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Comparative efficacy of passive and mechanical fan-pad cooling system for microclimate modification and welfare in broiler production

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ABSTRACT

Efficacy of passive cooling vis-à-vis mechanical fan-pad cooling system was assessed for microclimate modification to alleviate heat stress and improving growth performance and welfare of broilers. Cooling treatments comprised of T_c (control without any cooling system), T_{JSC} passive cooling (jute sheet roof shading and curtains with gravity flow sprinklers), T_{GSC} passive cooling (green sheet roof shadings and curtains with gravity flow sprinklers) and T_{FP} (fan pad mechanical cooling systems). The results of shed microclimate indicated that maximum ambient temperature, temperature humidity index (THI) and duration and level of heat stress in control were significantly higher than passive (T_{JSC} and T_{GSC}) and mechanical (T_{FP}) cooling group. Growth performance and feed efficiency, in both passive (T_{JSC} and T_{GSC}) and mechanical cooling (T_{FP}) were significantly better than control. However, growth performance and feed efficiency of chicks was significantly higher in T_{FP} than chicks in passive (T_{JSC} and T_{GSC}) cooling groups. In passive cooling systems (T_{JSC} and T_{GSC}), the plasma catalase, glutathione peroxidase (GP_x) and BUN were significantly lower than control (T_c) but significantly higher than mechanical cooling (T_{FP}) system. The stress related behavioural activities, panting, preening, scratching and wing flapping were significantly higher in control as than in cooling system. It was concluded that passive cooling system can be an environment friendly and energy independent alternate to intensive mechanical cooling system to reduce heat stress and improve growth and welfare in broiler production.

Key words: Broiler welfare, Heat stress, Mechanical cooling, Microclimate modification, Passive cooling

Broiler is a fastest growing livestock sector with a cumulative growth of 12.39% between 2007 to 2013 (Anonymous 2012). But India being a tropical country (21.7679° N and 78.8718° E), heat stress is a major problem for sustainable growth of broiler production in India. Broilers are more vulnerable to heat stress as their core body temperature (41°C) is closer to upper critical temperature, lack of sweat glands, high metabolic heat production and thick plumage cover, therefore microclimate modification to reduce heat stress is quite indispensible for efficient broiler production. However, mechanical cooling strategies, viz. fan pad, fan fogger and tunnel ventilation systems have been effectively utilized (Bayraktar *et al.* 2004, Petek *et al.* 2013, Gupta *et al.* 2014) to modify microclimate in broiler sheds but high initial cost, inadequate and interrupted power supply during peak summer season (Kamal 2012) and environmental pollution in energy generation (IPCC 2014) are some major constraints in installation and operating mechanical cooling systems in Indian conditions.

In such situations, passive cooling strategies, aimed at reduction and modification of heat gain and removal of internal heat through natural means of minimizing thermal heat gain (Geetha and Velraj 2012) can be alternative to costly energy intensive mechanical cooling systems for broiler production, especially in rural areas during hot season.

Therefore, in view of above discussed problems and prospectus present study was planned to assess the efficacy of passive vis-à-vis mechanical cooling strategies for microclimate modification to minimize heat stress and improving growth and welfare of broilers.

MATERIALS AND METHODS

Experimental details: This study was conducted on 480 commercial Vencobb broiler chicks during May-June 2014, reared on deep litter system under standard management practices in open sided broiler sheds (12 × 10 square feet) with monitor type asbestos sheet roofing at Poultry Research Farm, Department of Livestock Production Management. From third week onwards, broiler chicks were subjected to different cooling treatments installed in sheds. Cooling treatments comprised of T_c (control), without any cooling system. T_{JSC} passive cooling, with jute sheet roof shading

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and curtains attached with gravity flow sprinklers; T_{GSC} passive cooling, with polystyrene green net roof shading with 75% solar reflectance and curtains with 50% solar reflectance attached with gravity flow sprinklers. The roof shadings were fixed at 1 foot above the roof and curtains were fixed with 0.5 inch diameter PVC water pipe line installed at both the open sides of shade. This PVC pipe line having pores at the distance of 1 inch was connected with overhead water tank. The water circulation rate through pipes was controlled by a manually operated valve attached with water pipeline. Whereas, T_{FP}, fan pad mechanical cooling, consisted of cellulose pads made up of cellulose paper haised in GI casing with a water distributor through a PVC header. The intricately woven cellulose pads were efficient to provide necessary amount of water to achieve maximum cooling of air coming in contact. The evaporative pads were placed at one end of the shed and exhaust fan of 24 inch dimension at the opposite end. The water was pumped to the pads through a pump and the pad was kept wet. The crossing air with the wind velocity of 0.5–0.7 m/s through the system cooled the shelter. The entire experimental period was divided into 3 phases namely starter (0–2 weeks), grower (3–4 weeks) and finisher (5–6 weeks). The starter, grower and finisher rations were formulated to contain 22, 20 and 18% crude protein and 2,896, 2,932 and 2,979 Kcal ME/Kg, respectively. The feed and water was available *ad libitum* to chicks.

Observations: The shed microclimate was assessed with dry and wet bulb mercury thermometer and minimum and maximum alcohol thermometer installed in each broiler shed at 0.5 feet above the ground level. While to assess the macroclimate outside of the shed, thermometers were installed at around 6 feet above the ground level in open to ensure no hindrance to wind. In order to assess diurnal variation in shed microclimate, dry bulb and wet bulb temperature were recorded seven times in a day at 6:00, 9:00, 12:00, 15:00, 18:00, 21:00 and 24:00 IST. The data of dry and wet bulb temperature was used to determine temperature-humidity index (THI) and relative humidity of shed. Temperature and humidity index (THI) in each group was calculated by using the formula as mentioned under (Tao and Xin 2003)

$$THI_{broilers} = 0.85\ T_{db} + 0.15\ T_{wb}$$

where, T_{db}, dry bulb temperature; T_{wb}, wet bulb temperature. Relative humidity (%) was determined with the help of psychometric chart for a set of dry and wet bulb temperature. THI value was classified for qualitative characterization of shed microclimate on the basis of following table.

THI	Stress level
Up to 70	No stress
75 – 80	Mild stress
80 – 85	Moderate stress
>85	Severe stress

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The weekly feed intake and body weight of chicks were recorded to assess the growth performance of broilers. Broilers' welfare was assessed on the basis of heat stress related behavioural activities and serum biochemical changes. The behavioural response to heat stress of the birds was recorded using handy cam video recorder using instantaneous focal sampling technique. The behaviour activities of 4 birds/replicate were recorded for 10 min for 3 times a week between 14.00–15.00 IST from 3–6 weeks of age. Six (3 male + 3 female) after fourth and sixth week age from each treatment were randomly picked up to collect blood samples to assess the biochemical changes in response to heat stress. Blood samples were drawn from wing vein with sterilized syringe in to test tube having anticoagulant. Blood samples were centrifuged at 3,000 rpm for 10 min to separate plasma, which was stored at –20°C for further analysis of total protein, glucose, albumin, cholesterol, blood urea nitrogen, immunoglobulin, catalase and glutathione peroxidase.

The data were subjected to two way analysis of variance (ANOVA), using SPSS 16 software to assess efficacy of cooling system in relation to age of birds for microclimatic modification and broiler welfare. The means were compared for statistical significance difference at 5% level by Tukey's pair wise comparison.

RESULTS AND DISCUSSION

Shed microclimate: The data on diurnal variation in microclimate indicate that ambient temperature (Table 1) in different sheds gradually increased from 6:00 to 15:00 IST and subsequently decreased from 15:00 to 24:00 IST. At 6:00, 9:00 and 24:00 IST, ambient temperature of sheds among control T_c, passive cooling (T_{JSC} and T_{GSC}) and mechanical cooling (T_{FP}) groups did not differ significantly. In comparison to control, maximum temperature recorded at 15:00 IST was significantly ($P \leq 0.05$) lower in both the passive cooling (T_{JSC} and T_{GSC}) and mechanical cooling (T_{FP}) groups during different phases of experiment. The data of maximum and minimum ambient temperature presented in Table 2 indicated that average maximum ambient temperature of sheds during different phases in control, T_{JSC}, T_{GSC} and T_{FP} ranged from 35.42 to 42.29°C, 32.73 to 34.69°C, 32.69 to 35.21°C and 30.95 to 33.53°C, respectively. Maximum ambient temperature of shed during the entire experimental period in T_{JSC}, T_{GSC} and T_{FP}, respectively, was 2.69 to 6.57°C, 2.73 to 6.08°C and 4.47 to 7.70°C lower than the control group (T_C).

The data on diurnal variation in shed THI (Table 3) showed gradual increase in temperature humidity index (THI) from 6:00 to 15:00 IST and subsequent gradual decrease from 15:00 to 24:00 IST. During different phases, maximum THI recorded at 15:00 IST ranged 83.98 to 86.43 in control (T_c) was significantly ($P \leq 0.05$) higher than passive cooling treatments (81.29 to 83.91 in T_{JSC} and 81.12 to 83.00 in T_{GSC}) followed by 78.96 to 82.21 in T_{FP} mechanical cooling treatment. The qualitative characterization of THI

Table 1. Diurnal variation in ambient temperature (ºC) of broiler sheds under different cooling treatments

Time (IST)	Treatment	Growth phases (Age in weeks) Phase I (3–4 week)	Phase II (5–6 week)
6:00	Macro climate	30.13±0.72	27.68±0.63
	T_C	30.81^{abc}±0.56	27.84^{a}±0.42
	T_{JSC}	31.25^{abc}±0.56	27.76^{a}±0.38
	T_{GSC}	31.21^{ab}±0.49	27.89^{a}±0.39
	T_{FP}	30.53^{a}±0.41	27.78^{a}±0.30
9:00	Macro climate	33.38±0.69	32.31±0.34
	T_C	32.27^{abcd}±0.70	30.44^{cdef}±0.82
	T_{JSC}	31.11^{ab}±0.55	30.36^{cdef}±0.37
	T_{GSC}	31.60^{abcd}±0.46	30.49^{cdef}±0.83
	T_{FP}	31.25^{abc}±0.72	29.78^{abc}±0.38
12:00	Macro climate	39.91±1.13	34.64±0.83
	T_C	34.67^{ef}±1.44	33.10^{h}±0.83
	T_{JSC}	$34.10^{ab\ c}$±0.46	32.03^{fghi}±0.81
	T_{GSC}	34.17^{def}±0.48	31.99^{ghi}±0.65
	T_{FP}	33.38^{bcde}±0.99	29.14^{cdef}±0.79
15:00	Macro climate	43.36±1.24	37.80±0.76
	T_C	41.14^{g}±0.67	35.00^{i}±0.92
	T_{JSC}	34.60^{abcd}±0.58	31.97^{hi}±0.65
	T_{GSC}	35.14^{ef}±0.64	32.71^{hi}±0.29
	T_{FP}	33.88^{cde}±0.62	30.87^{defg}±0.57
18:00	Macro climate	39.19±0.34	34.22±0.43
	T_C	38.03^{g}±0.64	32.80^{hi}±0.86
	T_{JSC}	33.50^{abc}±0.49	32.68^{defg}±0.29
	T_{GSC}	33.81^{cde}±0.69	31.85^{efgh}±0.45
	T_{FP}	33.14^{abcd}±0.89	30.30^{bcde}±0.45
21:00	Macro climate	34.46±0.61	31.23±0.27
	T_C	36.01^{fg}±0.60	30.15^{cde}±0.69
	T_{JSC}	31.88^{abcd}±0.48	31.78^{defg}±0.44
	T_{GSC}	32.96^{bcde}±0.65	31.56^{cdef}±0.64
	T_{FP}	32.00^{abc}±0.90	29.64^{abc}±0.44
24:00	Macro climate	31.14±0.81	30.42±0.24
	T_C	32.36^{bcde}±1.22	30.11^{ab}±0.48
	T_{JSC}	31.03^{a}±0.58	30.31^{ab}±0.42
	T_{GSC}	31.46^{abc}±0.54	30.56^{ab}±0.64
	T_{FP}	31.17^{ab}±1.11	28.99^{a}±0.45

Means with different superscripts across rows or columns differ significantly (P<0.05).

Table 3. Temperature humidity index (THI) of broiler sheds under different cooling treatments

Time (IST)	Treatment	Growth phase (Age in weeks) Phase-I (3–4 week)	Phase-II (5–6 week)
6: 00	Macro climate	82.05±0.83	75.38±0.23
	T_C	80.29^{ab}±0.51	75.34^{abc}±0.80
	T_{JSC}	80.20^{ab}±0.62	74.27^{ab}±0.38
	T_{GSC}	80.49^{ab}±0.58	74.43^{ab}±0.40
	T_{FP}	80.42^{ab}±0.58	73.72^{a}±0.38
9: 00	Macro climate	84.27±1.16	82.96±0.52
	T_C	81.74^{abcd}±0.82	79.78^{fgh}±0.80
	T_{JSC}	81.43^{ab}±0.78	78.63^{defg}±0.78
	T_{GSC}	81.94^{abcd}±0.78	78.80^{efg}±0.80
	T_{FP}	80.97^{abc}±0.58	76.01^{abcde}±0.76
12: 00	Macro climate	96.55±0.88	89.65±0.61
	T_C	86.47^{ef}±1.29	83.93^{i}±0.81
	T_{JSC}	83.00^{abc}±0.85	81.12^{ghi}±0.58
	T_{GSC}	83.91^{def}±0.61	81.29^{ghi}±0.59
	T_{FP}	81.32^{bcde}±0.45	77.87^{cdef}±0.48
15: 00	Macro climate	105.43±1.01	93.71±0.76
	T_C	92.18^{g}±0.58	87.26^{j}±0.77
	T_{JSC}	84.44^{abcd}±1.01	82.43^{hi}±0.25
	T_{GSC}	84.58^{ef}±0.58	82.59^{hi}±0.29
	T_{FP}	82.21^{cde}±0.58	78.96^{fg}±0.40
18: 00	Macro climate	98.95±1.07	88.45±0.94
	T_C	91.18^{g}±1.10	83.85^{i}±0.62
	T_{JSC}	82.51^{abc}±0.83	81.08^{ghi}±0.39
	T_{GSC}	83.40^{cde}±0.42	81.24^{ghi}±0.41
	T_{FP}	81.05^{abcde}±0.52	77.801^{bcdef}±0.43
21: 00	Macro climate	89.11±1.08	80.00±0.36
	T_C	88.92^{fg}±0.58	79.45^{fg}±0.48
	T_{JSC}	81.65^{abcd}±0.60	78.95^{fg}±0.57
	T_{GSC}	82.97^{bcde}±0.66	79.12^{fg}±0.61
	T_{FP}	80.61^{abc}±1.15	75.84^{abcd}±0.45
24: 00	Macro climate	82.52±0.35	76.34±0.41
	T_C	82.27^{bcde}±1.12	75.99^{abcde}±0.37
	T_{JSC}	80.65^{ab}±0.84	74.69^{ab}±0.38
	T_{GSC}	80.43^{ab}±0.93	74.86^{ab}±0.40
	T_{FP}	79.70^{a}±0.88	73.56^{a}±0.30

Means with different superscripts across rows or columns differ significantly (P<0.05).

Table 2. Maximum and minimum temperature (ºC) of broiler sheds under different cooling treatments

Week		Macroclimate	T_C	T_{JSC}	T_{GSC}	T_{FP}
Phase I	Max.	43.58±1.35	41.29^{c}±1.26	34.69^{b}±1.63	35.21^{b}±1.10	33.53^{a}±1.31
(3–4 weeks)	Min.	28.25±0.28	28.36±0.44	28.34±0.19	28.44±0.51	28.00±0.61
Phase II	Max.	38.67±0.72	35.42^{c}±0.57	32.73^{b}±0.49	32.69^{b}±0.83	30.95^{a}±0.28
(5–6 weeks)	Min.	26.00±0.53	26. 18±0.28	26.14±0.51	26.00±0.39	26.00±0.68

Means with different superscripts in a row differ significantly (P<0.05).

level indicated that broiler chicks in control (T_C) experienced severe heat stress for maximum duration, whereas chicks in passive (T_{JSC} and T_{GSC}) and mechanical cooling groups never experienced severe heat stress. The maximum shed temperature in T_C, T_{JSC}, T_{GSC} and T_{FP} treatment groups, respectively, were 2.29–3.25°C, 5.94–8.89°C, 5.98–8.37°C and 7.72–10.05°C lower than environmental temperature. Similarly, Xin *et al.* (1994) and Dagtekin *et al.* (2009) in fan pad evaporative cooling system reported a decrease in shed temperature by 7–8°C and 9°C, respectively. These findings of sheds ambient temperature and THI reveals that along with fan pad cooling systems, passive (T_{JSC} and T_{GSC}) cooling strategies were also effective in reducing duration and severity of heat stress to broilers.

Growth performance: The data on growth performance (Table 4) indicate that final body weight, body weight gain, feed conversion ratio (FCR), protein efficiency ratio (PER) and energy efficiency ratio (EER) of chicks in both passive (T_{JSC} and T_{GSC}) and mechanical cooling (T_{FP}) were significantly higher than control (T_c). However, there was no significant ($P \leq 0.05$) difference in final body weight, FCR, PER and EER of chicks between passive (T_{JSC} and T_{GSC}) and mechanical (T_{FP}) cooling treatments. However, chicks in T_{FP} had significantly ($P \leq 0.05$) higher body weight gain, than chicks in passive (T_{JSC} and T_{GSC}) cooling groups (Table 5). Better growth performance of broiler chicks in passive and mechanical cooling groups could be attributed to better nutrient utilization (Bonnet *et al.* 1997) as indicated by significantly better FCR, PER and EER due to lower heat stress (Purswell *et al.* 2012).

Table 4. Qualitative characterization of microclimate of broiler sheds under different cooling treatments

Level of stress	Treatment	Growth phase (Age in weeks)	
		Phase-I (3–4 week)	Phase-II (5–6 week)
Severe stress	T_C	50.00±1.24	28.50±1.75
	T_{JSC}	00	00
	T_{GSC}	00	00
	T_{FP}	00	00
Moderate stress	T_C	42.86^a±1.75	28.50^a±1.31
	T_{JSC}	78.50^b±3.74	42.85^b±2.71
	T_{GSC}	92.85^c±4.35	42.85^b±2.34
	T_{FP}	71.40^b±2.53	00
Mild stress	T_C	7.14^a±0.24	28.50^a±0.98
	T_{JSC}	21.42^b±1.23	35.71^b±1.19
	T_{GSC}	7.14^a±0.53	42.85^c±2.75
	T_{FP}	28.51^c±1.63	64.28^d±3.52
No stress	T_C	00	14.28^a±0.57
	T_{JSC}	00	21.42^b±0.94
	T_{GSC}	00	14.28^a±0.48
	T_{FP}	00	35.71^c±2.59

Means with different superscripts across rows or columns differ significantly ($P<0.05$).

Table 5. Growth performance of broilers under different cooling treatments

Parameters	Treatment	Growth phase (Age in weeks)	
		Phase-I (3–4 week)	Phase-II (5–6 week)
Average body weight (g)	T_C	771.69^a±13.75	1319 .39^a±20.59
	T_{JSC}	858.21 ^{b}±22.86	1457.90^b±34.65
	T_{GSC}	864.52 ^{b}±12.66	1431.90^{ab}±5.85
	T_{FP}	877.36 ^{b}±12.52	1524.57^b±42.06
Average body weight gain (g)	T_C	500.25^a±9.55	547.70^a±20.10
	T_{JSC}	593.21^b±13.85	599.69^b±6.10
	T_{GSC}	592.12^b±7.49	567.38^{ab}±5.74
	T_{FP}	609.36^c±7.12	646.21^c±15.65
Feed conversion ratio (FCR)	T_C	2.10^b±0.10	2.71^b±0.25
	T_{JSC}	1.92^{ab}±0.08	2.41^a±0.15
	T_{GSC}	1.87^a±0.09	2.53^{ab}±0.12
	T_{FP}	1.80^a±0.07	2.35^a±0.16
Protein efficiency ratio (PER)	T_C	2.56^b±0.17	2.26^c±0.10
	T_{JSC}	2.37^a±0.11	2.04^a±0.10
	T_{GSC}	2.39^a±0.09	2.03^{ab}±0.05
	T_{FP}	2.31^a±0.13	2.00^a±0.14
Energy efficiency ratio (EER)	T_C	6.16^b±0.29	8.09^b±0.60
	T_{JSC}	5.63^a±0.24	7.65^a±0.52
	T_{GSC}	5.51^a±0.17	7.82^{ab}±0.14
	T_{FP}	5.35^a±0.25	7.30^a±0.49

Means with different superscripts in column differ significantly ($P<0.05$).

Broiler behaviour: The data on broiler behavior (Table 6) indicated that average feeding and resting time of chicks in control (T_C) were significantly ($P \leq 0.05$) lower and duration of panting, scratching and wing flapping activities were significantly ($P \leq 0.05$) higher than chicks in passive cooling (T_{JSC} and T_{GSC}) and T_{FP} mechanical cooling groups. Over the period, feeding time significantly ($P \leq 0.05$) decreased with increase in age of chicks. Gupta (2012) and Mack *et al.* (2013) observed that birds subjected to heat stress conditions spend less time feeding, more time drinking and panting, as well as more time with their wings elevated, less time moving or walking, and more time resting. In present study, results of decreased feeding time and increased panting, scratching and wing flapping showed that heat stress in birds increased with age. During different phases, broiler chicks in passive cooling (T_{JSC} and T_{GSC}) and mechanical cooling (T_{FP}) groups experienced less heat stress than control (T_C). Therefore, broiler chicks in control group consumed less feed to reduce metabolic heat production and showed panting, scratching and wing flapping activities to increase evaporating cooling to alleviate heat stress.

Biochemical changes: The results of biochemical changes (Table 7) indicated that plasma glucose, cholesterol, albumin, total protein and total immunoglobulin at fourth and sixth week of age among different treatment groups did not vary significantly ($P \leq 0.05$) and were within normal physiological range. However, BUN in control (T_C) group was significantly ($P \leq 0.05$) higher than passive (T_{JSC} and T_{GSC}) and mechanical (T_{FP}) cooling groups at fourth and

Table 6. Percent duration of time for different behavioural activities by birds under different cooling treatments

Percent duration	Treatment	Age			
		3rd week	4th week	5th week	6th week
Feeding	T_C	$9.76^{aB}\pm3.30$	$10.96^{aB}\pm1.80$	$4.66^{aA}\pm2.56$	$3.98^{aA}\pm1.27$
	T_{JSC}	$43.43^{bB}\pm9.70$	$39.33^{bB}\pm5.82$	$21.70^{bcA}\pm5.85$	$17.50^{cA}\pm3.16$
	T_{GSC}	$38.76^{abC}\pm10.37$	$33.46^{abC}\pm7.15$	$19.50^{bB}\pm4.61$	$12.30^{bA}\pm2.16$
	T_{FP}	$43.26^{bB}\pm10.36$	$41.46^{bB}\pm10.36$	$24.66^{cA}\pm6.76$	$19.66^{cA}\pm1.56$
Resting	T_C	$9.78^{aB}\pm3.88$	$5.22^{aA}\pm2.19$	0.00	0.00
	T_{JSC}	$51.33^{bD}\pm9.51$	$38.29^{bC}\pm9.51$	$21.04^{bB}\pm5.92$	$13.01^{bA}\pm2.31$
	T_{GSC}	$52.32^{bD}\pm8.78$	$36.80^{bC}\pm9.27$	$15.16^{aB}\pm6.21$	$9.16^{aA}\pm1.14$
	T_{FP}	$50.29^{bD}\pm9.05$	$37.17^{bC}\pm9.05$	$22.12^{bB}\pm6.52$	$15.12^{bA}\pm2.82$
Drinking	T_C	$8.33^{B}\pm3.20$	$6.03^{A}\pm0.90$	$8.87^{bB}\pm2.92$	$8.96^{bB}\pm1.39$
	T_{JSC}	4.17 ± 2.35	5.27 ± 2.19	$6.22^{ab}\pm2.87$	$6.02^{ab}\pm0.92$
	T_{GSC}	6.56 ± 2.83	7.26 ± 1.46	$8.10^{b}\pm2.80$	$8.30^{b}\pm0.71$
	T_{FP}	5.72 ± 2.82	6.42 ± 2.82	$5.33^{a}\pm3.20$	$5.33^{a}\pm1.05$
Panting	T_C	$64.71^{b}\pm5.16$	$65.03^{b}\pm3.24$	$66.19^{b}\pm3.64$	$66.81^{b}\pm4.84$
	T_{JSC}	0.00	$13.54^{aA}\pm0.38$	$43.86^{aB}\pm1.11$	$54.02^{aC}\pm2.46$
	T_{GSC}	0.00	$16.44^{aA}\pm0.46$	$45.94^{aB}\pm3.21$	$59.00^{abC}\pm3.27$
	T_{FP}	0.00	$12.43^{aA}\pm0.27$	$41.34^{aB}\pm2.11$	$53.07^{aC}\pm4.18$
Wing flapping	T_C	$3.26^{bA}\pm0.68$	$5.64^{bB}\pm0.61$	$6.72^{bB}\pm0.39$	$6.23^{bB}\pm0.25$
	T_{JSC}	$0.58^{aA}\pm0.26$	$1.10^{aB}\pm0.35$	$3.36^{aC}\pm0.28$	$3.13^{aC}\pm0.35$
	T_{GSC}	$0.98^{aA}\pm0.47$	$1.90^{aB}\pm0.39$	$4.98^{abC}\pm0.43$	$4.87^{abC}\pm0.66$
	T_{FP}	$0.35^{aA}\pm0.14$	$1.20^{aB}\pm0.26$	$2.67^{aC}\pm0.53$	$2.86^{aC}\pm0.17$
Head and litter scratching	T_C	$2.34^{bA}\pm0.45$	$4.84^{bB}\pm0.58$	$6.29^{bC}\pm0.76$	$6.34^{bC}\pm0.32$
	T_{JSC}	$0.48^{aA}\pm0.10$	$1.46^{aB}\pm0.21$	$3.21^{aC}\pm0.34$	$3.54^{aC}\pm0.65$
	T_{GSC}	$0.86^{aA}\pm0.26$	$2.12^{aB}\pm0.45$	$4.24^{abC}\pm0.19$	$4.29^{abC}\pm0.26$
	T_{FP}	$0.38^{aA}\pm0.09$	$1.35^{aB}\pm0.19$	$2.70^{aC}\pm0.64$	$2.98^{aC}\pm0.18$
Preening	T_C	$2.08^{bA}\pm4.86$	$2.08^{bA}\pm1.38$	$7.27^{bB}\pm2.85$	$7.68^{bB}\pm1.34$
	T_{JSC}	0.00	0.00	$1.44^{aB}\pm1.04$	$1.04^{aB}\pm0.18$
	T_{GSC}	$0.52^{aA}\pm1.80$	$1.62^{aB}\pm0.73$	$2.08^{aC}\pm1.45$	$2.08^{aC}\pm0.55$
	T_{FP}	0.00	0.00	$1.28^{aB}\pm1.42$	$1.08^{aB}\pm0.62$

Means with different superscripts across rows and column differ significantly (P<0.05).

sixth weeks of age. This higher blood urea nitrogen (BUN) concentration of chicks in control (T_C) group could be due to higher rate of gluconeogensis, involving conversion of plasma protein in glucose and depressed kidney function in heat stressed broiler chicks. The plasma catalase, indicating muscle and tissue catabolism (Altan *et al.* 2003) and glutathione peroxidase (GP_X), indicating lipid per oxidation of cell membrane (Lin *et al.* 2010), levels in

Table 7. Biochemical changes in broilers under different cooling treatments

Parameters	Treatment	Growth phase (Age in weeks)	
		Phase-I (3–4 week)	Phase-II (5–6 week)
Glucose (mg/dl)	T_C	106.50±0.86	107.50±2.25
	T_{JSC}	106.25±0.85	107.00±2.16
	T_{GSC}	119.50±7.93	107.50±3.09
	T_{FP}	108.00±1.77	108.25±1.49
Cholesterol (mg/dl)	T_C	180.50±11.67	190.75±17.35
	T_{JSC}	198.50±10.26	176.75±12.73
	T_{GSC}	164.25±15.84	154.50±7.81
	T_{FP}	196.25±13.21	154.25 14.34
Albumin (g/dl)	T_C	1.52±0.33	1.80±0.17
	T_{JSC}	1.85±0.12	1.92±0.08
	T_{GSC}	1.90±0.09	1.95±0.20
	T_{FP}	1.80±0.18	2.00±0.10
Protein (g/dl)	T_C	4.55±1.03	5.87±0.25
	T_{JSC}	4. 80±0.25	6.12±0.12
	T_{GSC}	3.80±0.27	6.12±0.10
	T_{FP}	4.70±0.94	6.30±0.12

(*Contd.*)

(*Table 7 continued*)

Parameters	Treatment	Growth phase (Age in weeks)	
		Phase-I (3–4 week)	Phase-II (5–6 week)
BUN (mg/dl)	T_C	$59.65^{b}\pm5.82$	$58.51^{b}\pm4.34$
	T_{JSC}	$40.59^{a}\pm6.78$	$25.75^{a}\pm3.32$
	T_{GSC}	$33.08^{a}\pm3.86$	$23.51^{a}\pm3.47$
	T_{FP}	$32.64^{a}\pm2.87$	$20.15^{a}\pm2.17$
Immunoglobulin (g/dl)	T_C	1.92±0.08	1.96±0.10
	T_{JSC}	1.83±0.09	1.84±0.03
	T_{GSC}	1.97±0.07	1.97±0.11
	T_{FP}	1.66±0.05	1.63±0.03
Catalase (µmole H_2O_2 decomposed/ mm/g Hb)	T_C	$7.25^{c}\pm0.12$	$7.39^{d}\pm0.08$
	T_{JSC}	$6.02^{b}\pm0.11$	$6.25^{b}\pm0.13$
	T_{GSC}	$6.18^{b}\pm0.19$	$6.82^{c}\pm0.10$
	T_{FP}	$2.64^{a}\pm0.12$	$3.24^{a}\pm0.11$
Gpx (u/g Hb)	T_C	$0.95^{b}\pm0.065$	$0.98^{b}\pm0.02$
	T_{JSC}	$0.94^{b}\pm0.08$	$0.94^{ab}\pm0.02$
	T_{GSC}	$0.91^{b}\pm0.011$	$0.96^{b}\pm0.021$
	T_{FP}	$0.85^{a}\pm0.015$	$0.90^{a}\pm0.012$

Means with different superscripts in a column differ significantly (P<0.05).

control (T_C) group were significantly ($P \leq 0.05$) higher than the passive cooling (T_{JSC} and T_{GSC}) and mechanical cooling (T_{FP}) groups. Similarly, Gupta *et al.* (2014) also reported significant production of catalase (CAT) and glutathione peroxidase (GP_x) and malondialdehybe (MDA) in heat stressed broiler chicks.

From these findings, it can be concluded that passive cooling strategies can be an alternate to mechanical cooling system to modify shed microclimate to reduce heat stress, improve growth performance and welfare of broilers.

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