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Impacts of Climate Change on Animal Production and Quality of Animal Food Products

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1. Introduction

Nowadays, almost all inhabitants of the Earth are affected by different health problems associated with nutrition, although their causes are in striking contrast with each other. In the developed societies certain chronic, non-infectious diseases are caused not only by overfeeding but also by an unhealthy ratio of the ingested nutrients. According to the statistics, 50% of deaths can be attributed to diseases of the cardiovascular system, and 30% to tumor diseases. Diet is one of the major risk factors in the development of these illnesses. That is why through changing undesirable dietary habits and consuming food more satisfactory to human nutrition requirements we may have every right to hope that an ever-increasing percentage of the population can live up to their genetically determined lifespan. In addition to numerous other factors, the quality of foods of animal origin (e.g. meat) is probably influenced by the quality of feed most of all, therefore a very important area of food science research is focused on improving meat quality by feeding so that it can better meet the requirements of human nutrition.

Animal nutrition in the 21st century aims to provide safe and good quality foodstuffs of animal origin besides a high efficiency of production and a low level of environmental pollution. These criteria, however, contribute to the complexity and rapid expansion of nutrition science. The continuously increasing demand of the human population needs to be supplied from a diminishing agricultural area, while maintaining the sustainability of production. According to the global trends, the challenges facing animal nutrition in the 21st century can be summarized as follows: more awareness and activity of participation is needed in animal production to supply quality and safe food in sufficient quantities, in accordance with the requirements of the society.

Considering the limited nature of available agricultural area, the efficiency of animal production needs to be improved. This can be achieved by (i) increasing biological efficiency, ii) technological efficiency and iii) economic efficiency. The science of animal nutrition deals with the first two factors by using advanced knowledge. One of the practical solutions for saving grains for human consumption is to increase the amount of feedstuffs

available for animal nutrition by using by-products. This concept is also in agreement with the principles of sustainability (Babinszky & Halas, 2009).

Further growing global populations, land degradation, loss of arable land due to urbanization anticipated climate change involves many challenges for agriculture. Food production on a global scale is able to keep pace with population growth as well as serious regional deficits only, and poverty related nutritional deficiencies affect nearly one billion people.

It is very well known that agriculture is very sensitive to climate variability and extreme weather events, such as droughts, floods and storms etc. The forces that shape our climate are also critical to farm productivity. Human and industrial activities have already changed plenty of atmospheric properties, such as temperature, precipitation, concentration of carbon dioxide in the air and ozone at ground-level. The experts forecast that these trends will continue. While food production may benefit from a warmer climate, the increased risk of droughts, floods and heat waves will pose challenges for agriculture. Moreover, the long-term changes in climate, water supply and soil moisture could make it less feasible to continue crop production in some regions (<http://www.epa.gov/climatechange/effects/agriculture.html>).

The research on climate change and its implications is at present in the focus of much scientific interest. In addition to comprehensive research efforts there is an increasing need for incorporating the fact and impacts of climate change both in the area of regular education and of agricultural extension services. Since neither the present status of climate change nor its expected future development are unequivocal facts – particularly in consequence of the expected influence of the international treaties on climate protection– the continuous monitoring of the process, of changes and their influence are necessary both from the meteorological and from the user side.

The question most frequently raised in connection with climate change is concerning its impact on agriculture (crop and livestock production), and from a broader perspective on our food supply. In other words, how animal production and thus the production of foodstuffs of animal origin and their quality are influenced by climate change through feed crop production?

The question can be asked at various levels – local, regional, continental and global – but no unequivocal reply is possible, just as there is none for the question of climate change. The global weather forecasting models used for long-term climate forecasts are undergoing continuous development. Downscaling is an area where particularly rapid progress is expected. Climate scenarios prepared by climatologists should be downscaled and evaluated in the most sophisticated manner possible and should be linked to the local regional production situation. Any action program, elements of response, prevention, adaptation, remedy and remediation steps can essentially be based on the climate changes predicted for the given region.

Interactions existing among the available biological, biometrical (yields) and meteorological data can be explored by using various statistical methods. The expected changes are entered into the equation as independent parameters and these can provide a basis for drawing conclusions for the future. By the practical application of the results of plant and animal growth simulation models (relying on a background of advanced computer technology), and of open-field small plot trials (open top chambers, in which for example the effects of atmospheric carbon dioxide can be studied) and climate chamber animal trials the stability

of food production and sustainable agricultural production can be ensured even beside changing environmental conditions (Babinszky et al., 2011)

It should be noted moreover, that food supply predictions based on climate change scenarios also imply a broad margin of error, since in addition to climate other factors (genetics, agrotechnology, adaptive abilities) have a major influence on agricultural production as well. The study of these factors is expected to become a focal point of future research work. The effect of climatic change on crop production and animal nutrition should be studied in the near future, together with the investigation and evaluation of different climate scenarios, in the interest of maintaining sustainability of production

The aim of this chapter is to present the impact of changing meteorological factors on crop production, on the metabolism of farm animals and in consequence on the volume and quality of animal products from the aspect of human nutrition. The chapter also investigates how the adverse effects of climate change can be alleviated.

2. The impact of climate change on feed crop production

Agriculture – and thus the stability of food supply – is an activity, which besides natural vegetation is the most sensitive to the changing climate and weather. Unfavourable climatic factors may lead to a significant decline, and sometimes to the complete elimination of crops. Efforts to research the adaptive potential of crops are urgently needed to prevent this turn of events. Production technologies adapted to the cropping site conditions and to the requirements of the crops, the increased use of varieties / hybrids that better tolerate drought and the extreme conditions, and the selective breeding aimed at these objectives are of key importance.

A possible consequence of climate change may be the necessity of switching from natural precipitation based production to irrigation-based production wherever it is possible. The development pattern of soil humidity as expressed in percentage of the maximum useful water content of the soil provides immediate information about how the water supply conditions of the soil meet the requirements of different crop species. Several studies conducted in temperate zone countries agree in their finding that a 10 % decline in precipitation raises the irrigation water requirement by at least 7-8 %, but this is also subject to the crop species and the environmental conditions.

Much of the relevant data in literature suggests the necessity of distinguishing between the *potential* and the *actual* vegetation periods. A consequence of the higher daily mean temperatures is that the *potential* vegetation period will be longer. At the same time the higher temperature leads to accelerated growth and this in turn shortens the crop lifecycle, and thus the duration of the *actual* vegetation period is also shortened. Under such circumstances it is reasonable to either grow varieties having a longer growth season (these usually produce higher yields than varieties with a shorter growth season, and can also be stored better), or to grow after crops. In this latter case the same area can be harvested twice within the same year (Babinszky et al., 2011).

There are three distinct types of photosynthesis: C3, C4, and CAM (Crassulacean Acid Metabolism). C3 photosynthesis is the typical photosynthesis used by most plants. C4 and CAM photosynthesis are both the outcome of adaptation to arid conditions because they result in better water use efficiency. In addition, CAM plants can save precious energy and water during harsh times, while C4 plants, in contrast to C3 plants, can photosynthesize faster under the high heat and light conditions of the desert, because they use an extra biochemical pathway and special anatomy to reduce photorespiration.

The three different types of photosynthesis can be characterized as follows (http://wc.pima.edu/Bfiero/tucsonecology/plants/plants_photosynthesis.htm):

C3 Photosynthesis: C3-plants – with stomata open during the day – get their name from CO₂ being first incorporated into a 3-carbon compound. The enzyme involved in photosynthesis is called Rubisco, and it is also involved in the uptake of CO₂. Photosynthesis takes place throughout the leaf. Their adaptive value is more efficient under cool and moist conditions and under normal light than that of the C4 and CAM plants because it requires less machinery (fewer enzymes and no specialized anatomy). Most plants are C3.

C4 Photosynthesis: C4 plants are called so because the CO₂ is first incorporated into a 4-carbon compound. Their stomata are open during the day. They use PEP (phosphoenolpyruvate)-carboxylase as the enzyme involved in and enabling a very fast uptake of CO₂, which is then "delivered" to Rubisco for photosynthesis taking place in the inner cells. In contrast to C3 plants this photosynthesis occurring under high light intensity and high temperatures is faster because CO₂ is delivered directly to Rubisco, not allowing it to grab oxygen and undergo photorespiration. Water use efficiency is better too, because PEP Carboxylase brings in CO₂ faster and so the stomata do not need to be kept open that much (less water lost by transpiration) for the same amount of CO₂ gain for photosynthesis. C4 plants include several thousand species in at least 19 plant families.

CAM Photosynthesis: CAM plants are named after the plant family in which it was first discovered (Crassulaceae) and because the CO₂ is stored in the form of an acid before being used in photosynthesis. The stomata are open at night (when evaporation rates are usually lower) and are usually closed during the day. The CO₂ is converted to an acid and stored during the night. During the day, the acid is broken down and the CO₂ is released to Rubisco for photosynthesis. In contrast to C3 plants the water use efficiency of this group is better under arid conditions due to their stomata being open at night when transpiration rates are lower (no sunlight, lower temperatures, lower wind speeds, etc.). CAM plants include many succulents such as cacti and agaves, and also some orchids and bromeliads (http://wc.pima.edu/Bfiero/tucsonecology/plants/plants_photosynthesis.htm).

The increase in temperature usually favors species with C4 type photosynthesis, which are better from several aspects than the C3 type species. Worth highlighting of these are the high net productivity of photosynthesis and the fact that they use significantly less water per unit of dry matter production. In addition, for C4 plants the CO₂ absorbing capacity of PEP-carboxylase – the primary enzyme of CO₂ fixation – is more than 30 times higher than that of RuDP (ribulose 1,5 diphosphate)-carboxylase, and consequently they are also able to absorb more efficiently any CO₂ released during photorespiration. This is particularly advantageous for C4 plants under stress conditions (high temperature, aridity, high photo intensity), as they are not forced to rely on CO₂ replenishment through the stomata. Under such circumstances the stomata remain closed, which substantially reduces the loss of water caused by transpiration.

Peer reviewed studies also report that besides the increase in temperature and aridity, the third dominant environmental element of climate change, i.e. the increase of atmospheric CO₂ concentration is more favorable for the C3 photosynthesis species. Due to the simultaneous change of these three factors in the future, it is difficult to make predictions either at the level of the biosphere or of the natural and artificial biocoenoses. In case of the most prevalent weed in Hungary, i.e. the common ragweed, the simultaneous increase of the two abiotic factors (temperature, carbon-dioxide concentration) equally favored the

production of biomass and of pollen, and also the initial phenophase of the flowering period shifted to an earlier time.

Of the 18 weed species considered to be the most dangerous worldwide, 14 belong to the C4 group, while of the 15 crops most important for global food supply only 3 species are C4. In consequence, the result of any increase in the carbon-dioxide concentration is that in the competition between weeds and crops the competitive ability of crops in the agroecosystems is enhanced, and thus their weed suppressing potential is strengthened (Babinszky et al., 2011).

The impact of climate change on feed crop production also influences the feed base of farm animals because it affects the yield, quality and price of forage and concentrate crops, since – as mentioned before – the photosynthesis of C4 feed crops (corn, sorghum, millet) is more efficient, their heat and drought tolerance is better than those of the C3 crops (wheat, barley, rye, oat, sunflower, alfalfa, soy).

In summary it can be concluded, that climate change has a major impact on feed crop production. Thus for instance C3 plants will face more stress in consequence of higher temperatures and of any eventual decline in the annual amount and/or change in the annual distribution of precipitation. For this reason the selective breeding of plants will have to focus on selecting for drought resistant varieties of C3 plants for example in order to avoid loss of yields.

Nutritionists are also going to face a serious challenge. Using the latest results of animal nutrition and its related disciplines (microbiology, immunology, physiology, molecular biology, precision nutrition, information technology, etc.) they are to develop feeding technologies and feed formulas in which the latest feed crop varieties of improved drought resistance are used more extensively. All this should be used in the everyday practice of producing foodstuffs of animal origin besides avoiding any decline in the quality and safety of the product (foodstuffs of animal origin) and alleviating the environmental load of livestock production.

3. The impact of climate change on the performance of farm animals and the quality of animal food products

As mentioned in the above sections, recent research data and model predictions suggest that the average temperature of the Earth is increasing, which will have a significant impact on agricultural production (Bernstein et al., 2007). However, it is also forecasted that climate changes will result in more extreme weather in different parts of the world, leading to storms and frequent changes of hot and cold temperatures. It appears reasonable to expect not only the feed crop sector but also the livestock sector to come up with solutions and new strategies for maintaining and even increasing the production potential under the altered climatic conditions. The development of an action plan is crucial considering the increasing food demand of the human population.

3.1 Thermoneutral zone and thermoregulation of farm animals

In order to better understand how climate change affects livestock performance it is necessary to become acquainted with the bases of livestock production, and particularly with the processes pertaining to the utilization of dietary energy, since the ambient temperature has a major impact on the energy metabolism of food producing farm animals.

The concept and importance of the thermoneutral zone and the thermoregulation of the animals are briefly reviewed below for this purpose.

Physiological processes are associated with heat production, which is the sum total of non-productive energy utilized by the animal and of the energy “lost” in the course of converting the dietary nutrients. The non-productive energy is used for maintenance, i.e. it satisfies the energy requirement of such essential physiological processes as the maintenance of the body temperature, the nervous system, organ functions, ion pumping, energy requirement for minimal activity, etc. The total of heat produced in the course of digestion, excretion and metabolism of nutrients is called heat increment. Within a certain range of ambient temperature and besides unvarying feed and nutrient intake the total heat production of the animal remains constant (Figure 1). This temperature range is called the thermoneutral zone. In a thermoneutral environment the heat production of the animal is at the minimum, and thus the dietary energy can be used for production (growth, egg and milk production) efficiently. Unfavorable temperatures (too cold or too hot environments) lead to an increased heat production by the animal, i.e. there is more loss of energy, and in consequence less energy remains for production at the same level of energy intake, and the efficiency of energy utilization deteriorates. The upper and lower critical temperatures for different animal species and age groups are shown in Table 1. The species, age and body condition of the animals all have a significant influence on the critical temperature, but other environmental factors affecting their thermal sensation and heat dissipation, such as air velocity and air humidity, are also crucial. Increasing the airflow improves the efficiency of evaporative cooling, but higher humidity has the opposite effect. In cold, humid conditions the heat conductivity of wet hair increases, thus the animal becomes more sensitive to the lower ambient temperature. Based on these examples it can be seen that in case of high humidity levels the comfort zone of the animals becomes narrower, the lower critical temperature increases while the upper critical temperature decreases.

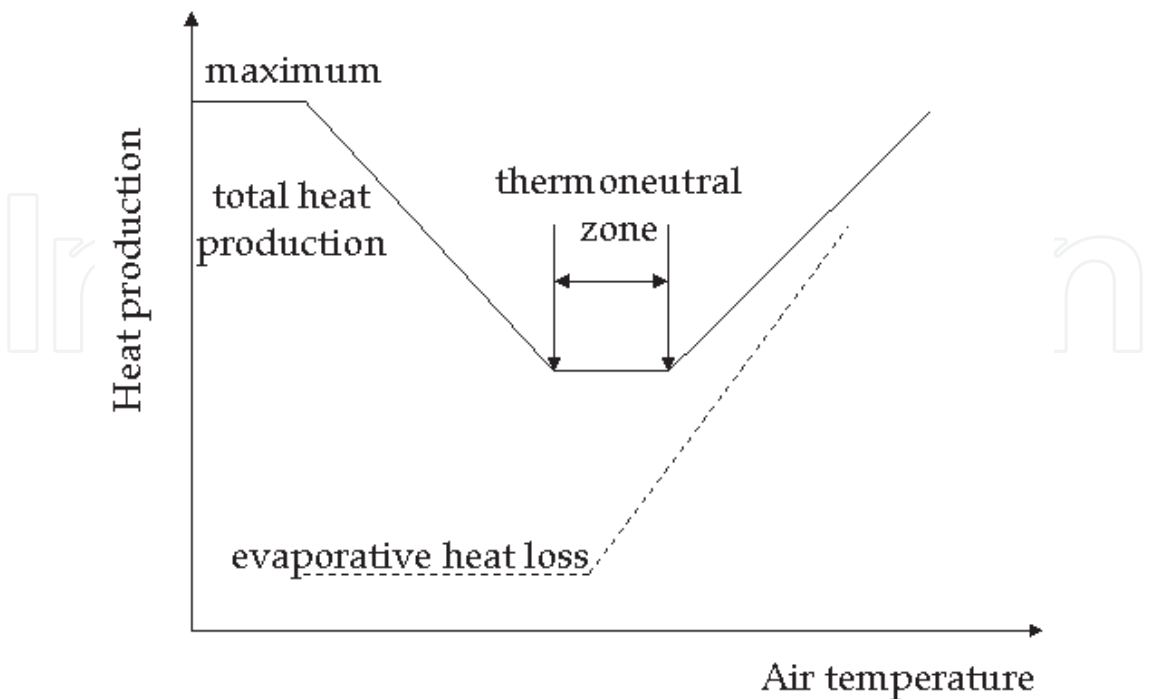


Fig. 1. Relationship between ambient temperature and heat production of farm animals.

	Lower	Upper
	critical temperature (°C)	
Lactating sow with piglets	15°C for sow 32°C for piglets	26°C for sow No practical upper limit for piglets
Prenursery, 3-15 kg	26	32
Nursery, 15-35 kg	18	26
Growing pigs, 35-75 kg	15	25
Finishing pigs, 70-100 kg	10	25
Sow, boar >100 kg	10	25
Dairy cow	-12/-1*	24
Newborn dairy calf	8-10	35
1-day-old chicken	32	35
Finishing broiler	16	26
1-day-old turkey	35	38
Finishing turkey	16	26
Laying hen	16	27-29

*Lower critical temperature: -12 °C for Holstein and Brown Swiss, -1°C for Jersey

Table 1. Lower and upper critical temperature of farm animals at different age or body weight (FASS, 2010).

Thermoregulation is the ability of the animals to maintain their body temperature in cold or hot environments, consisting of behavioral, physiological and anatomical responses that affect energy metabolism. In a cold environment the rate of oxidation increases, in other words, the body “burns” more nutrients, thus boosting its heat production, in order to compensate for the higher heat loss caused by the lower ambient temperature. Shivering is a tool aiding this process; since the energetic efficiency of muscle work is low, the resulting heat production is quite significant. If heat loss exceeds heat production, the result will be hypothermia and death. As the thermoregulatory mechanisms of newborn and young animals – particularly in swine and poultry species – are poorly developed, the cold environment increases the number of mortalities. According to predictions a characteristic feature of climate change will be the rising average temperatures, and this may become an advantage for the survival rate of young animals.

As seen in the above, the maintenance energy requirement of animals increases in a cold environment, which reduces the amount of energy available for production. However, the higher use of non-productive energy is not the only factor reducing the amount of energy available for production. Another contributing factor is the poorer digestibility of nutrients caused by the low ambient temperature. This means that in cold temperatures the higher energy consumption is associated with a relatively lower energy supply. Higher feed or energy intakes can help the animals to compensate for this lower energy supply to a certain extent.

From a practical perspective higher temperatures are much more hazardous for growing/finishing and breeding animals than a cold environment. Temperatures exceeding the higher critical level compromise animal performance not only by changing the energy

and nutrient metabolism, but also by upsetting the body homeostasis, with detrimental consequences both for immunocompetence and for product quality. In general, livestock with high production potential are at greatest risk of heat stress, thereby requiring the most attention (Niaber & Hahn, 2007). Therefore, in the present chapter the high temperature induced metabolic changes and its consequences will be discussed in detail.

3.2 Effect of global warming on the metabolism of farm animals – biological background

At thermal equilibrium the difference between heat production and heat loss of the animal is zero. If heat production exceeds heat loss from radiation, convection, evaporation, and conduction, heat is stored and hyperthermia results in an increased body temperature. In farm animals with only a few sweat glands or none at all (poultry, swine), evaporation through rapid air exchange (panting) is one of the most important mechanisms for cooling the body. It is well known, that rectal temperature is a good indicator of internal body temperature. For this reason rectal temperature and respiratory rate are the usual indicators of heat stress even in cattle (Brown-Brandl et al., 2001; Kadzere et al., 2002). Animals respond to an unfavourable ambient temperature in a very complex manner. Figure 2 shows the most important influences of the climatic environment on the physiological processes of the animals, together with the consequences of these changes in their production potential and product quality. In a hot environment, when the air temperature is above the upper critical temperature, the ability to lose heat is limited; therefore, farm animals reduce their feed intake and thus the heat increment in order to keep the thermal equilibrium. Studies have reported a strong negative correlation between rectal temperature and feed intake in pigs, poultry, and dairy cows at the time of heat stress. High ambient temperature causes hyperthermia in the body, which reduces the activity of the appetite center in the medulla oblongata. Thus it is the higher temperature that triggers the reduction of feed intake, in proportion to the increase of the ambient temperature. In order to lower the heat production, farm animals reduce their physical activity as well (Collin et al., 2001) and spend less time with eating (Brown-Brandl et al., 2001).

The lower feed intake results in a poorer nutrient supply, which obviously compromises the production performance and parameters. This loss of performance, however, is usually more than what would be justified by the reduced feed intake. The cause of the lower efficiency of nutrient and energy utilization is partly the higher energy use of animals due to heat stress, and partly the altered electrolyte balance of body fluids that may impair the protein metabolism (Patience, 1990). The changes in the protein metabolism are then clearly affecting the milk production, egg production and growth of the animals. As discussed earlier, above the upper critical value the respiratory rate linearly increases with the ambient temperature. The enhanced respiration results in a higher CO₂ emission, which may cause respiratory alkalosis. The CO₂ concentration in the body fluids is a metabolite with significant acidic properties playing a significant role in the acid/base balance. The shift in the acid/base balance can be compensated for by the electrolytes fed in the diet. The results of a large number of studies with birds, dairy cattle and lactating sows show the benefit of changing the dietary electrolyte balance (DEB) during heat stress in order to avoid any loss of performance when compared to animals kept in a thermoneutral environment (West et al., 1991; Dove & Haydon, 1994; Sayer & Scott, 2008). The optimal temperature for fast growing, lean genotypes is lower than that for the unimproved animals or conventional

hybrids (Brown-Brandl et al., 2001), since heat production related to the maintenance processes is linearly related to muscle mass. The underlying problem is that the genetic selection for rapid growth rate, high egg or high milk production results in a high metabolic heat production by the animals without a significant increase in their ability to lose heat (Renaudeau et al., 2010). It follows from the foregoing that intensive genotypes tolerate global warming much less than the extensive or semi-intensive breeds.

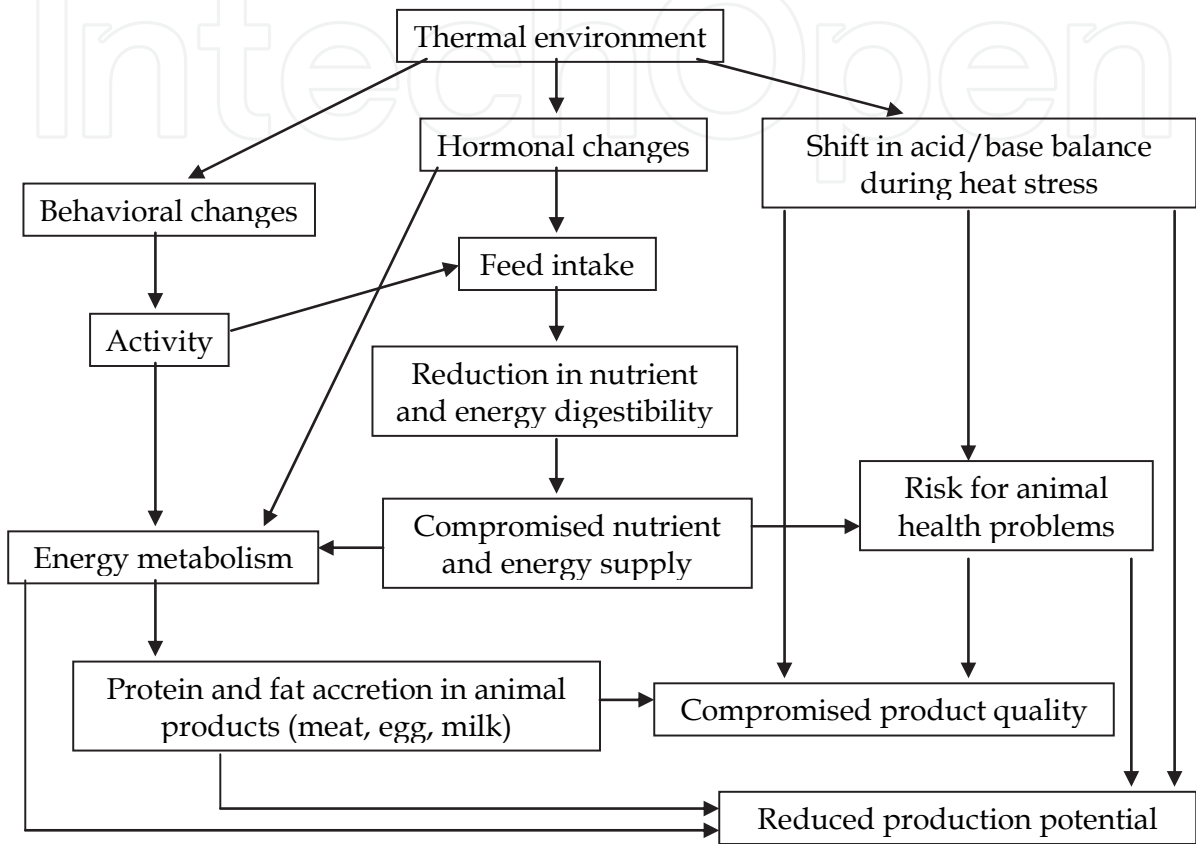


Fig. 2. Schematic representation of the potential mode of action of inconvenient thermal environment on the production potential and product quality of livestock.

Several studies have demonstrated that heat stress may reduce disease resistance or immune responsiveness of domestic animals; however, it depends on several variables, such as species and breed, duration of the exposure, severity of stress, and the type of immune response considered. A moderate heat stress would probably not modify immunological parameters (Lacetera et al., 2002); severe heat stress however may cause immune suppression, such as lower number of circulating white blood cells (Heller et al., 1979) and a reduction in antibody production (Zulkifi et al., 2000). Due to the production potential oriented selection, intensive genotypes are usually more susceptible to any disease; and it should also be noted that the increasing temperature provides better conditions for microorganisms and viruses. At the same time the use of pharmaceuticals, such as antibiotics or other drugs in food-producing animals may impair product quality and/or may constitute a food safety hazard, and can finally lead to a loss of consumer confidence in the product. Consumers are increasingly aware in their selection of foodstuffs, and as a consequence of their traceability animal food products originating from animals fed with medication lose their competitive edge compared to products from non-medicated animals.

3.3 The effect of heat stress on the production of farm animals and product quality

3.3.1 Meat and egg production in poultry

There is a large number of reports on the effects of high ambient temperature and humidity on poultry production, since the poultry industry is concentrated in hot climate areas of the world, mainly in Asia and South America (Daghir, 2009). However, their higher production performance and feed conversion efficiency make today's chickens more susceptible to heat stress than ever before (Lin et al., 2006). The thermoregulation characteristics of poultry differ to some extent from those of mammals due to their high rate of metabolism associated with more intensive heat production and low heat dissipation capacity caused by their feathers and lack of sweat glands. Evaporative cooling is achieved exclusively by panting. In the first days of their life poults need hot climate (32-38°C, Table 1), but the optimal temperature decreases rapidly with age by 2.5-3.0°C per week (FASS, 2010). After feathering birds prefer mean ambient temperatures between 18-22°C for their growth performance and egg production although the optimal temperature for feed efficiency is higher. The crucial temperature for poultry is 30°C, because up to this point birds, through a better feed conversion rate and lower basal metabolic rate, are able to compensate for the energy loss caused by the lower feed intake (Daghir, 2009). Above 30°C the feed and energy intake declines to such an extent that birds are no more able to compensate for it, production declines rapidly and the rate of mortality increases.

The reduction of feed consumption in response to high temperatures is closely associated with the severity and duration of exposure. In broilers the rate of feed refusal during heat stress increases with age (Gonzalez-Esquerria & Leeson, 2005) and can be as high as 50%. Accordingly, layers reduce their feed intake by approximately 30-50% in severe heat stress (34-35°C). In addition, several studies reported that high ambient temperatures decrease the digestibility of nutrients in poultry likely due to a reduced activity of trypsin, chymotrypsin, and amylase (Hai et al., 2000). Consequently, the lower and by most probability insufficient nutrient supply limits egg production and egg mass in layers, and the growth rate in broilers. During heat stress birds lose a large amount of carbon dioxide by panting; CO₂ however, is essential for Ca-carbonate in eggshell formation. Therefore, in addition to an insufficient nutrient supply, the compromised egg shell formation limits the egg production further (egg/day or egg production/number of birds), which can be very substantial as the egg production percentage might decline from 80-90% to 50-60%, with a 10 g lower egg weight on average (Mashaly et al., 2004; Table 2). Furthermore, the lack of carbon dioxide results in decreasing eggshell thickness and an increasing number of broken eggs that further aggravates the profit losses in hens kept in a hot environment.

As mentioned before, hyperventilation during heat stress results in respiratory alkalosis due to the high rate of CO₂ excretion. This means that there will be an excess of alkaline metabolites in the body, as the formation of HCO₃⁻ is insufficient due to the high loss of CO₂. In order for the body to be able to maintain the homeostasis of electrolytes in body fluids it increases the level of K⁺ and Na⁺ excreted in the faeces and urine, while the Cl⁻ concentration of the blood rises. Due to the anyway considerable surplus of Cl⁻ ion it is recommended to discontinue chlorination – where chlorinated water is used – on extremely hot days (Daghir, 2009). The high rate of monovalent ion discharge also impairs the water balance of the birds. Despite the fact that at high temperatures the birds have a higher water intake, the water retention capacity of the body decreases significantly due to the altered electrolyte balance; accordingly, the reduction in intracellular water alters the osmotic pressure and electrical potential of cell membranes as well as the intracellular-extracellular

	Weeks of treatment					
	1	2	3	4	5	Mean
Daily feed consumption (g/bird per day)						
Control	76.3 ^a	96.1 ^a	93.7 ^a	84.1 ^a	83.2 ^a	86.7 ^A
Cyclic	50.9 ^b	74.5 ^b	62.8 ^b	70.5 ^b	70.8 ^b	65.9 ^B
Heat stress	23.2 ^c	38.4 ^c	54.4 ^c	48.2 ^c	43.8 ^c	41.6 ^C
Egg production (%)						
Control	81.2 ^a	88.3 ^a	89.0 ^a	91.0 ^a	87.4 ^a	87.4 ^A
Cyclic	78.4 ^a	81.9 ^a	85.7 ^a	83.3 ^a	83.1 ^a	82.5 ^A
Heat stress	48.0 ^b	52.9 ^b	63.1 ^b	61.1 ^b	55.8 ^b	56.2 ^B
Egg weight (g)						
Control	56.4 ^a	56.3 ^c	56.2 ^a	56.2 ^a	57.1 ^a	56.4 ^A
Cyclic	53.2 ^b	53.3 ^b	53.5 ^b	53.5 ^b	54.0 ^b	53.5 ^B
Heat stress	51.1 ^c	46.8 ^c	46.0 ^c	45.4 ^c	45.0 ^c	46.9 ^C
Egg shell weight (g)						
Control	5.03 ^a	5.13 ^a	5.09 ^a	5.10 ^a	4.96 ^a	5.06 ^A
Cyclic	4.45 ^b	4.77 ^b	4.90 ^b	4.87 ^b	4.82 ^a	4.76 ^B
Heat stress	3.44 ^c	3.62 ^c	3.60 ^c	3.51 ^c	3.31 ^b	3.50 ^C
Egg shell thickness (x 0.01 mm)						
Control	35.2 ^a	36.2 ^a	35.8 ^a	33.9 ^a	33.1 ^a	34.8 ^A
Cyclic	32.2 ^b	35.0 ^b	35.8 ^a	33.6 ^a	33.0 ^a	33.9 ^A
Heat stress	26.8 ^c	29.3 ^c	28.3 ^b	28.4 ^b	28.7 ^b	28.3 ^B

¹ Control: 23.9°C and 50% relative humidity; Cyclic: ranging from 23.9 to 35°C and from 50 to 15% relative humidity, representing natural cyclic temperatures during hot summer months; heat stress: 35°C and 50% relative humidity.
a, b, c and A, B, C means in the same column with no common superscript differ significantly at P≤ 0.05 level

Table 2. Effect of heat stress on different production parameters in commercial laying hens kept different thermal conditions¹ (Mashaly et al., 2003).

homeostasis (Borges et al., 2003). The lack of homeostasis and the heat stress per se accelerate the production of free radicals in the body and lead to a higher risk for oxidation, which is detrimental for the hatchability of eggs, as well as for the growth performance and meat quality of poultry. Broilers were observed to respond to high ambient temperatures by a decreased protein synthesis and increased protein breakdown (reviewed by Lin et al., 2006). This appears to be supported by trial findings that report lower body protein and muscle tissue protein plus higher fat levels in heat stress (Gonzalez-Esquerria & Leeson, 2005; Aksit et al., 2006). The deterioration of meat quality is not limited to the altered protein/fat ratio, as the mobilization of minerals and vitamins from tissues due to heat stress (Sahin et al., 2009) further compromises the nutritive value of eggs and meat (Sahin et al., 2002). The prevalence of other deficiencies of meat quality, such as high drip loss, too pale color (Aksit et al, 2006; Table 3), and PSE (pale, soft and exudative) meat also increase (McKee & Sams, 1997) and these contribute to a significant decline in consumer confidence.

	Yield		Meat nutrient composition		Meat quality ²			
	Carcass (%)	Breast (%)	Moisture (%)	Protein (%)	pH	L*	a*	b*
Control	73.8 ^a	29.9 ^a	74.7 ^a	23.5 ^a	6.00 ^a	48.94 ^a	2.99 ^a	4.19 ^a
28-22°C	72.9 ^b	29.5 ^a	74.4 ^a	22.1 ^{ab}	5.95 ^{ab}	53.04 ^b	4.49 ^b	5.71 ^b
34°C	71.5 ^c	28.4 ^b	72.4 ^b	21.6 ^b	5.89 ^b	53.94 ^c	5.21 ^b	4.44 ^a
SEM	0.2	0.2	0.2	0.3	0.02	0.30	0.28	0.31
P-values	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003

¹ Control: temperature was maintained at 22°C; 28-22°C: temperature was 28°C from 1000 h to 1700 h and at 22°C from 1700h to 1000 h; 34°C: temperature was kept at 34°C from 3 to 7 weeks of age
² L*: lightness; a*: redness, b*: yellowness
a, b, c means in the same column with no common superscript differ significantly at P≤ 0.05 level
SEM: Standard Error of the Mean

Table 3. Effect of rearing temperature¹ on carcass and breast meat percentage, meat composition and some meat quality traits (Aksit et al., 2006).

In summary, high ambient temperatures impair egg production by decreasing the number and weight of eggs as well as by reducing the eggshell quality, whereas in meat-type chickens lower growth rates and higher feed per gain ratios are predominant. The deterioration of meat quality traits due to heat stress occurs mainly in consequence of the associated higher rate of lipid peroxidation and the altered electrolyte balance.

3.3.2 Pig performance and pork quality

The climate change with rising mean temperatures may cause a permanent stress load for pigs, especially in continental summer or warmer climate areas. As shown in Table 1, the upper critical temperature for pigs from nursery to adult ages is 25-26°C; however, some research data suggest that the optimal temperature decreases with the increase in body weight. The heavier an animal, the less ability it has to lose heat due to the relative small surface area compared to its body weight. In consequence feed refusal increases with body weight at high ambient temperatures (Close, 1989; Quiniou et al., 2000). In case of sows kept at high ambient temperatures (29°C vs 18°C) the feed intake over the entire lactation period may fall back by more than 50%, resulting in a loss of body condition far exceeding the optimum and also leads to poorer growth of the piglets (Table 4).

	Ambient temperature (°C)				
	18	22	25	27	29
Daily feed intake (g/d)					
Day 1 to 21	5666	5419	4947	4520	3079
Day 7 to 19	7161	6401	6084	5321	3483
Body weight loss (kg)	23	22	25	30	35
Backfat thickness loss (mm)	2.1	1.9	2.7	3.5	3.5
Pig growth rate (d 1-21; g/d)	244	245	233	212	189

Table 4. Effect of ambient temperature on performance of multiparous lactating sows (Quiniou & Noblet, 1999).

The condition of the sows is also in close correlation with the number of days to oestrus and the reproductive performance. Studies with pair fed sows showed that the energy metabolism and hormonal status of the animals changed during heat stress and the lower milk production is not exclusively explained by the reduced feed intake (Prunier et al., 1997; Messias de Bragan et al., 1998). Renaudeau et al. (2003) suggest, that the apparent inefficiency of the sow mammary gland in hot conditions could be attributed to an increased rate of blood flow irrigating the skin capillaries in order to dissipate body heat and this in turn results in a lower blood flow to the mammary gland cells. Feeding high fat diets (125 g fat per kg of dry matter) to the sows during lactation in order to alleviate hyperthermia leads to decreased heat production, which may reduce the feed refusal of the sows kept at high ambient temperatures (Babinszky, 1998). Feeding high fat diets also improves the energetic efficiency of milk production when compared to sows fed high starch diets (with low dietary fat levels, Table 5). From the aspect of energetic efficiency milk fat production is more efficient from dietary fat than from dietary carbohydrates because it is converted more directly (Babinszky, 1998).

	Exp. 1*			Exp. 2*		
	LF	MF	RMSE	LF	HF	RMSE
ME intake (MJ/kg ^{0.75} /d)	1605	1626	160	1445	1404	112
Heat production (MJ/kg ^{0.75} /d)	795	779	20	771 ^a	719 ^b	18
Energetic efficiency of milk production (%)	71	72	1	70	73	1

* In exp. 1 LF: low fat diets (43g/kg dry matter); MF: medium fat diets (75 g/kg dry matter); in exp. 2 LF: low fat diets (37 g/kg dry matter); HF: high fat diets (125 g/kg dry matter)
RMSE: Root Mean Square Error
^{a, b} means in the same row with no common superscript differ significantly at P≤ 0.05 level

Table 5. Effect of dietary energy source on the heat production of lactating sows and on the energetic efficiency of milk production (Babinszky, 1998).

Since the milk production of the lactating sow determines the performance of the suckling pigs in terms of their growth rate, mortality and morbidity, any reduction in the milk yield will have a negative impact on the profitability of pig production. Moreover, heat may also compromise the parameters of fertility: the quality of eggs and sperm deteriorates; embryo mortality between days 1 to 15 increases and maturity is delayed. In consequence, the number of piglets per sow may be less when sows are exposed to high ambient temperatures for longer periods of time. High temperatures cause loss of appetite in pigs; however, both the upper critical temperature and the rate of feed refusal are influenced by the relative humidity of the air (Collin et al., 2001; Huynh et al., 2005). With the increase of humidity a 60 – 70 kg pig may lower its feed intake by up to 80-150 g/day (Huynh et al., 2005). The lower feed intake compromises the daily gain, however, after exposure to hot periods of 30-33°C pigs display compensatory growth, they overcome their heat stress and grow further, but they can't compensate for temperatures as high as 36°C (Babinszky et al., 2011). There is a curvilinear relationship between the increase of temperature and the average daily gain and feed conversion rate of pigs fed *ad libitum* (reviewed by Noblet et al., 2001). The average daily gain reaches its maximum between temperatures of 15 to 25°C in young pigs (up to 30-34

kg) and between 10-20°C in growing and finishing pigs. Both cold and severe heat stress compromise feed conversion; however, during moderate heat stress (2-3°C above the upper critical temperature) pigs have the ability to compensate for the lower feed intake by decreasing their maintenance related heat production. Besides constant heat stress, diurnal high temperatures can also be detrimental to pig performance. The average daily feed intake and the average daily gain decreased by 10 and 20%, respectively, and the feed conversion (feed/gain) increased by approximately 8% when pigs were kept in a daily range of 22.5 to 35°C in contrast to the thermoneutral (20°C) temperature (Lopez et al., 1991). In the interest of performance and immune response it is recommended to avoid any higher fluctuations ($\pm 12^\circ\text{C}$) of the mean of 20°C (Noblet et al., 2001).

Recent publications highlight the fact that high temperatures not only impair growth but also change body composition and thus can impair the nutritive value and quality of pork. Prolonged heat stress (30-33°C) reduces the rate of protein deposition in growing and finishing pigs (Kerr et al., 2003; Le Bellego et al., 2002). As seen in the above, the lower protein deposition is probably not just in consequence of the lower nutrient supply. Halas et al. (2004) demonstrated in their model simulation that the rate of protein deposition is sensitive to any changes occurring in the maintenance energy requirement of the body. Heat stress triggers hormonal changes that influence the metabolism of nutrients. Reduced levels of thyroid hormones were consistently observed in swine kept in a hot environment in contrast to a thermoneutral milieu (Messias de Bragan et al., 1998; Renaudeau et al., 2003). Thyroid hormones are responsible for the metabolic rate and thermogenesis besides influencing the protein turnover within the body. Although carcass fatness decreases as a result of lower feed intake during heat stress, the shift of fat distribution from external sites towards internal sites was found to be attributable to a reduced activity of the lipogenic enzyme in backfat and a higher activity of lipoprotein lipase in lean fat (Noblet et al., 2001). In conclusion, heat stress impairs feed intake and swine performance in the lactating sow and in growing and fattening pigs. The extent of this detrimental effect depends mainly on body weight and the actual temperature and relative humidity of the air. Recent studies show that growing and fattening pigs kept in hot environments deposit less protein, which compromises pork quality with regard to the protein to fat ratio in the meat. Any means of reducing heat production or increasing heat loss of the animals are beneficial in the efforts to avoid the weakening of the production potential of swine when facing with global warming.

3.3.3 Cattle production: milk production, milk quality and beef production

In dairy cows, similarly to other species the various factors of the environment, such as the average temperature, humidity and air velocity all play an important role in the fertility, reproductive performance and milk yield of the animals, and this is particularly true in animals with high genetic potential. The optimal ambient temperature for dairy cows is between 5 to 15°C. Over 15°C the animals start to sweat, although they are still able to maintain the equilibrium between heat production and heat dissipation. Heat dissipation by sweating gradually increases and although it becomes quite intense above the upper critical temperature (25°C) the cow is no more able to maintain the heat balance at such high temperatures. Kadzere et al. (2002) found that on days of heat stress the amount of water lost through evaporation may be up to or even exceed the amount of water excreted in the milk. The high rate of water loss stresses the importance of water supply for dairy cows at high temperatures. The efficiency of body cooling by evaporative water loss, however,

decreases with the increase of humidity. The use of the Temperature-Humidity Index (THI) is suggested as an indicator of the thermal climatic conditions ($THI = 0.72(W + D) + 40.6$, where W is wet bulb and D is dry bulb temperature in °C). When the THI is in the range of 72-80, 80-90 or 90-98, the corresponding heat stress is mild, medium or severe. Both the increasing ambient temperature (from 25 to 32°C), and the increasing THI (from 73 to 82) have a negative impact on the dry matter intake and milk production of cows (West et al., 2003). The relevant data show, that the shorter the animal is exposed to heat stress, the better they can tolerate it, although even a moderate heat stress will impair their production performance. As mentioned earlier, there are other environmental factors besides temperature and humidity that affect thermal sensation. According to the results of a model simulation the critical ambient temperature that can compromise the respiratory response of a 600 kg live-weight Holstein cow is largely dependent on the daily milk yield, coat depth, exposed surface area, air velocity and water vapor pressure (Berman, 2005; Table 6) and in varying environmental conditions the upper critical temperature of the animals can fluctuate in a wide range (8 to 42°C).

Item		Terms in model				
Milk yield (kg/d)		35	35	45	35	35
Coat depth (mm)		3	6	3	3	3
Exposed surface area (%)		100	100	100	75	50
Air velocity (m/s)	PW ^a	Predicted threshold air temperatures, °C				
0.2	1	37	36	32	29	16
0.2	3.4	30	27.5	25	24	8
1.5	1	41	42	36	34	22
1.5	3.4	40	39	34	33	14
0.85	1	39	37	36	34	20
0.85	3.4	36	31	31	31	11

^a water vapor pressure (kPa)

Table 6. Simulation values for air temperature (°C) at which threshold respiratory response (53% of maximal respiratory heat loss) is attained by a 600-kg body weight Holstein cow (Berman, 2005).

The heat stress caused feed refusal predisposes the animal to certain metabolic disorders, first of all to ketosis. The occurrence of ketosis at herd level not only leads to a temporary decline in milk production, but in consequence of the mortalities may also cause a drop in the number of dairy cows. The adaptive mechanisms that serve survival, for instance in the case of harsh ambient temperatures, weaken the production performance. One element of the long-term adaptation to high temperatures is slowing the heart rate, which leads to a lower level of heat production associated with maintenance. At the same time circulation in the mammary glands is impaired, resulting in poorer milk yield. The ability of dairy cows to adapt to the changes of their environment depends on their genetic potential. The present-day selection for production weakens heat tolerance, thus combined selection for heat tolerance and production is recommended when facing the challenge of climate change (Ravagnolo & Misztal, 2000).

The lower feed intake and higher water consumption during heat stress result in a modified fermentation and volatile fatty acid production in the rumen since the high temperature

may affect the functioning of rumen bacteria. Of the volatile fatty acids produced in the rumen and transported to the bloodstream acetic acid is primarily used for lipid synthesis, while the level of propionic acid influences the protein content of milk. In a study with Jersey cows the proportion of acetic acid in the rumen contents as well as the ruminal pH significantly decreased when the cows were kept at 30°C instead of 20°C (Bandaranayaka & Holmes, 1976). In consequence the protein and fat content of the milk, and also the proportion of middle-chain fatty acids (C₆–C₁₄) in milk fat decreased at high temperature.

The lower feed intake caused by high ambient temperatures compromises the protein supply of the cows in an indirect manner as well, in so far as the lower rations mean less sulphur supply, which may limit the protein synthesis by rumen bacteria, and which certainly affects the level of the essential amino acid, methionine. The lower level of microbial protein, which has a crucial role in the protein supply of ruminants, and/or the lower methionine content in the rumen flora clearly lead to a decrease of milk protein. Consequently the sulphur supply of rumen flora should receive particular attention at high ambient temperatures in order to avoid the fall of milk protein. Several studies have confirmed that adequate sulphur supply yields further benefits. Adding potassium, sodium, or magnesium sulfate to diets of dairy cows may enhance the digestibility of dry matter; therefore, it is recommended to increase dietary sulfur during heat stress in order to improve the digestibility of nutrients and to maintain the protein content of milk (Kadzere et al., 2002).

Heat stress increases loss of body fluids due to sweating and panting and results in an altered water balance of the body and the osmolarity of cells. Enhanced respiration associated with a higher rate of CO₂ loss leads to an altered blood pH and respiratory alkalosis. An increased urinary pH can help to overcome alkalosis caused by the high excretion of bicarbonate (HCO₃⁻) (Kadzere et al., 2002); however, these processes have energetic and thermoregulatory consequences. Excretion of sodium in the sweat and urine increases during heat stress, at the same time the level of Na available in the body determines, even if indirectly, the milk fat content. NaHCO₃ acts as a key buffering agent in the rumen, alleviating the low-fat milk syndrome. Several studies have shown significant increases in the milk production of heat-stressed dairy cows when fed higher than recommended (NRC, 1989) concentrations of sodium (NaHCO₃) and potassium (i.e. KCl) (reviewed by Silanikove et al. (1997).

In beef cattle the unfavorable meteorological conditions directly affect the animals and their physiology as discussed in the above section for dairy cows. Extreme weather conditions diminish the growth performance (weight gain, feed intake and feed conversion potential) of beef calves, particularly of those kept outdoors. Slower growth and smaller slaughter weight however are reflected in the quality of meat as well, since animals of the same age but smaller body weight have less muscle fat and also the taste panel traits of juiciness and tenderness are poorer (Keane & Allen, 1998). The predicted climate changes not only weaken the performance of livestock per se, but also compromise the conditions for production by reducing the quality of feedstuffs, as earlier discussed in this chapter. Increasing mean temperatures and declining precipitation reduce the dietary crude protein and digestible organic matter content of grass; it is unlikely, however, that any future increases in precipitation would compensate for the declines in forage quality following from the projected temperature increases (Craine et al., 2010). Aridity, water deficiency may lead to a drop in groundwater levels, alteration and thinning of pasture flora, and in

consequence to a decline in feed supply, besides aggravating the problems of water supply (Babinszky et al., 2011). As a result, cattle are likely to experience greater nutritional stress in the future with the two options of either accepting the loss of performance or being prepared to provide supplemental nutrition to the extensive beef sector as well. Feeding concentrate to beef cattle increases the costs of beef production, and it may also affect the nutritive and health value of meat. In respect of fatty acid composition, numerous publications suggest that the meat of grass fed cattle contains more n-3 fatty acids and conjugated linoleic acid than meat from their concentrate fed peers (Scollan et al., 2006; Nuernberg et al., 2005). These fatty acids play an important role in maintaining health and preventing diseases (i.e. cardio vascular diseases, cancer) and consumers are increasingly aware of these functional components of foods. In addition to the above-mentioned problems, extreme weather may result in respiratory disease, immune suppression and thus higher mortality of the animals, which further reduces the profitability of beef production. Summarizing the relevant data it can be stated that severe heat stress results in an average production loss of 1.5-2 liters/cow/day (5-10 % of the daily milk yield). Moreover, the altered rumen fermentation influences not only milk yield but also milk composition by reducing its protein and fat content. In case the predicted climate change occurs, the present beef production potential can only be maintained if supplemental feeds are offered, but this would significantly reduce the economic efficiency of cattle production and may have an impact on beef quality as well.

It is clear from the previous section that the efficiency of nutrient metabolism in farm animals suffers if the climatic conditions fall outside the thermoneutral environment. It should also be emphasized that poorer nutrient digestibility and efficiency of utilization both lead to a higher rate of nutrient excretion (i.e. N and P), with a consequent negative impact on the environment. The higher rate of nutrient excretion damages the actual production potential as well as the product quality, and it also compromises the health status of feed producing animals with possible feed safety consequences.

4. Feeding strategies in response to climate change

Climatic conditions determine the energy and nutrient metabolism of farm animals. According to relevant data climate change leads to a higher mean ambient temperature, and it may even result in extreme weather in certain parts of the World. This calls for a discussion of feeding strategies in response to climate change, including nutritional manipulation and feeding during cold and heat stress.

4.1 Feeding strategies during cold stress

As earlier mentioned, animals consume more feed at low ambient temperatures in order to compensate for the increased energy requirement used in thermoregulation. From the aspect of energy requirements a cold environment is essentially the equivalent of reduced energy supply, and thus higher feed intakes and higher energy intakes can meet the extra demand of thermogenesis. When the increased feed intake is prevented by the limitations of the animal's gastro-intestinal system, any means of boosting the dietary energy of the feed may be suitable for maintaining growth, and egg and milk production. Although increasing the dietary energy in a thermoneutral environment is associated with the improvement of feed conversion (the amount of feed required to produce 1 kg of product), in cold ambient

temperatures, however, feed conversion may become worse or in the best case does not change with the feeding of high energy density diets due to the higher use of maintenance – i.e. non-productive – energy.

The body attempts to compensate for the excessive heat loss suffered in cold temperatures by a higher rate of heat production, and one component of this is to increase the use of maintenance energy. Heat, however, is also generated in the course of digesting and converting the dietary nutrients (the thermic effect of diet), which helps to maintain body temperature in conditions below the lower critical temperature; accordingly the feeding of diets with a high thermic effect will help the animals cope with the too cold environment. Thus for example, when high fiber diets are fermented by the colon bacteria a relatively high portion of energy is lost as heat; and the oxidation of proteins / amino acids as a form of energy producing process also produces lot of heat. Therefore, feeds containing a high percentage of fermentable fibers or excess protein increase the heat production of the animals. In practical feeding, however, protein overfeeding is not recommended either from the economical or the environmental point of view.

4.2 Feeding strategies during heat stress

Since heat production after ingestion of the diet is high, farm animals reduce their feeding activity at high ambient temperatures, which bears significant consequences on their nutrient intake. The practice of feeding the daily ration in several smaller portions or during the cooler parts of the day follows from the above. Based on the previous sections other potential feeding strategies can be applied at the time of heat stress, which (i) reduce the heat production by the animals; (ii) compensate for the lower nutrient supply; and (iii) alleviate heat stress induced metabolic changes. It should be noted, however, that during severe heat stress these methods should be used in combination in order to maintain the production performance of the farm animals and the quality of their products.

4.2.1 Methods to reduce the total heat production of livestock

Methods to reduce total heat production of farm animals consist of (i) fat supplementation, (ii) feeding low protein diets with synthetic amino acids according to the ideal protein concept, and (iii) adding dietary betaine.

(i) In comparison to other nutrients, fat generates the least heat, either when deposited as body fat or when used for energy, thus high fat diets reduce the total heat production of the animals. Accordingly, fat supplementation moderates feed refusal, which is critical for the production potential. At the same time, fat supplementation boosts the energy density of the diet, as the energy content of fat sources (both of plant and of animal origin) is far the highest compared to the other nutrients and to compound feeds. By adding fat to the diet the energy requirement of the animals can be met accurately even if the feed intake decreases to some extent above the upper critical temperature.

(ii) The so-called ideal protein refers to a well-defined amino acid pattern, which expresses the requirement of essential amino acids in percentage of lysine. The amino acid pattern of the ideal protein changes to some extent during the life of the animals in accordance with their level of production (Table 7). Amino acid conversion and N excretion are the lowest when diets are formulated according to ideal protein concept. Excess amino acids that cannot be used in protein synthesis due to a limiting factor (such as a limiting amino acid, energy supply or genetic potential) are metabolized in the body. Compared to other

nutrients, the oxidation of amino acids yields the most heat contributing to the total heat production. Consequently, the heat increment is higher when excess amino acids are present in the diet. The heat increment from protein metabolism is at the minimum if the dietary protein level meets the requirements of the animal, and if the amino acid content or even the ileal digestible amino acid content corresponds to the ideal protein concept.

Amino acids, % of Lys	Body weight range		
	5-20 kg	20-50 kg	50-100 kg
LYS	100	100	100
THR	65	67	70
TRP	18	19	20
MET + CYS	60	65	70
ILE	60	60	60
LEU	100	100	100
VAL	68	68	68
HYS	32	32	32
PHE + TYR	95	95	95

Table 7. Amino acid composition of ideal protein as a percentage of lysine for growing and finishing pigs (Baker & Chung, 1992).

(iii) Betaine (trimethylglycine) is an intermediate metabolite in the catabolism of choline, which can modify the osmolarity, acts as a methyl donor, and has potential lipotropic effects. Schrama et al. (2003) showed that under thermoneutral conditions dietary betaine supplementation (1.23 g/kg) reduced the total heat production of pigs. Moreover, recent studies repeatedly recommend using betaine in pig and poultry feeds during heat stress (Metzler-Zebeli et al., 2008), as being a methyl donor it can be used in the antioxidant defense (for glutathione-peroxidase) system, and it also efficiently inhibits the reduction in cell water retention.

As previously mentioned, dietary fiber increases the heat production of the animals, and this raises the question as to how feed should be formulated for animals that require high levels of dietary fiber, such as gestating sows and ruminants. In gestating sows the diluted (low energy content) feed with high fiber content prevents the sows becoming overweight, which could otherwise lead to health problems and insufficient milk production during lactation. According to data reported by de Lange et al. (2006), the overall energy cost of ingesting and excreting indigestible material in growing pigs is very small, thus the use of poorly digestible fiber sources in gestating sow diets may be beneficial at high temperatures. In ruminants high dietary fiber content supplied in the daily ration is indispensable for adequate rumen fermentation. Bearing in mind the positive correlation between the metabolizability of the diet and the efficiency of energy utilization, it can well be recommended to feed high quality forages and other highly digestible fiber sources to ruminants during heat stress. This will result in a somewhat lower heat production by the animals, in contrast to cows fed with poor quality forages. At the same time it is probable, that due to the extreme weather conditions high quality forages can only be produced using special agro techniques, which will increase their price. The role of drought resistant grasses (e.g. brome grass, tall fescue, crested wheatgrass, etc.) and leguminous species becomes

more important in the flora of pastures for grazing animals (Babinszky et al., 2011); however, new varieties of grasses would likely be used requiring joint research projects of plant breeders with animal nutritionists.

The above sections discussed the extent of feed refusal during heat stress and its effect on livestock performance. If the decrease in feed intake can be alleviated or prevented, the nutrient supply will meet the requirements of the animals for high production potential and good quality food production.

4.2.2 Compensating for reduced nutrient supply

Since heat stress impairs feed intake and the digestibility of nutrients too, it is recommended to feed more concentrated diets with high levels of easily digestible nutrients in hot environments. This should be implemented with the use of various options offered by the feed manufacturing technologies (hydrothermic treatments, micronization), and also by increasing the level of dietary vitamins and minerals, and perhaps by improving their bioavailability. The bioavailability of nutrients can be achieved in part by enhancing the digestibility of nutrients in the small intestine (ileal digestibility) and also by boosting the utilization of absorbed nutrients (e.g. use of organic trace elements). Adding different enzyme supplementation to the diet can improve the ileal digestibility of nutrients, such as amino acids, carbohydrates and Ca and P. It is suggested, however, to use substrate specific dietary enzymes (phytase, xylanase, β -glucanase, etc.) in accordance with the composition of feed.

The use of methods that improve the digestibility and bioavailability of nutrients is also desirable from the aspect of environmental protection. Improving the digestibility and conversion of nutrients, and meeting the requirements of the animals accurately can serve to curb the environmental load from animal husbandry. At the same time it should be stated that enhancing the nutritive value of animal diets becomes particularly important in hot climates.

4.2.3 Alleviating heat stress induced metabolic changes

The third group of nutritional strategies aims to alleviate the heat stress induced metabolic changes within the body. These are means to enhance the oxidative defense or alleviate the shift in electrolyte balance within the body. Several micronutrients possess direct or indirect anti-oxidative properties; those most extensively examined in farm animals are vitamin C, E and A, zinc and selenium as well as methionine. According to the findings of relevant studies the nutrients listed in the above improve the defense of farm animals against lipid peroxidation; also the body requires more of these antioxidants during heat stress. This is why it should be stressed, that vitamin and mineral supplementation not always leads to the improvement of production performance or product quality of animals kept in hot environments, even though they are essential to maintaining their health status. The excretion of Na and K and the amount of water lost from the body increase during heat stress, which together may lead to a shift in the acid / base balance. Supplementing monovalent ions in the diet can lessen the decrease of water retention by the body. Salts suitable for the purpose are ammonium chloride, sodium and potassium bicarbonate, sodium and potassium hydro carbonate, potassium sulphate, etc., which can be equally used in poultry, swine and ruminant nutrition.

With respect to alleviating the non-desirable consequences of climate change, the combined application of the options discussed in the above can counteract the negative impact of

conditions outside the comfort zone of farm animals. Knowing the altered nutrient requirements and adjusting the nutrient supply to them can help to prevent the deterioration of production performance and product quality. However, in addition to precision feeding, housing should be adjusted to the climatic conditions as well, i.e. animals should be kept in well insulated, heated or cooled buildings, in accordance with the ambient temperatures. The most important action for alleviating the impact of heat stress is to open up enclosed buildings, in order to increase their cubic capacity. Outdoor pens become more important for breeding animals and further solutions can be to establish sprinkler systems, wallows, and to cool the buildings with adiabatic systems or heat exchangers (Babinszky et al., 2011). There is a consensus that genetic selection should aim to improve the heat tolerance of high producing farm animals without impairing their genetic potential. The continuously expanding poultry production in the tropical and subtropical regions of the Earth already necessitates the revision of selection strategies of breeding programs (Lin et al., 2006). There are promising results from efforts aimed at developing technologies to improve the adaptation of meat and egg type poultry to hot environments. The improvement of adaptive abilities to the changes of the ambient temperature besides maintaining the existing production potential will become one of the selection objectives and technical solutions in response to the climate change, and not only for poultry but for other farm animal species as well. Based on all this it can be concluded that the combined application of animal feeding and housing developments plus of genetic programs is required in order to maintain or even improve the production efficiency and product quality of farm animals despite the climate change.

5. Conclusion

In summary it can be concluded that we should expect climate change to cause long-term changes in the environment, which in turn affect feed crop production and the production of farm animals.

An important task facing feed crop breeders is to create C3 feed crop varieties that as a result of the selective breeding efforts become more drought tolerant besides maintaining their average yields and nutrient contents. It will be our task as nutritionists to use these improved feed crop varieties in a highly focused and professional manner when formulating diets.

When developing professional animal nutrition however, we should not only rely on traditional nutritional science but should also use the results of its related disciplines (microbiology, immunology, molecular biology, molecular genetics, digestive physiology, etc.) besides having a thorough knowledge of the energy metabolism of farm animals. As discussed earlier, there is a very close relationship between the energy metabolism of the animals and the ambient temperature, and the animal performance and the quality of their products. The knowledge of these factors enables us to alleviate by means of nutrition the stress caused by climate change and in consequence to produce high quality and safe foodstuffs meeting the requirement of human nutrition without increasing the environmental load of production.

This also means that the different disciplines can only provide an adequate response to the challenges of climate change in cooperation. Therefore, climate researchers, meteorologists, plant breeders, crop producers, animal nutritionists, biologists, geneticists, livestock producers, animal housing technicians, nutrition biologists, doctors, etc. should all work

together in the frames of a carefully structured and coordinated project to achieve this objective.

The task is given, and its accomplishment depends on us only.

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