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Effects of WBGT on the thermal and physiological responses of North-Eastern Indian agricultural workers during paddy transplanting operations

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ABSTRACT

In the hot and humid summer, the outdoor farmers in North-eastern India (NEI) area experience higher Wet Bulb Globe Temperature (WBGT), leading to heat stress. For the assessment of physiological and thermal responses of NEI agricultural workers at different WBGT conditions (27 ºC to 32 ºC), ten farmers were selected (n=10) for manual rice transplantation in open rice filed from June to July 2021 on selected sunny days. The study's findings show that the WBGT causes heat stress in farmers' bodies as statistical analysis of most of the data was highly significant with increasing WBGT ($p < 0.05$). It was observed that heart rate and oxygen consumption which reveal the physiological response, were increasing in trend with the increasing WBGT from 27 ºC to 32 ºC. Forehead and skin temperature was observed to decrease with the increase of WBGT from 27 ºC to 32 ºC due to heavy sweating and highly humid condition during rice transplanting operation in NEI conditions. Oral (core body temperature) and head temperature were observed to increase with the increase in WBGT. It was also noticed that a few subjects' core body temperatures (CBT) of more than 37 ºC led to an increasing threat of heatstroke or other heat illness in NEI outdoor field conditions. Further, proper design of the work-rest schedule, acclimatization, and heat-protecting measures are suggested to minimize the danger level of NEI farmers' physiological and thermal responses.

1. Introduction

The climate of India comprises a wide range of weather conditions throughout a large geographic area and with a diversified topography (Singh et al. 2017). Due to its proximity to the tropic of cancer, the North Eastern Region (NER) of India has a tropical and sub-tropical climate with hot and humid summers (Dikshit and Dikshit 2014). Because of the hot and humid summer, the outdoor farmers of North-east India (NEI) experience higher Wet Bulb Globe Temperature (WBGT), which leads to heat stress. The WBGT is a heat stress index based on wind speed, humidity, sun angle, solar radiation temperature, and other factors. It is a compound temperature that is used to calculate how much humidity, heat, wind, infrared and visible radiation will affect people. ISO has certified WBGT as the most acceptable method for assessing workplace heat stress (Hajizadeh et al. 2016). Due to this moderate temperature and high humidity, the outdoor workers of the NE region of India are easily coming under heat stress conditions. It was observed in this experiment that during the summer season, WBGT varies from 28 to 32 °C and sometimes above 32 °C in NEI conditions; according to ACGIH guidelines, this is a sign of heat stress (Kashyap et al. 2017).

Apart from this, heat stress is the outcome of a combination of climatic and non-climatic factors that cause heat strain in the body by convection or radiant heat gain or inhibit heat dissipation (Kashyap et al. 2017). Elevated heart rate, increased body-core temperature and other thermal indices, and perspiration are all physiological responses to heat stress when the body's ability to control its internal

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temperature begins to fail (Lumingu and Dessureault 2009; Singh et al. 2017). Increased heart rate is a sign of cardiac stress, which can be caused by physical exertion or heat exposure (Parsons 2002; Dey et al. 2007).

In addition, ISO 7243 is a heat stress standard based on the WBGT index, presented by Parsons K (2006), who considered its applicability for application worldwide (Parsons 2006). The WBGT index is calculated in the following way by commercial heat stress monitors (Singh et al. 2017):

$$WBGT = 0.7\ t_{wb} + 0.2\ t_{gt} + 0.1\ t_{db} \quad \text{.... (outdoors)}$$
$$= 0.7\ t_{wb} + 0.3\ t_{gt} \quad \text{.... (indoors)}$$

Where, t_{wb} = wet bulb temperature, t_{db} = dry bulb temperature, and t_{gt} = globe temperature

Because of the combined influence of the external thermal environment and heat created by interior organs owing to heavy muscular exertion, heat exposure is difficult for specific occupations such as agriculture (Riccò 2018). According to the International Labour Organization (ILO), agriculture and construction workers would be the hardest hit by environmental heat. Between 1995 and 2030, the agricultural sector alone accounted for 83 percent of global working hours lost and it will be missed owing to heat stress (ILO 2019). Heat stress is a significant factor in the lives of those who work in hot environments for long periods, according to Dash and Kjellstrom (Dash and Kjellstrom 2011). In most parts of India, climate change may result in a large increase in heat events and, thus heat stress occurred throughout the summer months. Heat stress has a detrimental impact on the local economy and family income by affecting workplace health as well as productivity (Keim et al. 2002). Sahu et al. (2013) experimented on rice harvesters in heat exposure conditions. They observed that most workers reported tiredness and pain on hot days. They concluded that in agriculture, excessive heat exposure resulted in heat exhaustion and decreased yield. Climate change will compound this decline, potentially jeopardizing the local economy (Sahu et al. 2013).

In addition, the NER has a wide range of agro-climatic conditions and topography (hills and valleys), with roughly 70% of the region being hilly (Yadav et al. 2013, 2019; Meena and Yadav 2014). Rice, the NER's basic food (Singh et al., 2019, 2020) , is grown on roughly 3.5 million hectares (Mha) against the 44 million ha of India (TNAU, 2011; Sahu et al. 2013), which accounts for nearly 8% of the country's land area and 6.5 percent of its rice production (Choudhary et al. 2016; Yadav et al. 2019). Rice transplanting in the Northeast is mostly done by hand due to a lack of suitable mechanization. Rice is transplanted in the NEI during the summer season, which runs from June through August, the hottest months in the region. Due to direct contact with external heat during specific months, farmers in the NE region are susceptible to heat stress. Agriculture is a crucial industry that necessitates a large amount of human workforce (FICCI 2015; Pal and Chattopadhyay 2020; Pal et al. 2021). The decline in human health will directly impact agriculture, which is the primary requirement of humans. It is well known that high WBGT has an impact on the physiology of workers. Furthermore, there have been very few studies on this topic in the NEI region. Hence, a detailed study to assess the impact of WBGT on the thermal and physiological responses of North Eastern Indian agricultural workers during paddy transplanting operations will be beneficial for the policymaker to determine the climate change effect on NEI agricultural workers' working capacity.

2. Materials and Methods

2.1 Design of Experiments

The assessment of physiological and thermal responses of NEI agricultural workers at different WBGT conditions (27 ^{0}C to 32 ^{0}C), ten farmers (n=10) were selected for manual rice transplanting operation in open rice filed from June to July 2021. The experiment took place in NEI, at 27.1305^{0} N and 93.7408^{0} E, respectively, in the nearby village of NERIST, Nirjuli Village –I. During the months of the experiment, the average temperature, wind speed, and relative humidity were 33 ^{0}C, 0.7 km/hr, and 81 percent, respectively, resulting in a significant heat stress situation in the experimental location. All elements of the study were carried out by ACGIH, ISO guidelines, and research committee ethical standard.

2.2 Population to be studied

The experiment was carried out on ten male agricultural workers based on anthropometric characteristics between the 5th and 95th percentile, and these ten workers handled all of the study's operations. The chosen ten farmers were in the age range of 20 to 40. All of the subjects chosen were instructed not to chew tobacco or consume any form of alcoholic beverage from the day head of the experiment. To meet the required heat stress, a ten-day period of clear skies was chosen between June to July. Based on functional WBGT temperature (27-28 ^{0}C, 29-30 ^{0}C & 31-32 ^{0}C), the paddy transplanting operation was carried out in three separate sessions: morning (8 to 10 AM), afternoon (11 AM to 1 PM), and evening (3 to 5 PM). It was considered ±1^{o}C for each observation of WBGT in the field experiments. Subjects were requested to conduct the transplanting operation continuously for a maximum of one hour to determine the influence of heat stress on physical and thermal responses. A single subject was chosen for the experiment in a day.

Before the ergonomic test, the chosen volunteers were familiarised with the equipment. Anthropometric measurements were taken, including weight (kg), age (years), height (cm), and heart rate (bpm). To establish the differential between total body weight and body fat weight, it was used Hume's formula to calculate lean body weight (LBM) (1966) (Hume 1966). The DuBois and DuBois formula was used to calculate the BSA (body surface area) given individual subject weight and height (Shuter and Aslani 2000).

BMI (body mass index) was computed by calculating the weight (kg) per square of their height (m^2). The mean value of the physical characteristics of rice workers(n=10) involved in the field experiment is presented in Table 1.

The study was conducted in an open rice field on male agricultural workers of Arunachal Pradesh with considering the following independent and dependent variables

i) Independent variables: WBGT, Temperature, Humidity, Wind speed, etc.
ii) Dependent variables: HR, Oxygen uptake, Energy expenditure, etc.

2.3 Instrumentation

Major instruments used for conducting the field experiments are an infrared thermometer, digital thermometer, COSMED Fitmate PRO, polar heart rate monitors, thermo-anemometer, WBGT meter, weighing machine, measuring tape, etc.

Table 1. Mean value of physical characteristics of rice workers involved in the field experiment(n=10)

Sl. No.	Particulars	Statistic of Subjects
1	Height (cm)	161.80±1.93
2	Weight(Kg)	60.20±3.08
3	Age(yr)	29.10±5.54
4	BMI(m^2)	22.98± 0.77
5	BSA(kg/m^2)	1.64±0.048
6	LBM (kg)	45.12 ± 1.59
7	HR_{max} (bpm)	185.86 ±3.79

Figure 1. Infrared Thermometer

Figure 2. Digital Thermometer

Figure 3. Fitmate PRO

Figure 4. HR Monitor

Figure 5. Thermo-Anemometer

Figure 6. WBGT Meter

An Infrared thermometer (Model: GILMA, Measurement Accuracy: 98%, Memory Feature: save up to 30 temperature readings) was used to measure the head and forehead temperatures of ten subjects (Fig. 1). Skin temperature was measured in four points of the body surface (ISO 4-points method) during the work described in the results and discussion.

A digital clinical thermometer (Accuracy: normally in 1 minute with 0.1 °C, Range: 32.0 °C to 42.9 ^{0}C) was also used to measure the oral temperature (core body temperature) of the subjects during the experiment (Fig. 2). Fitmate pro (Accuracy variation: ±0.02%, Range: 0-22% O_2 Measurement, Made by Cosmed Italy) was used to measure oxygen consumption (VO_2) during the field experiment (Fig. 3). A heart rate monitor (Polar M200, GPS facility, Operating temperatures are 0 ^{0}C to 50 ^{0}C) was used to measure heart rate during the experiment (Fig. 4). Thermo-Anemometer (Model: AN100, Brand: Extech, Accuracy variation ±3%) was used to measure air velocity at the experimental place (Fig. 5). A WBGT meter (RS-232 PC Interface, Range: 0 to 50 ºC, TG Black Globe Temperature Range: 0 to 80 ^{0}C, Accuracy:±2 ^{0}C, RH Range: 0 to 100%, Accuracy variation:±3%) also used for measuring WBGT in the experimental field condition (Fig. 6).

2.4 Statistical analysis

A computerized system was used to extract data from the above-mentioned instruments for statistical analysis. The results were expressed as the mean, standard deviation (SD), *t*-value, and *p*-value with the help of paired *t*-test in NCSS software. The significance (*p*-value) also check by paired *t*-test. It was considered that a *p*-value of less than 0.05 was statistically significant.

3. Results

The environmental parameters like dry air temperature, globe bulb temperature, natural wet temperature, and relative humidity (RH) were measured by the WBGT meter. All measurements were performed by following ISO-7243.

A. Measuring heart rate

B. Measuring oxygen uptake(VO_2)

C. Measuring oral temperature

D. Measuring forehead temperature

Figure 7. Evaluating thermal and physiological responses during field experiments

After consulting the Indian Meteorological Department's website in Pune, www.imd.gov.in, the clear days were chosen for conducting the experiments. The following were the parameters that were recorded during resting and working conditions at different WBGT temperatures:

1. Impact of WBGT on Heart Rate
2. Impact of WBGT on Oxygen Uptake
3. Impact of WBGT on Skin Temperature
4. Impact of WBGT on Oral Temperature
5. Impact of WBGT on Head Temperature
6. Impact of WBGT on Forehead Temperature

3.1 Impact of WBGT on heart rate

The participating farmers were asked to perform rice transplanting operations for 50 min on each experimental day. The subject performed the transplantation at a rate that is comfortable for them. Out of 50 minutes of heart rate (HR), the first five minutes show a resting heart rate, while the remainder of HR for 45 minutes shows a working heart rate (Fig. 7 A). A wearable heart rate monitor was used to measure heart rate every minute. The working heart rate is a good indicator of workload on the subject. The mean resting heart rate of farmers at WBGT of 27-28 ^{0}C varies from 78 to 82 bpm, WBGT of 29-30 ^{0}C varies from 80 to 85 bpm, and WBGT of 31-32 ^{0}C varies from 81 to 87 bpm.

It was noticed during the field experiment that the working heart rate of farmers during rice transplanting at 27-28 ^{0}C WBGT varies from 83 to 108 bpm, at 29-30 ^{0}C WBGT varies from 88 to 117 bpm and at 31-32 ^{0}C WBGT varies from 92 to 122 bpm ($p<0.05$) (Fig. 8). The rising trend in working heart rate was a result of heat stress generated by an increase in WBGT. The mean value of HR during the transplanting operation was found to be 108,112 &114 bpm, respectively in the WBGT of 27-28 ^{0}C, 29-30 ^{0}C & 31-32 ^{0}C($p<0.05$).

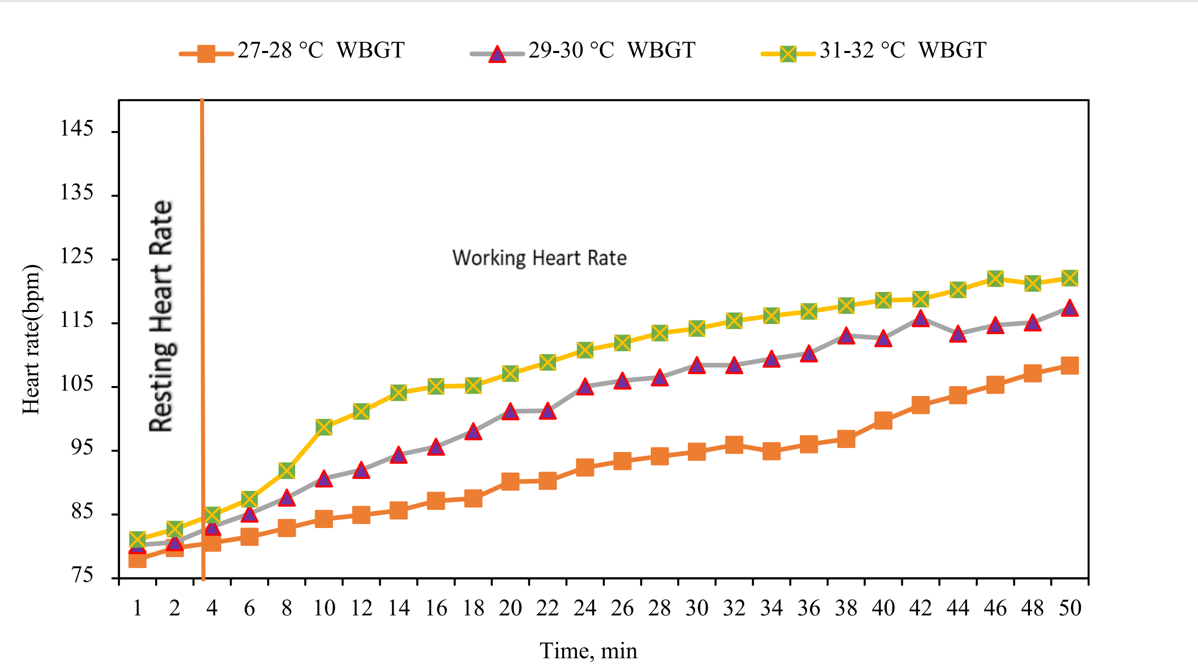


Figure 8. Graphical presentation of resting & working heart rate at different WBGT in field conditions

The data were statistically analyzed with the help of NCSS software to determine the significance of the influence of WBGT on working heart rate. Table 2 A & B shows paired *t*-tests of heart rate variance with WBGT.

Table 2 A & B present the statistical analysis of heart rate at different WBGT in Field Condition

A. Comperative analysis for 27-28 °C WBGT and 29-30 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	92	9	9	11.54	0.0001
29-30 ^{0}C WBGT	10	102	12			

B. Comperative analysis for 27-28 °C WBGT and 31-32 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	**10**	92	12	9	13.83	0.0001
31-32 ^{0}C WBGT	**10**	108	13			

3.2 Impact of WBGT on oxygen uptake

The stroke volume, heart rate, and arteriovenous oxygen differential all influence oxygen uptake (VO_2). When it's hot outside, blood pools in the skin veins to distribute more heat across the skin, resulting in less venous return to the heart, which causes stroke volume to drop and heart rate to rise to compensate. VO_2 was measured during 25 min of transplanting work and 5 min of resting for each WBGT condition (Fig. 7B). VO_2 at resting varies from 5.18 to 5.23 kg/ml/min at 27-28 ^{0}C, 5.73 to 5.78 kg/ml/min at 29-30 ^{0}C, and 6.05 to 6.33 kg/ml/min at 31-32 ^{0}C respectively. It was also observed mean VO_2 during the transplanting of rice varies from 5.88 to 11.83 kg/ml/min at 27-28 ^{0}C, 6.24 to 16.44 kg/ml/min at 29-30 ^{0}C, and 7.14 to 17.37 kg/ml/min at 31-32 ^{0}C respectively (Fig. 9) (p<0.05).VO_2 was higher under higher WBGT circumstances (31-32 ^{0}C) compared to those under a more moderate condition due to the increase in stroke volume and blood flow to the working muscles affected by the hot environment.

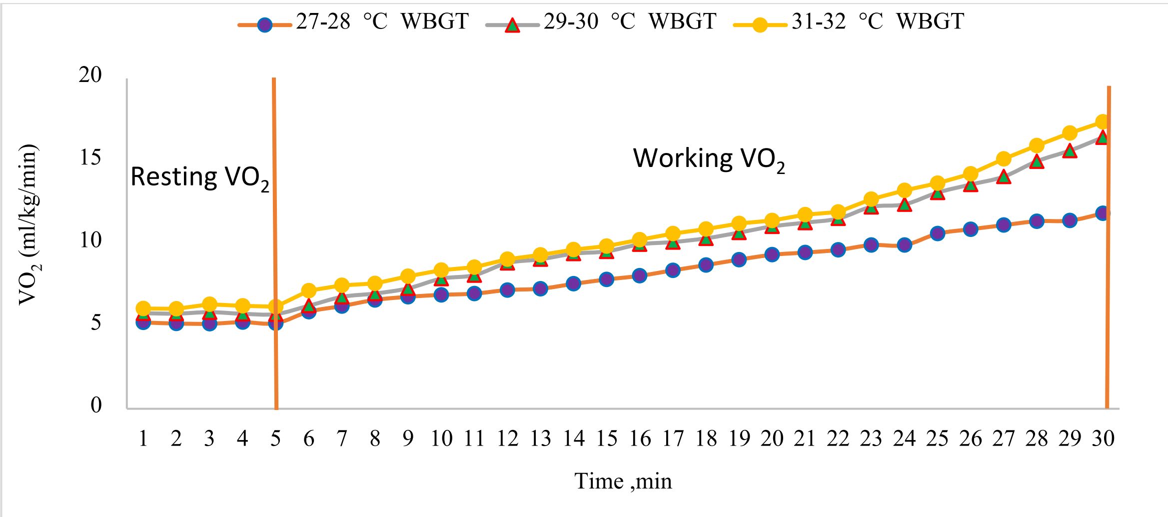


Figure 9. Graphical presentations of oxygen uptake (VO_2) at different WBGT in field conditions

The data were statistically analyzed with the help of NCSS software to determine the significance of the influence of WBGT on working VO_2. Table 3 A & B shows paired *t*-test of VO_2 variance with WBGT.
Table 3 A & B present the statistical analysis of oxygen uptake (VO_2)

A. Comperative analysis for 27-28 °C WBGT and 29-30 °C WBGT

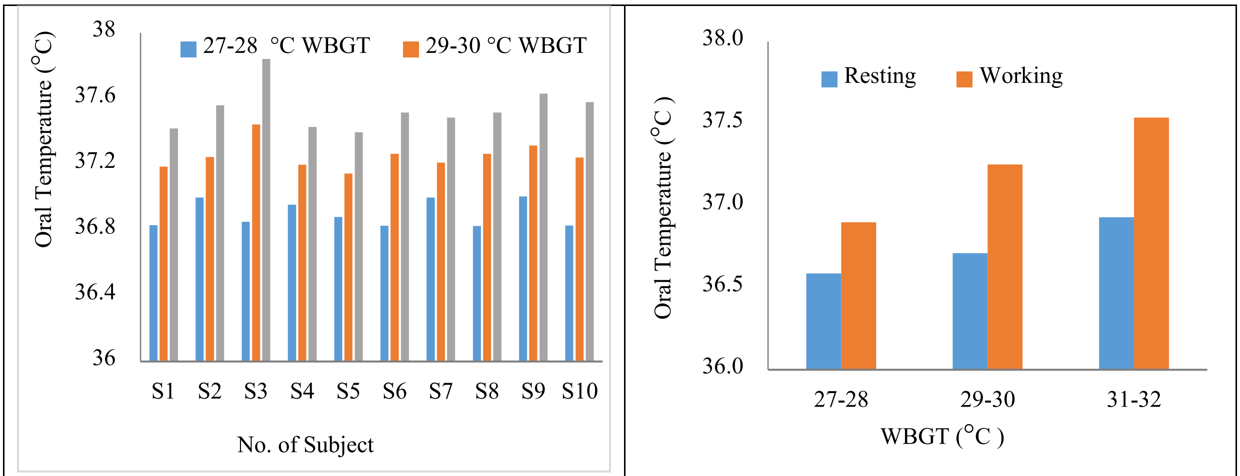
Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	8.15	2.12	9	8.40	0.0001
29-30 ^{0}C WBGT	10	9.87	3.18			

B. Comperative analysis for 27-28 °C WBGT and 31-32 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	8.15	2.12	9	9.88	0.0001
31-32 ^{0}C WBGT	10	10.42	3.31			

3.3 Impact of WBGT on oral temperature

The oral temperature was considered as a core body temperature during the field experiment. It was also considered hypothetically that oral temperature increase with heat stress conditions. The average oral temperature during resting condition was 36.59 ^{0}C at 27- 28 ^{0}C WBGT, 36.71^{0}C at 29-30 ^{0}C WBGT, and 36.93 ^{0}C at 31- 32 ^{0}C WBGT respectively. It was also observed that the average oral temperature during working conditions was 36.89 ^{0}C at 27-28 ^{0}C WBGT, 37.25 ^{0}C at 29-30 ^{0}C WBGT, 37.53 ^{0}C at 31-32 ^{0}C WBGT, respectively) (p<0.05) (Fig. 7C). Fig. 10 (A) presents the variation of the oral temperature of an individual subject at different WBGT. Fig. 10 (B) represents a bar diagram of the variation of resting and working oral temperature at different WBGT conditions. Due to high humidity and warmth in higher WBGT conditions, core body heat is not able to transfer from the body to the surrounding, which leads to a rise in oral temperature. The oral temperature increased as WBGT increased owing to heat stress & raising a chance of heat stroke probability as the temperature above 37 ^{0}C at 31- 32 ^{0}C WBGT.



A. Variation of the oral temperature of selected subjects at different WBGT

B. Variation of resting and working oral temperature at different WBGT conditions

Figure 10. Responses of oral temperature with different WBGT

The data were statistically analyzed with the help of NCSS software to determine the significance of the influence of WBGT on working oral temperature. Table 4 A & B shows paired t-tests of oral temperature variance with WBGT.

Table 4 A & B Statistical analysis of oral temperature for three different WBGT conditions

A. Comperative analysis for 27-28 °C WBGT and 29-30 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	36.89	0.09	9	7.96	0.0001
29-30 ^{0}C WBGT	10	37.24	0.08			

B. Comperative analysis for 27-28 °C WBGT and 31-32 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	36.90	0.09	9	13.33	0.0001
31-32 ^{0}C WBGT	10	37.53	0.12			

3.5 Impact of WBGT on skin temperature

During the work, skin temperature was measured at four points on the body surface (ISO 4-points method) Right shin, Neck, Right scapula, and Left hand (Fig. 11). The skin temperature was calculated in degrees Celsius as follows (1)(Nassiri et al. 2017):

Mean skin temperature = (Right shin x 0.28) + (Neck x 0 .28) + (Right scapula x 0.28) + (Left hand x 0.16) ... *(1)*

Constant values here represent the ratio of the selected skin surface area to the size of the entire skin surface of the body.

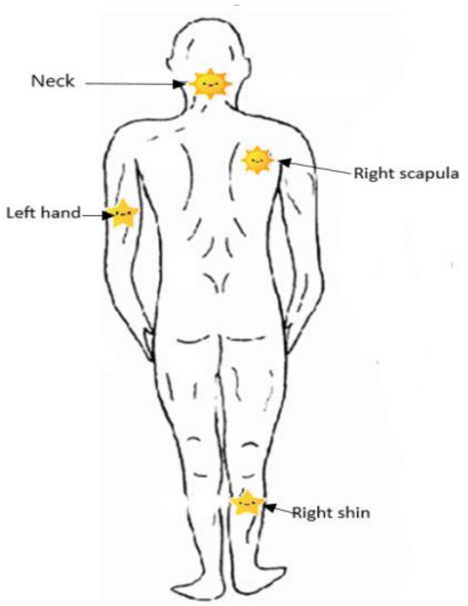
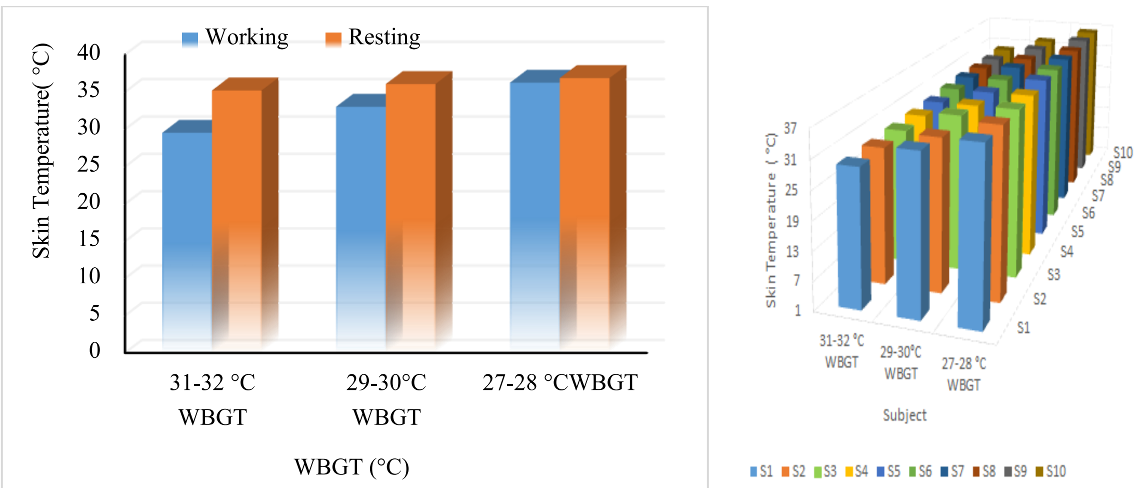


Figure 11. Points of skin temperature measurement

The average skin temperature during the resting condition for 5 min was 36.87 ^{0}C at 27- 28 ^{0}C WBGT, 36.07 ^{0}C at 29-30 ^{0}C WBGT, 35.22 ^{0}C at 31- 32 ^{0}C WBGT. It was also observed the average skin temperature during the working condition for 25 min was at 36.25 ^{0}C 27- 28 ^{0}C WBGT, 33.03 ^{0}C at 29-30 ^{0}C WBGT, 29.46 ^{0}C at 31- 32 ^{0}C WBGT (p<0.05). Fig. 12 (A) presents the variation of resting and working skin temperature at different WBGT. Fig. 12 (B) represents a bar diagram of the variation of skin temperature of selected subjects at different WBGT.



A Variation of resting and working mean skin temperature at different WBGT

B Variation of working skin temperature of selected subjects at different WBGT

Figure 12. Thermal responses in the form of skin temperature with different WBGT

The data were statistically analyzed with the help of NCSS software to determine the significance of the influence of WBGT on working skin temperature. Table 5 A & B shows paired *t*-tests of skin temperature variance with WBGT

Table 5 A & B Presenting the statistical analysis of skin temperature

A. Comperative analysis for 27-28 °C WBGT and 29-30 °C WBGT

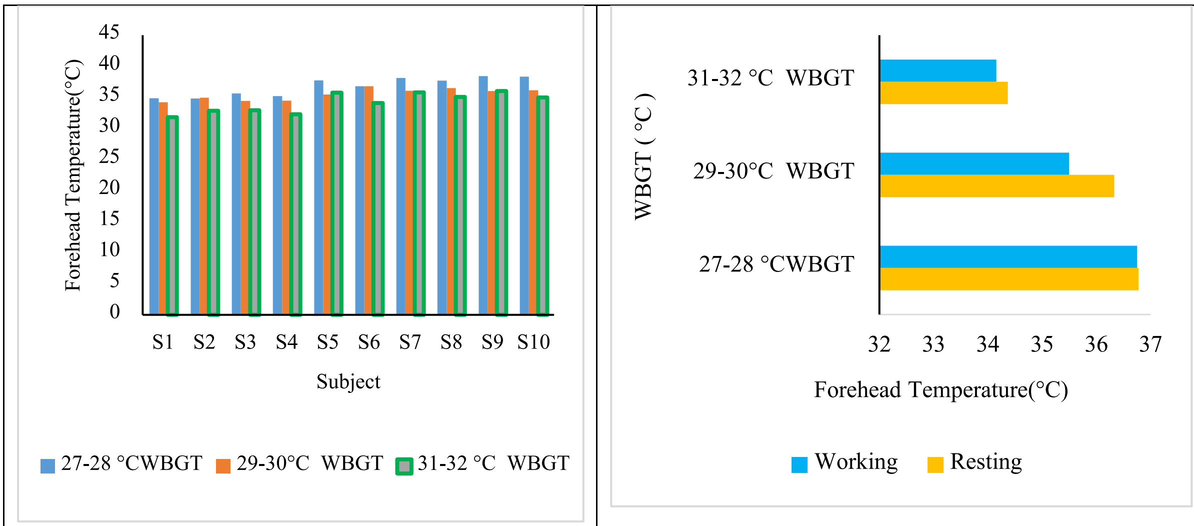
Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	36.27	0.26	9	25.00	0.0001
29-30 ^{0}C WBGT	10	33.07	0.44			

B. Comperative analysis for 27-28 °C WBGT and 31-32 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	36.27	0.26	9	70.97	0.0001
31-32 ^{0}C WBGT	10	29.46	0.12			

3.6 Impact of WBGT on forehead temperature

The average forehead temperature during the resting condition for 5 min was 36.77 ^{0}C at 27- 28 ^{0}C WBGT, 36.32 ^{0}C at 29-30 ^{0}C WBGT, 34.36 ^{0}C at 31- 32 °C WBGT. The average forehead temperature during the working condition for 25 min was 36.75 ^{0}C at 27- 28 ^{0}C WBGT, 35.50 ^{0}C at 29-30 ^{0}C WBGT, 34.15 ^{0}C at 31- 32 ^{0}C WBGT (Fig. 7 D) (Fig 13) (P<0.05). Fig 13 (A) represents a bar diagram of the variation of forehead temperature of selected subjects at different WBGT during the working condition. Fig 13 (B) presents the variation of resting and working forehead temperature at different WBGT. With an increase in WBGT, the temperature of the forehead was found to drop. At high WBGT, there was a lot of sweating, which caused the forehead temperature to drop.



A Variation of forehead temperature of selected subjects at different WBGT

B Variation of resting and working forehead temperature at different WBGT

Figure 13. Graphical presentations of forehead temperature at different WBGT in field condition

The data were statistically analyzed with the help of NCSS software to determine the significance of the influence of WBGT on working forehead temperature. Table 6 A & B shows paired *t*-tests of forehead temperature variance with WBGT.

Table 6 A & B Statistical analysis of forehead temperature for three different WBGT conditions

A. Comperative analysis for 27-28 °C WBGT and 29-30 °C WBGT

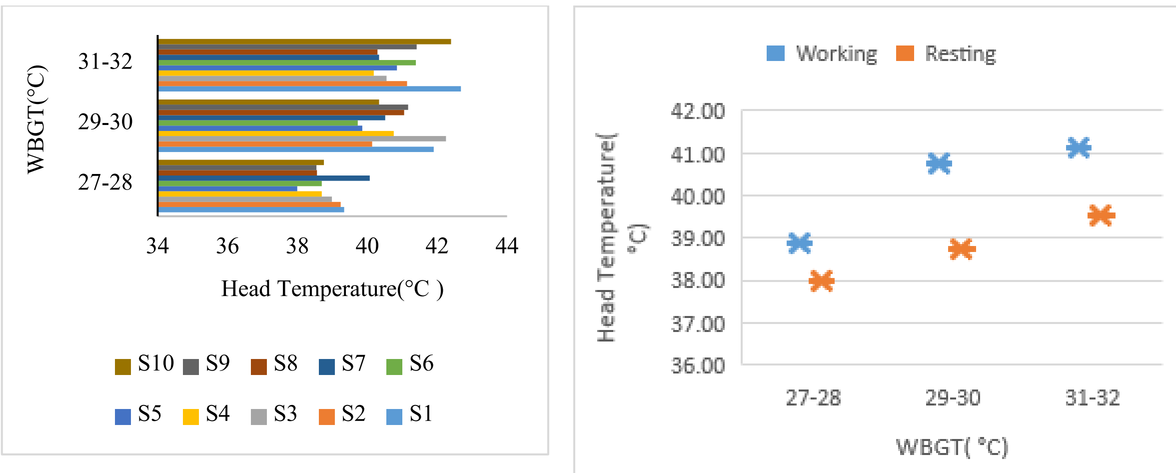
Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	36.75	1.48	9	4.25	0.0021
29-30 ^{0}C WBGT	10	35.50	0.92			

B. Comperative analysis for 27-28°C WBGT and 31-32 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	36.75	1.48	9	18.65	0.0001
31-32 ^{0}C WBGT	10	34.15	1.58			

3.7 Impact of WBGT on head temperature

The average head temperature during resting condition was 37.99 ^{0}C at 27- 28 ^{0}C WBGT, 38.73 ^{0}C at 29-30 ^{0}C WBGT, and 39.55 ^{0}C at 31- 32 ^{0}C WBGT (Fig 14). The average head temperature during working conditions was 38.88^{0}C at 27- 28 ^{0}C WBGT, 40.77^{0}C at 29-30 ^{0}C WBGT, and 41.12 ^{0}C at 31- 32 ^{0}C WBGT (Fig.14) ($P<0.05$). Fig 14 (A) presents a bar diagram of the variation of head temperature of selected subjects at different WBGT during the working condition. Fig 14 (B) represents the variation of resting and working head temperature at different WBGT. The head temperature was much influenced by WBGT according to an earlier study (Yao et al. 2008; Heidari et al. 2015; Kashyap et al. 2017). Because the Head absorbs direct solar radiation, its temperature increased as WBGT increased owing to heat stress.



A Variation of the head temperature of selected subjects at different WBGT

B Variation of resting and working head temperature at different WBGT

Figure 14. Graphical presentations of head temperature at different WBGT in Field Conditions

The data were statistically analyzed with the help of NCSS software to determine the significance of the influence of WBGT on working head temperature. Table 7 A & B shows paired *t*-tests of head temperature variance with WBGT.

Table 7 A & B Statistical analysis of head temperature for three different WBGT conditions

A. Comperative analysis for 27-28 °C WBGT and 29-30 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	38.88	0.56	9	6.65	0.0001
29-30 ^{0}C WBGT	10	40.77	0.83			

B. Comperative analysis for 27-28 °C WBGT and 31-32 °C WBGT

Condition	Sample	Mean	SD	df	*t*-value	*p*-value
27-28 ^{0}C WBGT	10	38.88	0.56	9	6.90	0.0001
31-32 ^{0}C WBGT	10	41.12	0.86			

4. Discussion

The field experiment was conducted on ten farmers to evaluate the physiological and thermal responses in an open rice field under three different WBGT conditions in the hot summer of NEI. The findings show that the WBGT causes heat stress in farmers' bodies, as statistical analysis of data was highly significant with increasing WBGT ($p<0.05$). It was observed that heart rate and oxygen consumption which reveal the physiological response, were increasing in trend with the increasing WBGT from 27 ^{0}C to 32 ^{0}C. Forehead and skin temperature was observed to decrease with the increase of WBGT from 27 ^{0}C to 32 ^{0}C due to heavy sweating and highly humid condition during the rice transplanting operation. Oral (core body temperature) and head temperature were observed to increase with the increase in WBGT. It was also noticed that in the case of a few subjects CBT more than 37 ^{0}C at 31-32 ^{0}C that is led to the increasing threat of heatstroke WBGT. The Head absorbs direct solar radiation and hence its temperature increases with an increase in WBGT due to heat stress. The physiological and thermal responses are much influenced by WBGT, according to an earlier study (Yao et al. 2008; Heidari et al. 2015; Singh et al. 2017; Kashyap et al. 2017). After analyzing all data of the field experiment, it was reached the decision that farmers of NEI are impacted by heat stress conditions during the summer session of an agricultural operation under open sunny climatic conditions. Further, proper design of the work-rest schedule can minimize the physiological and thermal responses of farmers under higher WBGT conditions. Moreover, for sustainable agriculture in NEI conditions, introduce of proper heat gear, and a cooling vest is essential to minimize the increase in head temperature and skin temperature of agricultural workers during field operations in which they are exposed to direct sunlight.

5. Conclusions

In order to analyze the physiological and thermal responses of NEI agricultural workers in an open rice field under three distinct WBGT circumstances during the hot summer of NEI, a field experiment was undertaken with ten farmers. After analyzing all data of the field experiment, it was reached the decision that farmers of NEI are impacted by heat stress conditions during the summer session of an agricultural operation under open sunny climatic conditions. Further, proper design of the work-rest schedule can minimize the physiological and thermal responses of farmers under higher WBGT conditions. Moreover, for sustainable agriculture in NEI conditions, introduce of proper heat gear, and a cooling vest is essential to minimize the increase in head temperature and core body temperature of agricultural workers during field operations in which they are exposed to direct sunlight.

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