EFFECT OF HEAT STRESS ON INTAKE, RUMEN PHYSIOLOGY, MILK PRODUCTION AND COMPOSITION AND SUPPLEMENTATION OF DIETARY FIBER AND DIETARY FATS TO ALLEVIATE HEAT STRESS: A REVIEW

Shuangming Yue¹, Chao Yang², #, Jia Zhou¹, Zhisheng Wang¹, Lizhi Wang¹, Quanhui Peng¹ and Bai Xue¹,*

¹Animal Nutrition Institute, Sichuan Agricultural University, Chengdu 611130, China; ²Sichuan Water Conservancy Vocation College, Chengdu 611845, China

*Contributed equally with the first author
*Corresponding author’s e-mail: xuebai@sicau.edu.cn

In livestock production system, dairy breeds are typically more sensitive to heat stress than meat breeds. Higher producing dairy animals like Holstein dairy cattle are more susceptible since they generate more metabolic heat. Heat stress negatively influences intake, rumen physiology, milk production and composition in dairy animals. Due to the rise in global warming issues, it is expected that heat stress in dairy cows will be more widespread in the future. Heat stress in dairy animals directly affect feed intake and rumen physiological functions thereby reduces milk yield and negative impact on milk composition. To address the negative impact of heat stress in dairy animals, researchers have examined various available nutritional strategies, including dietary fiber, dietary fat, dietary microbial additives, vitamins, minerals, metal ion buffer, plant extracts, and other anti-stress additives. However, two major nutrients fiber and fats are easily available macronutrients that can alleviate the negative impact of heat stress in dairy animals. This review will provide evidence for the efficacy of these nutritional strategies to mitigate the negative effects of heat stress in dairy cows. Furthermore, information on this review may provide an appropriate dietary strategy to cope with heat stress at dairy farms.

Keywords: Heat stress; intake; rumen; dietary fats; dietary fiber; dairy cows.

INTRODUCTION

In modern dairy industry, animal scientists have concentrated on genetic improvements to increase milk production and on nutrient supply to the dairy cows (Kadzere et al., 2002). However, they ignored the segment of the thermoregulatory ability of the modern cow. Hence, climate change is one of the major threats to the sustainability of the dairy production system across the world, especially in tropical and temperate countries (Das et al., 2016). Recently, Silanikove and Koluman (2015) also forecasted the severity of climate issues on dairy production as an increasing problem in the near future because of global warming progression. It is widely believed that the temperature of the earth has been increased by 0.2°C per decade. Furthermore, it has also been predicted that the global average surface temperature would be increased to 1.4-5.8°C by 2100 (Das et al., 2016). The rise in environmental temperature above 20-25°C in the temperate climate and 25-37°C in a tropical environment, enhance heat gain beyond that lost from the body and induces heat stress (Vale, 2007; Das et al., 2016).

Heat stress responses are now regarded as an expensive problem in the dairy production system. Heat stress responses negatively influence animal health and performance, especially feed intake, rumen physiology, milk production, and milk quality (Min et al., 2019). Moreover, severe heat stress in dairy cows in hot summer can result in deaths (Vitali et al., 2009). Therefore, heat stress represents a significant financial burden to the dairy farmers (St-Pierre et al., 2003) that may hinder the further development of the modern dairy industry. Thus, effective strategies are required to alleviate the negative effects of heat stress in dairy cow and to improve production performance of dairy cows.

In modern dairy system, several genetic, managerial, and nutritional strategies have been practiced to overcome the negative impact of heat stress in dairy cows. It has traditionally been believed that cooling systems and dietary approach can elevate the negative effects of heat stress in dairy cows (Min et al., 2019). Therefore, a review of literature has been compiled to evaluate the potency of macronutrient feeding to overcome negative effect in heat-stressed dairy cows. Providing the details of the significance of dietary fiber and dietary fat in heat-stressed dairy cows will enable the dairy industry to select the most appropriate macronutrient for the heat-stressed dairy cow and to improve heat-stressed dairy cow productivity.
**Effects on heat stress on feed intake of dairy cows:**
Environmental increased temperature has a negative impact on the appetite centre of the hypothalamus that leads to decreases feed intake. Feed intake begins to decline at air temperatures of 25-26°C in lactating cows and reduces more rapidly above 30°C in temperate climatic condition, and at 40°C, it may decline by as much as 40% (Das et al., 2016). This decrease in intake is related to mitigate heat stress because of production of a large amount of metabolic heat for digesting roughage, which increases the body temperature of cows and together with higher environmental temperature it caused heat stress on animals. It has been reported that the reduction in feed intake is an important index of heat stress in dairy cows (Yue et al., 2020). As a result, animals experience a stage of negative energy balance. Consequently, body weight and body condition score go down. If environmental factors can be actively monitored and management practices altered accordingly to alleviate heat stress in dairy cows and maintain the feed intake (Renaudeau et al., 2012).

Normally higher temperature is considered the important factor of causing the heat stress in dairy cows (Yue et al., 2020). However, the humidity is another factor, high temperature along with humidity lead to cause heat stress in dairy animals. Temperature humidity index is good indicator to find heat stressed dairy cows(Yue et al., 2020). It has been suggested that temperature humidity index is a vital indicator to assess heat stress in dairy farming, and it is normally known that temperature humidity index above 68 dairy cows experienced heat stress (Armstrong, 1994; Yue et al., 2020). In the recent study, it was observed that the increase in averaged temperature-humidity index above 75 causes serious heat stress in lactating dairy cows (Yue et al., 2020). Another recent study of 22 Holstein and eight Jersey cows found temperature-humidity index negatively affected feed intake, where a temperature-humidity index>72.1 resulted in a decrease in the feed intake of Holstein and Jersey cows (West et al., 2003). In addition, Xue et al. (2010) found that the dry matter intake increased from 18.5 to 19.8 kg/d when temperature-humidity index increased from 42 to 68, but decreased from 19.8 to 15.8 kg/d when the temperature-humidity index increased from 68 to 80. This indicates that dry matter intake responds to temperature-humidity index in a biphasic manner, where dry matter intake increases slowly with an increase in temperature humidity index until a critical point, after which it decreases sharply with an increase in temperature humidity index when the temperature humidity index value is higher. Therefore, cows gradually enter a state of heat stress when temperature humidity index exceeds 68, and decreased gradually with increasing heat stress.

**Effect of heat stress on rumen physiology:** Previous studies focus nutritional effects on rumen physiology (Qiu et al., 2018; Xia et al., 2018a; Xia et al., 2018b; Xia et al., 2018c; Qiu et al., 2019a; Qiu et al., 2019b; Qiu et al., 2020a; Qiu et al., 2020b). It has been reported that nutritional composition of diet has an impact on production performance and behavior of livestock species (Su et al., 2013; Zhang et al., 2015; Wang et al., 2016; Niu et al., 2017; Sharif et al., 2018; Chen Dong, 2019; Li et al., 2019; Rehman et al., 2019; Qiu et al., 2020b; Chen et al., 2020). Therefore, a lot of researchers worked on nutrient composition before the start of experiments (Aziz ur Rahman et al., 2017; Hussain et al., 2018; Aziz ur Rahman et al., 2019; Li et al., 2019; Rehman et al., 2019; Xu Jingyi, 2019; Hussain et al., 2020).

Recently, scientists are focusing on the role of nutrition to alleviate heat stress in dairy animals. It has been reported that increase environmental temperature alters the basic physiological mechanisms of rumin which negatively affects the ruminants with increased risk of metabolic disorders and health problems (Nardone et al., 2010; Soriani et al., 2013). Nonaka et al. (2008)] reported animal under heat stress has reduced acetate production whereas propionate and butyrate production increased as rumen function altered. As a response animal consumed fewer roughages, changes rumen microbial population and pH decreasing rumen motility and rumination (Nardone et al., 2010; Soriani et al., 2013). Subsequently, affects health by lowering saliva production, variation in digestion patterns and decrease dry matter intake (Nonaka et al., 2008; Soriani et al., 2013). Moreover, heat stress also results in hypofunction of the thyroid gland and effects on metabolism patterns of the animal to reduce metabolic heat production (Helal et al., 2010).

Blood metabolites could be other indicator that changes due to heat stress (Yue et al., 2020). For determination of blood metabolites in heat stressed dairy cows, blood is normally take from jugular vain or tail of cows as described in literature (Huang et al. 2019; Wuryastuty et al. 2019; Zhang et al. 2020).

**Effects of heat stress on milk production:** Hot and humid environment that cause heat stress not only affects milk yield but also effects milk quality (Yue et al., 2020). The adverse effect of heat stress on milk production is more prominent in animals of high genetic merit (Bouraoui et al., 2002; Kadzere et al., 2002; West et al., 2003; Spiers et al., 2004; Wheelock et al., 2010). It has been reported that effective environmental heat loads above 35°C activate the stress response systems in lactating dairy cows (Berman, 2005). Yue et al. (2020) showed that the temperature-humidity index values in spring and summer above 72 cause heat stress in cows. However, in autumn and winter, when temperature-humidity index values were usually less than 72, the cows rarely experiencing heat stress.

Moreover, a study that investigated seasonal effects on milk yield showed that the milk yield of Holstein cows decreased by 10% to 40% in summer in comparison to the milk yield in winter (du Preez et al., 1990), further highlighting the influence of heat stress on milk production. In response dairy cows reduce feed intake, which is directly associated with negative energy balance, which largely responsible for the
decline in milk synthesis (Wheelock et al., 2010). As previously mentioned, heat stress leads to a decrease in feed intake of dairy cows (Ammer et al., 2018), thereby leading to a reduction in milk production (Ravagnolo et al., 2000; Ufuk, 2020). Reduction in feed intake not only decreases the energy supply for milk production, but maintenance requirements of energy also increased by 30% in heat stress dairy animal. West et al. (2003) reported a reduction in dry matter intake by 0.85 kg with every 1°C rise in air temperature, this decrease in intake accounts approximately 36% of the reduction in milk production. According to Bouraoui et al. (2002) daily temperature-humidity index negatively correlated to milk yield, as the increase of temperature-humidity index value from 68 to 78 decreases dry matter intake by 9.6% and milk production by 21%. Spiers et al. (2004) reported that milk yield decreases by 0.41 kg/cow/day for each temperature-humidity index unit increase of above 69, feed intake decreased within a day after initiation of heat stress, while milk yield decreased after two days of heat stress. Drop-in milk production up to 50% in dairy animals might be due to reduced feed intake (Baumgard and Rhoads, 2013), whereas, rest could be reasons of metabolic adaptations to heat stress as heat stress response markedly alters post-absorptive carbohydrate, lipid, and protein metabolism a part of reduced feed intake (Baumgard and Rhoads, 2013). Increased in basal insulin levels with improved insulin response in heat-stressed cows (Baumgard and Rhoads, 2013; Rhoads et al., 2013) and in ewes (Sejian et al., 2010; Rhoads et al., 2013) were observed that explains the shift in glucose utilization in non-mammary gland tissue affecting milk synthesis (Rhoads et al., 2013). Heat stress during the dry period (i.e., last 2 months of gestation) reduced mammary cell proliferation and so, decreases milk yield in the following lactation (Tao and Dahl, 2013).

Effects of heat stress on milk composition: Heat stress not only decreases milk yield, but also affects milk fat, solids-not-fat and milk protein and somatic cell count (Kadzere et al., 2002; Nasr and El-Tarabany, 2017). Kadzere et al. (2002) also reported that milk protein percentage decreased by 16.9% due to heat stress. In another analysis of milk, quality represented that hot protein content of milk decreased by 0.009 kg, for each unit of increase in temperature humidity index above 72 (Ravagnolo et al., 2000). Also, the analysis of protein fractions also showed a reduction in percentages of casein, lactalbumin, immunoglobulin G (IgG) and IgA. 80% of these were associated with loss of productivity and 20% with health issues which might be due to disruption of internal homeostasis mechanism (Nardone et al., 2010). A separate analysis showed that the fat decreased by 0.012 kg, respectively, for each unit of increase in temperature humidity index above 72 (Ravagnolo et al., 2000). Bouraoui et al. (2002) observed lower milk fat in the summer season. Yet another study regarding milk components in the Mediterranean showed that, when the average temperature humidity index increased from 68 to 78 (from spring to summer), fat contents of milk decreased from 2.96% to 3.24. It has been reported that fat content seems delayed when temperature humidity index is above 72 (Bernabucci et al., 2010). The content of fats was significantly higher in spring period than in summer. However, values for the percentage of lactose varied slightly in the summer period in these two seasons (Joksimović-Todorović et al., 2011). Another study reported that heat stress significantly reduced milk fat, protein, lactose, SNF and ash contents from 3.79%, 3.20%, 4.78%, 8.69%, 12.48% and 0.71% during the winter season to 3.49%, 3.07%, 4.59%, 8.34%, 11.83% and 0.67% during summer season (Gaafar et al., 2011). A reduction in casein percentage and casein index (casein/total proteins ratio) was also decreased in summer (2.18% vs. 2.58% and 72.4% vs. 77.7%, respectively) compared to spring season (Basiricò et al., 2009; Bernabucci et al., 2010). These studies illustrate that the performance of dairy cows in summer is greatly affected by heat stress, which is indirectly reflected in changes in feed intake, milk yield, and milk components (Basiricò et al., 2009; Bernabucci et al., 2010).

Use of dietary fats to alleviate heat stress: Dietary fat, dietary fiber, dietary microbial additives, minerals, vitamins, metal ion buffer, plant extracts, and anti-stress additives are being used in the feed of heat-stressed cows to alleviate negative effects of heat stress (Drackley et al., 2003; Wang et al., 2010; Asad et al., 2019; Butt et al., 2019). However, dietary fat is being effectively used in the feed of heat-stressed cows to mitigate the negative effects of heat stress.

During heat stress, reduction in feed intake results in negative energy balance in heat-stressed dairy cows. Dairy cows in negative energy balance are unable to meet the requirement for lactation and even for maintenance. The classical approach to fulfill the energy requirement of negative energy balance dairy cows is the supplementation of additional fats in the diet of dairy cows. Supplementation of fat in the diet of heat-stressed dairy cows reduce thermogenesis (Wang et al., 2010). It has been reported that fat generates less heat increment than dietary carbohydrate or protein and help to cope with the heat stress in dairy animals (Wang et al., 2010). Normally supplement of 3% unprotected fat had been advised for use during hot summers (Drackley et al., 2003). Feeding of a higher energy diet resulted in greater circulating non-esterified fatty acids concentrations, reflecting a diminution in the energy deficit of heat-stressed Holstein dairy cows. Supplementation of unprotected fat significantly increased milk production and reduce milk fat content because supplementation with unprotected fat interfered with ruminal fermentation, decreasing the ruminal acetate to propionate ratio and therefore milk fat synthesis. Thus, it may be preferable to use a form of protected fat, such as saturated fatty acid, hydrogenated fish fat, fatty acid calcium salts, or oilseeds.
Palmitic acid is a lipid form that is known not fermented in the rumen. It has been reported that feeding the Palmitic acid in the diet of ruminants in summer season increase milk yield and milk true protein contents (Warnjes et al., 2008). The supplemental saturated fatty acids in diet heat-stressed Holstein dairy cows results in reduction in rectal temperature during the hot season and increase in milk yield and improvements in milk composition with regard to fat, protein, and lactose content (Wang et al., 2010). A remarkable amount of metabolic heat was saved by energetically replacing fermentable carbohydrates with supplemental saturated fatty acids. Hydrogenated fish fat is another type of dietary fat supplement that is not degraded in the rumen and is used for dairy cows in countries where fishmeal is produced. It has been reported that dietary supplementation of hydrogenated fish fat in dairy cows in summer results in increased milk production, as well as improvements in milk protein and fat content (Gallardo et al., 2001). Therefore, hydrogenated fish fat could be a good ingredient to sustain high productivity in dairy cows during heat stress. Calcium salts of fatty acids are another alternative that could be used in heat stressed dairy cows. It has been reported that supplementation of calcium salts of fatty acids had no effect on milk yield in heat-stressed Israeli-Holstein dairy cows, but it increased the energy density of dairy cow diet dramatically, enhanced milk protein, milk yield per kg feed intake and reduced metabolic heat production (Moallem et al., 2010). Furthermore, (Serbester et al., 2005) reported that feeding with 2.54% calcium salts of fatty acids in the diet would increase 4% fat corrected milk and milk fat yield of mid-lactation Holstein dairy cows during summer.

To sum up, fat supplementations based on whole flaxseed could enhance milk yield and milk composition of dairy cows exposed to heat stress.

Use of dietary fiber to alleviate heat stress: Strategy to minimize the energy deficiency in heat-stressed cows is to increase energy input by replacing the total mix ration roughage component with more readily digestible neutral detergent fiber of non-roughage origin. High-quality dietary fiber tends to improve feed digestibility and palatability and further increase feed intake. It has been reported replacing roughages neutral detergent fiber with soy hulls (readily digestible dietary fiber) increases dry matter intake, increased milk production and milk fat content, 4% fat corrected milk (Halachmi et al., 2004). In another study, cassava chips were used to partly replace grass silage in heat-stressed dairy cows that resulted in increased intake, milk yield and 4% fat corrected milk (KanjanaPruthipong et al., 2010). Beet pulp contains a high proportion of digestible neutral detergent fiber and pectic substances, implying that it increases nutrient intake and improvement of production performance in dairy cows. In a study, it has been reported that replacing of corn silage with shredded beet pulp in the diet of heat-stressed Holstein dairy cows increase milk production, milk protein, and milk lactose content (Naderi et al., 2016). Feeding slowly fermentable grains reduce the amount of heat released from fermentation and digestion, which ameliorate the physiological responses to heat stress and improve productivity in dairy cows during the summer. (Gonzalez-Rivas et al., 2018) reported that that feeding total mixed ration plus 27% crushed corn to Holstein-Friesian dairy cows ameliorated the heat stress responses and enhanced milk yield.

Conclusion: Extended periods of high air temperature coupled with high relative humidity compromise the ability of the dairy animal to dissipate excess body heat which affects feed intake, milk production, and milk composition and ultimately reducing profitability for dairy farmers. Moreover, supplementation of dietary fiber and fats improves the performance of heat-stressed dairy cows. In summary, dietary fats and fiber provide clues or perspectives for the selection of an appropriate methodology for particular dairy farms to mitigate heat stress in their stock.

Acknowledgement: Authors acknowledge the help of undergraduate students to collect data.

Funding: This review was a part of a project funded by the ‘Science and Technology Support Program of the National Science and Technology Ministry, China, Grant number 2012BAD12B02’

REFERENCES


Heat stress and nutritional strategies to alleviate heat stress


Heat stress and nutritional strategies to alleviate heat stress


[Received 21 Mar 2020; Accepted 09 Aug 2020; Published (online) 01 Sept 2020]