WHAT YOU NEED TO KNOW ABOUT HEAT STRESS IN CATTLE TO MANAGE IT!

A BOOKLET BY

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A Bluestar Company

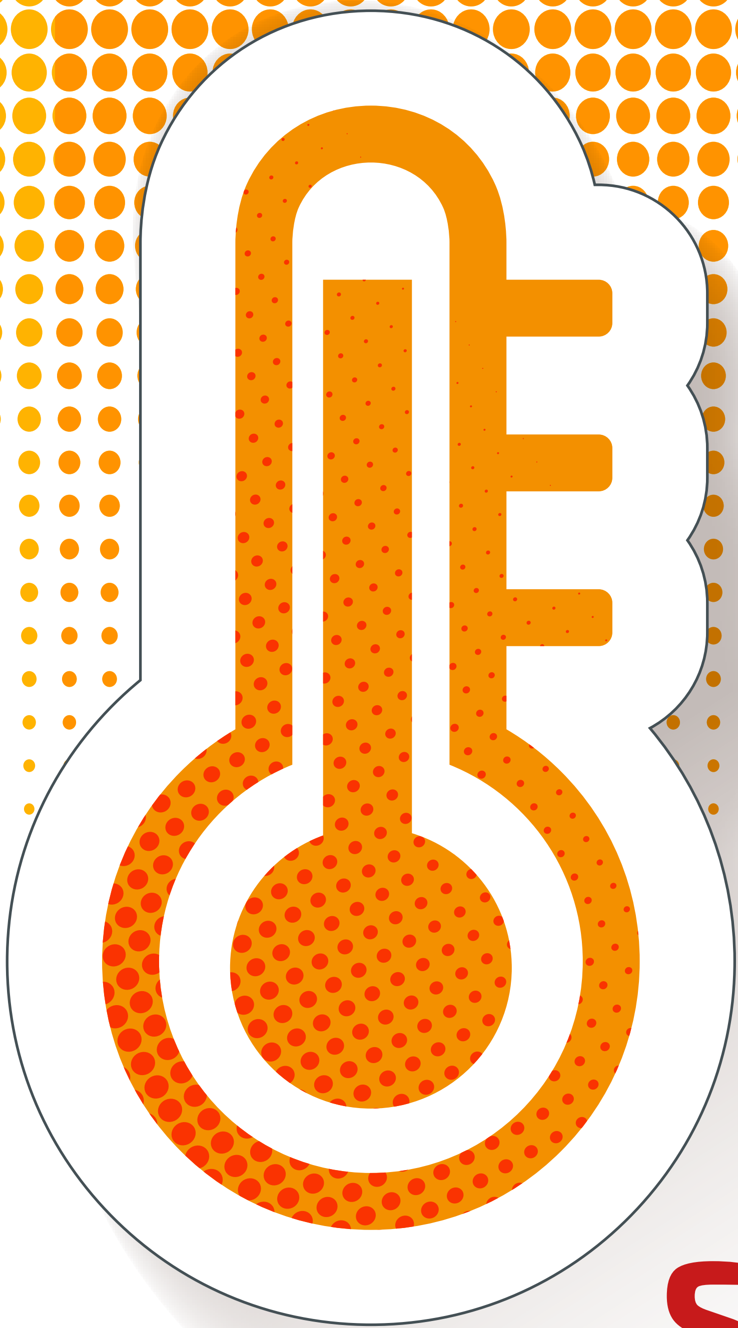
SUMMARY

INTRODUCTION

Unlike other animals, cattle have great difficulty in dissipating their heat loads efficiently, as they do not sweat enough and rely on respiration to cool down. Moreover, the fermentation process that takes place in the rumen generates additional heat that the animal has to dissipate. A heat load therefore accumulates during the day and is dissipated at night when it is cooler. In extreme weather conditions, when the environment at night is insufficiently cool, the animal accumulates heat that it cannot dissipate, thus putting it in a situation of heat stress. Heat stress affects the health and the welfare of herds, as well as their production and reproductive performance.

Heat stress is one of the main challenges livestock farmers have to face. Indeed, over the last quarter of a century, cows, as well as other livestock categories, have mainly been selected on the basis of their productivity performance, and not for their thermotolerance or climate adaptation capacity. As a result, animals have been obtained that are highly productive, but also particularly sensitive to environmental variations and hot conditions. Furthermore, in the context of global warming, which is accompanied by an increase in the frequency of heat waves, this phenomenon is becoming increasingly alarming and is likely to intensify in the coming years.

This little booklet will offer you some keys to understanding heat stress in cows and how to alleviate it in order to limit its negative effects.



WHAT IS HEAT STRESS?

Chapter 1

WHAT IS HEAT STRESS? HOW IS IT DEFINED?

Heat stress refers to the inability of the body to maintain a normal temperature under conditions of high temperature and humidity. An unbalance occurs between the metabolic heat produced inside an animal's body and its dissipation to the surroundings. Animals increase their respiratory rate and consume energy to dissipate excess heat, which contributes to a significant increase in their maintenance requirements.

Modern, high-producing cattle have a relatively small thermal comfort zone: between 5 and 25°C. They can withstand very low temperatures, even as low as -23°C, but they have a very poor resistance to temperatures above 25°C, which can cause heat stress when combined with high humidity, poor air circulation and/or direct sun exposure.
Heat stress can be evaluated through **the Temperature Humidity Index (THI),** which takes into account the ambient temperature and the relative humidity.

$$THI = 0.8 * T + RH * (T - 14.4) + 46.4$$

Mader et al,. 2006

T = Temperature
RH = Relative humidity expressed as a proportion

The higher the THI is, the more cattle need to fight the heat.
Below a THI value of 72, cattle are in a thermoneutral condition and are able to maintain a balance between heat gain and heat loss.

Above values of 72, cattle start to suffer from mild to moderate or even up to severe heat stress, a condition that leads to both metabolic and physiological changes in the body.

WHAT IS HEAT STRESS? HOW IS IT DEFINED?

HEAT STRESS AND TEMPERATURE HUMIDITY INDEX (THI) (Collier et al, 2012)

°F	°C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
72	22.0	64	65	65	65	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71	72	72
73	23.0	65	65	66	66	66	67	67	68	68	68	69	69	70	70	71	71	71	72	72	73	73
74	23.5	65	66	66	67	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73	74	74
75	24.0	66	66	67	67	68	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75
76	24.5	66	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76
77	25.0	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76	77
78	25.5	67	68	68	69	69	70	70	71	71	72	73	73	74	74	75	75	76	76	77	77	78
79	26.0	67	68	69	69	70	70	71	71	72	73	73	74	74	75	76	76	77	77	78	78	79
80	26.5	68	69	69	70	70	71	72	72	73	73	74	75	75	76	76	77	78	78	79	79	80
81	27.0	68	69	70	70	71	72	72	73	73	74	75	75	76	77	77	78	78	79	80	80	81
82	28.0	69	69	70	71	71	72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82
83	28.5	69	70	71	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	82	83
84	29.0	70	70	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84
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92	33.5	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92
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95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	35.5	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96
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98	36.5	76	77	78	80	80	82	83	83	85	86	87	88	89	90	91	92	93	94	95	96	98
99	37.0	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	95	96	98	99
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109	43.0	81	82	84	85	87	89	89	91	92	94	95	96	98	99	101	102	103	105	106	108	109
110	43.5	81	83	84	86	87	89	90	91	93	94	96	97	99	100	101	103	104	106	107	109	110
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112	44.5	82	84	85	87	88	90	91	93	94	96	97	99	100	102	103	105	106	108	109	111	112
113	45.0	83	84	86	87	89	91	92	93	95	96	98	99	101	102	104	105	107	108	110	111	113
114	45.5	83	85	86	88	89	92	92	94	96	97	99	100	102	103	105	106	108	109	111	112	114
115	46.0	84	85	87	88	90	92	93	95	96	98	99	101	102	104	106	107	109	110	112	113	115

EVALUATION OF STRESS IN DAIRY COWS ON THE BASIS OF THI

(ZIMBELMAN et al., 2009; DASH et al., 2016)

THI	Level of stress and impact on livestock /on cows
68-72	**Stress threshold:** Milk yield losses begin, and reproductive losses are detectable. Respiration rate exceeds 60 BPM, Rectal température > 38,5°C
72-80	**Mild-Moderate stress:** Shadow search, increased respiratory rate, peripheral vasodilation. Respiration rate exceeds 75 BPM, Rectal temperature > 39°C"
80-90	**Moderate stress:** Shadow search, decreased appetite, increased respiratory rate and salivation, peripheral vasodilation, increase in body temperature and decreased reproductive performance. Respiration rate exceeds 85 BPM, Rectal temperature > 40°C
90-98	**Severe stress:** Pronounced decrease in reproduction performance, 20% drop in milk production. Respiration rate exceeds 120-140 BPM, Rectal temperature > 41°C.
>98	**Lethal stress:** death of the animal

THE SIGNS OF HEAT STRESS

The visible signs of heat stress result from the physiological and metabolic responses of an animal's organism under heat stress.

Heat stress

Physiological Responses

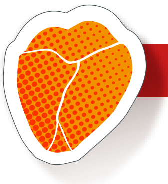
- ↗ Respiration rate
- ↗ Heart rate
- ↗ Body temperature
- ↘ Feed intake
- ↗ Water intake
- ↘ Growth rate

→ Respiratory alkalosis-Metabolic Acidosis
↓
Tissue hypoxia – **Oxydative stress**
↓
Gastrointestinal tract barrier dysfunction
↓
Endotoxemia

Metabolic Responses

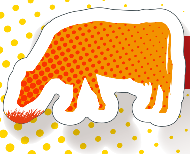
- ↗ Glycolytic potential
- ↗ Anaerobic glycolytic metabolism
- ↗ HSPs
- ↘ Lower thyroid hormone
- ↗ Body fat
- ↗ Protein catabolism

Physiological and metabolic responses to heat stress (Gonzalez-Rivas et al., 2020)



INCREASE IN BREATHING AND IN THE HEART RATE

The respiratory function allows an animal to thermoregulate itself.
The respiratory frequency will therefore increase as the temperature increases, and this is known as superficial polypnea, because the breathing is just superficial. The animal breathes with its mouth open while panting, and its tongue hanging out, and it slobbers due to increased salivation.
The increase in the respiratory rate is accompanied by a rise in the heart rate.
A respiratory rate (RR) > 60/min, associated with a body temperature > 39°C, indicates cows are undergoing a sufficiently high level of heat stress to affect the milk yield and fertility (Das et al., 2016).
If the respiratory rate exceeds 100 breaths per minute, then the animal suffers from hyperpnea, its situation becomes critical and measures must be taken to reduce the stress.



DROP IN FEED INTAKE

As a result of heat stress, an animal losses its appetite, which results in a drop in feed intake and a slower rumination, and this in turn leads to ruminal imbalances and a drop in production.
Reducing the feed intake is one way of reducing the metabolic heat generated during digestion. The feed intake begins to decline at air temperatures of 25-26°C in lactating cows and it may decline by as much as 40% at temperatures of 40°C (Das et al,. 2016). After a heat stress episode, the feed intake takes some time to re-stabilize, even at lower temperatures.

THE SIGNS OF HEAT STRESS

BEHAVIORAL CHANGES

- The lethargic behavior of cows: cattle start to significantly decrease their overall activities to overcome unfavorable environmental conditions. The vital functions are reduced to a great extent. They reduce their movement and remain standing for prolonged periods, which can increase the risk of lameness.
- They remain lying in groups and often in the same place in the shade or around a water point, which promotes mastitis.
- They make more frequent visits to water points.

INCREASE IN THE BODY TEMPERATURE OF BOVINES

Under high heat conditions, cattle, especially lactating dairy cows, create a large quantity of metabolic heat and accumulate additional heat from radiant energy.

Heat production and accumulation, coupled with a compromised cooling capability, because of the environmental conditions, causes a heat load in the cows. As a result, the core temperature of the cattle (which is normally around 38-38.5°C) rises and reaches its maximum two hours after the ambient temperature peak. In order to evaluate this phenomenon, the rectal temperature of the animal is measured.

SWEATING

Thermal sweating is used as the principle evaporative cooling mechanism to dissipate excess body heat and to maintain the body in a thermoneutral zone and in physiological homeostasis when the ambient temperature rises.

An animal dissipates 2.43J of heat for 1 mL of sweat; this is the latent vaporization heat (Kadzere et al., 2002). The sweating rate is positively correlated with an increased blood flow to the skin. Cattle in temperate and tropical regions have the same type of sweat glands, but tropical species and breeds have a higher density of hair follicles, which improves sweating (e.g. *Bos indicus vs. Bos taurus*).

Sweating is obviously accompanied by significant water and mineral losses.

FACTORS THAT INFLUENCE THE SUSCEPTIBILITY TO HEAT STRESS

GENETIC CHARACTERISTICS

- High-producing dairy cows are more sensitive to hot conditions and high humidity since they generate more metabolic heat (linked to their high feed intake), and their zone of thermal neutrality, or 'comfort zone', shifts to lower temperatures. Therefore, they show more severe signs of heat stress than low-producing cows. Moreover, with a similar body size and surface area, lactating cows have significantly more heat to dissipate than nonlactating cows and have greater difficulty dissipating heat.
- Dark-haired cattle suffer more than light-haired breeds.
- Body composition: the fat layer slows down heat dissipation. Late fattening cattle are affected more because of their smaller body surface area relative to their weight.
- Each genotype has a different and characteristic comfort zone from which different physical responses and levels of adaptation to heat stress arise. The "Comfort zone" of *Bos taurus* cattle ranges between 4ºC - 24ºC, whereas the "Comfort zone" of *Bos indicus* (e.g. Zebu) is 10°C to 27°C. As a consequence, the impact of the heat load on female reproduction may be more pronounced in *Bos taurus* cows. However, this does not mean that there are no negative implications for *Bos indicus* cows (Lees et al., 2019). Variations are also observed according to the breed; Jersey cows, for instance, are less sensitive to heat stress than Holstein-Friesians.

PHYSIOLOGICAL CONDITION

Animals that cumulate other stresses, such as diseases, respiratory problems, but also stresses related to calving or the pick of production, are at higher risk for heat stress.

- As the respiratory function is crucial to dissipate heat, cattle that have suffered from severe respiratory disease will have a reduced ability to regulate their heat load.
- Dairy cows are particularly vulnerable to health problems that can be caused by heat stress during the transition period (from late gestation to early lactation). It has been noted that during this period, they are particularly susceptible to oxidative stress, which may contribute to periparturient disorders.

THE HUSBANDRY SYSTEM

Pasture cattle are not as sensitive to heat stress as feedlot cattle. Indeed, they can benefit from shade, water and air movement to cool down. The radiant heat from dirt or concrete surfaces is increased for feedlot cattle. However, indoor farms can benefit from permanent cooling systems and shade.

THE CONSEQUENCES OF HEAT STRESS

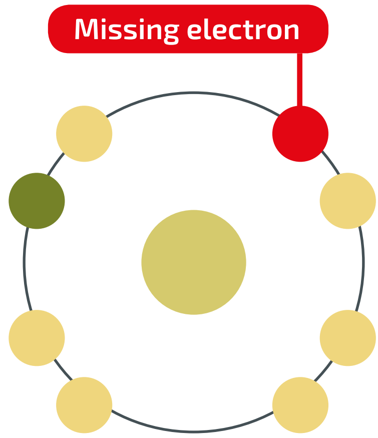
Chapter 2

WHAT HAPPENS
AT THE CELLULAR LEVEL?
FROM HEAT STRESS TO OXIDATIVE STRESS

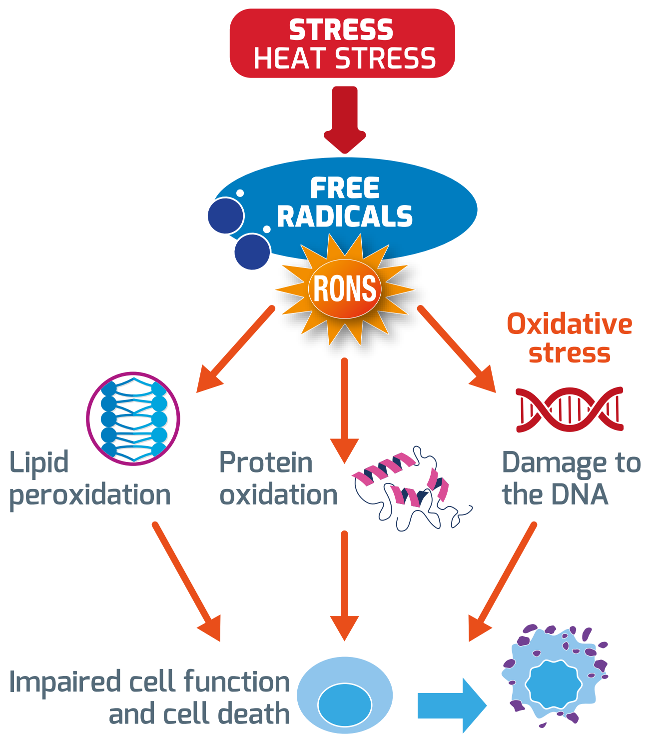
WHAT ARE FREE RADICALS?

These are any molecular species capable of existing independently that contain an unpaired electron in an atomic orbital. This characteristic makes them unstable and highly reactive to the organic constituents and cell structures.

They are involved in the control of a wide variety of redox reactions that are essential for life and growth, and are formed continuously in a healthy body, but they become dangerous when they are produced and/or are present in excess.



THE CELLULAR CONSEQUENCES OF OXIDATIVE STRESS



Any situation of stress, including heat stress, causes oxidative stress, i.e. an imbalance between the excessive amount of free radicals and antioxidants that neutralize free radicals. On the one hand, there is an increase in the flow of free radicals, and on the other hand there is a depletion of the body's reserves of antioxidant compounds, which are the essential part of the defense mechanisms involved in the fight against free radicals and help maintain the redox balance of the body.

The overproduction of free radicals, including reactive oxygen and nitrogen species (RONS), leads to an alteration of the cell components and tissue structures. Indeed, free radical attacks cause:

- **The peroxidation of cellular components (lipids and carbohydrates)**
- **Protein oxidation and protein aggregation**
- **DNA damage and gene codification errors**

This state can in turn alter cellular functions and even cause cell death. Oxidative stress leads to a disruption of the normal metabolism and physiology.

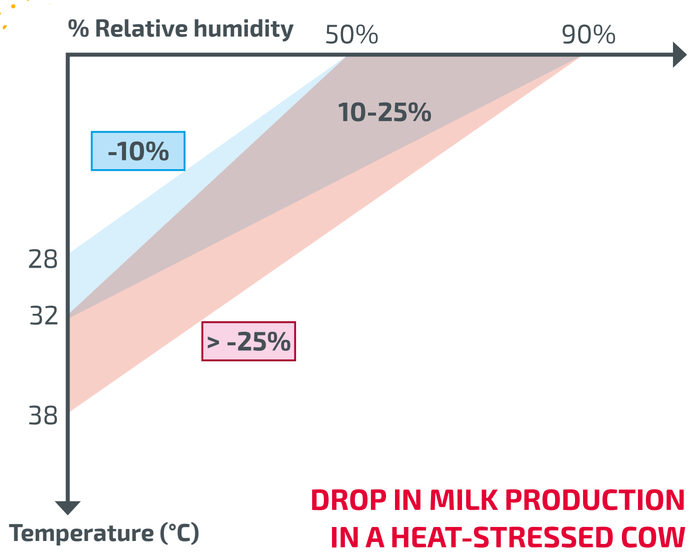
WHAT ARE THE CONSEQUENCES OF HEAT STRESS?

The harmful effects of heat stress are due to the metabolic and physiological changes and to the adaptation that animals put in place when trying to re-establish body homeostasis. These conditions are known to cause oxidative stress.
At the organismal level, oxidative stress compromises the health status of animals and leads to immunosuppression, as well as a drop in the production and reproductive performance.

DROP IN MILK PRODUCTION

Under heat stress, cows reduce their feed intake in order to slow down their metabolism and to generate less heat (as a high feed intake leads to increased metabolic heat). Their milk production, which is closely related to their feed intake, will then drop. Both the yields and the solids content are affected.

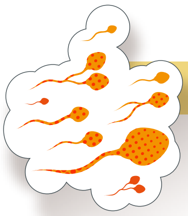
Quantity: The decrease in milk production can be explained by considering several factors, including a reduction in the secretion of the T3 and T4 thyroid hormones (in order to reduce the production of metabolic heat) and the displacement of part of the blood flow to peripheral tissues for cooling purposes, which can alter the nutrient metabolism and thus contribute to reducing the milk production. As a result, heat stress can be responsible for a reduction in milk yield of 10% at temperatures of between 27 and 32°C and 50% to 90% humidity; and a decrease of more than 25% between 32 and 38°C and 50 to 90% humidity. The effects on milk yield as well as on DMI (dry matter intake) are felt two days after a high THI has been recorded.
The milk production of Holsteins decreases on average by 0.88 kg per unit increase in THI and DMI by 0.85 kg for each degree (°C) of average air temperature (West et al,. 2003). More globally, **production losses are estimated at -1 to-4 kg/milk per cow per day of heat stress.**



DROP IN MILK PRODUCTION IN A HEAT-STRESSED COW

Quality: Heat stress impacts milk protein and the fat content. On average, the protein rate decreases from 0,03 to 0,07 kg per day of heat stress, and the fat rate decreases from 0,01 to 0,07 kg (Rhoads et al., 2009; S. Adam, 2019).
In addition, metabolic, hormonal and vascular changes affect the immune defenses, thereby increasing the somatic cell count in milk cows (Wegner et al., 1976; Igono et al., 1988).

WHAT ARE THE CONSEQUENCES OF HEAT STRESS?



DROP IN REPRODUCTIVE PERFORMANCE

The negative effects of summer heat stress on animals may have adverse effects up to autumn, when cattle start to breed. Indeed, heat stress leads to reduced fertility in females. It has a negative impact on:

- Ovarian activity: the development of oocytes throughout the later stages and their fertilizing power. It has been found that follicular growth is disrupted in autumn if summer heat stress has been experienced beforehand. Deregulation of the oestrus cycles and a disrupting activity of the corpus luteum have also been observed.
- Deregulation of the sex hormones.
- The cycle and behavior of the females at oestrus.
- The development and implantation of the embryo: this may result in higher embryonic mortality.
- Foetal and newborn vitality: premature abortions, dystocia, retained foetal membranes (post-calving) and weaker calves.

A decrease in the quality and quantity of sperm is observed in males: in a situation of oxidative stress, radical attacks can alter the fertilizing abilities of the sperm. Consequently, farmers may observe an increased time to first post-partum insemination, an increased number of inseminations per conception, lower conception rates and an increased number of days open.

VARIOUS HEAT STRESS EFFECTS ON COW REPRODUCTION

(from A. Sammad et al., 2019)

Heat stressed cow
Reproductive efficiency ↘

Gestation
- Uterine alterations
- Embryonic losses
- Reduced fœtal growth
- Placental changes
- Abortions and teratologies

General effects
- Compromised physical state
- Reduced feed intake
- Negative energy balance
- Morphological and biochemical changes
- Increased breeding costs

Luteal dynamics
- Low progesterone
- Induction of PGF2alpha which causes embryonic losses

Follicular Change
- Disturbed ovarian follicle development
- Biochemical and morphological changes

Oocyte
- Antral follicle susceptibility leads to low development competence
- Polyspermy
- Susceptible fertilized Ova

Oestrus cycle
- Impaired follicular dominance
- Anoestrus
- Poor estrus behavior

WHAT ARE THE CONSEQUENCES OF HEAT STRESS?

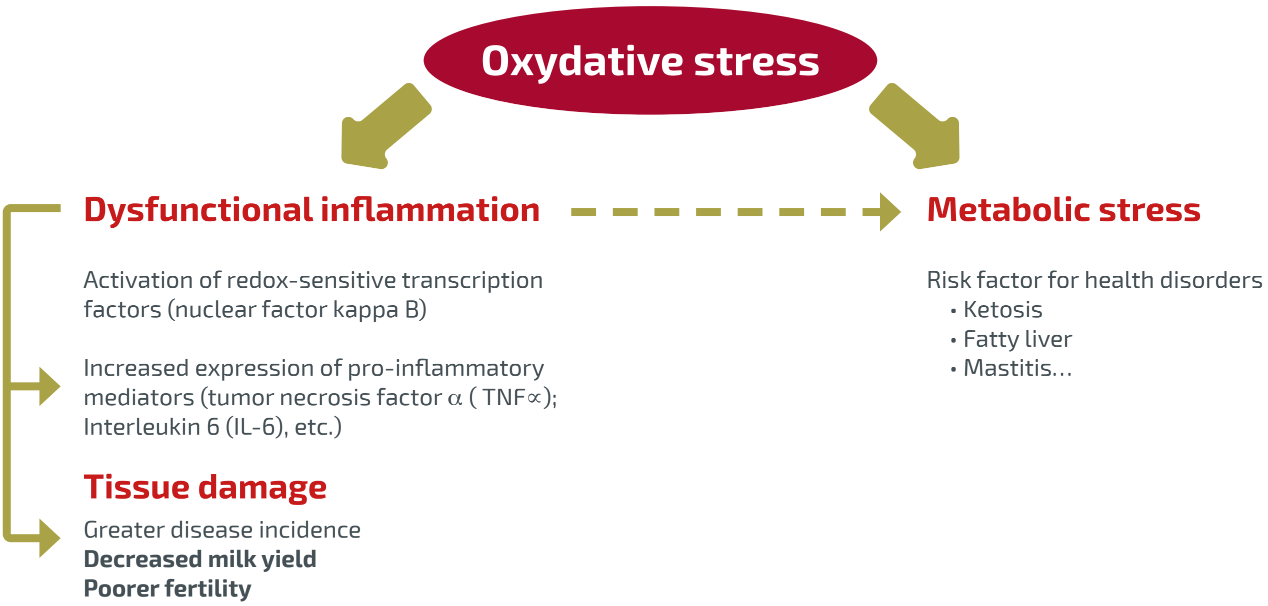
IMMUNITY DECLINE AND INFLAMMATORY RESPONSE

Heat stress leads to metabolic, hormonal and vascular changes, all of which affect an animal's immune defence and endocrine system. Moreover, oxidative stress is a significant underlying factor in the dysfunctional host immune and inflammatory responses, which enhances a cow's susceptibility to various diseases, such as mastitis, acidosis, ketosis, enteritis, pneumonia and respiratory diseases. Animals that experience a higher inflammatory response also show a lower daily milk yield and poorer fertility.

At the cellular level, it has been observed that the white blood cells, red blood cells, hemoglobin (Hb), packed cell volume (PCV), and the glucose and protein concentrations in the blood are altered as a result of heat stress. The leukocyte concentration in the blood increases by 21-26%, while the erythrocyte cellular levels drop by 12-20% (destruction by radical attacks) and the synthesis of hemoglobin is slowed down (Abuelo et al., 2015). In addition, an increase in circulating cortisol, due to heat stress, causes an increase in the cellular levels of heat shock proteins (which induce the destruction of pathogenic bacteria), thereby causing a deregulation of the immune system.

THE INTERPLAY BETWEEN METABOLIC STRESS, DYSFUNCTIONAL INFLAMMATION AND HEALTH DISORDERS.

(Abuelo et al., 2015)

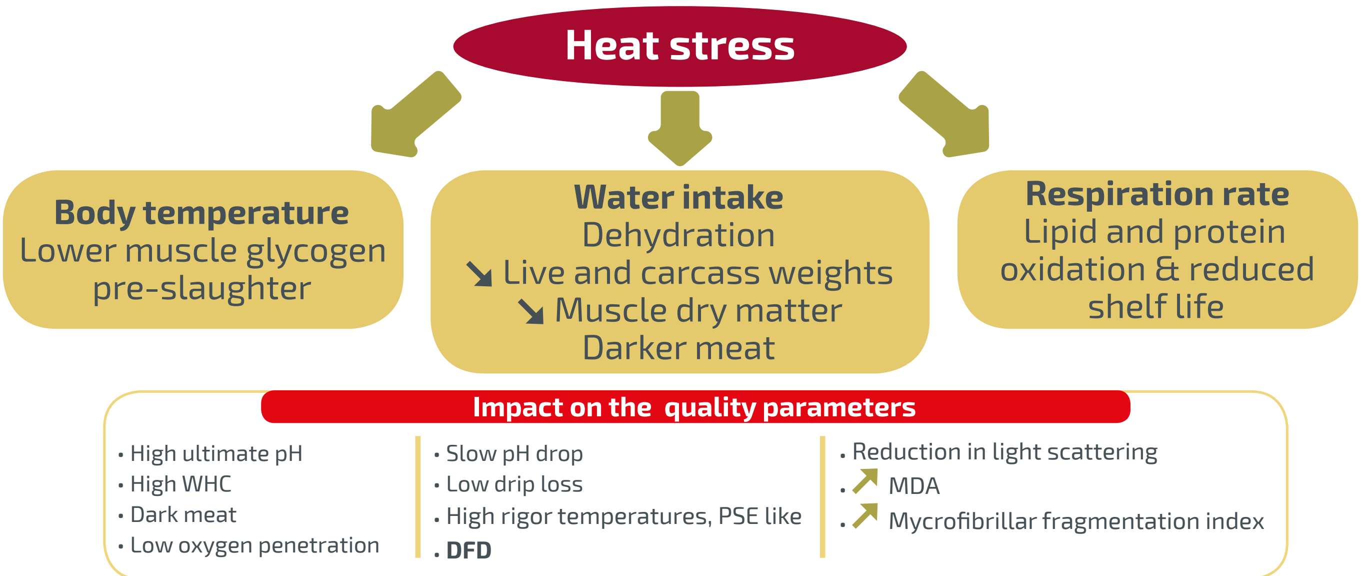


WHAT ARE THE CONSEQUENCES OF HEAT STRESS?

IMPACT ON MEAT QUALITY AND SAFETY

- **Quality:** Heat stress can affect the quality of meat, thus resulting in a downgrading of the meat, output losses and economic losses for farmers. Heat stress is known to cause DFD (dark, firm and dry) meat problems (Gonzalez-Rivas et al., 2020). Studies have shown that DFD incidence is greater in warm weather than in cooler weather. In addition, higher percentages of DFD meat are observed during late spring and in autumn associated with important temperature differences, that is, cold nights and hot days (Boykin et al., 2017). Dark, firm and dry meat (DFD) refers to a meat which has a high pH and dark color; this results in a hard and tasteless meat. It is caused by pre-slaughter stress, which depletes the glycogen reserves of the muscle, which in turn results in a high pH and meat that fails to bloom when exposed to oxygen. Moreover, sub-acidosis, which is caused by heat stress, leads to metabolic changes that increase the risk of PSE meat (pale , soft and exudative). PSE meat can also be caused by any type of stress before slaughtering.
- **Meat safety:** Sudden temperature changes and higher environment temperatures, which induce heat stress in animals, may also impact the transmission of foodborne pathogens (both zoonotic and environmental) by increasing the risk of contamination of the meat during slaughtering and processing (Gonzalez-Rivas et al., 2020).

RELATIONSHIP BETWEEN HEAT STRESS AND THE CONSEQUENCES ON MEAT QUALITY FOR RUMINANTS (from Gonzalez-Rivas et al., 2020)



DFD: dark firm and dry, **PSE:** pale soft and exudative, **WHC:** water holding capacity, **MDA:** malondialdehyde

WHAT ARE THE CONSEQUENCES OF HEAT STRESS?

OTHER CONSEQUENCES ON ANIMALS

SUB-ACIDOSIS

A drop in rumen pH, due to heat stress, can induce subacute rumen acidosis (a disturbance of the acid-base balance in the rumen). This drop is due to a lower feed intake, which induces an increase in the total rumen carbonic content. Moreover, hyperventilation, due to panting during heat stress, produces respiratory alkalosis, which is compensated for by an excessive loss of bicarbonates from the blood (which buffer the pH of the blood) via the urine, and this leads to a drop in rumen pH (West et al., 2003). There are many different consequences of acidosis:

- Consequences on the performance: reduced rumen absorption, reduced growth and fattening of cattle (drop in ADG and fat cover), reproductive disorders, and a lower milk fat content (Plaizier et al., 2008);
- Consequences on animal health: mastitis, diarrhea and bacterial infections, immune suppression (Plaizier et al., 2008) and locomotor disorders, due to claw horn lesions, among others, and sub-acidosis may also be one of the triggering factors of laminitis (Cook et al., 2004).

All of this may result in significant cost increases for farmers.

LAMINITIS

Laminitis (or diffuse aseptic pododermatitis) is an inflammation of the hooves or toenails of livestock (acute inflammatory congestion of the foot). Heat stress and its consequences on feeding (undernutrition, rumen inefficiency), and on the metabolism and inflammatory processes in animals can trigger acute laminitis. Nutrition is important for the health of the feet in particular for two reasons (Cook et al., 2004):

- undernutrition (involving weight loss) leads to a reduction in the plantar pad, which should be thick enough to ensure good shock absorption when walking, and hence to the development of lesions (Bicalho et al., 2009).
- The diet must provide the nutrients necessary to obtain good quality horns.

Furthermore, inadequate ambient humidity conditions deteriorate the hoof and predispose it to developing infections (during drought: hardening and dehydration of the hoof, when the air is too humid: very soft and flexible hooves).
Laminitis is characterized by a violent, clear lameness, and the animals find it difficult to walk or even stand upright (Blondaux, 2006). Calving and early-lactating cows are particularly sensitive and more prone to developing sub-acute laminitis.

WHAT ARE THE CONSEQUENCES OF HEAT STRESS?

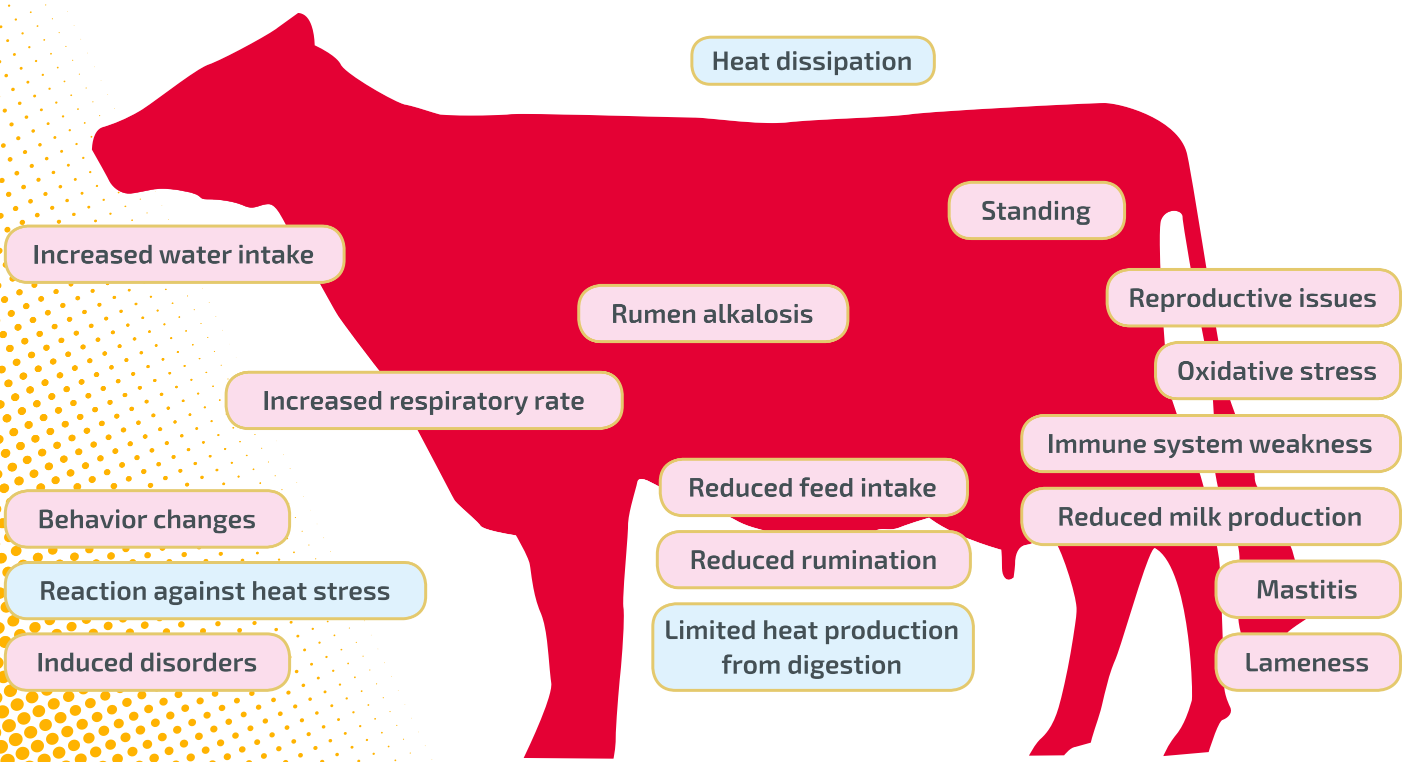
ANIMAL'S MORBIDITY

The multiple underlying consequences of heat stress can lead to animal morbidity. The diseases to which they may be exposed, as a result of metabolic stress induced by heat stress, are numerous: mastitis, diarrhea, metritis, acidosis, ketosis, enteritis, pneumonia and respiratory diseases, etc. Biomarkers can be used to predict the likelihood of disease or production impairment (certain lipids, blood levels of beta-hydroxybutyrate (BHB), a ketone body, and non-esterified fatty acids) in stress situations (Abuelo et al., 2015). Indeed, high NEFA blood levels (which may induce an accumulation of triglycerides, ketone bodies and BHB) and ROS production are characteristics of metabolic stress and have been recognized as risk factors for diseases, such as mastitis, retained foetal membranes, ketosis and fatty liver, in transition cows (Herdt, 2000; Sordillo & Raphael, 2013).

Heat stress can be lethal during the reproductive phase: embryonic, foetal and newborn mortality, when the mother has experienced heat stress in late gestation (West et al., 2003).

In extreme cases, if cows accumulate several sources of stress, such as in calving, which is a critical period for their health (Kaewlamun et al., 2014), they can succumb to prolonged hyperthermia as they fail to maintain thermoneutrality.

THE CONSEQUENCES OF HEAT STRESS



ECONOMIC LOSSES
DUE TO HEAT STRESS

Heat stress causes significant economic losses on livestock farms. These economic losses have various origins, namely: a drop in milk production, slower growth rates, lower fertility, increased veterinary costs and lower quality, all of which results in the downgrading of the meat, additional expenses linked to heat stress abatement, etc.

St-Pierre et al. (2003) developed a model that can be used to calculate the economic losses due to heat stress by taking into account the effects of heat stress on the dry matter intake, milk production, reproduction, culling, and death of both young stock and adult cows .

They estimated US$2.4 billion is lost annually in livestock production due to the effects of heat stress. The dairy industry contributes with roughly US$900 million to this total. **This loss is almost US$100 per dairy cow per year. Without heat abatement systems, this loss would be about US$167 per dairy cow per year.**

Adding to this are the veterinary costs associated with the increased incidence of mastitis and acidosis due to heat stress; these losses can be as high as several hundreds of dollars per dairy cow per year.

Furthermore, as global temperatures rise and heat waves are more frequent, due to global warming, higher economic losses due to heat stress can be expected for the future. Investments in heat abatement systems and more effective nutritional and long-term solutions to combat the harmful effects of heat stress are therefore needed to cope with this present and future challenge. A study has been conducted to investigate the cost-effectiveness of heat abatement strategies during the 21st century, using climate projections. It has shown that intense heat stress abatement strategies (e.g. with air conditioning) in the mid-21st century would reduce the costs by -US$30 to US$190 /cow and -US$20 to US$590 /cow in late 21st century (Gunn et al., 2019).

ECONOMIC LOSSES
DUE TO HEAT STRESS

SAINT-PIERRE ET AL (2003) TRIED TO MODEL THIS PHENOMENON AND PROPOSED THIS WAY OF CALCULATING THE ECONOMIC IMPACT OF HEAT STRESS ON DAIRY PERFORMANCES:

Drop in milk production

- **DMI_losses:** the reduction in DMI from heat stress (kilogram per animal per day)
  DMI_loss = 0.0345 × (THImax – THIthreshold)2×D
- **MILK_losses:** the reduction in milk production (kilogram per cow per day)
  MILK_loss = 0.0695 × (THImax – THIthreshold)2×D

Drop in reproductive performance

- **PR:** monthly pregnancy rate
  PR = 0.20 – 0.00090 × THILoadm

Losses due to mortality

- **PDeath:** probability of dying
  PDeath = 0.000855 × EXP (0.00981 × THILoadm)
- **RCullRate** = the change in the monthly culling rate
  RCullRate = 100 – 102.7 × (1 – 1.101 × EXP (10.19 ×PR))

Animal class	THI_ threshold	DMI_losses (US$/kg)	MILK_losses (US$/unit)	Rcull_losses (US$/unit)	Death (US$/unit)
Dairy cows	70	0.13	0.287	1 200	1 800
Dairy heifers (0 to 1)	77	0.11	2.20	-	900
Dairy heifers (1 to 2)	72	0.088	2.20	-	1 350

THI is the temperature-humidity index; THIthreshold is the THI threshold above which heat stress occurs for that animal class; THImax is the maximum THI during a day; D is the proportion of a day where THI > THIthreshold; THILoadm is the monthly average THILoad; DMILossUS$ is the unit price of DMI for that animal class; MilkLossUS$ is the price of one kg of milk; RcullLossUS$ is the price of one culled production unit for that animal class; DeathUS$ is the price of one dead animal in that animal class.

HOW TO LIMIT HEAT STRESS?

ACT ON THE BREEDING PRACTICES

ACT ON THE ENVIRONMENT

NUTRITIONAL MANAGEMENT

Chapter 3

HOW TO LIMIT HEAT STRESS:
ACT ON THE BREEDING PRACTICES

ADAPTING THE RHYTHM OF THE DAY TO THE HEAT

Animals should not be taken outside during periods of extreme heat, but only in the early morning when it is cool or at night. The time spent in waiting areas before milking should be reduced. Cattle should not be worked in the evenings, even if it is cooler, as the core temperature of the cattle peaks two hours after the ambient temperature peak and it takes at least 6 hours for the cattle to dissipate their heat load.

WATERING

In the case of heat stress, the water consumption of the animals increases drastically (+ 50%), and can increase from 85L to more than 120L/day.
The water supply must be able to provide 1.1% of the cattle's body weight per hour. A 700 kg animal needs about 5.7L of water per hour. Therefore, it is essential to provide water continuously and to install additional water tanks before periods of extreme heat to accustom the animals to drinking more. Water troughs should be kept clean to encourage livestock to consume sufficient water. Drinking troughs should be kept out of direct sunlight to prevent water temperatures from rising.

HOW TO LIMIT HEAT STRESS:
ACT ON THE BREEDING PRACTICES

ADJUSTING THE FEED

Feed intake and multiple of feed distributions should be stimulated to clip the ruminal fermentation peaks.
More feed should be distributed at the end of the day to avoid overheating, especially for finishing cattle, as the ration is mostly ingested in the evening and in the early morning.
Fresh forage, which is easily degradable by cows, should be used; a ration concentrated in more digestible energy is preferable in order to limit ruminal fermentation, which generates metabolic heat, and to make up for the drop in feed intake (supplement 2-3% DM fat; protein level < 17%; rumen degradable protein < 60% of the total protein (Noordhuizen et al., 2011) and well balanced in Metabolizable Amino Acids (Methionine should be above 2.2% MMet in MP and ideally 2.5% MMet in MP and Lysine above 6.8% MLys in MP and ideally 7.3% MLys in MP, according to INRA, France, for example)).

AVOID OTHER SOURCES OF STRESS

The handling of livestock should be avoided in hot, humid weather. If it is necessary to perform stressful procedures, such as castration or vaccination, it should be done early in the morning.

The transport of livestock should be avoided in hot weather; cattle should be transported between 8:00 p.m. and 8:00 a.m., and the loading density should be reduced. Animals should not be moved from a relatively cool environment to one that is hot in the summer.

HOW TO LIMIT HEAT STRESS:
ACT ON THE ENVIRONMENT

INCREASING THE AIRFLOW AROUND THE ANIMALS

Optimizing ventilation: windows and/or doors should be opened to create drafts. Fans can be used when the animals are indoors. The fans must be sufficiently numerous, depending on the size of the stall, and they should be powerful enough to ensure an air flow of 0.47 m^3/s. There should be one fan for every 10 cows or 13 m^2 of stall space, including exercise, feeding and lying areas. Fans should be inclined at 30° to the vertical. The air speed should be up to 20 km/h and fans should be switched on as soon as the temperature reaches 22°C (Noordhuizen et al., 2011).
Ensure the animals are well spaced.

USING SPRINKLERS

A fine mist can be sprayed in the barn to cool the air; this will reduce the heat load on the cows. Indeed, breathing cooler air will help cows cool faster; cows cooled with ducted air and spraying have been shown to maintain an almost normal rectal temperature (below 39°C) and normal respiratory frequency (50 rpm). The use of sprinklers for dairy cows in pasture systems, while the cows are waiting for the afternoon milking reduces heat stress.
The direct wetting of a cow's skin is also very effective in enhancing evaporative cooling from the body surface.

HOW TO LIMIT HEAT STRESS:
ACT ON THE ENVIRONMENT

FIGHTING AGAINST FLIES

Biting flies lead to the grouping of animals, which in turn favors heat stress. Fly populations should be reduced before periods of heat stress by applying insecticides and flytraps.

MAXIMIZING THE SHADE

The best shade orientation depends on the cow management practices and on the type of flooring under the shade.
The best shade orientation for cows in stalls with concrete floors is south-west. This provides the maximum shade under the roof, while north-south or east-west orientations increase direct radiations, especially in the afternoon. ,
A north-south orientation is recommended for situations with dirt floors and where cows are able to move outside the structure, and this prevents sunlight from covering more than 50 percent of the floor, while still providing shade outside the structure. In this case, the installation of curtains on the west side will limit the entry of heat between 1:00 p.m. and 8:00 p.m. (Noordhuizen et al., 2011).
The right materials need to be chosen to create artificial shade ; white aluminum, nylon with a double layer of neoprene, white galvanized metal, unpainted wood and fodder balls are the best insulators.
In addition to providing shade, trees refresh the ambient air in a pasture system through the evaporation of moisture from the surface of leaves (Das et al., 2016).

HOW TO LIMIT HEAT STRESS: NUTRITIONAL MANAGEMENT

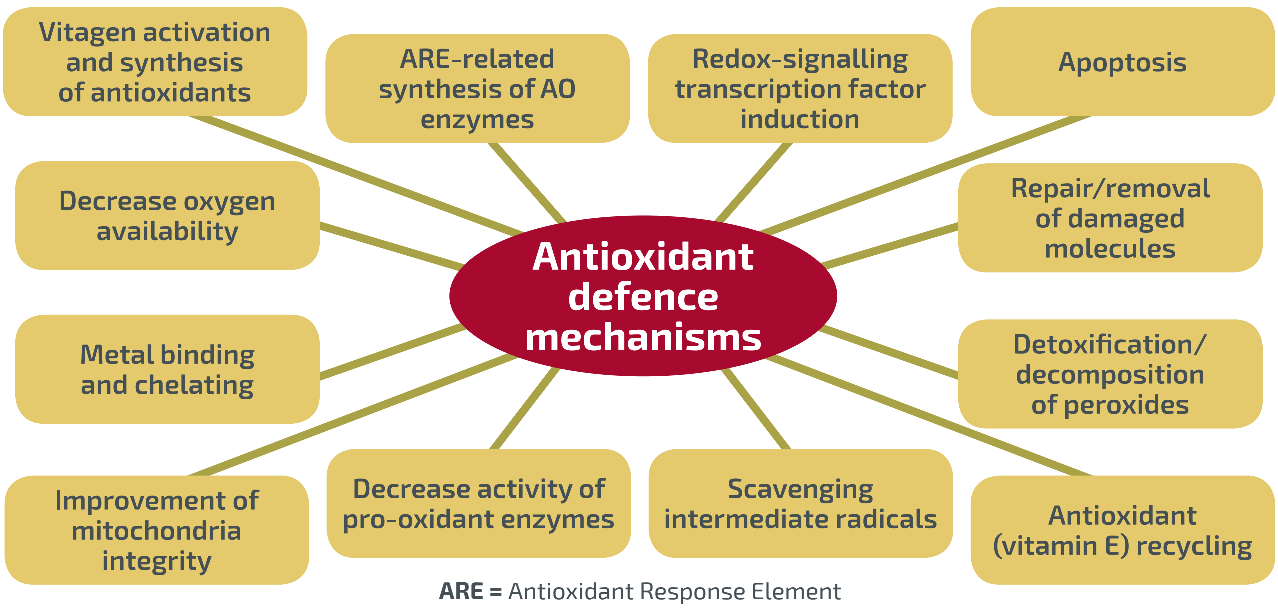
SUPPLEMENTING THE RATION WITH MINERAL COMPONENTS

During heat stress, a significant loss of minerals (sodium, potassium, chlorine) occurs through sweating and in the urine. A temporary increase in the mineral supplement (K, Na et Mg) can therefore compensate for these losses.
Cows should be supplied with bicarbonate to reduce the risk of sub-acidosis.

IMPROVING AN ANIMAL'S ANTIOXIDANT DEFENCE SYSTEM WITH ANTIOXIDANT SUPPLEMENTATION

To counteract the effect of heat stress, an animal's antioxidant defense mechanism works by scavenging free radicals, detoxifying the products of their metabolism and repairing damaged molecules. These systems are based on the synthesis of biological antioxidants, including antioxidant enzymes, glutathione, thioredoxin and coenzyme Q. The players in the antioxidant system are fat-soluble antioxidants (vitamin E), water-soluble antioxidants (vitamin C), antioxidant enzymes (GSH-Px) and the thioredoxin system.
A range of dietary antioxidants that can be added to an animal's diet to improve its antioxidant defense is available (vitamin E, carotenoids, polyphenolics and selenium), thereby improving the animal's health status and maintaning its performance.

ANTIOXIDANT DEFENSE MECHANISMS IN THE BODY (from Surai et al., 2019)



ARE = Antioxidant Response Element

HOW TO LIMIT HEAT STRESS: NUTRITIONAL MANAGEMENT

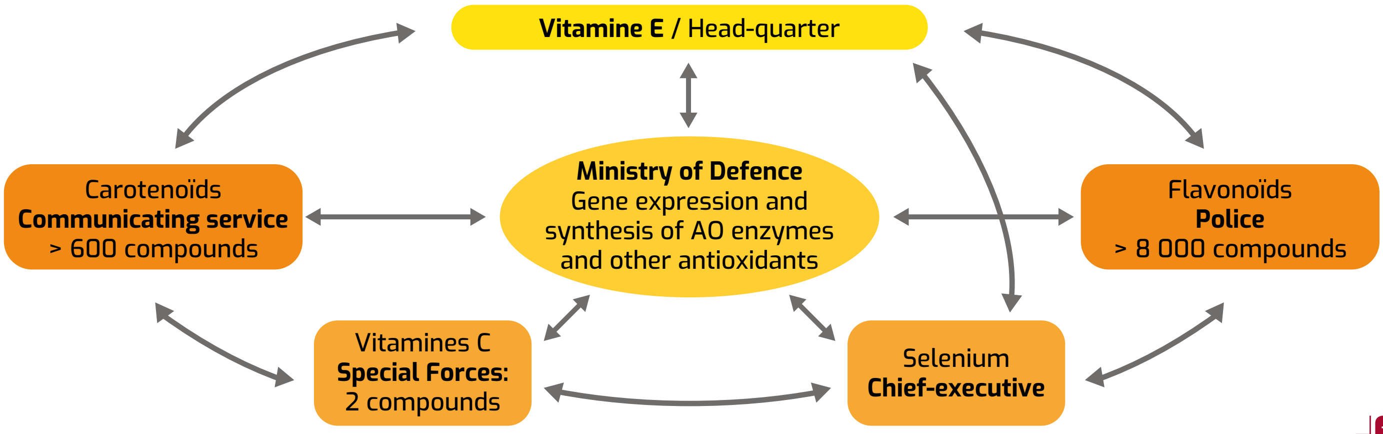
8 THE IMPORTANCE OF SELENIUM SUPPLEMENTATION

Animals supplemented with Se are more resistant to oxidative stress, and maintain their performance and their general state of health. Indeed, selenium (Se) plays a pivotal role within the antioxidant system; it is a key component of two amino acids, selenomethionine (SeMet) and selenocysteine (SeCys).
Currently, 25 selenoproteins have been identified in animal tissues, and more than half of them are directly or indirectly involved in the maintenance of the body redox balance and antioxidant defense (e.g. glutathione peroxidase).
Selenoproteins are also involved in the thyroid metabolism, spermatozoa function, as well as in the inflammatory and immune responses.
SeMet is the natural storage form of selenium, while **SeCys** is the active form found at the catalytic site of selenoproteins.
Se bioavailability depends on the form of dietary Se that is offered to the animal.
Selenium additives can be divided into two main families:

- inorganic sources, such as Sodium Selenite (SS), selenate, proteinate and glycinate (which are SS-based products);
- organic sources, including selenized yeast (Se-Yeast on average provides 60% of Se as SeMet) and the pure form of organic Se (100% of Se as selenomethionine or its hydroxy analogue), such as hydroxy-selenomethionine (OH-SeMet, Selisseo® 2%, Adisseo France SAS).

The main advantage of feeding SeMet to animals is that the SeMet is stored in body tissues in advance of a stressful episode. This allows the creation of a reservoir of Se that the animal can utilize when the stress levels increase, and the intake of nutrients, Se and of other antioxidants decrease. This feature allows the animals to maintain selenoprotein synthesis, even during stressful situations, and to help them to cope better with heat stress and to maintain better performance.

SELENIUM THE CHIEF-EXECUTIVE OF THE ANTIOXIDANT SYSTEM



HOW TO LIMIT HEAT STRESS: NUTRITIONAL MANAGEMENT

SUPPLEMENTING COWS WITH RUMEN PROTECTED METHIONINE (RP MET)

Feeding diets balanced with appropriate amino acid proportions of MP (metabolizable protein), using rumen-protected amino acids, helps lactation performance as well as milk protein and fat concentrations, but also improves responses to stressful conditions when DMI decreases. Improved lactation performance and reduced inflammatory responses have been reported in trials such as Osorio et al., 2013, 2014, Zhou et al., 2016, when rumen protected methionine was added to the diet of cows during the transition period. Pate et al., (2020) recently showed that feeding RP Met improves milk composition during heat stress, primarily as a result of higher milk fat and milk protein concentrations, without altering the physiological parameters.

Moreover, RP Met may help to maintain homeostasis in immune responses during heat stress. A study has shown that cows supplemented with RPM showed a lower abundance of TLR2 (toll-like receptor 2) in the whole blood (Coleman et al., 2020). TLR2 is involved in bacterial recognition and an elevated level of TLR2 indicates an increase in the immune response, as there is an upregulation in inflammation and immune response in cows enduring HS.

RP Met supplementation during heat stress may also help cows maintain their hepatic homeostasis and may enhance the antioxidant response (Coleman at al., 2020).

Care must be taken in selecting an RP Met source, such as Smartamine® or MetaSmart® (Adisseo France SAS), to ensure efficacy. The most accurate method for assessing product bio-availabilities is the blood plasma dose-response method published by the University of New Hampshire, USA.

CONCLUSION

The metabolic and physiological responses of an animal under heat stress have negative impacts on its performance, in terms of production and reproduction, and alter its general state of health. Heat stress is becoming more and more problematic as cattle are particularly sensitive to it (especially dairy cows), it is a recurrent problem every year and it will surely get worse due to global warming. The economic consequences are and will become even more disastrous for livestock farms.

However, there are solutions available to limit the harmful effects of heat stress. Feeds in particular are a major lever of action: supplementing animals with antioxidants is an effective way of fighting against heat stress.

References can be provided upon request.