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Parameters for the determination and evaluation of heat stress in dairy cattle in South Africa

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ABSTRACT

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Not all parameters are trustworthy and practical to use as parameters to determine heat stress in dairy cattle. The temperature-humidity index (THI) is still the best, simplest and most practical index (parameter) for measurement of environmental warmth which cause heat stress in dairy cattle. It is practical, easy to determine and relatively trustworthy to use body temperature and respiratory rate as parameters to determine heat stress in dairy cattle. These physiological parameters must always be used together with THI values to determine and evaluate heat stress in dairy cattle.

For practical purposes, plasma cortisol concentration and milk composition cannot be used as parameters to determine heat stress in dairy cattle although good indications of acute or chronic heat stress can be obtained. Vanillic acid is a break-down product of adrenalin found in milk, but before its concentration in milk can be used as an indicator/parameter of heat stress in dairy cows, more about the pharmacodynamics of adrenaline in the milk has to be known. Selection and breeding of dairy cows on the basis of their adaptibility to heat stress using the most practical heat stress parameters will ensure that their offspring will have superior performance in the prevailing environmental conditions.

Keywords: Body temperature, cortisol, heat stress parameters, respiratory rate, temperature-humidity index, vanillic acid

INTRODUCTION

Heat stress in dairy cattle can be measured because there is a change in metabolic rate of normal equilibrium in response to an increased change in ambient temperature. Stress, in its physical sense, cannot easily be measured in a biological system, but specific manifestations of the stress, such as changes in body temperature, heart rate and respiration can be measured because the animal responds functionally to maintain homeostasis. Maintenance of homeostasis prior to the stress or the adjustments of this state to a new level of physiological integration can be brought about by the integrated actions of a number of mechanisms in which the nervous and endocrine systems both play important roles (Yousef, 1985a).

Abiotic environmental factors which have an important influence on productivity of dairy cows are air temperature, humidity, solar radiation and wind. The impact of hot environments can be severe, particularly for high-producing dairy cattle. A good index, the temperature-humidity index (THI), for measurement of environmental warmth and its effects was developed for cattle (Kibler, 1964). The humidity factor is the reason for the frequent use of the THI which was established for Holstein cattle (Berry, Shanklin & Johnson 1964).

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According to Johnson (1985), there are increases or decreases in the physiological responses to high seasonal temperatures with regard to growth, milk composition, milk yields and reproduction. The hormones associated with heat loss functions and water regulation of dairy cattle which experience heat stress tend to increase, whereas colorigenic pituitary and target organ hormones decrease and growth rate reproductive and milk production performance decline. Adrenaline is primarily synthesized and stored in the adrenal medulla, it is secreted into the circulation and acts on distant organs during stress situations. Adrenaline provides a rapid physiological response to emergencies such as cold, fatigue and shock. Both circulating adrenaline and noradrenaline induce metabolic effects, including glycogenolysis in the liver and skeletal muscle, and an increase in circulating free fatty acid levels as a result of stimulation of lipolysis in adipose tissue. Many investigators have demonstrated the importance of catecholamines, i.e., adrenaline, noradrenaline, dopamine, serotonin and histamine in mammalian thermoregulation. Short-term exposure to heat stress increases plasma levels of noradrenaline in ungulates (Yousef & Johanson 1985). Exposure to heat (35 °C) for 24 days causes high and sustained plasma levels of adrenaline and noradrenaline in cattle (Alvarez & Johnson 1973). Appropriate behavioural patterns will follow these physiological changes.

In nature, the main force responsible for selection is the survival of the fittest in a particular environment. Natural selection is of interest because of its effectiveness and the scientific principles involved. There is a tendency for nature to select against the weaker ones, and only the stronger survive to reproduce the species. Artificial selection increases the frequency of desirable genes, or combinations of genes according to human needs, in the herd by locating and saving for breeding purposes animals with superior performance or which have the ability to produce superior performing offspring when mated with animals from other lines. Natural selection leads in the long run to an improved genetic acclimatization to the prevailing environmental interactions. Both the environment and heredity cause phenotypic variation in quantitative traits in dairy cows. The genotype of the dairy cow is fixed at conception and remains constant throughout the individual's life. Adaptability of the dairy cow to heat stress depends on the adjustments made by the cow to cope with the changing environmental conditions (Johansson & Rendel 1972).

The present work is an attempt to describe and evaluate body temperature, respiratory and heart rate, plasma cortisol, somatic cell count (SCC) in the milk, milk composition, vanillic acid, and temperature-humidity index (THI) as parameters which can be used to determine heat stress in dairy cattle. The most practical parameter/s to use under South African circumstances are determined.

MATERIALS AND METHODS

Calculation of THI values as an index of heat stress

The THI index for cattle was calculated as follows (Bosen 1959; Kibler 1964):

$$\text{THI} = \text{tdb} + 0{,}36\ \text{tdp} + 41{,}2$$

where tdb = dry-bulb temperature in °C (maximum temperature at 14:00)

tdp = dew-point temperature in °C

The dew-point temperature is the temperature at which condensation first occurs when an air-water vapour mixture is cooled at constant pressure and is calculated as follows:

tdp = dry-bulb temperature at 14:00 minus wet-bulb temperature at 14:00.

This value is used in the hygrometric table (Weather Bureau, Department of Transport) to arrive at the correct atmospheric pressure (mb) for the corresponding tdp. The meteorological data to calculate the THI values were obtained from the Onderstepoort Veterinary Institute weather data recording system.

Classification of THI values

The Livestock Weather Safety Index (LWSI) of the Livestock Conservation Institute (1970) was used as a basis for classifying the various categories of the THI values (Table 1).

TABLE 1 Livestock Weather Safety Index (LWSI) categories according to the temperature-humidity index (THI) values

THI value	LWSI category
70 or less	Normal
71–78	Alert
79–83	Danger
83 or above	Emergency

Body temperature, respiratory and heart rate

Differences in body temperature (rectal temperature) and respiratory and heart rates of the same ten lactating Holstein-Friesian cows which experienced heat stress during February 1998, (THI > 70, 10-day period) and which did not experience heat stress during June 1998 (THI < 70, 10-day period) with different daily THI values and ambient temperature (14:00) at Bethal, Mpumalanga Province, South Africa (latitude 26°27'S, longitude 29°29'E and altitude 1663 m) were determined.

Plasma cortisol, somatic cell count (SCC) and milk composition

Two random groups of lactating Holstein-Friesian cows selected according to milk yield, lactation stage and average daily milk yield (ten in the experimental and ten in the control group) which experienced heat stress at Baberspan, North West Province, South Africa (latitude 26°33'S, longitude 25°36'E and altitude 1 350 m) were used to determine the effect of direct evaporative cooling via spraying (wetting) and air movement on the plasma cortisol concentrations and milk composition for five consecutive days. The experiment started 4 weeks after initial direct evaporative cooling of the experimental group of cows. The cows were kept in two camps adjacent to each other. The herd was machine-milked three times a day. The camp in which the experimental group of cows were kept was provided with artificial shade (8 m^2 per cow) while other camp containing the control group was without shade. The cows received an appropriate quantity of a complete dairy ration twice a day.

The following equipment was used for direct cooling of the dairy cows before milking (14:00–15:00):

- Four 800-mm axial flow fans, direct driven by a 1,1 kW electrical motor (380 V), with a capacity of 5 m^3/s.
- Spray nozzles with a 180° pattern each with a delivery of 14,7 ℓ/min at 150 kPA (1,5 Bar) pressure. A total of 42 nozzles were used.
- A 2 500 ℓ water reservoir.
- A 4 kW (350 V) centrifugal pump with a glycerol pressure gauge.
- 50 mℓ O.D. Class 6 PVC pipe, connectors and saddles.

The pipes and nozzles were fixed underneath the shade structure, at a height of 3,0 m above ground level. Two fans were placed on each side of the square holding yard and constructed at an angle of 30 ° inwards. The height of the fan construction was also 3,0 m above ground level. The choice of the spray nozzles was very important to ensure big droplets of water. This, together with the correct spacing and pressure, ensured that the cows would be wet to the skin. Too small droplets would have tended to overheat the cows as they would not have penetrated their hair coat.

Cooling of the cows was followed, 20 min before milking each day at 12:30 if the ambient temperature rose to or above 27 °C:

- Spray nozzles – 30 s on
- Fans – 5 min on

Only one cycle of cooling was used in this experiment regardless of the temperature for the rest of the day. It is important to use high quality water for cooling, because salt deposits on a cow's skin can cause health problems. The run-off water from the cooling process can be re-used to flush dung alleys or passages. About 310 ℓ of water were used per day for the one cooling cycle. The specific holding yard could accommodate 60 dairy cows, which meant a water usage of 5 ℓ of water per day per cow.

The Coat-A-Count (Diagnostic Products Corporation, USA) Cortisol radio-immuno-assay method was used for the quantitative measurement of cortisol (hydrocortisone, Compound F) in plasma.

The SCC was determined by the Fossomatic 90 (Foss Electric, Denmark) and the milk composition by the Milko-Scan 130 (Foss Electric, Denmark).

Differences in plasma cortisol concentrations, butterfat and protein for cooled and non-cooled dairy cows were compared by analysis of variance by using the Systat (SPSS Science Products, USA) statistical package.

Catecholamines: vanillic acid (4-hydroxy-3-methoxybensoic acid) in milk

The relation between the concentration of vanillic acid in the milk and of adrenaline in the blood of three Holstein-Friesian lactating cows was determined. Two Holstein-Friesian cows were injected intramuscularly with 5 mg of adrenaline (as batartrate, 1:000) and milked (100 mℓ composite milk sample per cow), 5, 10 and 15 min later. These samples were used to develop the initial chemical method. An important step in chemical method development is the selection of a detector capable of detecting relevant concentrations and these concentrations can only be estimated. Assuming an average dairy cow has a body mass of 550 kg and an equal distribution of adrenaline over its mass, then the vanillic acid concentration in its milk could be 9 $mg\ell^{-1}$. Based on these estimates, it was decided that a method capable of detecting 3 $mg\ell^{-1}$ would be sufficient for the vanillic acid determination experiments.

The methods for determination of vanillic acid in milk consisted of:

- Removal of the proteins from the milk
- Extraction of the carboxylic acids
- Derivatization to form either trimethylsilyl (TMS) or pentafluorobenzyl bromide (PFBB) derivatives
- Capillary gas chromatography (GC) with flame ionisation detection (FID) or electron capture detection (ECD).

Differences in body temperature and respiratory rate for heat-stressed and non-heat-stressed dairy cows

TABLE 2 Daily mean body (rectal) temperature, respiratory and heart rate of lactating Holstein-Friesian dairy cows during heat stress (*n* = 10) and no-heat stress (*n* = 10) periods in 1998 according to the temperature-humidity index (THI) at Bethal (latidude 26°16'S, longitude 29°31'E and altitude 1663 m)

Heat stress period (THI > 70), February 1998							No heat stress period (THI < 70), June 1998						
Day	Date	Ambient temp. (°C) 14:00	THI	Body temp. (°C) 14:00	Respiratory rate (min)	Heart rate (min)	Day	Date	Ambient temp. (°C) 14:00	THI	Body temp. (°C)	Respiratory rate (min)	Heart rate (min)
1	11.2.98	27,7	73,4	39,2	90	80	1	5.7.98	16,4	55,2	38,5	52	76
2	12.2.98	28,3	72,6	39,8	80	72	2	6.7.98	16,7	56,0	38,7	48	70
3	13.2.98	29,2	75,1	39,5	82	74	3	7.7.98	17,4	56,8	38,5	44	66
4	14.2.98	29,3	75,4	39,3	79	78	4	8.7.98	15,0	53,6	38,8	50	84
5	15.2.98	31,3	76,4	39,6	96	81	5	9.7.98	22,6	63,7	38,4	60	80
6	16.2.98	30,9	77,7	39,7	92	75	6	10.7.98	21,4	62,7	38,6	56	76
7	17.2.98	29,9	75,9	39,2	76	76	7	11.7.98	16,6	56,0	38,5	40	68
8	18.2.98	25,2	72,2	38,9	78	82	8	12.7.98	16,4	55,2	38,6	46	72
9	19.2.98	27,2	73,4	39,3	65	78	9	13.7.98	21,3	62,6	38,5	48	67
10	20.2.98	24,3	70,9	38,8	75	74	10	14.7.98	17,4	56,8	38,4	42	64
Mean		29,1		39,3	81,3	77			18,1	57,9	38,6	49	72

TABLE 3 Daily mean composition of milk and plasma cortisol concentrations for cooled (*n* = 10) and non-cooled (n = 10) lactating cows during a period in summer in 1998 with corresponding temperature-humidity index (THI) values at Baberspan (latitude 26°33'S, longitude 25°36'E and altitude 1350 m)

Day	Date	Ambient temp. (°C) 14:00	THI	Cooled cows					Non-cooled cows				
				Plasma cortisol content nmolℓ$^{-1}$	Milk composition				Plasma cortisol content nmolℓ$^{-1}$	Milk composition			
					Buffer Fat (%)	Protein (%)	Lactose (%)	SCC x 10^3 mℓ$^{-1}$		Buffer Fat (%)	Protein (%)	Lactose (%)	SCC x 10^3 mℓ$^{-1}$
1	1.02.98	36	79,5	65,8	4,9	3,5	5,1	45	35,8	2,7	3,1	5,0	70
2	2.02.98	38	80,5	62,5	4,2	4,1	5,0	55	48,7	3,7	3,1	5,1	188
3	3.02.98	32	76,9	56,7	3,8	3,3	5,0	38	52,4	3,1	3,0	5,0	87
4	4.02.98	27	72,7	51,9	4,0	3,4	5,1	29	44,7	3,4	3,1	5,1	60
5	5.02.98	33	77,6	59,2	4,2	3,6	5,1	61	45,4	3,2	3,1	5,1	159
Mean for 5 days		33,2	77,4	59,2	4,2	3,6	5,1	46	45,4	3,1	3,1	5,1	112

SCC = Somatic cell count

TABLE 4 Diagram of parameters for the determination and evaluation of heat stress in dairy cattle

Factor	Parameter	Determinants
Environment	THI	Dry-bulb temperature Relative humidity Radiation Wind
Animal/dairy cow	Behaviour: comfort-seeking	Suboptimal performance Respiratory rate
	Physiological	Body temperature Respiratory rate Heart rate Milk yield and composition Hormones/metabolites: Plasma cortisol Vanillic acid
	Genetic	Acclimation Acclimatization Adaptation

at Bethal were compared by analysis of variance by using the Systat statistical package.

RESULTS

Body temperature, respiratory and heart rate with corresponding daily THI values

Difference in body temperature, respiratory and heart rate of the ten lactating Holstein-Friesian cows which experienced heat stress and the ten which did not experience heat stress with different daily THI values and ambient temperatures at Bethal are indicated in Table 2. The mean body temperature of the lactating Holstein-Friesian cows at Bethal which experienced heat stress was 39,3 °C versus the 38,6 °C (0,7 °C difference, $P < 0,0001$) of those cows which did not. The mean respiratory and heart rates per min of the cows which experienced heat stress was 81,3 and 77, respectively versus 49 (difference 31,7, $P < 0,0001$) and 72 for cows which did not.

Plasma cortisol, milk composition and somatic cell count (SCC)

Mean plasma cortisol concentrations, and butter fat and protein percentages were higher in the cooled than were those in non-cooled dairy cows (59,2 $\text{nmol}\ell^{-1}$, 4,2 % and 3,6 %, respectively vs 45,4 $\text{nmol}\ell^{-1}$ ($P = 0,319$), 3,2 % ($P < 0,001$) and 3,1 % ($P < 0,001$) at Baberspan, but the SCC was lower in the cooled (46 000/mℓ) than in the non-cooled (112 000/mℓ) cows (Table 3).

Catecholamines: vannillic acid

Initial results indicated the presence of minute quantities (in the $\text{mg}\ell^{-1}$ range) of vanillic acid in normal lactating Holstein-Friesians' milk. With the determination of vanillic acid about 70 % of added vanillic acid could be recovered from milk. Exploratory experiments showed no consequent increase in the vanillic acid of the milk of the cows to which 5 mg of adrenaline had been administered. Some milk samples contained vanillic acid before the cows from which the samples originated were treated with adrenaline, while in others an increase of 30 % in the vanillic acid in the milk was detected after adrenaline treatment.

Classification of heat stress parameters

Heat stress parameters were classified for practical purposes in environmental, behavioural and physiological categories. A diagram in which the parameters for the determination and evaluation of heat stress in dairy cows are explained is given in Table 4.

DISCUSSION

Heat stress is caused by any combination of environmental parameters producing conditions that are higher than the temperature range of the animal's thermal neutral zone (Buffington, Collazo-Arochu, Canton, Pritt, Thatcher & Collier 1981). The survival and performance of an animal during heat stress periods depend on several weather factors, especially temperature and humidity. Extended exposure to excess heat reduces feed consumption, milk production and breeding efficiency (Thompson 1973). Extensive effort has been put into the development of an index in which the effect of a given physical environmental condition is assessed in terms of one or more measurable physiological responses (Yousef 1985b). The development of a single index encompassing all climatic parameters is not available at present.

Heat stress results (THI values) must be interpreted according to the Livestock Weather Safety Index classification as modified for lactating dairy cows with due consideration to the THI values of 72 and 65 which are critical for milk production and the threshold for conception rate, respectively (Du Preez 1992, 1994). The average decline in milk production was approximately 15 % during the period in which the THI was above 72 (Johnson 1980a, 1980b).

Temperature-sensitive neurons are located throughout an animal's body and channel their information to the hypothalamus. The hypothalamus receives the information, integrates it and, by unknown means, invokes physiological, anatomical and/or behavioural changes, which serve to maintain an acceptable heat balance (Curtis 1983). One of the major outflows from the hypothalamus, which is often neglected, is the conscious sensation to either heat or cold. This in itself evokes the first line of defence, namely the behavioural response (Robertshaw 1985).

Various physiological parameters are influenced by adverse climatical conditions and may be used as indicators of climatic stress. The effects of heat on the stimulation of physiological functions can be divided into general responses, heat loss, heat production, neurotransmitter, pituitary hormones, organs and target organs and animal performance. It is readily apparent that an animal's first response to heat is to increase heat loss while simultaneously reducing heat producing functions. These responses depend on the animals genotype, environmental factors such as proper housing or shelter (shelter supposes protection), heat and wind and the presence or absence of adequate feed, diseases and care which can be limiting to its physiology and performance. Parameters that may be useful in the evaluation of heat stress in dairy cattle are rectal (body) temperature, respiratory rate, milk yield and composition, and changes in different hormonal secretions (Johnson 1985; Yousef 1985a).

Environmental factors affecting the exchange of energy between an organism and its environment are sunlight, skylight, thermal radiation, air temperature, air movement and water vapour pressure of the air. Animal properties which affect the exchange of energy are metabolic rate, moisture loss rate, and the geometric structure of fur or hair properties, such as hair colour, density, length, diameter, thickness, transmissivity and absorptivity. The mechanisms affecting energy exchange are conduction, radiation, convection and evaporation (Gebremedhin 1985). The exchange of energy between an animal and its environment affects the body temperature of the animal.

Deep body or core temperature may be measured at several locations and, for practical purposes, the most commonly used site is the rectum (taking the temperature for 1 min). The regulation of core temperature within the zone of thermoneutrality is accomplished by the autonomic control of the tone of the cutaneous vasculature (peripheral vasomotor tone) and by behavioural means, such as changes in posture (Bligh 1985). The normal body temperature of dairy cows varies between 38,3 and 38,8 °C. Various studies under field conditions have demonstrated that body temperature increase with increasing environmental temperatures above 21 °C in European dairy breeds (McDowell 1958).

Any exposure to an environmental temperature outside the thermally neutral zone induces in an animal a response which aims at maintaining deep body temperature within set limits. Death resulting from heat prostration occurs in most species when body temperature reaches 41,5–42,5 °C (Dougherty 1971). If the body temperature rises at an increasing rate until it exceeds 42–43 °C there will be damage to the central nervous system and other structures (heat stroke), with possible fatal consequences (Bligh 1985).

Cattle under most circumstances pant with the mouth closed, but sometimes open, and heat exchange therefore takes place at the mucosa of the upper respiratory tract in the region of the turbinate bone. Heat is contained in the blood supply to the nasal mucosa and the cooled blood drains into the venous sinuses at the base of the skull, where it joins blood draining the ears and horns. There they encircle the rete mirabile, the network of small arteries that makes up the blood supply to the base of the brain. The function of the rete mirabile is as a countercurrent heat exchanger the blood supplying the brain being coolled by the blood draining the nasal mucosa, the ears and the horns.

At high environmental temperatures when panting begins, respiratory rate increases but tidal volume decreases. In extremely hot environments when the body temperature of cattle rises continuously, rapid shallow panting is superseded by a second phase of slower, deeper panting (Ingram & Legge 1969). At high environmental temperatures, an increased respiratory rate is an important way of increasing heat loss by cattle and is usually the first visible sign of heat stress (McDowell 1972). During a hot summer, the respiratory rate of Friesian and Dairy Shorthorn cattle increased (Shafie 1985).

The most obvious effect of heat stress on the cardiovascular function of dairy cattle is an increase in heart rate (normal heart rate is 55–70 per min) with an concomitant increase in cardiac output. Arterial blood pressure decreases under mild heat stress as a consequence of the decrease in total peripheral resistance (Rübsamen & Hales 1985). This decreased arterial pressure stimulates heart rate.

Cortisol is the primary glucocorticoid produced by the adrenal cortex and has a wide variety of physiological actions: it influences metabolism, body water distribution, electrolyte balance and blood pressure. Plasma cortisol concentrations are higher in heat-stressed lactating dairy cows compared to those in lactating dairy cows maintained at 22 °C (Wise, Armstrong, Huber, Hunter & Wiersma 1988). Short-term exposure to heat of heat-stressed cows increased, and long-term exposure decreased plasma cortisol levels (Christison & Johnson 1972). Chronic heat stress is the most likely cause of the decreased plasma cortisol concentrations, and milk butter fat and protein percentages of the non-cooled dairy cows in comparison to those of the cooled dairy cows obtained in the present study (Table 3). Christison & Johnson (1972) have also determined that in chronic heat-stressed dairy cows' plasma, cortisol levels are significantly depressed compared to the values obtained in cows' maintained at thermoneutrality (18 °C). Stott & Wiersma (1974) noted a similar trend in dairy cattle exposed to a hot summer. Prolonged heat exposure of dairy cattle (33,5 °C) results in a general reducing effect of plasma cortisol concentrations (Albilay, Johnson & Madan 1975). The reduced plasma levels of glucocorticoids which occur during heat acclimation are beneficial regulatory mechanisms for reducing the animal's heat production (Yousef & Johnson 1967). Collier, Eley, Sharma, Pereira & Buffington (1981) also found elevated glucocorticoid concentrations during acute but not chronic thermal stress. There is evidence that cortisol and growth hormone both influence mammary metabolism, but details about their actions are incomplete. The available evidence suggests that cortisol may primarily influence glucose supply to the udder (Thompson 1985).

The protein content in milk of dairy cows kept in environmentally controlled rooms at 30 °C in comparison to those of cows maintained at 15 °C, decreases (Bandaranayaka & Holmes 1976). The composition of milk from dairy cows which experience heat stress changes: butter fat is reduced by 20–40 %, non-fat solids by 10–20 % and total milk protein by 10–20 %, whereas somatic cell counts (SCC) increase (Du Preez 1994). The SCC of the cooled dairy cows in the present study were lower than those of the non-cooled cows (Table 3).

Stress in dairy cattle causes an increase in the concentration of adrenaline in their blood (Johnson 1985). Catecholamines do not penetrate the blood-brain barrier (Harper 1973). L-DOPA, the precursor of catecholamines, possibly penetrates this barrier. Adrenaline is eventually metabolized to vanillic acid (Diem & Lentner 1971). This means that if enough adrenaline is transformed into vanillic acid, and if enough of this vanillic acid is transported into the milk, the concentration of the vanillic acid in the milk can be used as an indicator or parameter of stress and, possibly, specifically of heat stress. Compared to the determination of adrenalin in the blood, this vanillic acid indicator could be more reliable because taking a sample of milk usually does not induce stress in a lactating dairy cow, which may occur if blood is drawn. Collecting a milk sample is technically easier and simpler than collecting a blood sample.

CONCLUSIONS

Not all parameters are trustworthy and practical to use as parameters to determine heat stress which can be used to indicate that precautions against heat stress must be taken to help to prevent the deleterious effects of heat stress which hamper dairy cows= performance. The THI is still the best, simplest and most practical index (parameter) for measurement of environmental warmth which cause heat stress in dairy cattle. It is practical, easy, and relatively trustworthy to use body temperature and respiratory rates as parameters to determine heat stress in dairy cattle. These physiological parameters must always be used together with THI values to determine and evaluate heat stress in dairy cattle for management purposes, such as which precautions against heat stress should taken. Be aware of all the other factors (e.g. bringing cows to the milking parlour) which could also increase their body temperatures and respiratory rates.

For practical purposes, plasma cortisol concentration and milk composition cannot be used as parameters to determine heat stress in dairy cattle although good indications of acute or chronic heat stress can be obtained. Reasons for changes in dairy cows' milk compositions are numerous. Before the vanillic acid concentration in milk can be used as an indicator/ parameter of stress (heat stress) in dairy cows, more about the pharmacodynamics of adrenaline in their milk has to be known. The change in the concentrations of these metabolites in milk after the intramuscular injection of adrenaline may give an indication of which of these metabolites are suitable indicators of heat stress.

Selection and breeding of dairy cows using the most practical heat stress parameters with good adaptability to moderate heat stress will ensure that their offspring have superior performance in the prevailing environmental conditions. Elimination of dairy cows which show pronounced inadaptability to moderate heat stress from a known population will in time shift the population to one of superior adapted animals. The greatest short-term improvement in performance within a dairy herd would come from proper attention being given to environmental factors, such as nutrition, management (e.g. prevention and control of heat stress) and disease control.

Abnormal behaviour is absent or minimal in dairy cows well adapted to moderate heat stress. Adaptive capabilities of animals vary and may be influenced by genetics. The selection in breeding programmes of animals with phlegmatic temperaments, or animals that are easily trainable, could be a strategy for acquiring animals that are more adaptable. In genetic terms, this means that animals are selected even further to fit unnatural, human-made environments. In such a programme nervous animals and those which can cope less well with stress in general, will be excluded. However, the welfare implications of this decision should also be taken into consideration. Lack of adaptation can also be evaluated according to stress-related parameters, such as production, performance and reproduction. Furthermore, superficial measurements of stress (e.g. increased pulse and respiration rates, sweating and anxiety) can also be considered. More sophisticated measurements could include the determination of blood levels of metabolites, such as cortisol and adrenalin.

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