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REVIEW: THE INFLUENCE OF GENOTYPIC AND PHENOTYPIC FACTORS ON THE COMFORT AND WELFARE RATES OF COWS DURING THE PERIOD OF GLOBAL CLIMATE CHANGES

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ABSTRACT. The study of the influence of weather phenomena on behavioural and physiological processes plays an important role in the development of highly effective methods of dairy farming management. Climate and weather factors have important signification in the system of interaction "organism-environment". One of the main factors of cows' comfort improvement in different types of premises, on ground runs and pastures is the creation of such indicators of microclimate that would best meet the biological needs of dairy cows, depending on the season and productivity. Due to the constant metabolic processes, the body of cattle is very hurtable to ambient temperature. This is especially felt during periods of prolonged low or high-temperature shocks. Disorders of metabolic and thermoregulatory processes directly affect the duration and nature of behavioural and physiological reactions and cause stress in animals. Prolonged temperature stress is the reason for fluctuations in productivity, quality of milk and problems with reproduction and together significantly affect the profitability of production. To reduce the impact of temperature stress on the body of dairy cows, scientists have proposed management strategies during periods of high and low-temperature shock. These strategies are divided into genotypic: the selection of heat-resistant individuals of different breeds and phenotypic: the use of microclimate control methods and modernization of feeding management methods. The effect of temperature stress on the body of dairy cows can be minimized due to genotypic (breeding of heat-resistant breeds) and phenotypic factors (water irrigation systems, ventilation, and the use of shade shaded shelters in summer and insulation of side curtains in winter), or a combination thereof. The purpose of this article is to summarize existing knowledge about the effects of temperature stress on the health, productivity and comfort rates of cows and to discuss management strategies that would mitigate the effects of these factors.

Introduction

Adaptation of livestock breeds to local climatic conditions is an important feature of modern agriculture, as it helps to reduce the influence of temperature stress to which animals are exposed, and leads to increased livestock production. Cattle under the influence of evolutionary factors (migratory movements together with human populations, as well as during the periods of natural migration to domestication) underwent a long natural selection and has adapted to various environmental conditions from equatorial Africa and America to central and northern Siberia (Upadhyay *et al*., 2017). Domestication has resulted in more than 1000 existing breeds with varying levels of productivity, product quality, feed conversion, and other economically important features (Berman, 2011; Zhang *et al*., 2013; Scheu *et al*., 2015).

In recent decades, the trend towards global warming has continued, which is already felt significantly at the regional and local levels (WMO, 2018; Hempel *et al*., 2019). The main direct effects of climate changes that have a negative influence on animal physiology, welfare, health and reproduction are rising air temperatures. The number of days with thermal stress caused by an increase in the temperature-humidity index (THI) increased by 4.1% during the period from 1973 until 2008 in Central Europe (Solymosi *et al*., 2010). Data from Novak *et al*. (2009) shows that in this region there are already more than 90 hot days a year. This affected the benefit of milk production at the stages from feed production to reproduction.

Along with the increase of the average annual temperature, the indicators of relative air humidity, amount of precipitation, as well as the direction and strength of the wind change (Herbut *et al*., 2013). Seasonal shifts and changes in the frequency and intensity of weather indicators affect most economic phenomena in agriculture (Nardone *et al*., 2010). Peculiarities of natural processes cause quite a frequent recurrence of unfavourable weather phenomena for agriculture, such as showers, hail, strong winds, dust storms, dry winds, droughts, touches of frosts, icy spots, etc. According to the Food and Agriculture Organization (FAO), approximately 26% of all losses and damages related to climate and weather calamities drop on such sectors of agriculture as crop science, farm animal production, fisheries, aquaculture and forestry (FAO, 2017).

The topic of the influence of climate changes on farm animal production is becoming increasingly urgent and relevant (Vitt *et al*., 2017). Adverse climatic conditions for farm animals lead to deterioration of their health, impaired thermoregulatory traits, growth and development, reduction of productivity and product quality, reproductive traits, metabolic status of animals and their resistibility (Broucek *et al*., 1991; Angrecka, Herbut, 2015). Thermoregulatory characteristics of cows are partly an individual feature and depend on body surface area, skin thickness, density and length of hair and fluffy, as well as the presence of dirt on animal hair (Herbut *et al.*, 2020).

The term climatic stress (*i.e*. heat and cold stress) means metabolic changes in farm animals in an attempt to adapt to changing weather conditions. This includes physiological and behavioural changes (Galán *et al*., 2018) and is caused by various combinations of air velocity, temperature, humidity, atmospheric pressure, and solar insolation (Mader *et al*., 2006).

Johnson (2018) identifies three strategies for managing and reducing the effects of temperature stress on the body of dairy cows: breeding heat-resistant breeds (genotypic factors), the use of microclimate control and the modernization of feeding management methods.

The purpose of this article is to summarize existing knowledge about the effects of temperature stress on the health, productivity and comfort rates of cows and to discuss management strategies that would mitigate the effects of these factors.

Genotypic factors

Breeding is one of the ways to reduce the influence of climate changes on dairy cows. The ability of dairy cattle to maintain body temperature during periods of excessively high and low-temperature stress is a feature that has recently been actively included in breeding programs (Kim *et al*., 2013; Kim *et al*., 2015). Currently, the development of DNA of animal bases with bio informative analysis of adaptation traits of certain breeds, lines and families to temperature stresses is becoming relevant (Srikanth *et al*., 2017; Liu *et al*., 2020). The use of such approaches leads to the correction of genes responsible for thermoregulatory processes and thus to the development of breeding strategies for breeding cows with good thermoregulatory traits.

Dikmen *et al*. (2008) indicate the attempts to improve the thermoregulatory traits of Holstein cattle by genetic means. To do this, the animals are injected with a smooth hair gene (SLICK). This gene is responsible for the length and density of the hair, which regulates heat input by evaporation. However, this method has not been widely used, because the breeding of shorthaired animals is relevant only in those regions where the average annual temperature does not fall below +15 °C.

Bernabucci *et al*. (2010) in their studies report that animals with lighter and shorter hair colour tolerate high temperatures better than animals with dark colour and long hair. This trait is characteristic of tropical cows of the Senepole breed in which the dominant gene is associated with increased sweating intensity, lower values of rectal temperature and respiratory rate (Mariasegaram *et al*., 2007).

Studies executed with African aboriginal cattle indicate that genes such as HSPA4 and SOD1 are responsible for adapting animals to hot housing conditions (Kim *et al*., 2017).

Heat stress genes have been identified and used as markers in the selection of thermotolerant bulls. The main heat shock proteins Hsp are Hsp100, Hsp90, Hsp70, Hsp60, Hsp40 and micro Hsps (so-called Hsp size below 30 kDa). HSPs play a crucial role in the recovery of cells from the effects of stress factors, as well as perform the function of cytoprotection. Hsp-gene expression during changes in temperature stress includes (i) activation of heat shock transcription factor (HSF1); (ii) increase of the expression of Hsp genes and decrease of the expression of the synthesis of other proteins; (iii) increase of the glucose and amino acids oxidation and decrease of fatty acids metabolism; (iv) activation of the endocrine system under stress; and (v) activation of the immune system through extracellular Hsp secretion. If stress persists, these changes in gene expression lead to a change in a physiological condition called acclimatization, a process that is largely controlled by the endocrine system (Collier *et al*., 2008).

Charoensook *et al.* (2012) noted the association of single nucleotide polymorphism (SNP) in Hsp genes in response to temperature stress. The association of Hsp90AB1 polymorphisms with heat resistance has been reported in studies of Thai aboriginal cattle and Sahival breed, and genes: HSF1, HSP70A1A, and HSBP1 at Chinese Holstein cattle (Li *et al*., 2011a; Li *et al.*, 2011b; Charoensook *et al*., 2012 Wang *et al*., 2013). Also, it has been found that genes that are not rated as Hsp genes fall for expression in response to temperature stress. These single nucleotide polymorphisms can be used as markers in the selection of heat-resistant animals (especially bulls) at an early age.

Feeding factors

Among the feeding strategies that can provide appropriate means to alleviate heat stress, the most important is the use of dietary fats, minerals, trace elements, vitamins, fibre, microbial ingredients (yeast), plant extracts and other additives that improve antioxidant and immune function (Min *et al*., 2019; Shan *et al*., 2020). Besides, bicarbonate, potassium, zinc, vitamins C, E and B_3 in feed rations should be increased during heat stress (Kadzere *et al*., 2002).

West (2003) reports that during periods of high temperatures, the protein content in the diets of dairy cows should not exceed 18% in terms of dry matter of feed.

Adjusting rations by increasing the proportion of concentrated feed or adding vegetable fats may contribute to lower milk losses during low temperatures (Kadzere *et al.*, 2002). However, these methods are not always effective in animals of other sexes and ages. Studies conducted in South Korea dealing with the effect of low temperatures (average daily temperature – 6.4 °C) on the growth rates of young cattle showed that the group of bulls fed with the bypass fat supplement did not differ from the group with a mixed diet (Kang *et al*., 2019). Ghasemi *et al*. (2017) in their studies conducted during the cold period (average daily temperature 5 °C) in Iran was divide sixty Holstein calves (3 days of age; 39.7 ± 3.8 kg of body weight) into 5 starter diets supplemented with (1) no fat or oil source (control), (2) 3% palm fat, (3) 3% soybean oil, (4) 3% tallow and (5) a 3.2% mixture of palm fat, soybean oil and fish oil. Feeding supplemental soybean oil tended to improve average daily gain and final body weight.

Holstein high-yielding cows are more prone to heat stress in comparison with less productive counterparts because they dissipate more metabolic heat (Spiers *et al*., 2004). During the period of thermal stress in the body of animals, there is an increase in the basic metabolism caused by the activation of the thermoregulatory system.

Climatic conditions have a direct influence on the health of cattle and can exacerbate or inhibit the development of diseases caused by temperature fluctuations. In addition, climatic conditions have a direct influence on the formation of immunity and the normal functioning of the endocrine system (Das *et al*., 2016). Climatic influence on the health and productive characteristics of cows occurs during periods of high temperatures when the feeding behaviour of animals changes significantly (there is an increase in concentrate consumption while reducing the total feed intake), which in turn contributes to acidosis, which causes lameness. In addition, reducing feed intake in high-yielding cows increases the risk of subclinical or clinical ketosis during the summer months (Lacetera *et al*., 1996; Rojas-Downing *et al*., 2017). The short period of heat stress during the final phase of embryonic development can have a significant impact on the health, growth and development of calves (Laporta *et al*., 2017). Fabris *et al*. (2019) indicate that cows exposed to heat stress during the dry period decreased productivity, protein, and lactose content in milk within the next lactation

Sunil Kumar *et al*. (2010) found in their studies conducted in India with adult buffaloes during periods of dry and wet heat loads that the addition of sodium bicarbonate, potassium carbonate and ascorbic acid polyphosphate to the diet prevents oxidative stress and increases immunity at the cell level.

The use of modern feeding approaches increase milk production per cow by 2–3% per year, but this leads to additional costs for veterinary measures, increased incidence of metabolic diseases and culling rates (von Keyserlingk *et al*., 2009). Bruno *et al*. (2009) report the effectiveness of the use of dry yeast culture (*Saccharomy cescerevisiae*) of 30 g per day during the period of high temperatures in the diets of adult cows. Milk productivity of such cows was 1.2 kg per day higher compared to cows that were not fed with dry yeast.

Gonzalez-Rivas *et al*. (2018) in their studies conducted in Queensland (Australia) during periods of high temperatures, divided lactating cows of the Holstein-Friesian breed into three groups: the first was fed with a total mixed ration (TMR) + flattened wheat; the second group TMR + flattened wheat grain treated with 2% starch solution, and the third group TMR + flattened corn grain. As a result, cows of the second and third groups had higher productivity compared to the first one, and cows of the third group had a lower rectal temperature than animals of the first and second groups.

Studies executed in New Jersey (Tinek Township) with a crossbreed of Holstein cows and Gir cows showed a positive effect thanks to the use of Omnigen-AF feed additive (1 kg of the additive: 650 g of bentonite, 250 g of purified diatomaceous earth and 100 g of dry brewer's yeast) during high-temperature shock. The experimental cows had higher rates of dry matter consumption (per 7%), fattening on the 56th day of the study (per 11%) and the average concentration of insulin in the serum (per 35%) in comparison with analogues from the control group. Thus, Omnigen-AF improves hyperthermia, appetite and immune parameters of the mammary glands in lactating dairy cows that were under the influence of heat stress (Leiva *et al.*, 2017).

Microclimate factors

Climate change, including global warming, and its consequences has a significant impact on productive and reproductive traits, and the well-being and health of cows. However, the system and method of animal housing play a fundamental role.

Among the weather factors that affect the functioning of dairy cattle, the greatest influence has an ambient temperature. Knizkova *et al*. (2002) found that thermo-neutral for the body of dairy cattle is a temperature in the range from –5 to +25 °C. Most breeds are quite sensitive to higher and lower temperatures in this range. Gregory (1995) reported that dairy cattle could produce milk at temperatures up to –30 °C under conditions limiting the effects of wind and precipitation. Yurchenko *et al*. (2018) report that meat and dairy Yakut cattle are found above the Arctic Circle and can adapt to very low temperatures (up to –50 °C).

The effect of air temperature on dairy cattle should be considered in combination with relative humidity. The influence of heat stress on dairy cows is determined by the temperature-humidity index (THI) (Bouraoui *et al*., 2002; Dikmen, Hansen, 2009).

Ambient temperature (from 25 °C to 26 °C) or critical limit of THI (THI = 72, respectively 28 °C at a relative humidity of 50%) is critical, at which dairy cows can maintain a stable body temperature without increasing metabolic cost (Berman, 2011). An increase in the number of hot days with temperatures above the upper critical limit of THI aggravates the superventions of heat stress. Nardone *et al*. (2010) believe that the influence of global warming on animal productivity and their welfare and health will lead to adjustments in housing technology elements in many parts of the world.

The system of keeping animals is a set of zootechnical, technological, veterinary and organizational measures that take into account natural and economic conditions and ensure the flow of production processes. Animal housing systems differ in the degree of intensity of animal use, the type of feed production, the level of mechanization of production processes and indicators of comfort and well-being of maintenance (Ruban *et al*., 2020).

More than 83% of dairy cows in the EU use yard housing, in winter – indoors, and during spring-autumn – at feedlots or pastures. These combinations of housing do not only reduce the workforce but also meets animal welfare requirements (Zähner *et al*., 2004).

Von Keyserlingk *et al*. (2009) considers that measures to reduce the influence of global warming in Central and Eastern European countries can be adopted through the experience of livestock management in hotter regions and countries (Israel, Mexico and Brazil). Various technological approaches have been used to mitigate the adverse effects on productivity, reproductive efficiency, health, and comfort of cows (West 2003). First, these are systems of mechanical ventilation and cooling of animals (fans and irrigation systems), use of rest mattresses with the pumping of cooled water through them, use of walking areas with tents for rest and feeding, as well as their combinations. Ventilators, which accelerate air movement and increase convection, have been used to reduce ambient temperature and alleviate heat stress by reducing the respiratory rate, rectal temperature, and increase dry matter intake of animals.

The use of air temperature cooling systems at the beginning of the dry period affects the total milk yield, and cooling throughout the dry period helped to increase productivity by 7.5 kg per day in subsequent lactation, compared to cows exposed to heat stress (Dahl *et al*., 2017).

Keeping dairy cattle in pastures is considered more comfortable than keeping them indoors, as the animals spend most of the day in the wild (von Keyserlingk *et al*., 2009). However, high temperatures and humidity adversely affect dairy cattle while on pasture. Legrand *et al*. (2009) reported that yard-housing cows in the indoor enclosure with attached pasture preferred to stay at pasture in the evening, at night, and in the morning, while staying indoors during the day. Behavioural activity during heat stress at pasture housing differs from indoor activity (de Palo *et al*., 2006). Due to the longer distances between waterers, animals spend more time walking and cooling themselves than keeping them indoors.

Provision shade to cows during the period of heat stress is an important component of managing the thermal energy of the animal body, which leads to an increase in the proportion of animal's food consumption (from 19 to 24%) (Blackshaw, Blackshaw, 1994), an increase of productivity (West 2003), and lowering of body temperature compared to animals in unshaded areas (Kendall *et al*., 2006). The use of tents that provide shade at grounds, feedlots (the plots for fattening) and pastures is an effective method of heat stress reduction.

Eigenberg *et al*. (2005) reported that keeping animals under tents reduced respiration rate, heart rate, and body temperature during peak periods of temperature stress. In addition, the use of tents decreased the average vaginal temperature and increased daily milk yield (Kendall *et al*., 2006). The use of tents is less effective than irrigation systems in terms of reduction of body surface temperature and respiration rate of dairy cows. However, in a study by Schütz *et al*. (2011) most cows (65%) during periods of peak temperatures preferred to stay and rest under tents rather than walk through irrigation systems.

The use of shaded areas by cattle is not only associated with higher temperatures but also is more noticeable during intense insolation (Brown-Brandl *et al*., 2005). Tucker *et al*. (2008) reported that cows, which were provided with rest areas with different levels of shading for protection from sunlight, were in more shaded areas for a longer period and had a lower minimum body temperature because their level of protection increased in comparison to animals, which were in less shaded or unshaded areas.

The use of irrigation systems reduces the air temperature and at the same time increases its humidity. In a study by Smith *et al*. (2006a), irrigation systems increased humidity by 22%. Wet aeration helped to reduce rectal temperature and respiration rate (Khongdee *et al*., 2006) and increased milk and milk protein yield in experimental Holstein cows (Broucek *et al*., 2006). US farms use high-pressure irrigation systems, which are injected with fans, or low-pressure sprinkler systems, which completely wet the cows by soaking their hair. West (2003) indicates that both of these systems increase feed activity, have a positive effect on reproductive traits, and reduce the severity of calving and rectal body temperature. Another way to reduce heat stress in cows is to install irrigation systems with an element of self-control, *i.e*. animals pass through systems of pressure-sensitive sensors mounted on the floor of the passages. This system has the advantage that it reduces the overall use of water (Legrand *et al*., 2011).

The orientation of rooms and ground runs depending on geographical location can also help to alleviate heat stress by reducing insolation and surface temperature of structures, which in turn increases heat transfer from the cow's body to the environment. Angrecka and Herbut (2016) conducted studies dealing with the effects of solar insolation during the summer in shade built with different geographical locations of longitudinal walls from north to south; from east to west; and with a 30° – deviation from north to south. They found that the use of the location of longitudinal walls: from north to south has the best effect on reducing the level of solar insolation during the summer.

Kendall *et al*. (2007) investigated the reduction of thermal capacity using three cooling systems: shaded shelters, irrigation systems and their combination. The use of shaded shelters reduced the respiration rate by 30% compared to the control group (without cooling systems), while the use of irrigation systems and a combination of both options reduced the respiration rate by 60% and 67%, respectively. Meyer *et al*. (2002) compared three ventilation systems in their studies. The productivity of cows was the highest in the room with the placement of fans (0.9 m fan blade) above the feeding passage (40.1 kg per day), compared with the option of placing longitudinal fan tubes above the cubicles (37.6 kg per day) or with ceiling (1.4 m blades) fans (37.1 kg per day). Also, with the option of placing fans above the feeding passage, the respiration rate constituted 75.3 times per minute, compared to the system of ceiling fans (83.5 times per minute) and longitudinal fan pipes above the cubicles (82.3 times per minute).

Combinations of different cooling systems have been extensively studied in investigations that took place in Israel using automated irrigation system (30 s) with the following ventilation (4.5 min) for 30-minute periods (Her *et al*., 1988; Wolfenson *et al*., 1988). The results showed that this combination of cooling was effective and helped to reduce heat stress in cows, as well as improved their heat balance, productivity and reproductive performance, lowered body temperature and met the recommended duration of behavioural responses.

Studies in the United States indicate a successful combination of tunnel ventilation and irrigation to reduce heat stress and improve milk production during dairy feeding (Smith *et al*., 2006b). Compared to traditional cooling technologies (cooling by fans and irrigation systems; cooling by shaded shelters and fans), the use of tunnel ventilation in combination with irrigation has reduced the effect of heat by 84%. The respiration rate and rectal temperature of cows cooled by this combination were reduced (Smith *et al*., 2006a). In addition, the combination of tunnel ventilation and irrigation had a positive effect on feed consumption (+11...12%), productivity (+2.6...2.8 kg per day), reduced the content of somatic cells in milk, while the quality of milk remained unchanged (Smith *et al*., 2006b).

The main disadvantages of irrigation and sprinkler systems are the consumption of large volumes of water (depending on the climatic characteristics of the region up to 215 litres cow^{-1} day^{-1} together with water consumption for milking, cleaning and watering). This in turn brings not only economic but also environmental consequences and is particularly irrational in regions (or countries) with limited freshwater reserves (von Keyserlingk *et al*., 2013). Besides, although the use of sprinklers significantly reduces the frequency of respiration and the influence of animals' distraction on insects (tail movements, shifting from foot to foot, twitching of the skin and throwing the head), their use also leads to increased cases when animals avoided irrigation and lowered the head at the time of the first stressful hit of water jets on the body (Schütz *et al*., 2011; Chen *et al*., 2016).

Avendano-Reyes et al. (2006) showed that the use of efficient cooling systems, *i.e.* fans in combination with irrigation systems in the calving pen during the period from 10.00 to 18.00 compared to cooling only by fans inhibits the reduction of productivity and milk fat content, improves calves growth and shortens the number of days open in cows.

The sense of heat from solar radiation could be partly reduced by changes in air velocity, which influence the convection cooling of cattle (Herbut *et al.*, 2020). The recommended air velocity for dairy farms in the United States during periods of high ambient temperatures is 1.8 to 2.8 m s^{-1} (Bailey *et al*., 2016). However, the airflow rate in naturally ventilated farms is not very uniform (Wu *et al*., 2012; Herbut *et al*., 2013) and depends not only on the characteristics of the internal layout of the room but also on such details as the presence of animals standing in the way of airflow and thus change its direction for other animals that lie or are at a lower or higher level (Berman, 2019).

The rate of air movement significantly affects the thermal balance of animals' body, providing a cooling effect and lowering the body temperature of animals (Yi *et al*., 2019). Increased air velocity at low humidity and high temperatures cause hypothermia and can lead to lung diseases. In winter, during the long-term stay of animals on feedlots (feeding grounds) at air velocities of 5–7 m s^{-1} and air temperature even up to –20 ºC, there are cases of frostbite of certain parts of the animals' body (Nusinovici *et al*., 2015; Rong *et al*., 2015).

Heat insulation of light and ventilation curtains in winter is important when keeping cows in light-duty premises in countries with temperate-continental climates. It has been established that the use of curtains heat insulation with the use of polyvinyl chloride can extend the permissible norms of wind speed indoors for 13 days and protect animals from the environment more effectively at different categories of wind speed, as well as reduce indoor airspeed by 11.68–21.74% compared with uninsulated rooms of different configurations and heights of longitudinal walls (Borshch *et al*., 2021).

Prolonged precipitation in the form of rain during the spring period when keeping animals on pastures of different types (with shaded shelters and without them) at average daily temperatures of 12.1 °C and below affects the daily energy expenditure spent on basic metabolism and heat exchange, as well as on indicators of rest in the lying position (Borshch *et al*., 2020).

There is a dependence of the influence of litter material during periods of low-temperature shock (–11.8 °C and below) on the indicators of metabolic energy expenditure for heat exchange and behavioural reactions in cows (Borshch *et al*., 2019). Thus, with the use of deep straw litter, the total energy consumption for heat production was 2.95 and 2.43 MJ lower, compared to the housing of sawdust and compost manure on the litter. Besides, with this variant of bedding material, the indicator of the duration of rest in the lying position was higher by 38 and 25 minutes, respectively.

Conclusions

Analyzing the data already established, we tried to systematize the results of scientific research and discoveries of scientists on the effects of temperature stress on the health, welfare and productivity of dairy cattle. Given the processes of global climate change, combating temperature stress in animal husbandry is becoming very relevant, because it has a direct impact on food security. The effect of temperature stress on the body of dairy cows can be minimized due to genotypic and phenotypic factors, or a combination thereof. Phenotypic factors, which include the use of microclimate control (water irrigation systems, ventilation, and the use of shade shaded shelters in summer and insulation of side curtains in winter), are more effective due to the speed of commissioning but carry inevitable depreciation, which will affect cost and profitability of all production. Due to these factors, the number of days (or hours of the day) with thermoneutral temperature increases and the well-being, productivity and reproductive characteristics of cows improve. The application of feeding strategies with the use of feed additives, which contribute to better resistance of the body to temperature stresses, will not have a full effect without the simultaneous action of technological solutions. In addition, it requires periodic costs that will affect the cost of feed. Genotypic factors, which are the breeding of heat-resistant breeds, are long and currently not conceptually studied in terms of differentiation of adaptive traits of animals in different continents, latitudes and climatic zones. The most promising in terms of impact on the health and welfare of cows is a strategy that combines all these factors. Further comprehensive research should include engineering, genetic and feeding solutions, primarily to minimize the negative effects of climate change on animal health.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

All authors made equal contributions in literature analysis and writing a manuscript.

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