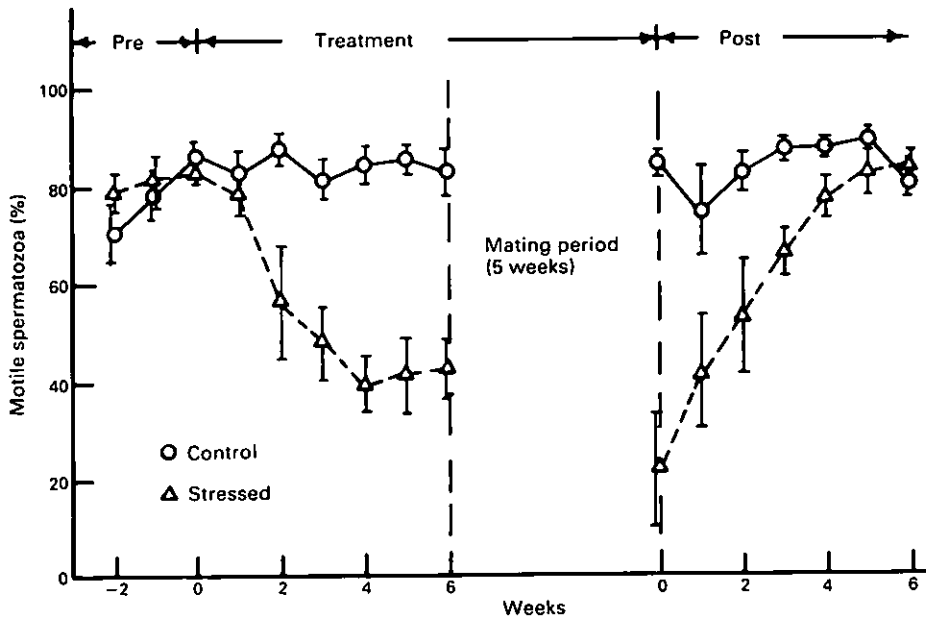
Heat stress of boars

The effects of heat stress on reproductive efficiency of boars is especially apparent compared with

males of other species because boars have minimal increases in sweating due to thermal stress (McNitt, Tanner & First, 1972). Characteristic responses observed in several mammalian species after prolonged exposure to whole body heat are: ejaculation of a large proportion of spermatozoa with reduced motility and increased morphological abnormalities, decreased sperm output, reduced fertility and interference with spermatocyte and/or spermatid maturation.

Exposure of boars to elevated ambient temperatures results in increased respiratory rates and rectal temperatures. Semen volume and gel weight per ejaculation are not altered by heat stress (6 weeks) but sperm motility and percentage normal cells with non-aged acrosomes are decreased and the percentage of abnormal cells and cells with aged acrosomes are increased (Wettemann *et al.*, 1976). Exposure of boars to heat stress for 3 days resulted in similar effects on semen quality (McNitt & First, 1970; Christenson *et al.*, 1972).

Recovery of semen quality after heat stress of boars is a gradual process (Wettemann, Wells & Johnson, 1979). At least 5 weeks after the end of exposure of boars to heat stress was required before the percentage motile spermatozoa was similar for control and stressed boars (Fig. 3). There is also a lag (2 weeks) from the initiation of heat stress until motility is reduced (McNitt & First, 1970; Wettemann *et al.*, 1979). This suggests that spermatozoa in the epididymis are more resistant to heat stress than are spermatozoa in the testis, or that epididymal function may not be altered until after several days of heat stress.



Text-fig. 3. Percentage motile spermatozoa from control and heat-stressed boars before, during and after exposure to elevated ambient temperature.

Fertility of heat-stressed boars is reduced (Wettemann *et al.*, 1976, 1979). When gilts were artificially inseminated with semen from heat-stressed boars (Exp. 1) or naturally mated with heat-stressed boars (Exp. 2) conception rate was reduced (Table 3). Embryo survival (the number of embryos present at Day 30 divided by the number of corpora lutea) was only influenced by heat stress when gilts were inseminated artificially. With artificial inseminations, 6×10^9 total spermatozoa in 100 ml of extender from an ejaculate were used on the first and second days of

Table 3. Fertility of gilts artificially inseminated or naturally mated with control or heat-stressed boars

Exp.	Treatment	No. of boars	No. of gilts mated	Gilts pregnant at 30 ± 3 days	
				%	% embryo survival*
1	Artificial insemination				
	Control	6	88	41	71 ± 4
	Heat-stressed	6	77	29	48 ± 5
2	Natural mating				
	Control	6	37	82	82 ± 2
	Heat-stressed	6	40	59	79 ± 4

* Number of embryos present at Day 30 divided by the number of corpora lutea.

oestrus. Sperm cell quality may not influence litter size at 30 days after mating when excess fresh spermatozoa are deposited by natural mating, but heat stress of boars may reduce litter size with artificial insemination.

The detrimental effects of heat stress on boar reproductive function are the result of an alteration in sperm production and testicular androgen biosynthesis (Wettemann & Desjardins, 1979). Exposure of boars to elevated ambient temperatures causes a transitory decline in concentrations of testosterone in plasma and testicular androgen biosynthesis is altered. Heat stress causes a suppression in spermatid maturation and sperm output is reduced (Wettemann *et al.*, 1979).

Evaporative cooling of boars

Evaporative cooling of pigs is limited unless water is sprinkled on the body because sweating is minimal. To determine the effectiveness of sprinkling as a method to alleviate heat stress of boars, animals were maintained with shade or a shade plus a sprinkler during the summer in Oklahoma (low humidity) and Florida (high humidity; Wettemann *et al.*, 1982). Boars that were sprinkled had respiratory rates less than 32/min in Oklahoma and 59/min in Florida, whereas the rates of boars with shade attained 147 and 136 breaths per minute in Oklahoma and Florida, respectively. Temperature humidity index, ambient temperature and black-globe temperature were correlated ($P < 0.001$) with respiratory rate of the shaded boars at both locations but not with the respiratory rate of boars that were sprinkled. These results indicate that heat stress can be reduced by sprinkling boars to increase evaporative cooling even in environments with elevated relative humidity.

Table 4. Fertility of gilts mated during August to boars maintained with shade, shade and sprinklers or at 21°C from May through October

Treatment	No. of boars	No. of gilts mated	Gilts pregnant at 30 ± 3 days	
			%	No. of embryos
Shade	6	34	44	11.8 ± 0.6
Shade and sprinkler	6	36	64	10.6 ± 0.5
Cool room (21°C)	6	31	68	10.4 ± 0.7

Fertility of boars can be improved by evaporative cooling. When boars (N = 6) were maintained in outside lots with a shade and a sprinkler from May until October in Oklahoma, respiratory rate was reduced compared to boars (N = 6) in outside lots with only a shade. Respiratory rate of boars with a shade and sprinkler was similar to that of boars (N = 6) in a building maintained at 21°C. When boars received only shade, 44% of the gilts naturally mated in August were pregnant 30 days after breeding (Table 4). If boars were sprinkled in addition to shade, 64% of the gilts became pregnant. The maintenance of boars at 21°C did not result in a significant improvement in fertility compared with boars having both shade and sprinklers. Litter size for the pregnant gilts at 30 days after natural mating was not significantly influenced by treatment.

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