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Improving Outdoor Thermal Comfort for Agricultural Workers: A Study of Heat Stress Relief Measures Using Sun Protection Lotions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The entire study was carried out on a group of 100 female farm workers at the CTAE university campus in Udaipur during the wheat crop harvesting season, with the aim of examining the effectiveness of various heat stress relief measures (sun protection lotion with different sun protection factors, SPF) in improving outdoor thermal comfort. The experiments were designed to assess the average skin temperature of Indian female farm workers under five fixed Wet Bulb Globe Temperature (WBGT) conditions (28, 29, 30, 31, 32°C), all falling within the heat stress category as per American Conference of Governmental Industrial Hygienists (ACGIH) standards. The mean skin

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temperature was determined using the Hardy du-bois 7-point model formula, which involved measuring the mean temperature of specific body parts of the 100 female farm workers. A variation of ± 0.5°C was considered due to the challenge of achieving precise thermal conditions in open field settings. The experiment aimed to evaluate the thermal and physiological responses of the participants. The findings revealed that the use of sun protection lotion alone resulted in increased cooling effect, thereby expanding the thermal comfort range. Additionally, the application of sun protection lotion alone reduced the mean skin temperature by 0.39, 0.38, 0.36, 0.30, 0.27°C by the end of the work period.

Keywords: Agricultural workers; thermal comfort; heat stress relief measures; sun protection lotion; mean skin temperature; WBGT conditions; physiological responses; outdoor environment.

1. INTRODUCTION

Udaipur experiences a hot semi-arid climate due to its location within the desert areas of Rajasthan, resulting in consistently high temperatures during the summer season, which typically spans from mid-March to June. During this period, temperatures range from 23°C to 44°C, with an average of 34°C. These temperature variations directly impact skin temperature. According to American Conference of Governmental Industrial Hygienists (ACGIH) norms, Wet Bulb Global Temperature (WBGT) heat stress is identified between 28°C and 32°C. Heat stress, commonly observed in outdoor agricultural operations, arises from prolonged exposure to high temperatures, particularly during manual labour pursuits such as ploughing, sowing, intercultural operations, and harvesting.

The majority of agricultural tasks in the country are carried out manually, including ploughing, sowing, intercultural operations, harvesting, and threshing, often under the hot sun. Many of these tasks rely on manual tools, and the combination of physical exertion and harsh weather conditions significantly amplify the toil experienced by farm workers (Dharaiya et al., 2015). Physiological responses to heat stress include elevated heart rate, increased body-core temperature, and perspiration (Huguette et al., 2009). In extremely hot-humid environments, a notable decline in cognitive performance is observed at temperatures exceeding 32.2°C (Basic Effective Temperature), and in hot-dry environments, this decline is observed at temperatures surpassing 33°C (Sharma et al., 1983). Prolonged exposure to high temperatures such as those referenced by the American Conference of Governmental Industrial Hygienists (ACGIH), can lead to a variety of adverse health effects, ranging from acute conditions to more serious and chronic ailments, and in extreme cases, may even result in fatalities.

"Heat Stress" refers to the external heat load resulting from a combination of various environmental factors, including muscle use and surrounding conditions. It is influenced by environmental conditions, work demands, and clothing requirements. The combined effect of internally generated metabolic heat from strenuous physical activity and external heat from the environment poses a significant risk of heat stress for workers (NIOSH). Projections for 2030 suggest a potential loss of 880,000 work-life-years due to occupational heat stroke mortality in both indoor and outdoor workplaces, particularly in temperature ranges typically between 27°C (80°F) and 40°C (104°F). Within this range, the risk of heat-related illnesses, including heat stroke, increases significantly, particularly when combined with high humidity and extended exposure times (Kjellstrom et al., 2009). International standards for occupational heat exposure, such as those set by the World Health Organization (WHO) and the International Labour Organization (ILO), typically recommend a maximum wet bulb globe temperature (WBGT) of around 28°C (82°F) for moderate work in hot environments. However, this standard may vary from country to country based on specific regulations and guidelines (Frimpong et al., 2017, Crowe et al., 2013, Sahu et al., 2013). Additionally, they often lack control over workplace health and safety practices and have inadequate access to water, shade, and rest breaks (Hansen et al., 2020, Fleischer et al., 2013).

Globally, there is a growing presence of migrants in the agricultural workforce, with 16.7 million migrants working in the agricultural sector worldwide (ILO). The migration of agricultural workers is influenced by various social, economic, and environmental factors, which are expected to worsen with climate change, leading to a decreased flow of migrants, particularly from low-income countries (FAO). Migrant agricultural workers often encounter unique vulnerabilities that impact their health and well-being, increasing their susceptibility to heat-related health issues. These workers are exposed to unsafe working conditions and heightened workplace harassment (Caxaj et al., 2019, Habib et al., 2020, Hiott et al., 2015). Furthermore, they lack protection from labor regulations, are not represented in labor unions, and frequently face language and cultural barriers, as well as limited access to social security (Svensson et al., 2013). Additionally, many of these workers are not provided with appropriate personal protective equipment (PPE), exposing them to various workplace hazards and increasing their risk of injury or illness on the job.

Research suggests that when female farm workers are exposed to high temperatures during wheat harvesting, they may be at risk of developing various heat-related disorders such as systemic disorders, heat syncope, heat edema, heat cramps, heat exhaustion, and heat stroke, WHO (World Health Organization). These conditions can cause the body's temperature to rise due to changes in skin and muscle temperature. To prevent heat stress, it is important to educate and train workers on best practices, such as recognizing the signs of heat-related illnesses, staying hydrated, and scheduling regular breaks in shaded or cool areas. Therefore, this study aimed to evaluate the thermal workload on the female body and physiological workloads during wheat crop harvesting operations.

2. JUSTIFICATION OF THE RESEARCH STUDY

The research study aims to assess the thermal workload and physiological workloads on the female human body during wheat crop harvesting operations. Wheat harvesting often occurs during peak summer months when temperatures are highest, making it a critical time for studying heat exposure. The intensity and duration of work during this operation can also contribute to heat stress. This is important to understand the impact of heat stress on female farm workers and to develop effective prevention and protection measures. The study addresses a gap in knowledge about the specific vulnerabilities and risks faced by female agricultural workers, particularly in the context of increasing global migration and climate change. Ultimately, the research has the potential to inform policies and practices to safeguard the health and well-being of female farm workers.

The objectives of the study were:

i. Assessment of thermal and physiological workload (Heart Rate and Energy Expenditure Rate) on female farm workers during harvesting of wheat crop with sun protection lotion-I
ii. Assessment of thermal and physiological workload on female farm workers during harvesting of wheat crop with sun protection lotion-II
iii. Assessment of thermal workload and physiological workload on female farm workers during harvesting of wheat crop with sun protection lotion-III
iv. Comparative analysis of sun protection lotion I, II and III.

3. MATERIALS AND METHODS

Heat stress levels were evaluated during wheat crop harvesting at the College of Technology and Engineering, CTAE Instructional farm in Udaipur. The study involved one hundred female farm workers selected from a representative population based on anthropometric criteria ranging from the 5^{th} to the 95^{th} percentile. All harvesting operations were carried out exclusively by these hundred female farm workers. The selected subjects relied primarily on agriculture for their livelihood and did not use tobacco or consume alcohol. They were aged between 18 and 45 years, free from chronic diseases and physical disorders, and deemed medically fit. The participants didn't wear any personal protective equipment (PPE), since the experiments were conducted on exposed body surfaces.

To evaluate the impact of environmental heat on the performance of female farm workers, five different WBGT (wet bulb globe temperature) conditions 28°C, 29°C, 30°C, 31°C, and 32°C were chosen as independent variables during wheat crop harvesting. Continuous monitoring of environmental conditions would be essential to ensure that the selected WBGT conditions accurately reflects the target temperatures throughout the experiment. Three dependent parameters were selected for the study: Mean skin temperature (MST) as a measure of thermal workload, Heart Rate (HR) and Energy Expenditure Rate (EER) as indicators of physiological workload.

In the morning, operations took place from 9 AM to 1 PM, and in the evening, from 2 PM to 5 PM. Prior to the task, all female farm workers were given a 15-minute rest period and then instructed to engage in continuous harvesting for 30 minutes, followed by another 15-minute rest period. This work-rest cycle was consistently maintained throughout the entire operation. Providing rest periods helps to reduce the risk of heat stress, especially in high-temperature environments. Short breaks allow workers to cool down, hydrate, and recover from the physical exertion associated with continuous harvesting.

A technique was developed to assess various calculation methods for Mean skin temperature with the aim of identifying suitable methods for use in human thermal comfort studies by Liu et al., 2011. Three criteria, namely reliability, sensitivity, and the number of measurement sites, were proposed to evaluate Mean skin temperature (MST) calculation methods. The findings revealed that a 7 to 10 site calculation method for mean skin temperature demonstrated the highest reliability, excellent sensitivity, and required fewer measurement sites. Consequently, in line with these findings, the mean skin temperature of the body was measured using the Hardy Du-Bois- 7 Point model, which calculates mean skin temperature at seven different locations: forehead, left forearm, left hand, left foot, left anterior calf, left anterior thigh, and left abdomen. The formula for measuring the mean skin temperature for both models is provided below.

Hardy Du-Bois- 7 Point model

MT_{SK} (°C) = 0.07 T_{sk} Forehead + 0.14 T_{sk} Left forearm + 0.05 T_{sk} Left hand + 0.07 T_{sk} Left foot + 0.13 T_{sk} Left anterior calf + 0.19 T_{sk} Left anterior thigh + 0.35 T_{sk} Left abdomen

3.1 Instrumentation

Instrumentation used to conduct the experiments for measurement of physiological and thermal workload is described below.

3.1.1 Physiological workload

1. Computerized ambulatory metabolic measurement system

The computerized ambulatory metabolic measurement system is capable of measuring oxygen consumption with each breath, which is why it is referred to as a breath-by-breath measurement system and is considered more precise than the mixing chamber measurement. Heart rate (both resting and during activity) and Energy Expenditure rate were assessed using the K4b2 device manufactured by Cosmed (Italy).

Increase in Heat rate, ΔHR (beats/min) = Average working heart rate – average resting heart rate

3.1.2 Thermal workload

1. Heat stress monitor

The Quest Temp 36 heat stress monitor was utilized to evaluate the heat stress index, specifically the Wet Bulb Globe Temperature (WBGT).

2. Contact type skin temperature thermometer

The EXTECH contact-type skin temperature thermometer (Model- SDL200) was utilized for measuring skin temperature. The skin temperature probes are specifically designed for continuous temperature monitoring using the skin as an indicator of body temperature. These probes have a 2-meter lead length and are designed to operate within the range of 0 to 50°C, making them suitable for applications such as biomedical temperature monitoring that require repeatability, high sensitivity, and rapid response. The four-channel data logging thermometer is compatible with both thermocouple and RTD probes. Data was recorded onto a standard SD memory card instead of a built-in memory, providing the advantage of easily changing out the SD card for unlimited data storage when the memory is full.

3. Assessment of thermal workload

1. Selection of natural sun protection lotion

Natural sun protection lotion contains natural ingredients, which have properties to protect the skin from environmental pollution and from harmful ultraviolet radiations (Mishra, 2011). Natural sun protection lotions leverage ingredients like zinc oxide, antioxidants, and moisturizing agents to shield the skin from UV radiation and environmental pollutants. These formulations create a physical barrier that reflects UV rays, while antioxidants neutralize harmful free radicals and anti-inflammatory components soothe skin irritation. Together, these properties enhance the skin's resilience against damage. Three commercial herbal sun protection lotions were selected for the study which has aloevera and carrot seed oil as major ingredients and was purchased from local market. Aloe vera and carrot seed oil are valued for their natural skin benefits. Aloevera offers soothing, moisturizing, and healing properties, making it effective for treating sunburns and maintaining skin hydration. Carrot seed oil is rich in antioxidants and provides natural UV protection, improving skin tone and regeneration. Sun protection lotions with these ingredients enhance the efficacy of sun protection formulations. The selected sun protection lotions were divided into 3 categories defined by the European commission recommendation, 2006, based on sun protection factor (SPF).

The economics of applying the selected three herbal sun protection lotions involves various factors. Although these lotions typically come with a higher initial cost due to the use of natural ingredients, the long-term health benefits, such as minimized skin damage and improved effectiveness in shielding against the sun can justify this expense.

2. Low protection (SPF 0 - 15) – Sun protection lotion I

The sun protection lotion I had major ingredients as aloevera (Aloe barbadensis) and vitamin E. The sun protection lotion I used in this study is shown in Fig. 1.

3. Medium protection (SPF 15 – 30) - Sun protection lotion II

The sun protection lotion II had major ingredients as aloevera (Aloe barbadensis), sunflower and safflower oils. The sun protection lotion II used in this study is shown in Fig. 1.

4. High protection (SPF 30 – 60) - Sun protection lotion III

The sun protection lotion III had major ingredients as pure carrot seed oil, extracts of carrot seed oil and lodhra bark, quince seed and aloevera. The sun protection lotion III used in this study is shown in Fig. 1.

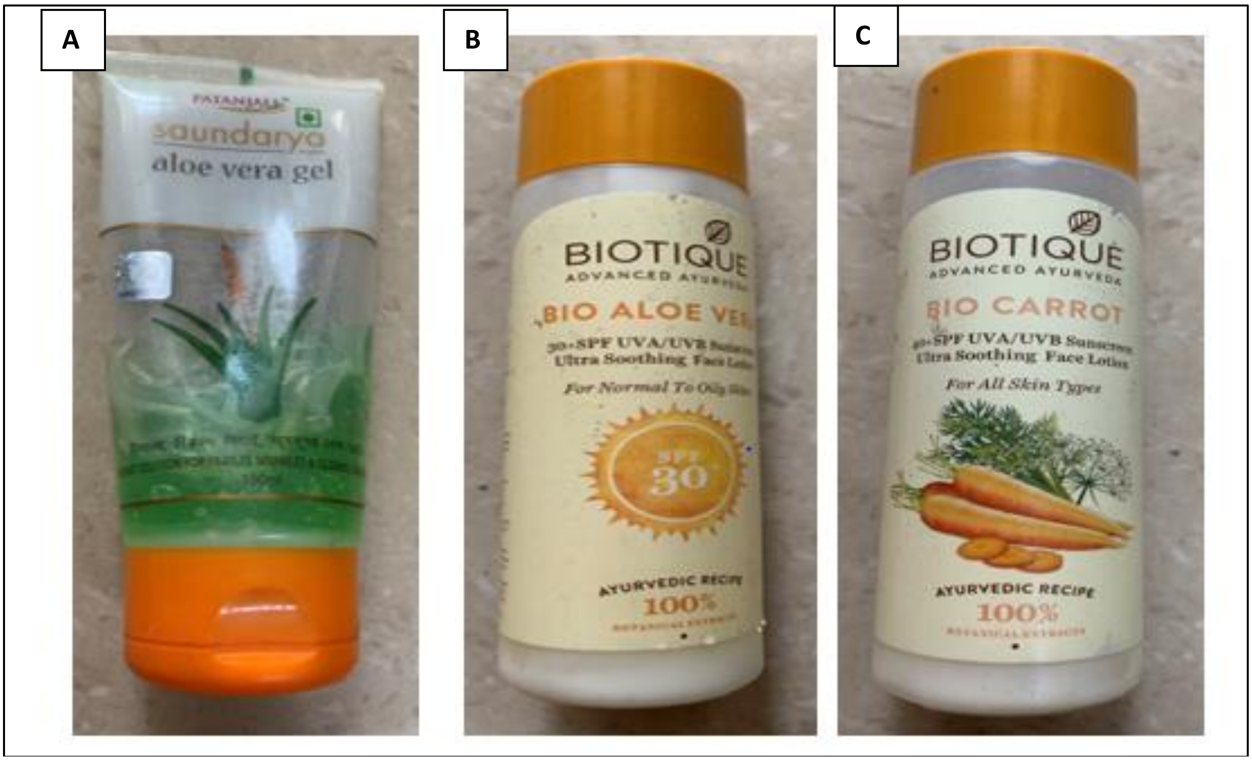

Fig. 1. Sun Protection Lotion used in this study (A)Sun protection lotion I (B) Sun protection lotion II (C) Sun protection lotion III

4. Application of Sun Protection Lotion

Five levels of WBGT 28, 29, 30, 31, and 32°C for outdoor conditions were chosen to access the thermal workload on human skin in the assessment of heat stress of female farm workers due to environmental conditions. Since achieving exact WBGT conditions in the field is difficult, a variance of 0.5°C was assumed in open field conditions. The mean skin temperature of the body was measured using the Hardy Du-Bois- 7 Point model. Skin temperature were measured at seven different body sites of farm workers namely, forehead, left forearm, left hand, left foot, left anterior calf, left anterior thigh, left abdomen. The three different types of sun protection lotions and hundred female farm workers were selected. The sun protection lotion was liberally applied to all over the exposed parts of the body for this study. The sun protection lotion was applied in significant amounts i.e., 2 mg/cm^2 on the exposed parts of the body (Sushma, 2019). The same amount of sun protection lotion was applied to all hundred female farm workers. Under study, effect of WBGT on female farm workers was accessed by using three different sun protection lotion and effect of WBGT without application of sun protection lotion.

Heart Rate (HR) and Energy Consumption Rate (EER) were also measured. In morning, the uniform time of 7 hours for all the operations was given in between 9 AM to 1 PM and in evening from 2 PM to 5 PM. All the female farm workers were allowed to take rest for 15 minutes before performing the task and asked to perform the operation continuously for 30 minutes and then allowed to take rest for 15 minutes. They must have had breakfast about two hours before the start of the work. Hypertension and hyper glycemia were not present in the participants. The temperature was determined using a non-contact infrared thermometer and a contact thermometer. After swiping the sweat with clean cotton, the temperatures were registered. Heart rate and Energy Consumption Rate was measured by K4b^2.

4. RESULTS AND DISCUSSION

4.1 Thermal Workload and Physiological Responses in Harvesting of Wheat

Experiments were conducted to assess the effect of sun protection lotion on physiological, and thermal responses on different sites of body. The effect of WBGT due to the application of different sun protection lotions on mean skin temperature, heart rate (resting HR, working HR, delta HR) AND Energy Expenditure Rate (EER) in the harvesting operation of wheat crop was assessed.

All the 100 female farm workers underwent all the four treatments (three different sun protection lotions and no sun protection lotion) in harvesting operation in wheat crop. There were no missing values that were left for any measurement.

4.1.1 Effect of WBGT on mean skin temperature without sun protection lotion

Table 1 indicates the mean skin temperature at different WBGT conditions at the beginning of the operation without application of Sun protection lotion. Mean skin temperature was calculated by using Hardy du-bois 7-point model formula by measuring the mean temperature of forehead, left forearm, left hand, left foot, left anterior calf, left anterior thigh, left abdomen of ten female subjects. As indicated in Table 1, the mean skin temperature at the beginning of the work increases with increase in WBGT. Kashyap *et al.* (2017) and Patil *et al.* (2019) also reported

Table 1. Mean skin temperature at the beginning of working period

Thermal parameters	WBGT, °C				
	28	29	30	31	32
Forehead	31.41	31.83	32	32.56	33.77
Left forearm	29.54	30.91	33.26	33.51	34.31
Left hand	32.27	33.60	33.69	34.58	34.86
Left foot	34.22	34.71	34.97	35.20	36.40
Left anterior calf	29.71	29.86	30.09	30.61	30.86
Left anterior thigh	31.81	32.66	32.91	33.05	33.11
Left abdomen	29.65	29.81	29.85	30.36	30.48
Mean skin temperature	30.67	31.25	31.83	32.05	32.43

similar result that temperature of the body sites increases with increase in WBGT. It was noted that the lowest mean skin temperature was recorded as 30.67°C at WBGT 28°C and highest as 32.43°C at WBGT 32°C.

Table 2 indicates the mean skin temperature at different WBGT conditions at the end of the operation. The value of mean skin temperature of hundred female subjects at the end of the work increases with increase in WBGT. But forehead, left abdomen temperature decreased with increase in WBGT. This is mainly due to the sweating caused with increase in WBGT. Due to the air, the sweat was evaporated and reduced the forehead temperature and left abdomen temperature. Thus, the increase in temperature due to environmental heat reduced the forehead and left abdomen temperature. Dhariya (2015), Patil *et al.* (2019) also reported that the forehead temperature decreased with increase in WBGT temperature. It was noted that the lowest mean skin temperature was recorded as 34.89°C at WBGT 28°C and highest as 36.22°C at WBGT 32°C.

4.1.2 Effect of WBGT on mean skin temperature with sun protection lotion-I

Table 3, indicates the mean skin temperature at different WBGT conditions at the beginning of working period of the operation. As shown in Table 2, the mean skin temperature at the beginning of working period increases with increase in WBGT. It was noted that the lowest mean skin temperature was recorded as 29.74°C at WBGT 28°C and highest as 32.15°C at WBGT 32°C. It can be seen that forehead, left forearm, left hand, left foot, left anterior calf, left anterior thigh and left abdomen temperature increases with increase in WBGT at the beginning of the working period. Kashyap *et al.* (2017) and Patil *et al.* (2019) also reported similar result that temperature of the body sites increases with increase in WBGT.

Table 4 indicates the mean skin temperature at different WBGT conditions at the end of the working period. The value of mean skin temperature of 100 female subjects at the end of the work increases with increase in WBGT. But forehead, left abdomen temperature decreased with increase in WBGT. As the environmental temperature increased, forehead and left abdomen temperature decreased due to more sweat accumulated at these points along with the cooling effect of sun protection lotion-I caused a drop in temperature. Connolly (1994) also concluded that the application of sun protection lotion significantly reduces the mean skin temperature. It was noted that the lowest mean skin temperature was recorded as 33.64°C at WBGT 28°C and highest as 36.03°C at WBGT 32°C.

4.1.3 Effect of WBGT on mean skin temperature with sun protection lotion-II

Table 5 indicates the mean skin temperature at different WBGT conditions at the beginning of working period of the operation. As evident in Table 5, the mean skin temperature at the beginning of working period increases with increase in WBGT. It can be seen that forehead, left forearm, left hand, left foot, left anterior calf, left anterior thigh and left abdomen temperature increases with increase in WBGT at the beginning of the working period. Kashyap *et al.* (2017) and Patil *et al.* (2019) also reported similar result that temperature of the body sites increases with increase in WBGT. It was observed that the lowest mean skin temperature was recorded as 29.69°C at WBGT 28°C and highest as 32.13°C at WBGT 32°C.

Table 2. Mean skin temperature at the end of working period

Thermal parameters	WBGT, °C				
	28	29	30	31	32
Forehead	35.80	35.42	35.14	34.92	34.75
Left forearm	34.72	35.46	36.01	37.30	37.51
Left hand	34.35	35.50	36.58	37.02	37.84
Left foot	34.95	35.87	36.76	37.34	37.69
Left anterior calf	32.83	33.57	34.93	35.36	35.75
Left anterior thigh	33.59	33.86	34.86	35.03	35.58
Left abdomen	35.14	34.88	34.62	33.87	33.74
Mean skin temperature	34.89	34.96	35.44	35.79	36.22

Table 3. Effect of sun protection lotion-I on mean skin temperature at the beginning of working period

Thermal parameters	WBGT, °C				
	28	29	30	31	32
Forehead	30.55	30.99	31.48	31.78	32.06
Left forearm	28.72	30.13	32.67	32.95	33.46
Left hand	31.59	32.60	33.06	34.09	34.14
Left foot	33.58	34.42	34.57	34.93	35.26
Left anterior calf	28.47	29.01	29.56	30.02	30.29
Left anterior thigh	30.95	31.69	32.32	32.53	32.78
Left abdomen	28.79	28.92	29.22	29.28	29.52
Mean skin temperature	29.74	30.84	31.56	31.79	32.15

Table 4. Effect of sun protection lotion-I on mean skin temperature at the end of working period

Thermal parameters	WBGT, °C				
	28	29	30	31	32
Forehead	34.69	34.30	33.99	33.80	33.64
Left forearm	34.47	35.20	35.91	36.16	36.35
Left hand	34.10	35.44	35.45	35.89	36.71
Left foot	34.85	35.63	35.74	36.20	36.55
Left anterior calf	31.60	32.38	33.85	34.26	34.64
Left anterior thigh	32.50	32.74	33.76	33.90	34.43
Left abdomen	34.02	33.72	33.54	32.77	32.64
Mean skin temperature	33.64	34.69	35.22	35.63	36.03

Table 5. Effect of sun protection lotion-II on mean skin temperature at the beginning of working period

Thermal parameters	WBGT, °C				
	28	29	30	31	32
Forehead	30.47	30.94	31.44	31.65	31.99
Left forearm	28.68	30.09	32.64	32.93	33.41
Left hand	31.53	32.56	33.03	34.04	34.09
Left foot	33.53	34.36	34.52	34.89	35.22
Left anterior calf	28.41	29	29.53	29.97	30.25
Left anterior thigh	30.9	31.65	32.27	32.50	32.73
Left abdomen	28.75	28.88	29.20	29.26	29.48
Mean skin temperature	29.69	30.72	31.42	31.78	32.13

Table 6. Effect of sun protection lotion-II on mean skin temperature at the end of working period

Thermal parameters	WBGT, °C				
	28	29	30	31	32
Forehead	34.65	33.24	33.96	33.75	33.59
Left forearm	33.42	34.14	35.84	36.07	36.25
Left hand	34.06	35.32	35.36	35.8	36.65
Left foot	34.79	35.53	35.67	36.11	36.47
Left anterior calf	31.56	32.28	33.82	34.22	34.58
Left anterior thigh	32.43	32.69	33.7	33.84	34.32
Left abdomen	33.94	33.68	33.47	32.71	32.58
Mean skin temperature	33.62	34.65	35.16	35.56	36.01

Table 6, indicates the mean skin temperature at different WBGT conditions at the end of the working period. The value of mean skin temperature of hundred female subjects at the end of the work increases with increase in WBGT. But forehead, left abdomen temperature decreased with increase in WBGT. As the environmental temperature increased, forehead and left abdomen temperature decreased due to more sweat accumulated at these points along with the cooling effect of sun protection lotion-II caused a drop in temperature. Connolly (1994) also concluded that the application of sun protection lotion-II significantly reduces the mean skin temperature. It was noted that the lowest mean skin temperature was recorded as 33.62°C at WBGT 28°C and highest as 36.01°C at WBGT 32°C.

4.1.4 Effect of WBGT on mean skin temperature with sun protection lotion-III

Table 7, indicates the mean skin temperature at different WBGT conditions at the beginning of working period of the operation. As indicated in Table 7, the mean skin temperature at the beginning of working period increases with increase in WBGT. It can be seen that forehead, left forearm, left hand, left foot, left anterior calf, left anterior thigh and left abdomen temperature increases with increase in WBGT at the beginning of the working period. Kashyap *et al.* (2017) and Patil *et al.* (2019) also reported similar result that temperature of the body sites increases with increase in WBGT. It was noted that the lowest mean skin temperature was recorded as 29.54°C at WBGT 28°C and highest as 32.03°C at WBGT 32°C.

Table 8 indicates the mean skin temperature at different WBGT conditions at the end of the working period. The value of mean skin temperature of left forearm, left hand, left foot, left anterior calf, left anterior thigh, of ten female subjects at the end of the work increases with increase in WBGT. But forehead, left abdomen temperature decreased with increase in WBGT. As the environmental temperature increased, forehead and left abdomen temperature decreased due to more sweat accumulated at these points along with the cooling effect of sun protection lotion-III caused a drop in temperature. Connolly (1994) also concluded that the application of sun protection lotion significantly reduces the mean skin temperature. It was noted that the lowest mean skin temperature was recorded as 33.50°C at WBGT 28°C and highest as 35.95°C at WBGT 32°C.

Table 7. Effect of sun protection lotion-III on mean skin temperature at the beginning of working period

Thermal parameters	WBGT, °C				
	28	**29**	**30**	**31**	**32**
Forehead	30.4	30.89	31.38	31.62	31.93
Left forearm	28.63	30	32.55	32.88	33.34
Left hand	31.48	32.49	32.97	33.97	34.02
Left foot	33.47	34.3	34.42	34.82	35.13
Left anterior calf	28.35	28.95	29.49	29.95	30.2
Left anterior thigh	30.84	31.58	32.21	32.33	32.67
Left abdomen	28.7	28.85	29.13	29.21	29.44
Mean skin temperature	29.54	30.63	31.36	31.64	32.03

Table 8. Effect of sun protection lotion-III on mean skin temperature at end of working period

Thermal parameters	WBGT, °C				
	28	**29**	**30**	**31**	**32**
Forehead	34.57	34.18	33.86	33.7	33.54
Left forearm	33.35	34.03	35.76	35.95	36.09
Left hand	33.95	34.19	35.24	35.67	36.54
Left foot	33.63	34.44	35.53	36.05	36.28
Left anterior calf	31.43	32.2	33.73	34.1	34.5
Left anterior thigh	32.36	32.62	33.63	33.77	34.15
Left abdomen	33.79	33.59	33.37	32.67	32.5
Mean skin temperature	33.5	34.58	35.08	35.49	35.95

4.1.5 Statistical analysis of mean skin temperatures at the beginning of working period

Statistical analysis was carried out to find the significant effect of WBGT on mean skin temperature by using three different sun protection lotions and without sun protection lotion condition at the beginning of working period by means of data analysis tool pack provided in Ms-Excel. Two-way ANOVA (analysis of variance) analysis was carried out to find the statistical significance between the factors given in Table 9. As from the results obtained from the statistical analysis that there was significant effect of WBGT on mean skin temperature at 1 percent level of significance (P<0.01) at the beginning of working period.

Mean skin temperatures by using different sun protection lotions and without sun protection lotion condition at the beginning of working period is given in Table 10. The results of the study showed that, application of all sun protection lotions significantly decreased the mean skin temperature of the body at different selected sites, when compared to the mean skin temperature without application of sun protection lotion condition. Table 9, also shows that mean skin temperature increased with increase in WBGT in resting period. Kashyap *et al.* (2017) also found the similar results of increasing mean skin temperature with increase in WBGT on using hand guards.

Sun protection lotion has given immediate cooling effect upon application. Mean skin temperature (MST) as being significantly decreased while using sun protection lotion-III, on approximately 0.83, 0.62, 0.47, 0.41 and 0.40°C at WBGT 28, 29, 30, 31 and 32°C respectively when compared to MST at without sun protection lotion condition at the beginning of working period. The greatest difference in mean skin temperature between all the three sun protection lotion condition and without sun protection lotion condition was observed on the immediate application of sun protection lotion at the beginning of working period at 28°C WBGT while using sun protection lotion-III. Connolly *et al* (1995) also observed reduction in MST on immediate application of sun protection lotion at lower WBGT conditions.

Mean skin temperature was highest in case of sun protection Lotion-I and lowest in case of Sun protection lotion-III when compared to no sun protection lotion condition at the beginning of the working period as shown in Fig. 2.

4.1.6 Statistical analysis of mean skin temperatures at the end of working period

From the results obtained from the statistical analysis given in Table 11, that there was significant effect of WBGT on mean skin temperature at 1 percent level of significance (P<0.01) at the end of working period. The results of the study showed that, application of all sun protection lotions decreased the mean skin temperature of the body at different selected sites, when compared to the mean skin temperature without application of sun protection lotion condition at the end of working period. Table 12, also shows that, mean skin temperature increased with increase in WBGT in working period.

Table 9. ANOVA for effect of different sun protection lotions on Mean Skin Temperature, MST on different sites of body at 28, 29, 30, 31, 32 °C WBGT at the beginning of working period

Source	SS	df	MS	F	P-value	F crit
Rows	0.50351667	2	0.25175833	59.5877712	0.0001101	5.14325285
Columns	2.842625	3	0.94754167	224.270217	1.556E-06*	4.75706266
Error	0.02535	6	0.004225			
Total	3.37149167	11				

**P-value significant at 0.01*

Table 10. Mean skin temperatures at the beginning of working period

Treatment	WBGT, °C				
	28	29	30	31	32
Sun protection lotion-I	29.74	30.84	31.56	31.79	32.15
Sun protection lotion-II	29.69	30.72	31.42	31.78	32.13
Sun protection lotion-III	29.54	30.63	31.36	31.64	32.03
No sun protection lotion	30.67	31.25	31.83	32.05	32.43
Mean	29.91	30.86	31.54	31.82	32.19
CV	5.74				

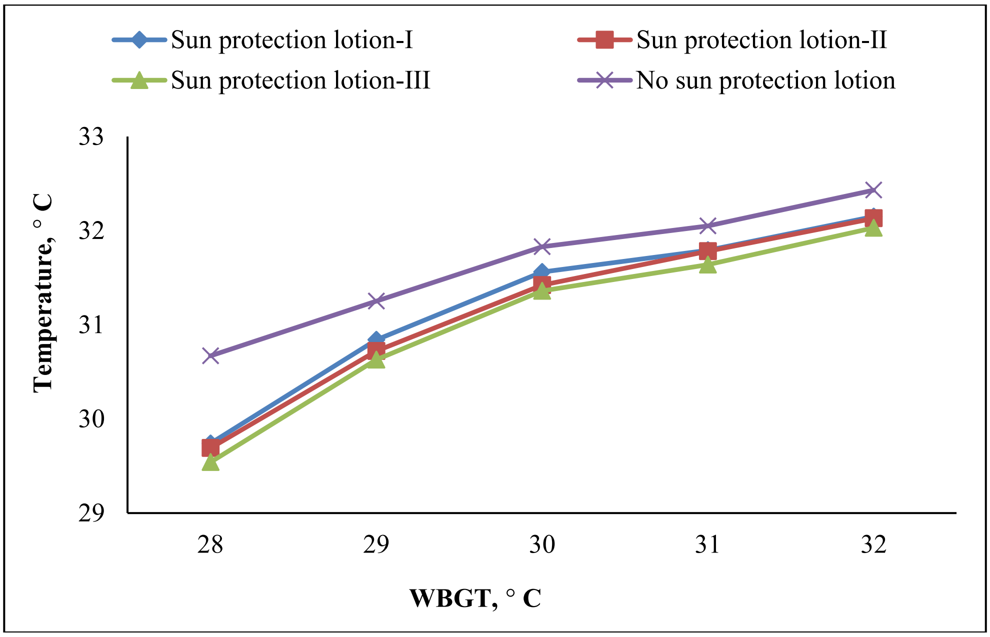

Fig. 2. Mean skin temperature at the beginning of working period

Table 11. ANOVA for effect of different sun protection lotions on MST on different sites of the body at 28, 29, 30, 31, 32 °C WBGT at the end of working period

Source	SS	df	MS	F	P-value	F crit
Rows	0.23795	2	0.118975	149.236934	7.652E-06	5.14325285
Columns	2.87949167	3	0.95983056	1203.96864	9.971E-09*	4.75706266
Error	0.00478333	6	0.00079722			
Total	3.122225	11				

**P-value significant at 0.01*

Table 12. Mean skin temperatures at the end of working period

Treatment	WBGT, °C				
	28	**29**	**30**	**31**	**32**
Sun protection lotion-I	33.64	34.69	35.22	35.63	36.03
Sun protection lotion-II	33.62	34.65	35.16	35.56	36.01
Sun protection lotion-III	33.5	34.58	35.08	35.49	35.95
No sun protection lotion	33.89	34.96	35.44	35.79	36.22
Mean	33.66	34.72	35.23	35.62	36.05
CV	5.93				

Mean skin temperature (MST) as being significantly decreased while using sun protection lotion-III, on approximately 0.39, 0.38, 0.36, 0.30, 0.27°C at WBGT 28, 29, 30, 31 and 32°C respectively when compared to MST at without sun protection lotion condition at the end of working period. That means sun protection lotion has given immediate cooling effect upon application and continued to give cooling effect till the end of working period. The greatest difference in mean skin temperature between all the three sun protection lotion condition and without sun protection lotion condition was observed on the immediate application of sun protection lotion at the end of working period at 28°C WBGT while using sun protection lotion-III. Connolly *et al* (1995) also observed reduction in MST on immediate application of sun protection lotion at lower WBGT conditions. Mean skin temperature was highest in case of sun protection lotion-I and lowest in case of sun protection lotion-III when compared to no sun protection lotion condition at the end of working period as shown in Fig. 3.

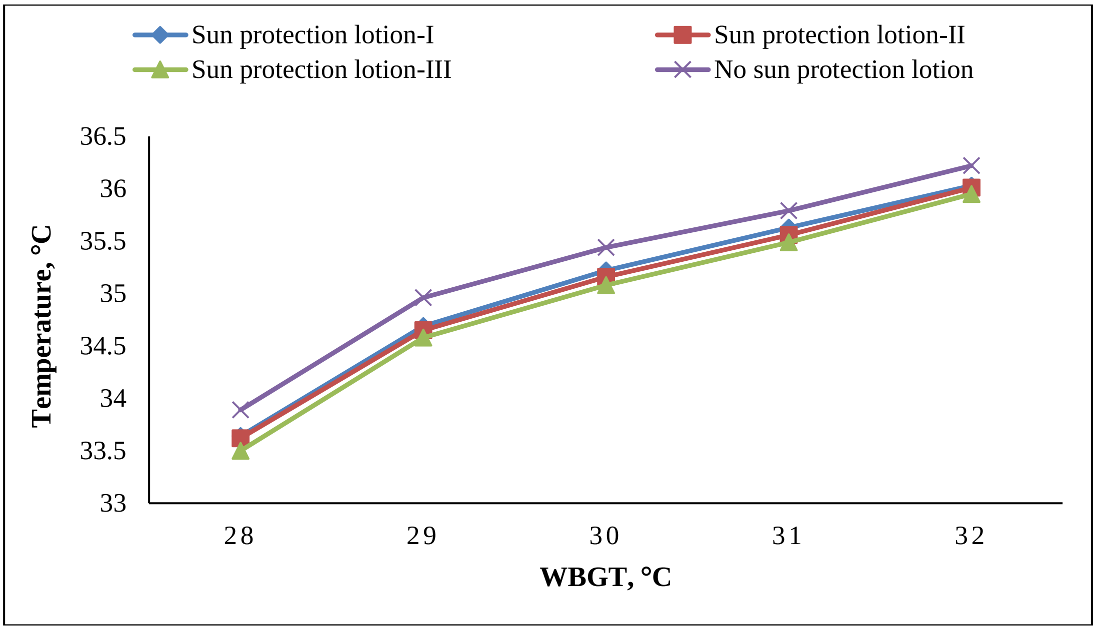

Fig. 3. Mean skin temperature at the end of working period

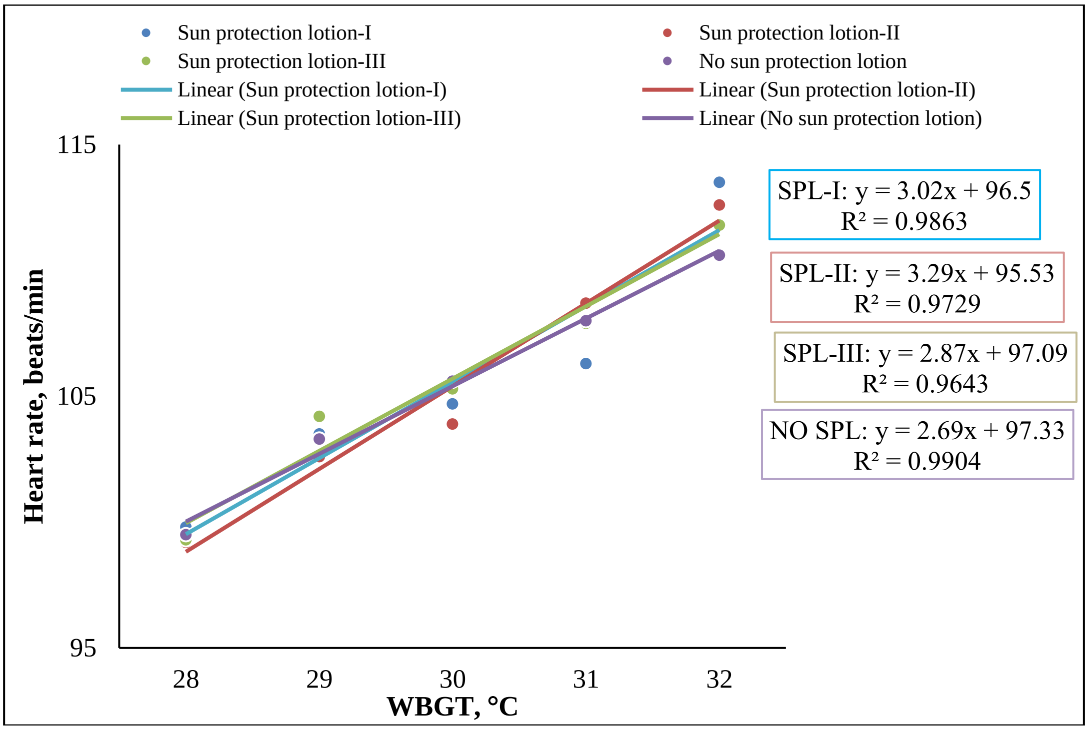

Fig. 4. Trendline of working HR at different WBGT conditions with sun protection lotions

4.1.7 Effect of sun protection lotions on physiological workload

Working heart rate (HR) and resting heart rate (HR) of 100 female subjects were measured by using three different sun protection lotions and without sun protection lotion under different WBGT conditions, i.e., 28, 29, 30, 31 and 32 °C. It was observed that the mean resting heart rate of 100 female farm workers by using sun protection lotion-I varied from 77.2 beats/min at 28°C to 83.4 beats/min at 32°C and mean working heart rate varied from 99.8 beats/min at 28°C to 113.5 beats/min at 32°C. Mean resting

Table 13. ANOVA for resting HR at different WBGT conditions with different sun protection lotions

Source	SS	df	MS	F	P-value	F crit
Rows	95.048	4	23.762	114.607717	0.8863	3.25916673
Columns	2.172	3	0.724	3.49196141	0.4993806*	3.49029482
Error	2.488	12	0.207333			
Total	99.708	19				

**Non-significant*

Table 14. ANOVA for working HR at different WBGT conditions with different sun protection lotions

Source	SS	df	MS	F	P-value	F crit
Rows	360.973	4	90.24325	225.655136	0.3304	3.25916673
Columns	6.0335	3	2.01116667	5.02896437	0.8744512*	3.49029482
Error	4.799	12	0.39991667			
Total	371.8055	19				

**Non-significant*

heart rate by using sun protection lotion-II varied from 78.3 beats/min at 28°C to 83.6 beats/min at 32°C and mean working heart rate varied from 99.3 beats/min at 28°C to 112.6 beats/min at 32°C. Mean resting heart rate by using sun protection lotion-III varied from 77.8 beats/min at 28°C to 84.1 beats/min at 32°C and mean working heart rate varied from 99.2 beats/min at 28°C to 111.8 beats/min at 32°C.

It can be clearly seen from the Fig. 4, that there was significant effect of WBGT on heart rate. Resting HR and working HR were observed to increase linearly with increase in WBGT. In Fig. 4, the working heart rate was observed to increase with increase in WBGT. This was mostly due to an increase in core body and skin temperature, which require additional pumping of blood to compensate for the temperature increase. The increase in working heart rate was almost same for all the sun protection lotions and without sun protection lotion condition. There was a linear relationship with between WBGT and working heart rate and R^2 values were higher than 0.964 in all the three sun protection lotions and without sun protection lotion condition, which shows higher degree of correlation with WBGT as shown in Fig. 3. Singh *et al.* (2013), , Dharaiya (2015), Kashyap *et al.* (2017), Patil *et al*. (2019) also found that resting HR and working HR increases with increase in WBGT conditions.

ANOVA of mean resting heart rate (RHR) in resting period and working heart rate (WHR) in working period given in (Table 13 and Table 14) was conducted to detect any differences between responses measured over different WBGT conditions for the three different sun protection lotions used versus no sun protection lotion treatment. Results of the study indicates that there was no significant difference between the heart rate measured with different sun protection lotions. There does not appear any effect of sun protection lotions at different WBGT conditions on resting heart rate (P=0.49), and working heart rate (P=0.87). Wells *et al* (1984) also reported that there were no significant differences in HR, VO_2, rectal temperature, or sweat loss in exercise trials while using sun protection lotion as compared to exercise trials without sun protection lotion. Conolly *et al.* (1994) also concluded that there was no significant effect of sun protection lotion on heart rate (P=0.51) and Rating of perceived exertion (P=0.92).

5. CONCLUSIONS

This study evaluated three different sun protection lotions under five varying WBGT conditions. The average skin temperature was found to be lowest at 28°C WBGT, followed by 29°C across all three lotions when compared to the condition without any sun protection. Upon immediate application, all three lotions effectively reduced skin temperature, particularly at 28°C WBGT, with notable cooling also observed at 29°C during the initial measurement period. Moreover, this cooling effect persisted throughout the working session, resulting in lower mean skin temperatures at 30°C,31°C, and32°C compared to the no sun protection scenario. Connolly (1995) also noted that the benefits of sun protection lotion endure throughout the exercise duration. Notably, sun protection lotion-III demonstrated a greater reduction in mean skin temperature during the working period compared to not using any lotion. While the specific cost of the cream used in the experiment was high, its economic feasibility in relation to other creams or protective measures hinges on its effectiveness and affordability. The selected lotion was likely chosen for its proven efficacy and safety, with locally available alternatives possibly lacking these qualities. Neglecting to use sun protection may lead to increased skin damage and heat stress, thereby decreasing worker productivity due to health complications. Overall, the findings from this study could yield substantial economic benefits by decreasing healthcare expenses, enhancing worker productivity, and fostering safer working environments through effective sun protection strategies.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that she has no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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