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Assessing thermal neutral zones in Sri Lanka for ten different dairy cattle breeds and crosses: An approach using temperature humidity index (THI)

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The magnitude of heat stress in dairy cattle is assessed using temperature humidity index (THI) widely in the world. The present study was conducted to assess the appropriateness of incorporating THI in recommending dairy cattle breeds to different areas of Sri Lanka. The study considered 10 different cattle genotypes commonly reared for milk production in the country. Daily THI values were computed by employing a thermal model, THI = Tdb - [0.55 - (0.55 × RH/100)] × (Tdb - 58) using data collected from 26 meteorological stations from 2005-2014. The THI values for different regions and the threshold THI values for milk production of 10 genotypes were used to produce THI maps. Among the crosses, Jersey crossbreds, except Jersey × Friesian cross, showed a high coping ability with comparatively high milk production capacity. Local cattle were not affected within the THI range observed in the country. THI based recommendation for distribution of dairy cattle could be made by identifying the variation of coping ability of cattle genotype and minimizing the vulnerability to climate change. Therefore, costly management interventions needed to mitigate the heat stress and related low productivity of dairy cattle under smallholder production systems could be abated.

Key words: Climate change, dairy cattle breeds, heat stress.

INTRODUCTION

Responses of animals in challenging thermal environments are gradual, extending from coping to reproduction and production functions which is the last in the sequence of responses (DeShazer et al., 2009). Animals have an ability to cope with environmental stressors to a certain extent by adjusting physiologically, behaviorally and immunologically to minimize adverse effects or even compensate (Hahn et al., 2009). However, the intensity and duration of adverse environmental conditions can challenge this ability of animal to mobilize coping mechanisms and maintain its performance (DeShazer et al., 2009).

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Exchange of heat with environment is an essential natural phenomenon in coping mechanism of all animals.

Heat exchange of animals is a complex process, and it depends on both, biological or internal factors of the body of the animal and physical or external factors of the surrounding environment such as temperature, relative humidity, thermal radiation, precipitation and wind movement (Du Preez, 2000). Under farm conditions, surrounding environment is mainly representing the man-made entities with appropriate structures and conditions. Several indices have been developed to measure level of comfort of the animal by combining different environmental or meteorological parameters depicting a unique thermo-physiological effect (Hahn et al., 2009). Thus, it has been revealed that the adverse effect of thermal environments occurs when it exceeds thresholds beyond which animals can cope. The threshold varies according to various factors such as genotype of the animal, age or life stage, level of nutrition and prior conditioning describing the combinations of environmental requirements for livestock. In this context, Hahn et al. (2009) argued that air temperature alone does not make an adequate representation of the hot thermal environments on animal. Temperature and relative humidity are the two major meteorological factors focused in several studies (Bouraoui et al., 2002; St-Pierre et al., 2003; West, 2003; Correa-Calderon et al., 2004). THI has been developed as a weather safety index to measure and alleviate heat-stress-related losses from animal production systems (Hahn et al., 2009). Thus, THI could be used as a basis of categorization of geographical regions of a country according to suitability for different livestock breeds.

Recommendations of animal breeding activities in Sri Lanka, particularly for cattle, are primarily based on climatic and physiographic parameters such as rainfall and elevation (agro-climatic zones) along with land use or farming systems in the area (DAPH, 2010). Given the fact that performance of cattle, particularly milk production varies widely according to the climatic factors such as temperature and humidity, the applicability of present recommendations is questionable. Therefore, the present study was carried out to identify the feasibility of THI as a key for the recommendation of dairy cattle breeds and their crosses for different geographical regions of the country, instead of physical parameters such as elevation and rainfall that are of little importance in animal physiology.

MATERIALS AND METHODS

Acquisition of meteorological data

The meteorological data were extracted from the records maintained at the Natural Resources Management Center, Department of Agriculture for 10-year period from January 2005 to December 2014. As the ambient temperature regime of the country during the most recent past (2015-2018) was abnormally high, the 10-year period for the study was considered as from 2005 to 2014. Weather records covering 26 major meteorological stations located throughout the country, namely Sita-eliya, Rahangala, Bandarawela, Peradeniya, Kundasle, Matale, Batalagoda, Ratnapura, Giraduarukotte, Mahailluppallama, Trincomalee, Lunuwila, Ambalantota, Monaragala, Jaffna, Aralaganwila, Mannar, Maho, Bombuwala, Weerawila, Batticaloa, Vanathavillu, Makandura, Labuduwa, Angunakolapelessa and Kantale.

Calculation of THI value as an index of heat stress

The THI values were calculated using the equation which combined the effects of ambient temperature and Relative Humidity (RH) to assess the heat load intensity. The THI equation was originally developed by Thom (1959) and extended to cattle by Berry et al. (1964) which is now being used to estimate cooling requirements of dairy cattle in temperate countries under summer weather conditions. The improved version of the equation used by Collier et al. (2012) is given in Equation 1 in which dry bulb temperature (T_{db}) and Relative Humidity (RH) were considered as the two variables. The T_{db} provides a measure of the sensible heat content of air, and represents a major portion of the driving force for heat exchange between the environment and an animal (Hahn et al., 2009). The other important measure of the thermal environment that affect the total heat exchange is the humidity which represent the latent heat content of the air, thermal radiation and airflow (Yamamoto, 1983).

$$THI = (T_{db}-(0.55-(0.55\times RH/100) \times(T_{db}-58) \quad (1)$$

where T_{db}= dry bulb temperature in °F and RH= Relative Humidity.

Construction of maps

THI maps were created using ArcGIS 9.4 GIS package. The threshold THI for each breed, location coordinates of the meteorological stations and THI values of the meteorological stations were used in map development process under a GIS platform. These maps were developed by interpolated point data using Inverse Distance Weighted Interpolation Method of the software of the aforementioned GIS software.

Estimation of threshold THI for breeds and crosses

Milk yield was considered as an indicator for estimating the THI for the relevant breed or cross in the present study. This is based on the reporting of Armstrong (1994) who described that for temperate cattle THI value of 72 was critical beyond which temperate cows start to decrease productivity, and Bohmanova et al. (2007) who reported various THI values corresponding to milk yield in cows. Accordingly, variation of milk yield of each breed/cross was assessed to realize the threshold temperature at which the milk yield starts to decrease.

For this purpose, milk yield data of breeds and crosses used for milk production of the country were collected from 140 farms all over the country. Milk yield data of each breed or cross was collected from at least five farms having similar management conditions, and at least three cows in each farm. The farms were either under smallholder or semi-intensive management conditions where cattle were housed in free stalls and fed *ad libitum* with grass, rice straw, and supplementary concentrates according to their production performance. Animals were allowed to graze in natural pasture in coconut lands, fallow paddy fields and non-cultivated areas during the day time. Night feeding was done with locally available cut grasses like *Bracharia* species along with Coconut Poonac or rice bran and concentrate mix. Locations of farms were identified to represent the environmental temperature

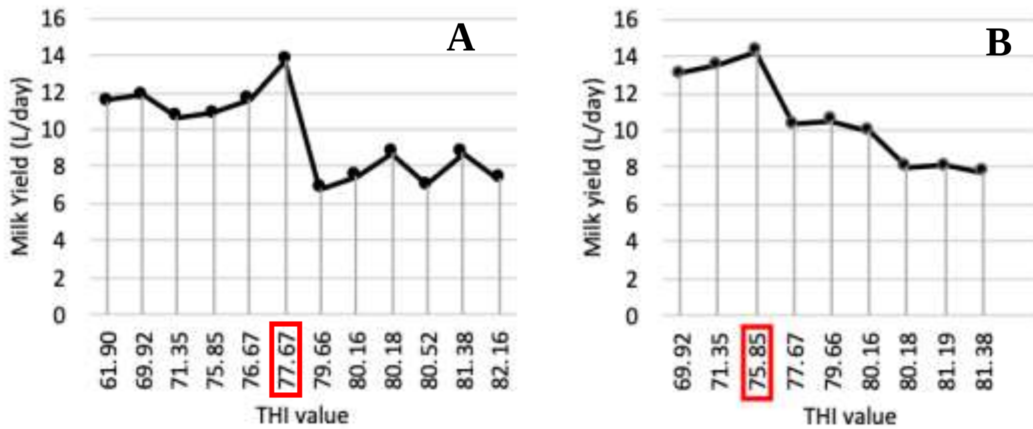

Figure 1. Identification of threshold THI for (A) Jersey breed and (B) Jersey × Friesian crossbred.

gradient of the country. Milk yields (L/day) of four different commonly reared breeds/types of dairy cows, namely Friesian, Jersey, Sahival, Local, and five crossbred cows, namely Jersey × Friesian, Friesian × Sahiwal, Jersey × Sahiwal, Jersey × Australian Friesian Sahiwal (AFS), Local × Sahiwal were plotted against THI values corresponding to each area where the farms were located. The THI value corresponding to a sharp drop in the milk yield of each plot (Figure 1) was considered as the threshold THI value of the respective breed or cross.

Livestock weather safety index (LWSI) categories associated with THI values

The LWSI is a qualitative indication of THI that describes categories of heat stress of livestock exposed to extreme conditions, and serves as a strategic guide for mitigating the effects of heat associated environmental stress conditions on animals in different production systems as well as in transportations. The qualitative categorization of LWSI described by Hahn et al. (2009) was used in the present study: Normal (<74), Alert (74-78), Danger (79-83) and Emergency (>84).

RESULTS AND DISCUSSION

Meteorological information of the 26 meteorological observation stations revealed that average T_{db} varied between 21.3 (Sita Eliya) and 29.8°C (Kanthale) throughout the country during the 10-year period considered (2005 to 2014) in the study. The T_{db} provides a measure of the sensible heat content of air, and represents a major portion of the driving force for heat exchange between the environment and an animal (Hahn et al., 2003). The use of T_{db} in the present study enabled to capture the complex interactions between the physical and biological components in the THI. The mean THI values computed for 26 meteorological observation stations are shown in Table 1. The THI values ranged between 62 and 83, suggesting a fluctuation of THI across the country according to the general climatology of the country which is mainly governed by the Island position in the warm Indian Ocean, presence of a central massif being perpendicular to two approaching monsoons (that is, summer monsoon and winter monsoon) from opposite directions in each year and the close proximity to vast land mass of Indian sub-continent (Punyawardena, 2007).

Threshold THI and cattle genotypes

Thermal stresses cause losses in animals due to coping responses related to physiology (Eigenberg et al., 2005). Coping responses are necessary for domestic animals to respond to changes in the environment for their survival. Animals belong to different breeds and crosses may possess varying degree of coping capacity. Those responses often negatively impact on productivity and profitability of livestock operations (Collier et al., 2018). According to Du Preez et al. (1990), milk productivity is not affected within the THI range of 35 to 72 in many dairy breeds.

As reported by Ferreira et al. (2009), THI values in the range of 69 to 70 were considered as non-stressful while values above 83 indicated a severe heat stress for 50% Holstein cattle. In Girolando cattle, the estimated upper critical value of THI ranged from 75 to 80 for different crosses (Azevedo et al., 2005). Accordingly, the present study identified the threshold THI for the 10 breeds/crosses using the respective changes of milk yield in different thermal environments (or THI conditions) of the country (Figure 1).

Table 2 presents the threshold THI values estimated for 10 different breeds and crosses commonly reared as dairy cows in Sri Lanka. The threshold THI values or upper critical THI value of thermal neutral zone estimated in the present study for Friesian and Jersey were marginally higher than the values reported in other studies elsewhere; THI 68 and 75 for Friesian and Jersey,

Table 1. Computed mean THI values of 26 meteorological observation stations across Sri Lanka.

Met. station	Mean THI value (Mean ± SD)	Met. station	Mean THI value (Mean ± SD)
Sita-eliya	62±0.54	Monaragala	80±3.52
Rahangala	70±1.85	Jaffna	80±0.16
Bandarawela	71±1.73	Aralaganwila	80±2.00
Peradeniya	76±1.17	Mannar	80±0.29
Kundasale	77±0.86	Maho	80±2.34
Matale	78±1.24	Bobuwala	80±1.28
Bathalagoda	79±1.08	Weerawila	81±1.57
Rathnapura	79±3.16	Batticalo	81±0.17
Girandurukotte	80±2.41	Vanathavillu	81±1.98
Mahailluppallama	80±1.79	Makandura	81±1.85
Trinco	80±0.20	Labuduwa	81±1.19
Lunuwila	80±1.64	Angunakolapalassa	82±2.14
Ambalanthota	80±1.24	Kantale	83±0.89

Table 2. Estimated threshold THI values of commonly found dairy breeds and crosses.

Breed/ Cross	Estimated Threshold THI
Friesian	69.92
Friesian × Jersey	75.85
Friesian × Sahiwal	75.85
Jersey	77.67
Jersey × Local	80.02
Jersey × Sahiwal	80.18
Sahiwal	80.18
Jersey × AFS	81.38
Local	81.38
Local × Sahiwal	81.38

respectively (Kadzere et al., 2002; Collier et al., 2012; Bryant et al., 2008; Giri et al., 2018). The THI values estimated in the present study revealed that Friesian and its crosses were having clearly low threshold THI values compared to other breeds and crosses confirming their low heat tolerance despite being a high milk producing genotype. However, the Jersey breed and its crosses showed a high tolerance to heat stress compared to its counterpart dairy breed; Friesian. Similar results have been reported by Smith et al. (2013) having compared the response of milk production of the two breeds at varying THIs. Hahn et al. (2009) divided the thresholds of heat stress depending on the productivity of the cows, and threshold THI values of 72 and 74 were assigned for high-yielding and low-yield dairy cows, respectively.

Mapping of threshold THI

THI map corresponding to the threshold THI values of each cattle breed or cross considered in the present study is as shown in Figure 2.

Figure 2 clearly indicates that thermal suitable area for pure Friesian dairy cattle breed under natural climatic environment with smallholder semi-intensive management is limited to small area of Central hills of the country (above 900 m elevation). Pure Friesian dairy cattle breed is thermally comfortable below THI value of 69.9 under Sri Lankan conditions, and it is the upper critical THI value of thermal comfort zone for pure Friesian dairy cattle found in the study. Figure 2 reveals that Sita-eliya, Thalawakale, Bandarawela and Badulla demarcate the boundary of thermal comfortable region for pure Friesian cattle breeds in Sri Lanka. According to the National Animal Breeding Policy Guidelines and Strategies for Sri Lanka (2010), Friesian dairy cattle breed is recommended for upgrading of dairy cattle in Up-country Wet zone under intensive and semi-intensive management systems. According to the assessment of the present study, the thermal neutral area (THI <69.9) for pure Friesian under

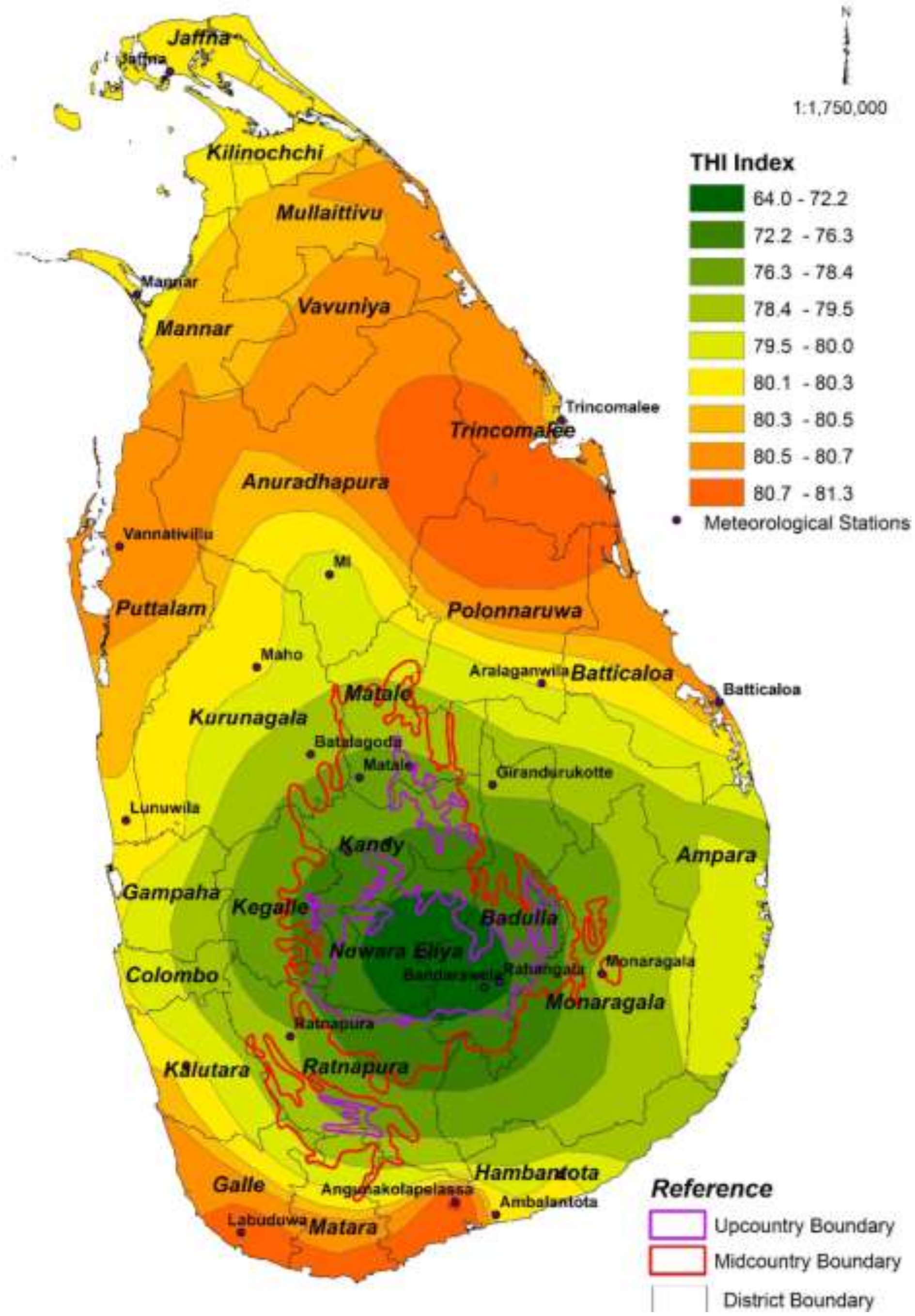

Figure 2. Temperature Humidity Index (THI) map of Sri Lanka with respect to g 10 different dairy cattle breeds and their crosses.

semi-intensive system is limited to the area demarcated earlier. However, common Friesian crosses used for milk production (Friesian × Jersey and Frisian × Sahiwal) could find their thermal neutral area extending up to an area bordering Kandy, Peradeniya, Ella, Balangoda within the Mid country Wet zone and Up-country Intermediate zone where the THI reaches up to 75.8 on average. However, Friesian crosses are popular and are reared in many climatic regions of the country mainly under intensive production system. Thus, it is necessary to be aware that the micro-environment created under intensive management condition should be below the threshold THI condition (THI < 76) in order to get the real benefit of milk production potential of these crosses.

The THI threshold value for pure Jersey dairy cattle breed was estimated as 77.7, proving the common understanding that pure Jersey breed possess more heat tolerance ability compared to pure Friesian breed. As depicted in Figure 4, whole Nuwara-Eliya district is comfortable for pure Jersey dairy cattle breed along with some parts of southern area of Kandy district. Matale, Hunnasgiriya, Madugoda and Victoria, Randenigala, Rantambe Rathnapura, are the bordering areas of the THI zone suitable for the breed. When Jersey crosses were considered, Jersey × Friesian, Jersey × Local, Jersey × Sahiwal and Jersey × AFS crosses generally contribute for comparatively larger share of milk production in the country. These crosses were showing varying threshold THI levels ranging from 80 to 81.4, excluding Jersey × Friesian which showed even lower threshold THI (75.85) value than pure Jersey breed (77.67). Accordingly, Jersey × local and Jersey × Sahiwal crosses are having thermal neutral zone extended up to Kalpitiya, Anuradhapura, Habarana, Polonnaruwa and Chenkaladi towards north and Horana, Matugama, Middeniya up to Kirinda towards south from the central part of the country. In addition, whole northern area bordering from Talladi, Vellankulam, Kilinochchi, and Chundikulam northwards also could provide the thermal neutral zone for these two Jersey crosses. The Jersey × ASF crossbreds showed higher threshold THI (81.4) than the other Jersey crosses according to the results of this study, and could be recommended for the whole country (where THI ranged between 64.1 and 81.3).

The threshold THI of pure Sahiwal cattle was reported as 80.2 in the present study which is higher than the value of 79 reported by Giri et al. (2018). Being a *Bos indicus* breed, Sahiwal is expected to be tolerant comparatively high heat regime and could be accommodated relatively wider range than the temperate breeds and their crosses in tropical regions. The threshold THI value of Sahiwal breed is comparable to Jersey × Sahiwal crossbred as revealed in the present study. Hence, the region specified earlier for Jersey × Sahiwal crossbreds could also be suitable for pure Sahiwal breed as well.

Both Local cattle type and Local × Sahiwal crossbreds showed threshold THI of 81.4 under semi-intensive management condition. Hence, they also could be recommended for the whole country (where THI value ranged between 64.1 and 81.3).

Implications of LWSI

The THI value and its impact on cattle performances often described in association with LWSI which is commonly used as a benchmark to assign heat stress levels to Normal: ≤ 74, Alert: 75-78, Danger: 79-83, Emergency: ≥84 categories (LCI, 1970). However, demarcation of thermal neutral or normal zone could vary ranging from 72 (Smith et al., 2013) to 75 (Nidumolu et al., 2010) in different studies. Developing different level of categories, Akyuz et al. (2010) identified THI values 72, 79, and 89 for mild, moderate, and severe heat stress conditions in cattle. However, all these categorizations have been done in relation to improve temperate dairy breeds under summer weather conditions. The present study used the commonly used categorization described in LCI (1970) to categorize THI zones in Sri Lanka. Accordingly, Sri Lanka does not have regions coming under emergency category (THI ≥84). In general, the Central hill area of the country comes under Normal category whereas Mid country area and small part of Wet and Dry zones in Central region of the country come under Alert category. Majority of the area of the country belong to Danger category (Figure 3).

When the distribution of dairy cattle breeds of the country is considered, Friesians are found mainly Normal to Alert LWSI zones whereas Jersey found in wider range of LWSI zones, ranging from Normal to Danger (Table 3). Sahiwal and Local breeds are found mainly in Danger LWSI zone of the country. According to the threshold THI values most of these cattle breeds, especially lactating dairy cattle of Sri Lanka are at an elevated risk of developing heat stress. This has a detrimental effect on production (milk) and reproduction performances (Conception rate), nutrition state (feed intake) and related aspects including respiratory rates (Ingram and Dauncy, 1985; Johnson, 1985; Nidumolu et al., 2010).

Responses to varying THI and LWSI categories by different cattle breeds and crosses

The present study attempted to assess the negative effect of unfavorable LWSI zones on production of different breeds in the country. In the absence of breed level information in detail, the cattle genotypes of the country could be categorized into three broad categories: Local, Indian type (Indian breeds and their crossbreds) and European (European breeds and their crossbreds). Currently, there are around 29% Local, 31% Indian and 40% European categories of cattle in total (DAPH, 2019), with the considerable variation among different administrative districts across the country. Accordingly, distribution of genotypes across districts varies from 81% Local and 19% improved in Batticoloa district to 2% local and 98% improved in Nuwaraeliya district (Figure 4).

The trend analysis of milk production (L/day/cow) of three of the main exotic breeds of cattle in Sri Lanka, namely, Friesian, Jersey and Sahiwal within the range of THI levels of the country found in the present study (62-83), it was revealed that, milk production was affected significantly ($P<0.05$) by the THI range across the country. In the case of Local cattle, the negative trend was not significant, indicating that Local cattle were able to maintain similar production level through the THI range

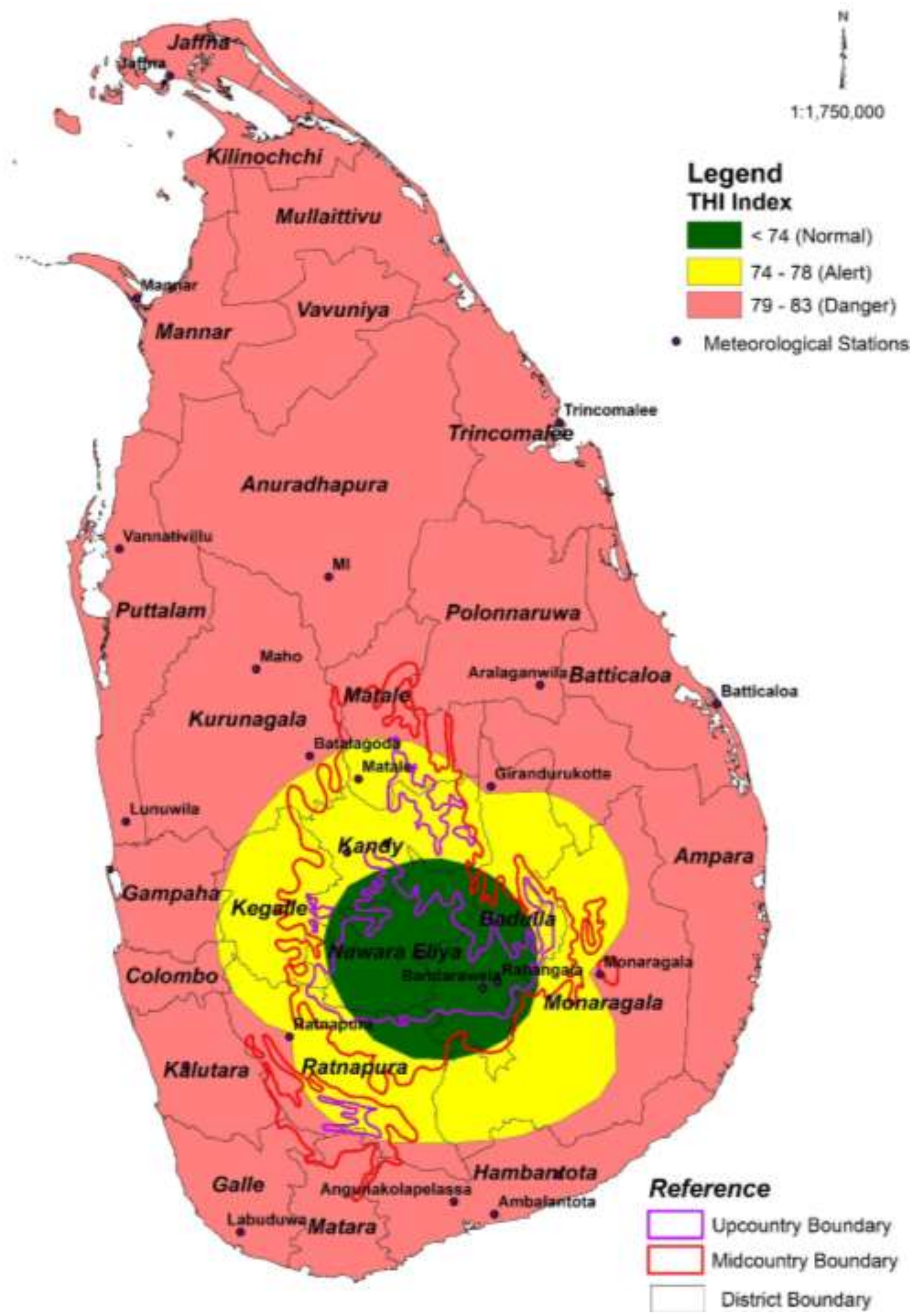

Figure 3. Livestock Weather Safety Index (LWSI) zones map of Sri Lanka.

of 80 to 83 within which they are found in Sri Lanka.

The trend analysis of milk yield of different breeds in the present study clearly depicted that there were varying responses of different breeds and crosses when the thermal environment deviates from the comfort zone of respective breeds/crosses. Johnson (1985) reported that there was a drop of milk yield in general when THI exceeds 72, and in particular, 17 - 21% reduction of milk production for Holstein and Jersey cow have been recorded by Mallonee et al. (1985), Du Preez et al. (1990) and Saleem and Bouraoui (2009). A considerably high 30 - 40% reduction of milk yield in crossbred dairy cows has

Table 3. Variation of response to heat stress by ten dairy breeds and crosses in Sri Lanka.

Breed/Cross	Threshold THI	Drop of milk yield (L/THI) within the range†	THI range of the breed/ crossbred‡	LWSI level for areas where breed/cross was found
Friesian	69.92	0.41	62-78	Normal - Alert
Friesian × Jersey	75.85	1.18	70-81	Alert - Danger
Friesian × Sahiwal	75.85	1.00	76-82	Alert - Danger
Jersey	77.67	1.41	62-82	Normal - Danger
Jersey × Local	80.02	0.41	80-81	Danger
Jersey × Sahiwal	80.18	0.44	80-82	Danger
Sahiwal	80.18	2.00	80-82	Danger
Jersey × AFS	81.38	2.30	80-82	Danger
Local	81.38	1.54	80-82	Danger
Local × Sahiwal	81.38	1.28	80-82	Danger

†Drop has been estimated for the THI range between the threshold THI of the breed/cross and the upper level of the THI range within which the breed/cross was found in the study. ‡The THI range within which the respective breed was found.

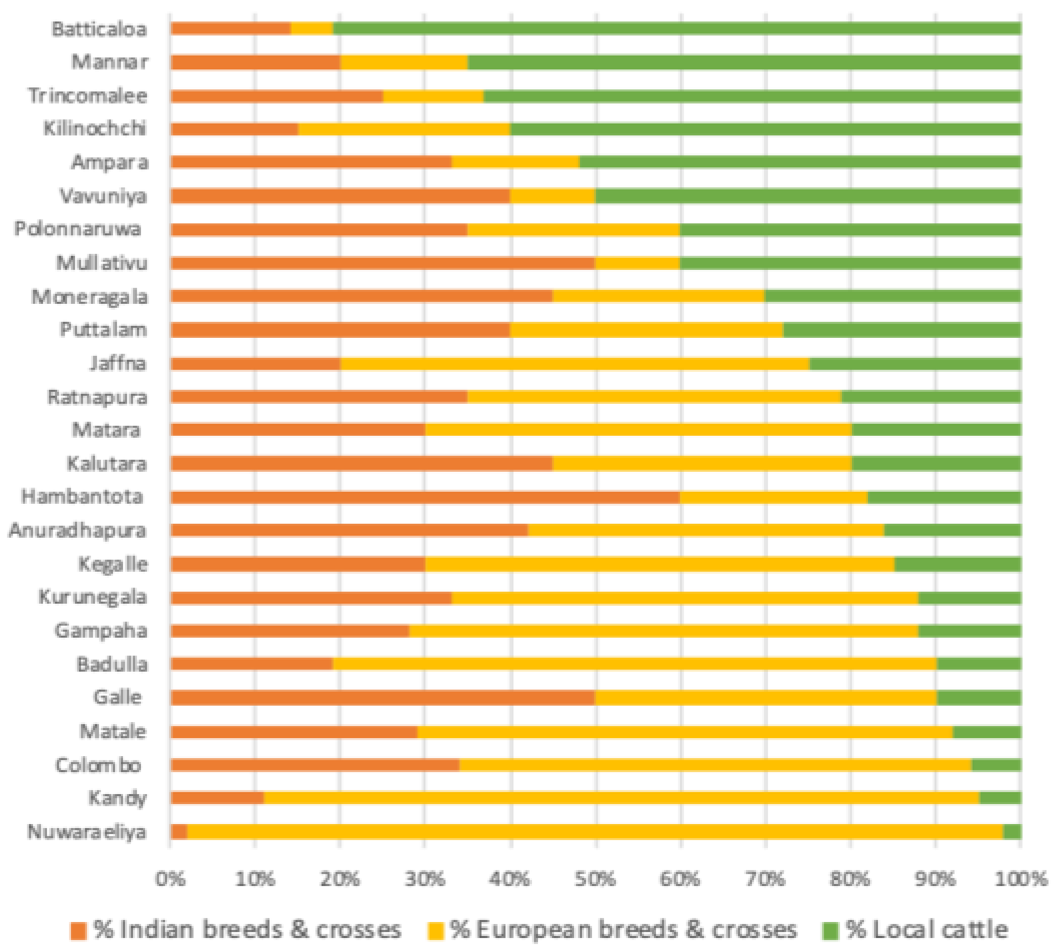

Figure 4. Distribution of local and improved (including crossbred) categories of Dairy cattle (Produced based on DAPH, 2019).

also been recorded when the heat stress changed from comfort zone to stress zone by Kohli et al. (2014). Results of the comparable analysis done in the present study revealed that 10% reduction of milk yield in Friesian cows at THI 74 - 78 and 32% reduction in Jersey cows at 74 - 82 THI range. Sahiwal and Local cows showed reductions of milk yield 20 and 16%, respectively at 80 - 82 THI range under semi-intensive production system.

Detailed analysis of reduction quantities of milk with respect to the changes of THI level in the 10 breeds and crosses under semi-intensive production system revealed that variation in a considerably wide range. This observation reveals a variation of responses to changing thermal environments by 10 different genotypes of cattle used for dairy production in Sri Lanka (Table 3).

Friesian breed is reared under semi-intensive production system only within a narrow range of THI (Normal - Alert LWSI zones) and therefore, the milk drop within the range was marginal (0.41 L/THI). However, Friesian crosses were found in a wider range of THI (representing Alert - Danger LWSI zones), and as expected the milk yields dropped considerably (Table 3). Jersey is the most popular temperate dairy breed in the country and found in all over the country under semi-intensive production system (all LWSI zones except Emergency). Thus, drop of milk yield of the pure breed was high. However, the Jersey crosses have shown a considerable coping capacity probably as a result of hybrid vigor in crossbred individuals. These crossbreds were performing even better than tropical breeds and crosses even at THI levels (Danger LWSI zone). Local cattle have shown a marginally better coping capacity than Sahiwal, and again the crossbreds of the two breeds showed a hybrid vigor. These findings are in-line with the report of Kohli et al. (2014) who explained the differences in coping ability of low and high yielding dairy animals. As reported by them, low yielding cows did not show any significant change when the THI was above 72 while high yielding cows showed a significant decrease in milk yield.

The present inferences were drawn from the data collected in local farming conditions under semi-intensive system which is the most popular dairy production system in the country. As implied in the estimates presented in Table 3, a considerable drop of milk yield is to be expected when animals with different coping levels were reared in thermal environments beyond their comfortable ranges. Therefore, appropriate management interventions are needed when certain breeds or crosses are reared under those environments, particularly the cattle with poorly adapted genotypes. Given the fact that some of the management interventions are expensive to implement, the most sustainable approach of ameliorating the effects of environmental stress factors would be to select the suitable genotypes of cattle having coping ability with minimum effect on their production. As revealed in the present study, Local, Sahiwal, their crossbreds and Jersey crossbreds are the most appropriate choices of breeds/crosses which can cope up with thermal environments with high THI while showing minimum production compensations under a changing and variable climate.

Conclusion

The corresponding Livestock Weather Safety Zones were Normal to Emergency. Genotype of the animal has a great influence in determining the coping ability of animals. Accordingly, Jersey crosses except Jersey × Friesian cross are particularly suitable for many parts of the country. Sahiwal, local cattle and their crosses showed the highest coping ability and could be recommended to zones with high THI levels. Many crosses showed hybrid vigor in coping ability where local cattle showed the greatest coping ability to high THI conditions among the breeds considered in the present study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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