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1 author:

Michael F. Rowe
Dillard University

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*Corresponding author

Michael F Rowe, Assistant Professor of Biology, School of STEM Biology-Program, Dillard University, 2601 Gentilly Blvd, New Orleans, La. 70122, USA

Email: mrowe@dillard.edu

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Effect of Shell Cover Color on Solar Absorptance and Environmental Heating of Cricket Helmets: A Pilot Study

Rowe MF* and Thomas DNO

School of STEM Biology-Program, Dillard University, New Orleans, La. 70122, USA

Abstract

The objective of this pilot study was to quantify and describe the effect of shell cover color on solar absorptance, α_l (%; mean ± SD) and the temperature of the cricket helmet shell covers, T_{hsc} (°C; mean ± SD) during exposure to a hot outdoor environment (WBGT 32.5 ± 1.9 °C; ACSM Heat Index Black; Extreme Danger STOP). We measured and recorded α_l in yellow, red and black cricket helmets using a micro-solarimeter. Thermographic imaging was used to quantify differential T_{hsc}. Variations in shell cover color had a statistically significant (p<0.0002) 2-fold effect on α_l. At the end of 30-minute trials, variations in color and α_l resulted in 3.6 to 6.0 °C difference in T_{hsc} between helmets. Although speculative, the color of cricket helmet shell covers may have a functionally significant effect of exertional heat illnesses, EHIs (ranging from dehydration to heat stroke). Incorporating reflective nanocomposites particles into the material used in the construction of the Lycra® shell covers and XENOY™ shells may facilitate passive cooling of cricket helmets and ultimately reduce EHIs.

Abbreviations: ACSM: American College of Sports Medicine; α_l: Solar Absorptance (%); E: Evaporative Heat Loss in units watts (W); EHIs: Exertional Heat Illnesses; H_d: Total Dry Heat Loss (Radiative + Convective) in units watts (W); H_e: Total Evaporative Heat Loss in units watts (W); NIR: Near Infrared Radiation; R: Longwave Thermal Radiation; ρ_l: Solar Reflectance (%); S: Shortwave Solar Radiation; T_a: Ambient Air Temperature (°C); T_b: Core Body Temperature (°C); T_{br}: Brain Temperature (°C); T_{es}: External Shell Temperature of Football Helmets (°C); T_{hsc}: Helmet Shell Cover Temperature (°C); T_{is}: Internal Shell Temperature of Football Helmets (°C); λ: Wavelength (nm); WBGT: Wet-Bulb Globe Temperature (°C)

Introduction

The transfer of radiative, convective, and evaporative heat from the head plays an important thermoregulatory function in active athletes [1-4]. Athletic helmets are designed to protect the head from impact injuries. However, the combination of a rigid plastic (e.g., polycarbonate, polypropylene, carbon-fiber reinforced polymer, or XENOY™ composite) shell and one or more layers of foam padding restricts heat transfers from the head to the ambient environment. Therefore, wearing cricket helmets can constrain heat loss from the head, and may contribute to athletes susceptible to Exertional Heat Illnesses (EHIs) ranging from dehydration to heat stroke [5-9]. An enhanced understanding of the effect cricket helmets may have on athletes' capacity to thermoregulate are warranted, particularly during a period of climate change and extreme weather events.

It is challenging to study the thermoregulatory constraints of athletic helmets on active athletes in a hot outdoor environment. Laboratory experiments (using heated thermal manikins in climate controlled environmental rooms or computer modeling) to simulate the head temperature active cricket athletes exposed to a wide range of ambient air temperatures, T_a (°C) have provided important data [10-14]. Cricket helmets do create resistance to the transfer of heat (i.e., longwave thermal radiation, R; Appendix I and evaporative heat loss, E) from the head to the surrounding ambient environment, and resistance to heat loss was dependent on T_a of the environmental chamber [14]. The resistance to R and E caused the temperature of the thermal manikins to increase rapidly immediately after helmets were secured, and the level of resistance to heat transfers were dependent on T_a of the environmental room [10-13]. At the end of the experimental trials, an ~ 50% reduction in dry total heat loss, H_d (W; radiative + convective heat loss) and depending on helmet type and ventilation, an ~ 19% to 55% reduction in total evaporative heat loss, H_e (W) was recorded [11,12,14].

Appendix I: Approximate wavelengths, λ (nm), of shortwave solar, S, near infrared, NIR and longwave thermal radiation, R [1].

Atmospheric Electromagnetic Radiation	Wavelength, λ (nm)
Shortwave Solar Radiation, S	~ 300-4000
Visible Light	~ 400-700
Near Infrared, NIR	~ 700-2500
Longwave Thermal Radiation, R	~ 4000-10^6

However, unlike laboratory conditions, when outdoors in full sun cricket players are also exposed shortwave solar radiation, S, from the atmosphere in the form of visible light and near infrared, NIR wavelengths, λ (nm; Appendix I). Unlike the transfer of R from the head to the shell and on to the environment [1,11,12], the absorption of S and NIR by athletic helmets is influenced by the color of the helmet shell [1,15,16]. For example, the color of white, red, or black American football helmets had a statistically significant (One-Way ANOVA; DF = 2; p < 0.001) ~ 2-fold effect on solar absorptance, α_l (%) the fraction of S absorbed by the helmet shell [1,15]. After ~ 30 minutes of exposure to a dangerously hot outdoor environment (mean WBGT 34.3 ± 1.1 °C; ACSM Heat Index Black; Extreme Danger Stop Play) the temperature of both the exterior shell surface, T_{es} (°C) and interior shell surface, T_{is} (°C) of the red and black polycarbonate helmets were ~ 53 and 59 °C, respectively. On the contrary T_{is} and T_{es} of white helmets, ~ 38 °C, remained close to core body temperature, T_b (°C). It has been proposed that hotter temperatures of red or black helmets may make some American football athletes more susceptible the early onset of EHIs than those wearing white helmets [16]. A similar relationship may exist in cricket helmets.

The shell of cricket helmets generally differ from those of football helmets in that they have an additional layer, the shell cover, which is constructed of fabric containing Lycra®. The goal of this pilot study was to determine whether variations in the color of (yellow, red, or black) cricket helmet shell covers (Figure 1a) had a statistically significant ($p < 0.05$) effect on α_l (Figure 2) and the temperature of the helmet shell covers T_{hsc} (°C; Figure 1b & 3). To achieve this goal, we had two specific objectives. Firstly, we used a micro-solarimeter to quantify α_l in cricket helmets (Figure 2) during exposure to mid-day sun [15-17]. Secondly, we used thermographic imaging techniques (Figure 1b) to quantify T_{hsc} (Figure 3) in cricket helmets [18]. We discuss our results in cricket helmets with our previously reported results in football helmets [15,16], and briefly describe one branch of our future research focus on passive cooling of cricket helmet shell covers and shells by incorporating reflective nanocomposites particles into materials used in their construction [19-23].

Figure 1a: Orientation of the cricket helmets to radiant heat characteristic of 1035 hr CST and environmental monitoring system used during measurements of mean (± SD) helmet shell cover temperature, T_{hsc} (°C).
Figure 1b: Thermogram showing differential mean (± SD) T_{hsc} of the superior/posterior shell cover surfaces of (L to R) black (T_{hsc} ~ 57.9 ± 11.8 °C), red (T_{hsc} ~ 53.0 ± 11.5 °C), and yellow (T_{hsc} ~ 50.4 ± 11.0) °C cricket helmets.

Figure 2: Illustrates the statistically significant (ANOVA; DF = 2; $p < 0.002$) differences in mean solar absorptance, α_l (%) between yellow (yellow solid symbol), red (red solid symbol), and black cricket (black solid symbol) shell covers. NOTE: One asterisk (*) indicates that α_l of the red shell cover was significantly (Tukey's All Pairs Comparison; $p < 0.003$) greater than α_l of the yellow shell cover. Two asterisks (**) denotes that α_l of the black shell cover was significantly (Tukey's All Pairs Comparison; $p < 0.022$) greater than α_l of both the yellow and red shell covers.

Figure 3: The positive curvilinear relationship between mean (± SD) cricket helmet shell cover temperature, T_{hsc} (°C) versus Elapse Time, t (min.), for yellow (yellow closed circled and short dashed line), red (red closed circles and long dashed line) and black shell covers (black closed circles and solid line). Second order polynomial equations describing the positive increase in T_{hsc} with increasing t (min.) in helmet shell covers are listed in Appendix I.

Methods and Material

Helmets

Three new Shrey Master Class AIR 2.0 Stainless Steel® cricket helmets were purchased directly from the manufacturer. Yellow, Red and Black helmets were chosen to compare with white, red and black Riddell Victor® youth football helmets used in our previous studies [15,16]. NOTE: No white cricket helmets were available from the manufacturer. The shell of the Shrey helmets was composed of XENOY™ (a polyester/ polycarbonate compound) and the shell covers were composed of Lycra® (Table 1). Lycra® is popular component of fabric commonly used in athletic uniforms because of its thermal properties that aid in thermoregulation [24,25].

Table 1: Mean (± SD) time of day (HHMM), and solar positions (°), recorded during measurements of solar reflectance, ρ_l (%), along with the emissivity, ε (%), of materials used in the construction of the cricket helmet shell (XENOY™) and shell cover (Lycra®). NOTE: The double dagger (††) symbol indicates statistically significant (Tukey's All Pairs Comparison; $p < 0.02$) differences in solar absorptance, α_l (%) between black and yellow, and black and red helmets. The single dagger (†) symbol indicates statistically significant (Tukey's All Pairs Comparison; $p < 0.02$) difference in α_l between red and yellow helmets. The asterisk (*) indicates emissivity values for Lycra® and XENOY™ were not measured but were assumed from published values for similar cricket helmets [14].

Shell Cover Color	Mean Time of Day (HHMM ± SD)	Mean Solar Azimuth (γ°; ± SD)	Mean Zenith Angle (θz°; ± SD)	Mean (±SD) Solar Reflectance (ρ_l %; n = 4; N = 12)	Emissivity of Lycra (ε %)	Emissivity of XENOY™ (ε %)
Yellow	1244 ± 0222	178.8 ± 83.6	39.4 ± 25.7	0.614 ± 0.09††	0.87*	0.97*
Red	1331 ± 0227	203.0 ± 60.4	25.0 ± 23.2	0.362 ± 0.06†	0.87*	0.97*
Black	1325 ± 0202	227.2 ± 38.9	23.9 ± 22.5	0.197 ± 0.02	0.87*	0.97*

Instrumentation and experimental procedures

A Swissteco® micro-solarimeter (Hawthorn. Vic. 3123 Australia) and the substitution methods developed by Hutchinson et al. [17] were used to estimate α_1 in cricket helmets (Figure 2). The superior/ posterior helmet surfaces were aligned with the Solar Azimuth and Zenith Angle (Table 1). Solar position was determined using the online NOAA solar position calculator *https://gml.noaa.gov/grad/solcalc/azel.html*. Thermal imaging was used to measure and record T_{hsc} in cricket helmets (Figure 1b & 3) using a FLIR E5 Pro® camera (Niceville, Fl. USA) and techniques described by Rowe et al. [18]. All measurements were recorded on the lawn of Dillard University, in New Orleans, Louisiana, USA (29.95° N latitude and 90.01° W longitude). To simulate environmental conditions on a cricket field, all experimental trials were carried out in full-sun exposure at a distance of ~ 30 to 50 m from any structures. Note: see [15,17,18] for detailed description of the experimental procedures. Environmental variables (Table 2) were measured and recorded using a Kestrel 5400 Heat Stress Tracker Pro (Boothwyn, PA. USA). The Kestrel 5400 was programmed to the American College of Sports Medicine (ACSM) Wet-Bulb Glob Temperature Heat Index guidelines for American football practice and competition [15]. We assume that similar guidelines should apply to the sport of cricket.

Table 2: Mean (± SD) environmental conditions measured during a total of (n = 3) simultaneously recorded experimental trials to quantify the effect of yellow, red and black shell cover color on the temperature of shell covers, T_{hsc} (°C) using thermographic imaging (Figure 3). NOTE: The double dagger (††) symbol indicates statistically significant (Tukey's All Pairs Comparison; $p < 0.009$) difference in RH (%) between Trial 1 and 2 and Trial 1 and 3.

Trial #	Time HHMM	Ambient Air Temp. (°C)	Relative Humidity (%)	Wind Speed ($m.s^{-1}$)	Globe Temp. (°C)	WBGT (°C)	ACSM Heat-Index
1	1310 - 1340	31.5 ± 1.8	44.0 ± 4.2 ††	0.00 ± 0.00	37.8 ± 10.2	33.6 ± 2.3	Black Extreme Danger STOP
2	1155 - 1225	31.2 ± 3.6	56.9 ± 5.2	0.00 ± 0.00	38.0 ± 10.1	33.7 ± 1.3	Black Extreme Danger STOP
3	1224 - 1315	33.5 ± 3.6	54.2 ± 7.2	0.00 ± 0.00	38.3 ± 1.77	30.4 ± 0.86	Black Extreme Danger STOP

Data and statistical analyses

Graphing and statistical analyses were performed using Kaleida Graph 4.5 (Synergy Software, Reading, PA. USA). One-Way ANOVA at the ($p < 0.05$) level was used to determine statistically significance.

Results

Experimental trials to measurement α_1 of shell covers lasted ~ 40 minutes in duration and were recorded between ~ 1245 to 1325 hrs. CST (Table 1). There was no statistically significant (One-Way ANOVA; DF = 2; $p > 0.24$) differences in mean Solar Azimuth, or Zenith Angle, between experimental trials (Table 1). The color of cricket helmet shell covers had a statistically significant (One-Way ANOVA; DF = 2; $p < 0.0002$) ~ 2-fold effect on α_1 of the yellow, red and black shell covers (Figure 2). The shell covers of yellow, red and black cricket helmets absorbed ~ 43.6 ± 0.10, 68.9 ± 0.06, and 85.3 ± 2.9% of S (Appendix I), respectively (Figure 2). The α_1 of the black shell cover was significantly, ~ 1.2- and 2.0-times greater than the α_1 of red and yellow shell covers, respectively. Similarly, α_1 of red shell covers was significantly, ~ 1.6-times greater than yellow shell covers (Tukey's All Pairs Comparison; $p < 0.02$).

The mean (±SD) T_{hsc} of all helmets shell cover colors recorded indoors (in the lab prior to outdoor trials) was ~ 31.8 ± 0.44 °C, and mean T_{hsc} of different colored helmets varied by < 0.1°C (Elapse Time, t = -5 min.; Figure 3). In the lab, there was no statistically significant (One-Way ANOVA; DF = 2; $p = 0.92$) difference in mean T_{hsc} between different colored helmets. Environmental conditions recorded during the T_{hsc} trials (Figure 1a & 3) were similar (Table 2). The only statistically significant (ANOVA; DF = 2; $p < 0.009$) difference between trials was relative humidity, RH (%). RH % recorded during trial 1 was significantly lower than RH (%) recorded during trial 2 and 3 (Tukey's All Pairs Comparison; $p < 0.03$).

Variations in helmet shell cover color (Figure 1a) and corresponding α_1 (Figure 2), influenced T_{hsc} (Figure 1b & 3). The T_{hsc} increased rapidly after exposure to hot outdoor conditions (Table 2). After ~ 10 minutes of exposure, the mean (± SD) T_{hsc} recorded outdoors were ~ 16.8 to 23.5 °C hotter than those recorded indoors, and the mean T_{hsc} of yellow, red, and black helmets were ~ 48.7 ± 2.5 °C, 51.2 ± 2.6, and 55.4 ± 3.6, respectively (Figure 3). It should be noted that the decrease in T_{hsc} (recorded at Elapse Time, t = 20 min. and 30 min.; Figure 3) resulted from intermittent cloud cover and not from characteristics of the materials used in construction of the helmets. Throughout the duration of the experimental trials, shell cover color had a statistically significantly (ANOVA; DF = 2; $p < 0.003$) effect on mean T_{hsc} (Figure 3). Over the course of the trials, mean T_{hsc} of the black helmet was significantly (Tukey's All Pairs Comparison; $p < 0.02$) 3.0 to 4.5 °C greater than T_{hsc} of red or yellow helmets, respectively. At the end of the experimental trials (Elapse Time, t = 30 min.; Figure 3), T_{hsc} of black helmets were ~ 3.6 to 6.0 °C hotter than the mean T_{hsc} of red and yellow helmets, respectively (Appendix II).

Appendix II: Second-order polynomial equations describing the increase in mean (± SD) helmet shell cover temperature, T_{hsc} (°C; Figure 3) with increasing Elapse Time, t (min).

Variable	Helmet Color	Second-Order Polynomial Equations	R^2
T_{hsc} (°C)	Yellow	$y = -0.027 x^2 + 0.96 x + 38.7$	0.80
	Red	$y = -0.029 x^2 + 1.07 x + 39.5$	0.78
	Black	$y = -0.038 x^2 + 1.37 x + 41.9$	0.83

Discussion

The statistically significant ($p < 0.0002$) 2.0-fold range of α_1 reported here in yellow, red and black shell covers (Figure 2), were similar to α_1 reported by Rowe & Lopez-Macias [15] in the polycarbonate shells of white, red and black football helmets, 44 ± 3.0, 61 ± 7.0 and 92 ± 2.0 %, respectively. Similarly, the statistically significant ($p < 0.003$) differences in mean T_{hsc} between yellow, red, and black cricket helmet shell covers (Figure 3) were similar to the mean (± SD) external shell temperatures, mean T_{es} of polycarbonate football helmets [15]. When exposed for the same duration to similar environmental conditions (Table 2), the mean T_{hsc} of black and red cricket helmets were ~ 4.6 to 5.9 °C cooler than mean T_{es} of similarly colored football helmets [15]. On the contrary, mean T_{hsc} of yellow cricket helmets were ~ 8.8 °C hotter than mean T_{es} of white football helmets [15]. The differences in mean T_{hsc} of cricket helmets (Figure 3) and mean T_{es} of football helmets [15] may have been influenced by three factors related the materials used in their construction. Firstly, the thermal and spectral properties of the Lycra® shell cover of cricket helmets. Secondly, the penetrance of S through the Lycra® shell cover. Thirdly, differences in the thermal and spectral characteristics of the polycarbonate versus XENOY™ shells of football and cricket helmets, respectively.

No measurements of mean internal shell temperature, T_{is} or internal T_a of cricket helmets were recorded in the present study. The Shrey Master Class AIR 2.0 cricket helmets had no visible air spaces separating the foam padding from the internal surface of the helmet shell. Therefore, it is difficult to estimate the thermoregulatory significance of variations in α_1 (Figure 2) and T_{hsc} (Figure 3) on EHI at this time [16]. Guan et al. [14] demonstrated that a portion of metabolic heat could be transfer from the head surface (36 to 38 °C) to the ambient environment when the mean T_{hsc} was equal to T_a (i.e., 35 °C). However, in an outdoor environment similar to those recorded in the current study (Table 2), the mean T_{hsc} of yellow, red, and black cricket helmets ranged from ~ 9.6, 12.8 and 16.7 °C, respectively, hotter than the T_a reported by Guan et al. [14]. Therefore, cricket athletes wearing different colored helmets, characterized by variations in α_1 (Figure 1a & 2) may experience differential susceptibility to EHIs, as reported in football athletes [16].

The survival of the sport of cricket has been brought into question due to increased frequency of EHIs and severe weather events, [26]. Innovative approaches to the design and construction of cricket helmets are needed. The addition of an internal helmet liner to shield solar radiation or use of reflective coatings to improve the thermal characteristics of industrial safety helmets was proposed over two decades ago [19]. At that time the increased mass of helmets and availability of low-cost reflective materials were prohibitive. Advances in the development and application of passive cooling of surfaces using highly reflective nanocomposite fibers [20,21,24,25] and coatings [22,23] that reduce α_1 may improve the thermal and spectral characteristics of cricket helmets, as well as football helmets. One branch of our future research will be the addition of reflective nanocomposite fibers [20,21] to cricket helmet shell covers. Theoretically, the addition of reflective nanoparticle composite fibers may reduce α_1 and T_{hsc} by enhancing the heat dissipating characteristics of Lycra® [24,25], while maintaining shell cover color. Similarly, the addition of reflective nanoparticle composites during the manufacture of XENOY™ or polycarbonate shells of cricket and football helmets, respectively, may also lower α_1 of highly absorptive helmets and ultimately reduce EHIs in athletes.

Conclusion

a. Laboratory studies of the thermal properties of cricket helmets may not fully replicate the thermal and spectral characteristics of cricket helmets exposed to a hot outdoor environment.
b. Color of cricket helmet shell covers had a significant ($p < 0.0002$) effect on mean α_1 and ($p < 0.003$) mean T_{hsc}. Although speculative, like football helmets, the color and associated variations in α_1 may influence the onset of EHIs.
c. The addition of reflective nanocomposite fibers and pigments in the design and manufacture of athletic helmets may help to reduce α_1 and T_{hsc} between different colored helmets.

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References

1. Gates DM (1980) Biophysical Ecology. Springer Verlag, New York, NY, USA, pp.12-24 & 75-344.
2. Rasch W, Sampson P, Cote J, Cabanac M (1991) Heat loss from the human head during exercise. J Appl Physiol 71(2): 590-595.
3. Brien C, Cadarette BS (2013) Quantification of head sweating during rest and exercise in the heat. Eur J Appl Physiol 113: 735-741.
4. Machado-Moreira CA, Wilmink F, Meijer A, Mekjavic IB, Taylor NAS (2008) Local differences in sweating secretion from the head during rest. Eur J Appl Physiol 104: 257-246.
5. Chathurangi A (2024) Impact of dehydration on the performance of cricket athletes in Sri Lanka: A systematic review. IRJSTEM 4(1): 82-91.
6. Gamage PJ, Fortington LV, Finch CF (2019) Risk perception for exertional heat illness in junior cricket in Sri Lanka. BMJ Open Sport Exerc Med 5(1): e000508.
7. Stay S, Cort M, Ward D, Kountouris A, Orchard J, et al. (2018) Core temperature responses in elite cricket players during Australian summer conditions. Sports 6(4): 164-171.
8. Periard JD, DeGroot D, Jay O (2022) Exertional heat stroke in sport and the military: epidemiology and mitigation. Exp Physiol 107(10): 1111-1121.
9. Singh G, Bennett KJM, Taylor L, Stevenson CJ (2023) Core body temperature responses during competitive sporting events: A narrative review. Biol Sport 40(4): 1003-1017.
10. Pang TY, Subic A, Takla M (2011) Thermal comfort of cricket helmets: an experimental study of heat distribution. Procedia Eng 13: 252-257.
11. Pang TY, Subic A, Takla M (2013) A comparative experimental study of the thermal properties of cricket helmets. Int J Ind Ergon 43(2): 161-169.
12. Pang TY, Subic A, Takla M (2014) Evaluation of thermal and evaporative resistance in cricket helmets using a sweating manikin. Appl Ergon 45(2): 300-307.
13. Pang TY, Shammas AN, Subic A, Takla M (2015) A comparative study of vent designs for effective ventilation in cricket helmets. Procedia Eng 112: 395-399.
14. Guan ZW, Dullah AR, Wang XL, Wang QY (2023) Finite element modelling of thermal and moisture mapping of layered cricket helmets. Heliyon 9(2): e13179.
15. Rowe MF, Lopez-Macias LA (2022) Heat transfer analyses of older versus modern youth football helmets: A preliminary study. MRS Adv 7(35): 1218-1224.
16. Rowe MF, Dubose TL, Thomas DNO, Durotoye DF, Johnson BP, et al. (2024) Modeling the thermoregulatory significance of differential solar absorptance in American football helmets. MRS Adv 9: 227-233.
17. Hutchinson JCD, Allan TE, Spence FB (1976) Measurement of the reflectance for solar radiation of the coats of live animals. Comp Biochem and Physio A 52(2): 343-349.
18. Rowe MF, Bakken GS, Ratliff JJ, Langman VA (2013) Heat storage in Asian elephants during submaximal exercise: behavioral regulation of thermoregulatory constraints on activity in endothermic gigantotherms. J Exp Biol 216(10): 1774-1785.
19. Hsu YL, Tai CY, Chen TC (2000) Improving thermal properties of industrial safety helmets. Int J Ind Ergon 26(1): 109-117.
20. Li Z, Zhang X, Yan L, Du H, Du A, et al. (2024) High reflectivity and high emissivity integrated double layer coating on the flexible alumina fiber fabric with enhanced heat-dissipation efficiency. J Ceram Int 50(16): 28857-28866.
21. Yao P, Chen Z, Liu T, Liao X, Yang Z, et al. (2022) Spider-silk-inspired nanocomposite polymers for durable daytime radiative cooling. J Adv Mat 34(51): e2208236.
22. Raman AP, Anoma MA, Zhu L, Rephaeli E, Fan S (2014) Passive radiative cooling below ambient air temperature under direct sunlight. Nature 515(7528): 540-544.
23. Jose S, Prakash A, Laha S, Natarajan S, Reddy MP (2014) Green colored nano-pigments derived from $Y_2 BaCuO_5$: NIR reflective coating. Dyes Pigm 107: 118-126.
24. Fayala F, Alibi H, Jemni A, Zeng X (2014) Study the effect of operating parameters and intrinsic features of yarn and fabric on thermal conductivity of stretch knitted fabrics using artificial intelligence. Fibers and Polymers 15(4): 855-864.

25. Shobanasree PC, Prakash C, Manickam RK, Lokesh KV (2022) Effect of elastane plating on physical & thermal comfort properties of lyocell single jersey knit fabric with different loop length. J Nat Fibers 9(15): 11574-11581.

26. A Sadak (2024) https://earth.org/cricket-in-peril-can-the-popular-sport-survive-in-the-face-of-a-rapidly-changing-climate/.