Use of Temperature-Humidity Index (THI) in energy modeling for broiler breeder pullets in hot and humid climatic conditions

N.C. Behura[1], F. Kumar[1], L. Samal[1*], K. Sethy[2], K. Behera[3] and G.D. Nayak[4]

[1]Post Graduate Department of Poultry Science, [2]Department of Animal Nutrition, [3]Department of Livestock Production and Management, [4]Department of Animal Genetics and Breeding Odisha University of Agriculture and Technology, Bhubaneswar-751003, India
[*]Corresponding Author, E mail: lipismitasamal@gmail.com

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Abstract

Accurate prediction of metabolizable energy (ME) requirement is important to formulate diets for poultry during different stages of growth and production. Earlier ME models involve a linear effect of temperature over energy requirements when the temperature is up to 27°C. But in humid tropics, the environmental temperature remains fairly high (>40°C) coupled with high relative humidity (>90%) during summer. Under such environmental conditions, the earlier ME models may not hold good. So, the present study was conducted to examine the influence of relative humidity (RH) on the ME requirement for maintenance (ME_m) of broiler breeder pullets by incorporating effective temperature-humidity index (THI) as a factor in energy prediction equation. Three groups of broiler breeder pullets (n = 288 each) in 2 seasons (summer and winter) were housed according to their 7th week body weight (BW). From 8th week onwards, feed restriction was practiced to achieve target BW of 2.2 kg at 20th week. The weekly feed intake was derived using ME prediction model. The dry-bulb temperature (T_{db}), wet-bulb temperature (T_{wb}) and RH were recorded daily. The T_{db}, T_{wb} and THI during summer were higher ($p<0.05$) than winter. The metabolizable energy for maintenance (ME_m) during summer (168.72 kcal/kgW$^{0.75}$) was significantly ($p<0.01$) higher than the ME_m during winter (132.80 kcal/kgW$^{0.75}$). The correlation between ME_m and climatic factors were highly significant ($p<0.01$) during summer unlike winter. Regression analysis also exhibited a similar trend. During summer, R^2 = 0.449 for effective T_{db} and 0.629 for effective T_{wb} indicating significant contribution of T_{wb} to ME_m. An equation has been suggested to predict the ME_m during summer in humid tropical climates as: $ME_m/W^{0.75} = 10.538\times THI - 138.92$. The THI, a measure of thermal stress, should be incorporated in energy models for accurate prediction of ME_m for broiler breeder pullets in hot and humid tropical climates.

Key words: Broiler breeder pullets; Metabolizable energy; Restricted feeding; Temperature-humidity index; Energy model

Introduction

Accurate prediction of energy intake is important to formulate diets for poultry during different stages of growth and production. Prediction of energy requirement has high significance in broiler breeder pullets where restricted feeding is practiced universally to achieve a target body weight (BW) at maturity. In the factorial approach, the partitioning of metabolizable energy (ME) requirement into maintenance, growth and production for laying and breeder hens is expressed by the model: $MEI = aW^b(T) + c\Delta W + dEM$ (where, MEI is ME daily intake, W^b is metabolic BW, T is environmental temperature, ΔW is change in BW, EM is egg mass output, a, c and d are the maintenance, growth and production requirement coefficients, respectively) (Peguri and Coon, 1988; Sakomura and Rostagno,1993; NRC, 1994). Many energy models have been suggested for laying-type pullets (Neme, 2004), laying hens (Peguri and Coon, 1988; Sakomura and Rostagno, 1993; NRC, 1994; Sakomura et al., 2005a), broiler chicks (Sakomura et al., 2005b; Longo et al., 2006), and for broiler breeder hens (Rabello, 2001). The only energy requirement model for broiler breeder pullets (Sakomura et al., 2003) like many other models for various other class of poultry, involve a linear effect of temperature over energy requirements. Sakomura (2004) reported that there was a decrease in ME requirement for maintenance (ME_m) when temperature increased up to 26°C in broiler breeder pullets and above that temperature, the ME_m increased. The linear effect of temperature as used in different ME prediction equations should be considered only for temperatures close to that which would provide a thematically comfortable environment. Lesson and Summers (2005) reported small variation in heat production of birds from 19-27 °C but above 27 °C, birds required energy to dissipate heat. In humid tropics, the environmental temperature remains fairly high (>40°C) during summer coupled with high relative humidity (>90%). Therefore, under such environmental conditions, the predicted ME model for broiler breeder pullets (Sakomura *et al.*, 2003) which involve a linear effect of temperature over energy requirement may not hold good.

In humid tropics, during summer the birds are exposed to thermal stress. The hot and humid climate can have a depressing effect on feed consumption and growth rate in broilers. Heat stress conditions are commonly considered as a product of ambient temperature and relative humidity (RH) (Yahav, 2000). To assess the effects of thermal stress, certain thermal comfort indices based on the correlation of physiological responses of a particular species to these climatic conditions such as wet-/dry-bulb temperature index (WD index) has been experimentally determined. The poultry researchers used the term temperature-humidity index (THI) instead of WD index. The THI is usually based on rectal temperature, respiratory rate or heart rate response to temperature and humidity combinations. The THI is a single value representing the combined effects of air temperature and RH associated with the level of thermal stress. Generally, THI is expressed as a weighted sum of dry-bulb and wet-bulb temperatures, e.g.

$THI_{broilers} = 0.85\ T_{db} + 0.15\ T_{wb}$ (Tao and Xin, 2003)

$THI_{layers} = 0.6\ T_{db} + 0.4\ T_{wb}$ (Zulovich and DeShazer, 1990)

Where,

THI = temperature-humidity index in °C

T_{db} = dry-bulb temperature in °C

T_{wb} = wet-bulb temperature in °C

Chepete et al. (2005) also developed THI relationships for broilers based on production parameters in naturally ventilated housing in a semi-arid climate throughout the production cycle.

The objectives of the present study was to compare the ME_m of six flocks of broiler breeder pullets during two different seasons (summer and winter) of a year from 8th to 16th week of age in the hot and humid climate of Odisha, India and to examine the influence of RH on the ME_m. An equation has been suggested by incorporating effective THI (which takes into account both T_{db} and T_{wb}) to predict the ME_m of broiler breeder pullets.

Materials and methods

The study was conducted in All India Coordinated Research Project (AICRP) on Poultry Breeding and Post-Graduate Department of Poultry Science, College of Veterinary Science and Animal Husbandry, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar (latitude: 20^0 15' N, longitude: 85^0 52' E, altitude: 25.9 meters above the sea level), Odisha.

The data obtained from restricted feeding of broiler breeder pullets from 8 to 16 weeks of age during summer season (from 1st March to 2nd May) and winter season (from 19th November to 20th January) were used for the study. Six groups of pullets (3 groups in each season) were housed according to their BW comprising 288 pullets per group. The pullets were raised on a starter diet with 20% CP and 2900 kcal ME kg^{-1} diet from 0 to 6 weeks and selected according to their 6th week BW. During 7th week, the birds were maintained under controlled feeding to acclimatize them to feed restriction. From 8th week onwards, feed restriction was practiced to achieve a target BW of

2.2 kg at 20th week. During this period, a grower diet containing 16% CP and 2750 kcal ME kg^{-1} diet was fed. The gross and proximate composition of the grower diet has been presented in Table 1. The weekly feed intake was derived using the ME prediction model by Sakomura et al. (2003) for broiler breeder pullets.

$$8^{th}\text{ week: } ME = W^{0.75}(174-1.88\times T) + 2.83WG$$

$$9^{th}\text{ to }14^{th}\text{ week: } ME = W^{0.75}(174-1.88\times T) + 2.5WG$$

$$15^{th}\text{ to }16^{th}\text{ week: } ME = W^{0.75}(174-1.88\times T) + 3.24WG$$

Where,

$W^{0.75}$ = metabolic BW in kg

T = effective ambient temperature in °C

WG = daily weight gain in g

Table 1: Gross and proximate composition of experimental grower diet

Attribute	Concentration	Attribute	Concentration
Gross composition (g kg^{-1})		Proximate composition (g kg^{-1})	
Maize	585	Moisture	92.7
Soya bean meal	175	Crude Protein	141.2
De-oiled rice bran	210	Ether extract	45.5
Mineral mixture[1]	30	Crude fibre	49.1
Common salt	3	Total ash	101.7
L-Lysine (98.5%)	1	Acid insoluble ash	26.3
DL-Methionine (99%)	1	Nitrogen-free extract	662.5
Trace mineral mixture[2]	1	Calcium	9.3
Choline chloride	5	Phosphorus	4.5
Toxin binder	2	ME[4] (kcal kg^{-1})	2750.18
Vitamin premix[3]	3		

Supplied, Ca: 32%, P: 6%, Mn: 0.27 %, Zn: 0.26 %, I: 0.01 %, Cu: 0.01 %, Fe: 0.01 %, F: 0.03 %

[2] Supplied per kg, Cu: 15 g, I: 1 g, Fe: 60 g, Mn: 80 g, Se: 0.3 g, Zn: 80 g

[3]Supplied per g, Vitamin A (retinyl acetate): 82500 IU, Vitamin B_2 (Riboflavin): 50 mg, Vitamin D_3 (cholecarciferol): 16500 IU, Vitamin K_3 (menadione dimethyl pyrimidinol): 10 mg, Folic acid: 10 mg, Vitamin E (dl-α-tocopheryl acetate): 200 mg, Se: 400 µg, Vitamin B_1 (thiamin mononitrate): 4 mg, Vitamin B_6 (pyridoxine): 8 mg, Vitamin B_{12} (cyanocobalamin): 40 µg, Calcium pantothenate: 40 mg, Niacin (niacinamide): 60 mg

[4]ME (metabolizable energy) calculated from data provided by NRC (1994)

The initial mean BW was recorded for each group at the end of 7th week. Taking the initial mean BW and final target BW into consideration, a linear graph was plotted and predicted weekly BW gain was derived. Weekly mean predicted minimum and maximum temperature were obtained from meteorological station and the effective temperature was determined as (2×maximum temperature + minimum temperature)/3 (Lesson and Summers, 2005). Using the mean BW, daily targeted BW gain and predicted effective temperature data for a particular week, the ME intake was determined as suggested by Sakomura et al. (2003). The BW of pullets (50 randomly from each group) was recorded at the end of each week using a digital electronic balance and compared with the targeted BW gain for the same week and accordingly the weekly BW gain target for the subsequent week was revised. This practice was repeated every week. The daily maximum and minimum T_{db} and T_{wb} and RH were recorded in the farm. The effective THI was calculated weekly from the effective T_{db} and T_{wb} i.e. effective THI = 0.6 effective T_{db} + 0.4 effective T_{wb} (Zulovich and De Sdazer, 1990).

The pullets were housed in floor pens providing 2.5 ft^2 floor space per pullet. The pullets were fed during morning hours in winter and during late afternoon hours in summer. Adequate feeders were provided to ensure better access of all the pullets to feed when offered. Water was provided through automatic bell drinkers. Partitioning of the ME intake was done as per the model. Using the formula, the predicted ME_m and ME requirement for growth (ME_g) was determined. From the actual weekly BW gain, the actual ME_g was calculated using the same formula. Actual ME_m was calculated by subtracting the actual ME_g from the MEI. For convenience of comparing the ME_m of different experimental groups, the ME_m of each group was converted to $ME_m/W^{0.75}$.

Statistical analysis: Data were analyzed using statistical SPSS V20 (SPSS Inc., Chicago, IL, USA). For comparison of pair means, 't' test was conducted. Regression (b ± SE) analysis was employed to know the ME_m response over the means. Pearson correlation coefficients (r) between the climatic variables and ME_m were calculated and significance levels were determined. Linear regression was done and scattered diagram was plotted to find out the linear equation.

Results

The daily maximum T_{db}, T_{wb} and THI during the two seasons have been illustrated in Figures 1-3. During winter, except for a few weeks the maximum T_{db} was within the thermo-neutral zone (TNZ; 18 to 24°C) whereas during summer it was above the TNZ for the entire experimental period. The THI during summer ranged between 24.93 and 31.76 where as during winter it varied from 19.12 to 25.58. The THI values during summer were plotted against the ME_m in a scattered diagram (Figure 4) and a linear effect of THI on ME_m was observed.

Figure 1 Daily maximum dry bulb temperature (T_{db}, ^oC) during the experimental periods

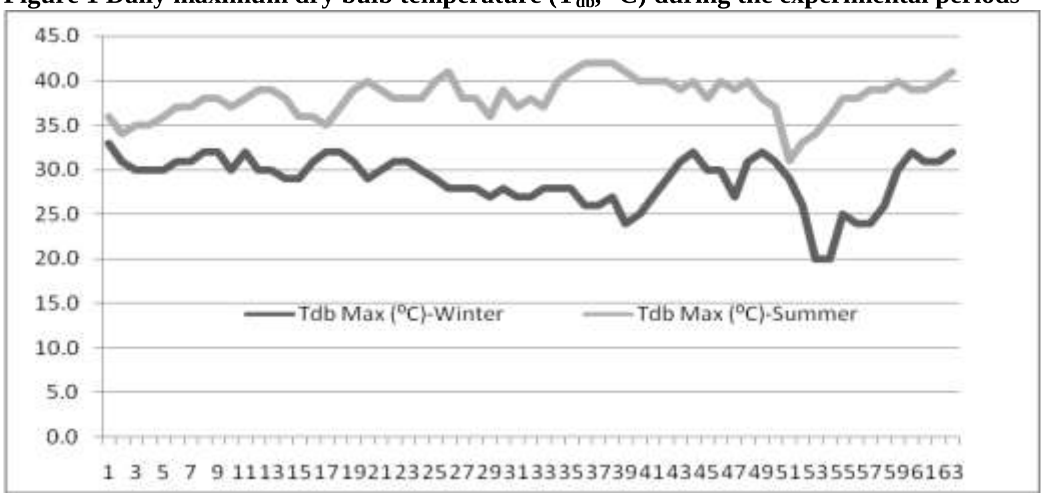
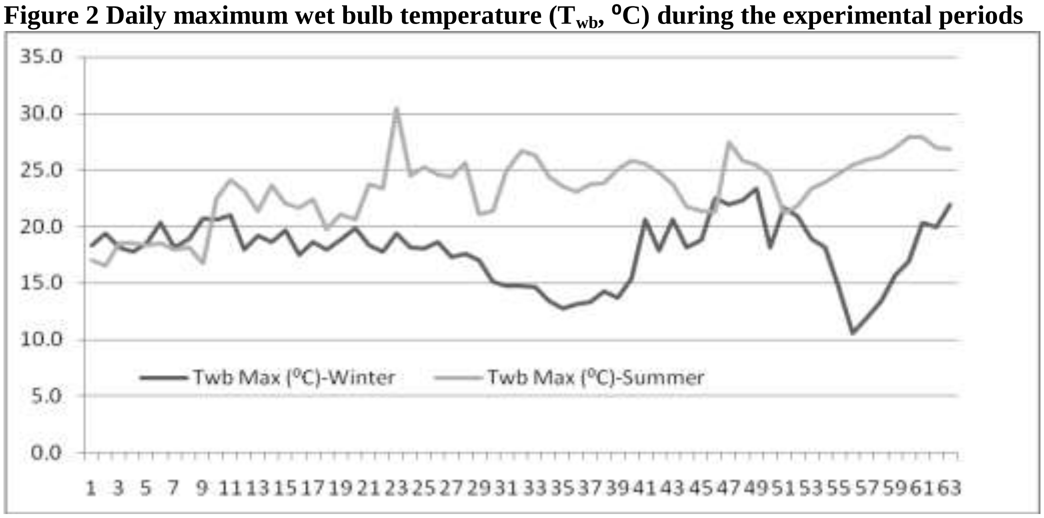


Figure 2 Daily maximum wet bulb temperature (T_{wb}, ^oC) during the experimental periods



Daily mean maximum, minimum and effective T_{db} and T_{wb} as well as THI values during summer and winter seasons (Table 2) were subjected to 't' test. During winter, the mean minimum and maximum T_{db} as well as T_{wb}, effective T_{db} and T_{wb} and THI values were significantly ($p<0.01$) lower than that during summer. The results of the analysis clearly exhibited that the climatic factors such as T_{db} and T_{wb} differed ($p<0.01$) between periods. The mean THI values for winter and summer were 22.48±0.42 and 29.19±0.41, respectively and the difference was highly significant ($p<0.01$). However, the predicted and actual T_{db} and T_{wb} for both the seasons did not differ significantly ($p>0.05$).

Figure 3 Effective temperature-humidity index (THI, ⁰C) during the experimental periods

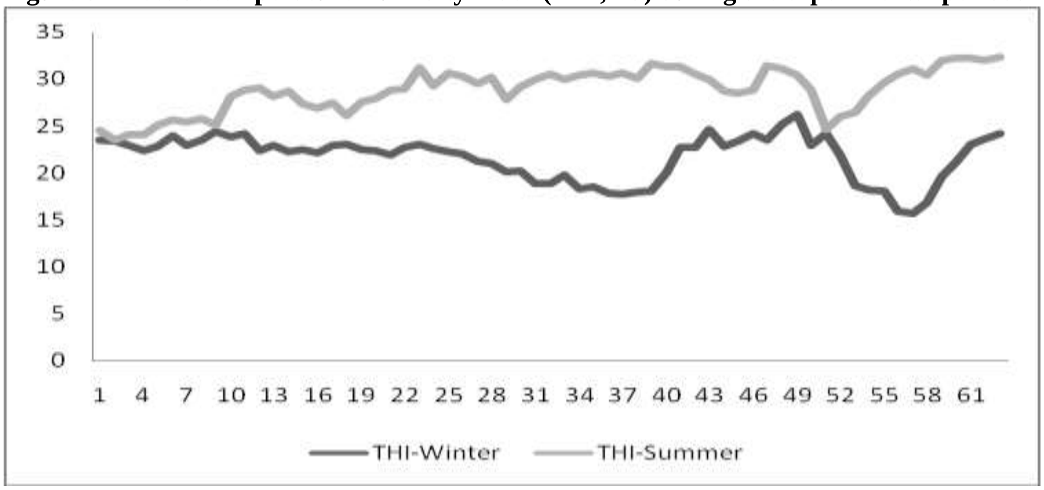
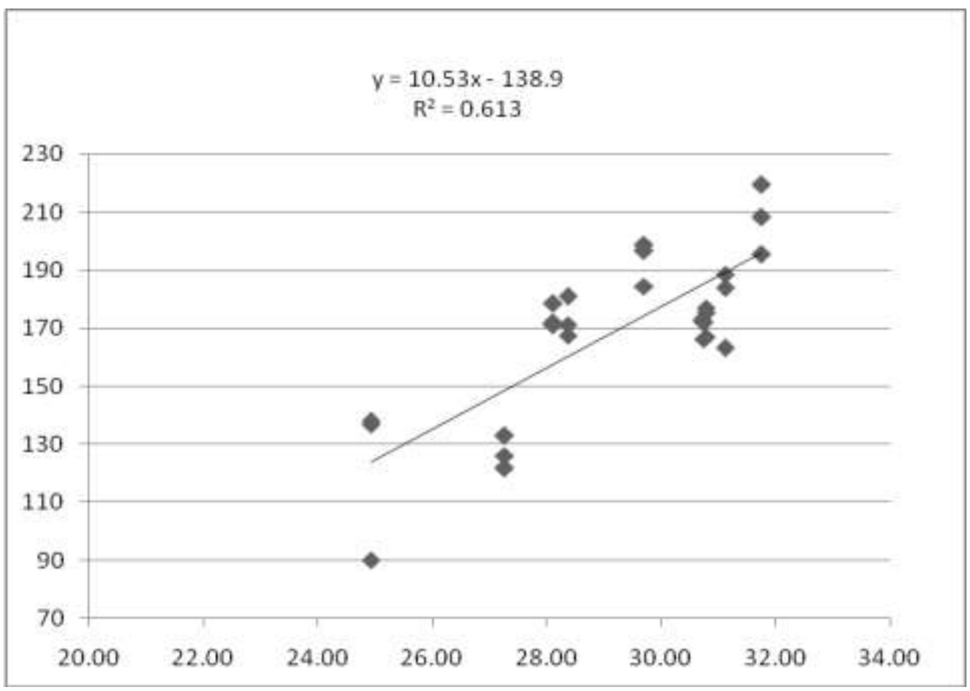


Figure 4 Scattered diagram exhibiting the correlation between metabolizable energy requirement for maintenance (ME_m) and temperature-humidity index (THI) during summer



The mean week-wise predicted and actual $ME_m/W^{0.75}$ of both the periods have been compared through a paired ‘t’ test and presented in Table 3. The weekly predicted and actual BW gain data during the two periods were also subjected to ‘t’ test. During winter, the actual daily BW gain was higher ($p<0.05$) than the predicted or targeted BW gain but in summer, the actual daily BW gain was lower ($p<0.01$) than the targeted BW gain. The actual ME_m during winter was lower ($p<0.05$) than the predicted ME_m but in summer, it was reverse and the actual ME_m was higher ($p<0.01$) than the predicted ME_m. While compared between seasons, the actual $ME_m/W^{0.75}$ was significantly

Table 2: Dry bulb temperature (T_{db}), wet bulb temperature (T_{wb}) and temperature-humidity index (THI) during summer and winter seasons

Climatic variables	Summer	Winter	't' value
Maximum T_{db} (°C)	38.1±0.28	28.9±0.35	20.27**
Minimum T_{db} (°C)	23.0±0.39	16.7±0.38	10.19**
Effective T_{db} (°C)	33.63±0.38	25.41±0.34	12.17**
Maximum T_{wb} (°C)	23.3±0.38	17.9±0.36	9.41**
Minimum T_{wb} (°C)	21.4±0.38	15.3±0.40	9.94**
Effective T_{wb} (°C)	22.54±0.59	18.08±0.61	5.11**
Effective THI[1]	29.19±0.41	22.48±0.42	9.19**

[1]Effective THI = 0.6 Effective T_{db} + 0.4 Effective T_{wb}

Table 3: Mean predicted body weight gain, actual body weight gain and metabolizable energy requirement for maintenance (ME_m) of broiler breeder pullets during summer and winter seasons

Parameters	Season	Predicted value	Actual value	't' value
Body weight gain (g/d)	Summer	16.38±0.40	10.81±0.84	4.08**
	Winter	8.35±0.29	11.85±1.21	2.420*
ME_m (Kcal/$W^{0.75}$/d)	Summer	156.73±3.64	168.72±4.13	3.77**
	Winter	139.07±0.96	132.80±2.78	2.21*

Table 4: Pearson correlation coefficients (r) between climatic variables and metabolizable energy requirement for maintenance (ME_m) during summer and winter seasons

Climatic variables	'r' value	
	Summer	Winter
Maximum T_{db}	0.6196**	-0.126NS
Minimum T_{db}	0.7501**	-0.485**
Effective T_{db}	0.7820**	-0.342NS
Maximum T_{wb}	0.7063**	-0.351NS
Minimum T_{wb}	0.7843**	-0.185NS
Effective T_{wb}	0.8020**	-0.327NS
Effective THI[1]	0.7829**	-0.361NS

[1]Effective THI = 0.6 Effective T_{db} + 0.4 Effective T_{wb} NS: Non-significant; ** p≤0.01

Table 5. Regression analysis depicting relation between climatic variables and metabolizable energy requirement for maintenance (ME_m) during summer and winter seasons

Climatic variables	R^2	b (slope)	a (intercept)	P (slope)	R^2	b (slope)	a (intercept)	P (slope)
	Summer				Winter			
Maximum T_{db}	0.56	6.86	23.93	<0.0001	0.24	-3.03	175.24	0.01
Minimum T_{db}	0.38	11.42	-286.78	0.0006	0.02	-1.57	181.54	0.53
Effective T_{db}	0.45	10.03	-168.53	<0.0001	0.34	-1.86	166.01	0.36
Minimum T_{wb}	0.62	8.83	-34.34	<0.0001	0.12	0.93	149.94	0.08
Maximum T_{wb}	0.61	8.36	-12.22	<0.0001	0.03	-1.86	166.01	0.36
Effective T_{wb}	0.63	9.08	-36.05	<0.0001	0.11	-1.97	168.37	0.96
Effective THI[1]	0.61	10.54	-138.92	<0.0001	0.13	3.15	20.36	0.06

[1]Effective THI = 0.6 Effective T_{db} + 0.4 Effective T_{wb}

higher in summer than the winter season. The mean minimum, maximum and effective temperatures T_{db}, T_{wb} and THI values during both the seasons were correlated with the ME_m (Table 4). The correlation between all the climatic factors with ME_m during winter were not significant (p>0.05). However, during summer the correlation between all the climatic factors and ME_m were significant (p<0.05). The regression analysis of the climatic variables with ME_m has been presented in Table 5. During winter, the regression coefficient (R^2) of all the climatic variables were non-significant but during summer, the R^2 for all the climatic variables were highly significant (p<0.01) except minimum T_{wb} which was significant at 95% level.

Discussion

During winter, the maximum T_{db} was within the TNZ for the major period of study (Figure 1) and above the TNZ during summer. Lesson and Summers (2005) reported that a small variation is observed in heat production of birds from 19 to 27°C. Below the lower critical limit, birds need to produce heat to maintain the body temperature and above 27°C, birds require energy to dissipate heat. Sakomura (2004) reported that there was a decrease in ME_m when temperature increased up to 26°C in broiler breeder pullets and above that temperature, the ME_m increased. This may be the reason for which the maximum T_{db} was negatively correlated with the ME_m during winter and positively correlated during summer. Therefore, significantly high (p<0.01) ME_m during summer may be attributed to the high ambient temperature.

Purswell et al. (2012) reported that in heavy broilers (BW > 3.2 kg), when THI exceeds 21°C, the birds performance was significantly declined and body temperature increased by 1.7°C. Tao and Zin (2003) observed that in male broilers (BW = 2.8 kg) at THI 30°C, the body temperature tend to rise. Thermal sensitivity to high temperature increases with BW (Lin et al., 2004). ME utilization for deposit of protein and fat varies with temperature (Sakomura, 2004). The effective THI values in the present study were 22.48 and 29.19 during winter and summer, respectively. Considering the higher (p<0.01) THI value during summer than winter, it is expected that the birds during summer might have been under more stressful condition than those during winter. Panting is the common way of respiratory evaporation to dissipate heat and it reduces production efficiency to maintain homeothermy (Dozier et al., 2007).

In the predicted ME requirement equation $ME_m = W^{0.75} (174-1.88\times T)$, only linear effect of temperature (i.e. T_{db}) is used in which increase in temperature results in reduction in ME requirement. In winter even though the temperature was almost within the TNZ, lower ME_m was recorded as compared to the predicted ME_m. Energy metabolism could be affected by several factors such as age, BW, body composition, size of organs, stage of growth and stage of production. The body composition is controlled genetically and may vary from strain to strain. The ME requirement for growth takes the body composition into account. The breed under the present study is a synthetic breed and the body composition could be different from the standard values used in the prediction model. However, as the same strain of birds was used during both the seasons, any such effect if anticipated could be similar during both the seasons. Moreover, the correlation between climatic factors and ME_m during winter was not significant.

The mean minimum, maximum and effective temperatures T_{db}, T_{wb} and THI values during both the seasons were correlated with the ME_m (Table 4). The correlation between all the climatic factors with ME_m during winter were not significant (p>0.05). However, during summer the correlation between all the climatic factors and ME_m were significant (p<0.05). The regression analysis of the climatic variables with ME_m has been presented in Table 5. During winter, the regression coefficient (R^2) of all the climatic variables were non-significant but during summer, the R^2 for all the climatic variables were highly significant (p<0.01) except minimum T_{wb} which was significant at 95% level.

The important finding of the present study was that the T_{wb} (an indicator of RH) had significant correlation with ME_m and the regression analysis showed a highly significant response confirming its contribution to ME requirement for maintenance during summer. The main pathway of heat dissipation in poultry is respiratory evaporation. When air temperature rises, the breathing frequency of chicken is increased and the evaporative heat loss is significantly enhanced (Wiernusz and Teeter, 1996). The amount of evaporative loss depends on RH and is suppressed when RH rises (Chwalibog and Eggum, 1989). While most discussion on environmental control of breeders is limited to only temperature, it must be emphasized that the prevailing RH is also another factor that causes distress to the bird. Conditions of high temperature and low humidity (32°C and 40% RH) are quite well tolerated by the bird, while high temperature and high humidity (32°C and 90% RH) are problematic (Lesson and Summers, 2005). However, T_{wb} has never been incorporated in energy modeling for poultry birds. The R^2 value for THI was 0.613 and it was significantly correlated (p<0.01) with ME_m. The THI is a thermal index developed from T_{db} and T_{wb}. Instead of using both T_{db} and T_{wb} in energy models which would complicate the equation further for practical application, an attempt was made to incorporate THI in the equation to predict ME_m requirement during summer in hot and humid climates. The THI values during summer were plotted against the ME_m in a scattered diagram (Figure 4). A linear effect of THI on ME_m was observed in the following equation.

$$\mathbf{ME_m/W^{0.75} = 10.538 \times THI - 138.92}$$

Where,
$W^{0.75}$ = metabolic BW in kg
THI = temperature-humidity index in °C

The envisaged model can be used for predicting ME_m of broiler breeder pullets in hot and humid climate.

Conclusion

The hot, humid climate has a negative impact on the performance and well-being of broilers. Particularly during summer, the temperature and humidity remains much above the thermally comfortable zone of broilers significantly influencing the metabolizable energy requirement for maintenance. The temperature-humidity index can be used to account for the effects of heat stress on performance of broiler breeder pullets and it should be employed in energy models for accurate prediction of their ME_m in such areas.

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