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Review

Amelioration Of Heat Stress in Dairy Cows Through Shelter Management- An Overview

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Abstract

Heat stress is an inevitable problem related to dairy production in tropical and sub-tropical countries due to prevailing hot and humid weather conditions. Such conditions decreased feed intake, growth, milk quality, and quantity as well as reproduction, thereby affecting animals' health and welfare. Over the past two decades, various heat mitigation techniques were tested and have been implemented accordingly in dairy farming. The key method for minimizing the negative impacts of hot weather is considered to be the physical alteration of the surroundings within the animal shed. Various modifications include the installation of a shade structure within farm premises, roofing designs and materials used, proper dimension of a shed, roof height, and good ventilation system at the disposal of farm premises for free flow of air. Therefore, this study reviewed the management of heat stress in dairy cows through shelter management.

Keywords: Dairy Cow, Heat Stress, Mitigation Strategies, Shelter Management

Introduction

Heat stress is one of the major concerns for the global livestock sectors under changing climatic conditions due to increased environmental factors (high ambient temperature and relative humidity) which hinders animal production during summer resulting in disastrous economic implications (El-Tarabany *et al* 2017; Chauhan *et al* 2021). Heat stress in animals occurs when the body temperature is elevated above the normal range and fails to dissipate body heat sufficiently to maintain homeostasis which is the result of high ambient temperature and relative humidity accompanied by slow air movement (Morrison, 1983; Bernabucci *et al* 2010). Among the various stressors experienced by dairy cows on farms, heat stress is frequently encountered and likely difficult to alleviate (Aggarwal and Upadhyay, 2012; Joy *et al* 2020). Animal discomfort due to heat stress is the prime factor for loss of production in dairy cows (Thatcher *et al* 2010) which has a variety of negative impacts on animal production traits such as milk yield, milk quality, milk composition, etc. (Brown-Brandl *et al* 2005; Mader *et al* 2006; Mandal *et al* 2016). Milk yield can be decreased by 40-50% during extreme heat stress in dairy cows. However, this reduction in milk yield is due to a decrease in dry matter intake by the animal (Rhoads *et al* 2009). To enhance the comfort of the dairy cow and minimize loss of production under extreme heat stress conditions, proper shelter design is of paramount importance in tropical parts of the world (Grant, 2012). Although the genetic selection and use of thermo-tolerant bulls might be one of the solutions for heat stress (Mandal and Tyagi, 2008), however, shelter management can play a vital role in the severity experienced by heat stress in the existing dairy cows. Mitigation of heat stress has received immense attention over the years due to the rise in concerns about global warming and animal welfare-related issues (Misra and Mandal, 2010). In the past 40 years, many researchers have studied and adopted different heat abatement methods through genetic selection of heat-tolerant cows, nutritional aspects, pharmacological treatment, embryo transfer technology, disease surveillance measures, etc. Considerable advances have been done in various management techniques to combat heat stress. However, heat stress still remains an expensive issue for animal production in the modern era. This review paper summarizes the various mitigation strategies to combat heat stress impact on dairy cows with reference to shelter modification in a dairy barn.

Methodology

A large volume of relevant articles was collected through scientific databases such as Google Scholar, Research Gate, Science Direct, Scopus, Sci-hub, etc. Accordingly, a systematic and proper review has been made on the basis of inferences made from cited articles. This review paper emphasizes the parameters like the significance of animal shelter design, provision of shade structure, roofing designs and material used, shed height, ventilation, and cooling facilities in dairy farming. The inclusion of these parameters in a dairy barn is associated with heat stress mitigation. Furthermore, the importance of all the parameters is addressed in the discussion section of this review.

Discussion

Animal Shelter Design for Mitigation of Heat Stress

One of the most important methods for mitigating the effects of heat stress on livestock is to maintain the shelter (Renaudeau *et al* 2012; Seijan *et al* 2012; De *et al* 2013; Seijan *et al* 2018). A good shelter should protect animals from harsh weather conditions without jeopardizing the animal's ability to perform with respect to growth, reproduction, and health. Considerable efforts should be attempted in reducing the potential of heat stress by minimizing direct solar radiation or by lowering the ambient temperature around the animal. In this regard, the dairy housing system required scientific design considerations to optimize comfort levels and maximize the production performances of dairy cows (Suraj, 2011; Mandal *et al* 2021a, b.).

Shade Structure

The most efficient and simplest method in reducing heat load in livestock during hot summer is the provision of shade (Blackshaw and Blackshaw, 1994; Kendall *et al* 2006; Kumar *et al* 2011; Renaudeau *et al* 2012; Das *et al* 2016; Fournel *et al* 2017; Somvanshi *et al* 2018; Becker and Stone, 2020; Wang *et al* 2020; Akbar *et al* 2021). Though shade reduces heat accumulation, it has no role in altering air temperature and relative humidity around the animal (Armstrong, 1994; West, 2003; Kimothi and Ghosh, 2005; Renaudeau *et al* 2012; Pennington and Karl, 2016). The provision of shade structure was found to minimize total heat load by 30-70 percent (Blackshaw and Blackshaw, 1994; West, 2003). During hot summers, provisions of shaded shelters for dairy cows have been found to improve reproductive and production performances (Gaughan *et al* 2010). To reduce the radiation from the shade roof to the cows, a mature dairy cow requires 3.5 to 4.5 m^2 of shaded space, and the height of the shade should be 3.5–4.5 m high (Armstrong, 1994). The use of shade in dairy cows effectively prevents heat load from direct solar radiation and could be used as the primary step in heat abatement (Roman-Ponce *et al* 1981; Collier *et al* 1982). During evening milking, shade is critical for dispersing heat generated by an increase in solar radiation radiated by hot flooring and overcrowding of animals in restricted spaces (Schütz *et al* 2010). It was reported by Bond and Kelly (1955) that the provision of shade can reduce about 30-50 percent of the total heat load caused by solar radiation in lactating cows. A similar finding was also reported by Blackshaw and Blackshaw (1994) in dairy cattle. In a comparative study between shaded and unshaded dairy cows, Collier *et al*. (2006) demonstrated that shaded cows have improved milk yield and reproduction, as well as lower respiration rate and rectal temperature recorded when compared with unshaded cows. Subsequently, dairy cows provided with well-designed shade tend to show increases in milk yield (about 3%) (Kendall *et al* 2006; Palacio *et al* 2015; Van Laer *et al* 2015) when compared with cows of non-shaded areas. Shade not only reduces heat load, it also prevents mortality in extreme climatic conditions (Bubsy and Loy, 1996). Subsequently, Entwistle *et al*. (2000) reported that shaded cows have a reduced mortality rate of about 0.2% when compared with unshaded cows (5.8% mortality rate). Somvanshi *et al* (2018) in shaded cows found that rectal temperature was reduced by 2 to 4.1%, respiration rate by 29 to 60%, and milk yield improved by 9.4 to 22.7% than unshaded cows. They also reported that cows provided with shade during dry periods tend to yield 4.5% and 13.6% more milk at 100 and 305 days after parturition. It was noted that the conception rate in dairy cattle has increased from 25.3% to 44.4% in the shaded situation (Roman-Ponce *et al* 1977). They also reported that shaded cows' gives 10% more milk as compared to unshaded cows, as well as lower rectal temperature (i.e., 0.1º C lesser in shaded cow) and decreased respiration rate (54 and 82 breathes/min) were also observed in shaded cows.

Collier *et al* (1981) discovered that dairy cows without shade had weaker ruminal contractions, higher rectal temperatures, a nd reduced milk production when compared to shaded cows. Furthermore, the provision of shade revealed a 0.2°C decline in vaginal temperature in shaded cows compared to unshaded cows. (Kendall *et al* 2007; Fisher *et al* 2008: Tucker *et al* 2008; Schütz *et al* 2010). Comparative studies were conducted by various researchers on the provision of shade vs. unshaded to dairy cows. It was also reported that shaded cows give 0.7 kg more milk per day than unshaded cows. (Muller *et al* 1994; Roman-Ponce *et al*1977; Kendall *et al* 2006; Fisher *et al* 2008; Schutz *et al* 2010). Heifers provided with 65.0 m^2 shade had significantly higher dry matter intake and average daily gain when compared with sprinkle heifers (Marcillac-Embertson *et al* 2009). The provision of shade showed there is a reduction in black globe temperature by 8 ºC (Roman-Ponce *et al* 1977). Hence, this will give a benefit to cool the microclimate and helps the dairy cow to relieve thermal stress. However, shade does not alleviate all the heat stress in animals (Gaughan *et al* 2010).

Roof and Roofing Material

Another strategy for physically altering the barn environment and limiting the negative impacts of high ambient temperature is effective thermal insulation of the barn roof (Calegari *et al* 2012). The roof is an integral part of shelter design which prevents the animal from direct solar radiation as well as rain (Narwaria *et al* 2017). Roofs may be of either single or double type with the same or different materials (Belsare and Pandey, 2008). Various types of roofing materials can be used (Renaudeau *et al* 2012) such as dry leaves, asbestos sheet, tin, paddy straw, thatch, clay tiles, reinforced cement concrete, plastic sheet, GI sheet, reinforced cement concrete (RCC), etc. for constructions of livestock shed in the Indian subcontinent (Narwaria *et al* 2017; Gautam *et al* 2020; Mandal *et al* 2022). The most effective roofing material for minimizing heat load is a reflective roof such as aluminum or white galvanized roof (Blackshaw and Blackshaw, 1994).

However, as per rural structure in the Tropics (FAO, 2014), the most common type of roofing material is thatch for animal housing in tropical countries and helps in heat dissipation due to lower thermal conductivity (Yazdani and Gupta, 2000). Belsare and Pandey, (2008) suggested that a shed roofing with 4-6 inches thick hay thatch will absorb minimum heat from solar radiation and will present a cooler micro-environment and subsequently comfort to the dairy cows. Roof insulation with paddy straw in dairy housing helps to reduce thermal radiation and presents a thermo-comfortable environment to the dairy Jersey cows (Mandal *et al* 2018; Sahu *et al* 2018a; Sahu *et al* 2019; Mandal *et al* 2021b). They also reported that milk yield improves significantly and showed better cardinal physiological indices. Subsequently, a gable roof was found to reduce heat load by 30% when compared with multiple shed roofs in the barn (Liberati, P., 2008).

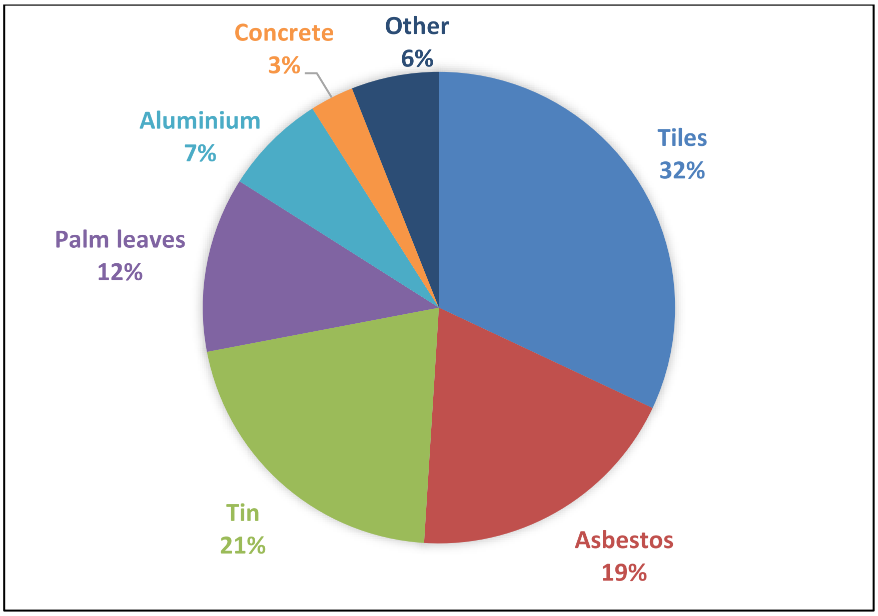

Fig. 1: Different roofing materials used in dairy housing (Adapted from Ambazamkandi *et al* 2015).

In a study on crossbred Jersey cows reared under double slope roof with an open ridge thatch roof (Mandal *et al* 2021a) shed it was demonstrated that changes in roofing design reduced heat stress on animals, checked heat-stress-induced production losses, improved milk quality, reduced somatic cell counts and increased net profit. Such housing designs also improved the milking behavior of cows and enhanced cow-comfort levels due to more comfortable microclimate conditions and natural cooling effects (Kumar *et al* 2020; Kumar and Mandal 2022).

Aluminum roofing insulation and painting with white color on the top and velvet black beneath (Buffington *et al* 1983) reduces heat stress or solar radiation (Seijan *et al* 2012) which was observed to be 13 BTU/ feet^2 /hour less than unpainted roof (Belsare and Pandey, 2008). In a study in crossbred cattle, Khongdee (2016) found that a modified roof with 80% of clothes covered on top helps to dissipate heat in crossbred cattle. He also reported that rectal and average daily gain of the cattle reared under a modified roof (39.02°C; 0.632 kg/d) was comparatively lower (P<0.01) and higher (P<0.01), respectively than the normal roof (40.05 °C; 0.350 kg/d) cattle. Similar findings were also observed by Sahu *et al* (2018b) which showed that a modified roof with a thatch ceiling under an asbestos roof provides a cool environment for dairy cows. They reported that the modified shed reduces the roof surface temperature by about 5-7ºC. Animals reared under-insulated roof to have a favorable microclimatic environment and tend to consume more feed, at the rate of 0.2 kg/day/cow, and consequently, milk yield increases by 0.6kg/day/cow (Daniel *et al* 1973; Fuquay *et al* 1979).

Height of Shed

The height of the shed plays an important role in free air circulation within the barn. Adequate shed height gives comfort to the animal and helps in heat dissipation. Animal sheds should have a minimum of 3 m height to allow sufficient airflow to provide comfort to the animals (Belsare and Pandey, 2008; De *et al* 2013). Similarly, Schütz et al. (2010) suggested that the height of the shed structure should be more than 2.4 m tall to allow free air movement in the shed. However, very tall structures >30.5 m high are economically infeasible. Hatem et al. (2004) reported that cows reared under the shed with greater height (8 m high) have more milk yield (25.1 kg/day) when compared with the shed of 5 m high (18.9 kg/day) and 3 m high (14.3 kg/day). They also reported that the cooling efficiency of the animal increased by 30% when the shed height was increased from 5 m to 8 m high. Belsare and Pandey, (2008) reported that total sun and sky radiation has a 61 percent impedance at 3.5 m shed height against 64 percent at 2.2 m shed height. In the same study, they suggested that less than 3 meters shed height will impede the flow of air leading to reduced heat loss from the animal body. As per Saini (2014), the height of the shed roof for the gable type preferably should be 20 feet at the center with 12 feet at the eaves while the height of the flat type roof shed should be 12 feet.

Ventilation

Air movement or ventilation is an important factor in dairy housing for heat stress mitigation. Two common types of ventilation in dairy housings are natural ventilation and forced or tunnel ventilation. In traditional or loose housing barns, we encountered natural type of ventilation with open sidewalls with continuous ridges. Natural ventilation types include continuous eave openings, large continuous sidewall openings, and continuous ridge openings. Good ventilation keeps the air quality higher and helps to maintain a less stressed environment within the barn. Ventilation is crucial to help dairy calves reduce their body heat and it also reduces the risk of respiratory illnesses (Dahl *et al* 2020). Heat stress during hot summer is thought to be mitigated by an air exchange of 40 to 60 liters per hour (Zychlinska-Buczek *et al* 2018). A well-oriented semi-opened building with a high and well-insulated roof can maximize natural ventilation rates (Holik, 2009). Mandal *et al* (2021a, b), demonstrated that crossbred Jersey cows reared under open-ridge ventilated double slope thatch roofs have a comfortable microenvironment and significantly affected cows' comfort index. They also reported that there is a reduction in a heat-stress-oriented drop in milk yield and milk composition as well as improved udder health of dairy cows. Further, Mandal *et al* (2021a) estimated a net profit of 110kg milk/cow/annum in such type of housing intervention. In hot and humid areas, the sidewalls should include a movable curtain to ensure cross-flow ventilation for the animals' comfort (Ugurlu and Uzal, 2010). The side walls in the barn should be provided with a height of a minimum of 1 meter and should not be fully covered to allow maximum airflow (De *et al* 2013). This dimension ensures the free flow of air and minimizes the thermal load. Another effective approach to minimizing heat stress is through the construction of a double wall in the shed. Consequently, Seijan *et al* (2012) and Bryant et al. (2007) demonstrated where extra wall layers were added at the shed's end, and the outer layers were situated about 10 cm from the inner wall, with vertical openings on both ends. In this, cold air was allowed to enter through the bottom aperture, while heated air was permitted to depart through the higher opening. The ten-centimeter spaces between the two walls act as a thermal barrier and prevent conductive thermal energy from entering the animal shed. Regardless of the barn ventilation system, sufficient airspeed near the cows is critical for controlling heat stress (Shoshani and Hetzroni, 2013). In this context, the University of Wisconsin-Madison (2018) in a recommendation document suggested that adult dairy cattle housing should have a minimum of 2 m/s airspeeds at cow level.

Cooling Systems

Evaporation is the basis of the cooling system, which is achieved by the use of fans, mists, sprinklers, foggers, and forced ventilation. According to a recent study, milk output losses due to thermal stress will rise at a rate of 174 ± 7 kg/cow/decade in the twenty-first century (Gunn *et al* 2019), however, heat abatement strategies with fans, water or air conditioning reduce milk yield loss and are associated with significant economic return for dairy producers. Consequently, the use of fans and sprinklers effectively reduces cow core body temperature and showed a 4-5% increase in milk yield of lactating dairy cows (Valtorta and Gallardo, 2004; Gallardo *et al* 2005; Dikmen., *et al* 2009) and enhances semen quality in buffalo bulls (Mandal *et al* 2002; 2004). As a result of installing fans and fogging inside the barn stalls, the dry bulb maximum average temperature was reduced, resulting in a significant increase in milk yield of 4.2 kg milk/day/cow (Naas *et al* 2003). In both hot-humid and hot-dry conditions, Singh and Aggarwal (2004) found that crossbred cows provided with fan and mist produced more milk (2.12 kg/d) than control (without fan & mist) cows, this may be due to evaporative cooling of the body. It was reported that using fans in the barn can reduce the cow's body temperature by 0.3 to 0.4 ºC (Seijan *et al* 2012). However, fans alone are not sufficient in reducing the thermal stress in high-producing dairy cows (Ghosh and Prasad, 2007; Mader *et al* 2007). In the same study, Ghosh and Prasad (2007) suggested that a combination of fan and sprinkling is a more effective technique in minimizing heat stress in high-yielding crossbred cows during hot summer. However, a combination of fans and sprinklers is considered to be highly expensive (Shearer *et al* 1999; Nienaber and Hahn, 2007) and are not cost-effective at the farm level. Water as a cooling agent has been demonstrated to be an effective strategy for minimizing the effects of heat stress on animals, especially in dry and hot humid conditions (Mandal *et al* 2002; 2004; Ghosh and Prasad, 2007). Consequently, as per Ugurlu and Uzal (2010), water is the primary cooling agent that cools the microenvironment and allows animals to cool through evaporation. Installation of air-conditioning in the barn reduces air temperature and relative humidity. A net increase of 0.5 kg milk/day/cow was reported in dairy cows with this cooling system (Hahn *et al* 1969; Bucklin *et al* 2009). They also reported that there was a reduction in average rectal temperature by 0.4 ºC and subsequently the cows experience a cool environment. Using air conditioning in sub-tropical countries can improve the milk yield by 10 % in dairy cattle (West, 2003; Collier *et al* 2006).

Conclusion

Heat stress and its consequences can be managed by shelter modifications by lowering total heat gain from direct solar radiation, as well as high ambient temperature. The scientific management of shelter design of microenvironment forms the basis of the heat abatement process. Various mitigation steps involved in reducing thermal stress in dairy cows include the provision of shade structure, roofing design, and material, adequate ventilation, cooling systems, etc. As a result, cows will experience a cool and comfortable environment at the farm level. Hence, modifications of shelter in a scientific manner will be beneficial and have a positive effect on the overall performance as well as, providing good animal welfare for dairy cows in tropical countries.

Contribution by authors

All the authors contributed equally to writing the manuscript. The final manuscript was read by all others and consented to publication.

Conflict of Interests

There is no conflict of interest.

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