Original Research Article

Assessment of heat stress on human physiology, thermal and physical discomfort of male farm worker

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ABSTRACT

India is characterized by strong temperature variations in different seasons ranging from mean temperature of about 10°C in winter to about 32 °C in summer season (Attri and Tyagi, 2010). The temperatures start to increase all over the country in March and by April; the interior parts of the peninsula record mean daily temperatures of 30-35 °C. Heat stress is a condition that is caused by worker's over-exposure to the high temperature work environments often found in outdoor agriculture operations. Workers should be informed of the nature of heat stress and its adverse effects as well as the protective measures provided in the workplace. This operation was performed by traditionally used manually operated sickle, when the average dry bulb temperature was above 32°C which caused the heat stress during the work because of high humidity in the field. Head temperature, forehead temperature, oral temperature, left lower hand temperature, middle left-hand temperature, upper right-hand temperature, left upper chest temperature, right scapula temperature, left calf temperature and right anterior thigh temperature were measured to assess the effect of environmental heat direct sun radiation on selected farm workers during both the agricultural operations. To assess the effect of heat on the human body, physiological parameters like heart rate (HR) and oxygen consumption rate (OCR). Thermal parameters like oral, head, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh, mean skin temperatures of farm workers increased with increase in WBGT due to heat stress.

Commented [WU2]: The abstract is detailed but overly descriptive and lacks clarity in its focus. It can be improved by condensing repetitive temperature data and focusing on the main objectives, methods, and findings.

Keywords: *Heat stress, Skin temperature, Heart rate, oxygen consumption rate, headgear, etc*

INTRODUCTION

Commented [WU3]: The introduction provides an overview of the growing concern over heat stress in agricultural workers, outlining its significant impacts on human physiology, thermal regulation, and physical discomfort. A review of existing literature highlights the current understanding of heat stress effects, yet a noticeable gap remains in assessing its comprehensive influence on male farm workers in specific climatic conditions.

India has the second largest population in the world, with 121 million people comprising 623.7 million males and 586.5 million females, according to the provisional 2011

Census report. Report on second annual Employment & Unemployment Survey (2011-12) reported that, 50.8 per cent or majority of the households are found to be having self employment as the major source of income under agricultural and related activities. It covers an area of 3.28 million square kilometres. As per the National Sample Survey Organisation's (NSSO) report on Employment and Unemployment Situation in India 2009-10, on the basis of usually working persons in the principal status and subsidiary status, for every 1000 people employed in rural and urban India, 679 and 75 people are employed in the agriculture sector, 241 and 683 in services sector (including construction) and 80 and 242 in the industrial sector, respectively. Agriculture and allied sectors achieved a growth rate of 2.82 percent in 2011-12 with food grains production of 246.2 million tonnes. Agriculture including allied activities accounted for 14.1 percent of Gross Domestic Product (GDP) in 2011-12. Adoption of high yielding varieties by the farmers coupled with the use of higher doses of fertilizer and assured irrigation through tube wells accelerated the pace of progress of agriculture.

Most of the agricultural operations in the country are still being performed by manual labour. Famer has to work under open sun from starting to the end of the cultivation. High drudgery and low income is the main hurdle in agricultural production. Ploughing, sowing, intercultural operations and harvesting are the main agricultural operations which are being performed in hot sunny days; some of them are performed by manual tools.

India is characterized by strong temperature variations in different seasons ranging from mean temperature of about 10°C in winter to about 32 °C in summer season (Attri and Tyagi, 2010). The temperatures start to increase all over the country in March and by April; the interior parts of the peninsula record mean daily temperatures of 30-35 °C. Central Indian land mass becomes hot with daytime maximum temperatures reaching about 40°C at many locations. Many stations in Gujarat, North Maharashtra, Rajasthan and North Madhya Pradesh exhibit high day-time and low night-time temperatures during this season. The range of the daytime maximum and night-time minimum temperatures is found more than 15 °C at many stations in these States. Maximum temperatures rise sharply exceeding 45 °C by the end of May and early June resulting in harsh summers in the north and north-west regions of the country. Maximum temperature attained at important stations of Rajasthan during May & June 2011 (Anonymous, 2011). Maximum temperature up to 49 °C was recorded in Phalodi of Rajasthan in 2011(Anonymous, 2011).

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Heat stress is a condition that is caused by worker's over-exposure to the high temperature work environments often found in outdoor agriculture operations. The best protection against heat stress is to educate and train the workers on the best practices for heat stress prevention. Heat stress is a build-up of heat in the body generated by muscle use and surrounding conditions. It is the result of a combination of environmental conditions, work demands, and clothing requirements that are likely to increase body temperature when the body cannot adequately cool itself, injury, illness, or even death can occur. The more intense the work, the hotter the conditions, and the higher the humidity, the faster heat will be generated and the body will struggle to get rid of excess heat.

Workers should be informed of the nature of heat stress and its adverse effects as well as the protective measures provided in the workplace. They should be taught that heat tolerance depends to a large extent upon drinking enough water and eating a balanced diet. In addition, workers should be taught the signs and symptoms of heat disorders, which include dizziness, faintness, breathlessness, palpitations and extreme thirst. They should also learn the basics of first aid and where to call for help when they recognize these signs in themselves or others.

MATERIAL AND METHOD

Commented [WU5]: The methodology for assessing heat stress on male farm workers involved the following steps: The methodology for assessing heat stress on male farm workers involved the following steps: (1) Selection of farm workers and identification of outdoor agricultural operations, (2) Measurement of environmental parameters including temperature and humidity, (3) Monitoring of physiological responses such as heart rate and oxygen consumption, (4) Recording of thermal discomfort through skin temperature measurements at various body sites, (5) Calculation of the Wet Bulb Globe Temperature (WBGT) index, and (6) Statistical analysis of the relationship between environmental conditions and workers' physiological responses to heat stress.

One agricultural operation harvesting of wheat crop were selected for the study. This operation was performed by traditionally used manually operated sickle, when the average dry bulb temperature was above 32°C which caused the heat stress during the work because of high humidity in the field. Head temperature, forehead temperature, oral temperature, left lower hand temperature, middle left hand temperature, upper right hand temperature, left upper chest temperature, right scapula temperature, left calf temperature and right anterior thigh temperature were measured to assess the effect of environmental heat direct sun radiation on selected farm workers during both the agricultural operations. To assess the effect of heat on the human body, physiological parameters like heart rate (HR) and oxygen consumption rate (OCR) were measured with the help of Computerized Ambulatory Metabolic Measurement System ($K4b^2$) which records the oxygen consumed in every breath. Overall discomfort rate (ODR) was calculated using the 10-point psycho-physical rating scale.

RESULT AND DISCUSSION

4.4.1 Effect of WBGT on body thermal parameters

Experiments were conducted to assess the effect of environmental temperature on the body thermal responses. Effect of WBGT on oral, head, forehead, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh and mean skin temperature during the wheat harvesting operation was measured. Mean Value table of thermal parameters is shown in Table 1.

Table 1: Mean values of thermal parameters at different WBGT

Treatment	**28 ºC WBGT**	**30 ºC WBGT**	**32 ºC WBGT**	**Increasing in temperature**	**CD**	**CV**
Oral Temp.	36.7	36.8	36.9	0.20	0.30	0.67
Head Temp.	38.907	39.648	41.495	2.59	0.39	0.79
Forehead temperature	37.64	36.43	35.36	-2.28	0.58	1.29
Left lower hand temperature	36.657	37.908	38.645	1.99	0.58	1.25
Middle left hand temperature	34.77	36.59	37.8	3.03	0.58	1.29
Upper right hand temperature	33.32	33.99	34.93	1.61	0.28	0.67
Left upper chest temperature	31.99	33.11	34.16	2.17	0.28	0.69
Right scapula temperature	34.28	35.3	36.31	2.03	0.28	0.65
Left calf temperature	32.03	33.34	34.74	2.71	0.58	1.41
Right anterior thigh temperature	33.35	34.62	35.66	2.31	0.23	0.53
Mean Skin Temperature	34.24	35.22	36.16	1.92	0.27	0.61

It can be seen that oral, head temperature, forehead, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh and mean skin temperature difference varied from 0.2, 1.9, -2.28, 1.99, 3.03, 1.61, 2.17, 2.03, 2.71, 2,31 and 1.92°C respectively at WBGT of 28 °C to 32 °C.

The forehead temperature of subjects significantly decreases with the increase in WBGT at 1 per cent level of significance. Oral, head, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh and mean skin temperature of subjects significantly increase with increase in WBGT at 1 per cent level of significance.

The difference of CD 1 per cent at 1 per cent level was observed in all the mean values of oral, head, forehead, oral, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh and mean skin temperature. The graph of variation of thermal parameters with WBGT is given in Fig. 1.

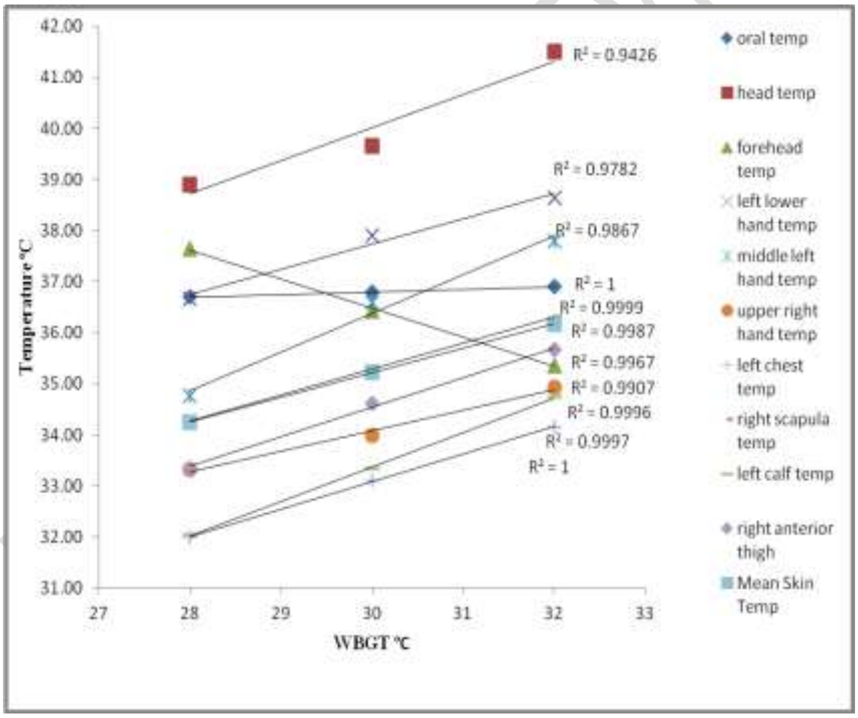

Fig. 1 Effect of WBGT on thermal parameter

There was a linear relationship and R^2 values were higher than 1 in all cases of variance of thermal parameters with WBGT which shows high degree of correlation. The forehead temperatures exhibited a negative linear trend while oral, head, forehead, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh and mean skin temperature showed positive linear trend with WBGT.

Forehead temperature was observed to decrease with the increase in WBGT. The decrease in temperature was because of condensation effect. The sweating caused in high WBGT conditions cools the skin as wind blows over the skin hence there is a drop in forehead temperature as the environmental heat increases. Oral, head, forehead, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh and mean skin temperature was observed to increase with increase in WBGT. Since oral temperature is also considered to be the core temperature of body, it increased with increase in WBGT. Head absorbs the direct solar radiations and hence its temperature increased with increase in WBGT due to heat deposition. It was also observed that the upper body parts have higher skin temperature as compared to the lower body parts. Similar observations were found by different researcher. Majid and Mansour (2006), Singh (2013), Dharaiya (2015) and Kashyap (2017) reported similar increase in oral temperature with the increase in WBGT.

Effect of WBGT on physiological responses

Experiments were conducted to assess the effect of environmental temperature on the physiological responses. Effect of WBGT on Heart Rate (Resting and Working) and Oxygen Consumption Rate (Resting and Working) during the harvesting of wheat operation were measured.

Effect of WBGT on heart rate

Resting Heart Rate and Working Heart Rate of the ten subjects were measured at different WBGT. Mean value table of Heart rates with WBGT is given below in Table 2.

Table 2: Mean Values of Heart Rates with WBGT

S. No.	Treatment	Resting HR beats/min	Working HR beats/min	Delta HR beats/min
1	28 ºC WBGT	77.86	117.03	39.17
2	30 ºC WBGT	78.96	122.04	43.08
3	32 ºC WBGT	80.91	129.05	48.14
	Mean	79.24	122.71	43.46

	CD at 1 per cent level of significance	4.82	4.82	4.82
	CV	4.90	3.17	3.90

It can be seen that Resting HR varied from 77.86 beats/min at WBGT of 28 °C to 80.91 beats/min at WBGT of 32 °C. Working HR varied from 117.03 beats/min at WBGT of 28 °C to 123.95 beats/min at WBGT of 32 °C.

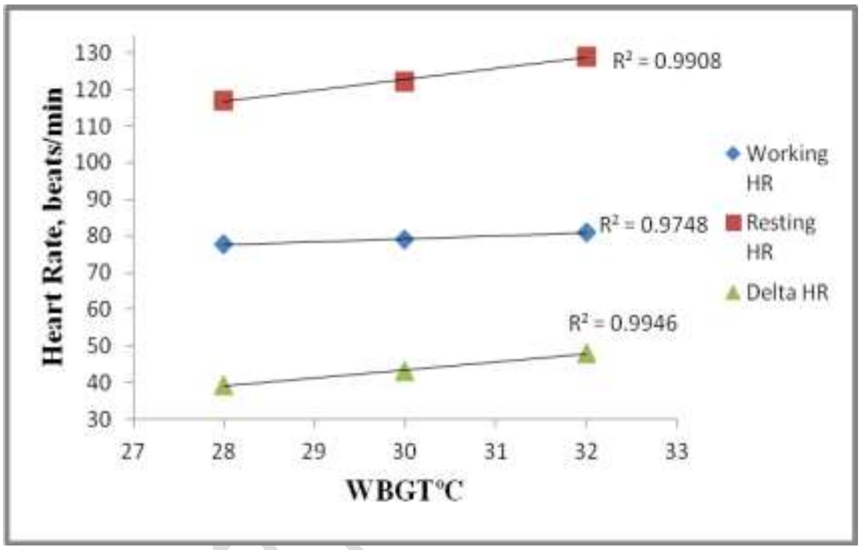

Fig. 2 Effect of WBGT on heart rate

In Fig. 2, resting and working heart rates were observed to increase with increase in WBGT. This increase in working heart rates was due to heat stress which was induced due to increase in WBGT. The increase in resting HR was found less in comparison to increasing in working HR with increase in WBGT. It reflects that there was more heat load during the work at higher WBGT. There was a linear relationship between HR and WBGT and R^2 values were higher than 0.9944 in all cases of variance of heart rates with WBGT shows high degree of correlation. Resting and working heart rates exhibited a positive linear trend with increase in WBGT. Suggs and Splinter (1961), Hori et al (1978) and Majid & Mansour (2006), Singh (2013) and Dharaiya (2015) also reported similar increase in heart rate with increase in environmental temperature.

Effect of WBGT on oxygen consumption rate

Resting and Working Oxygen Consumption Rate of the ten subjects were measured at different WBGT. Statistical analysis of the data was carried out to find out the significance of effect of WBGT on oxygen consumption rate. ANOVA table of oxygen consumption rates and their variance with WBGT is given in Appendix –I. Mean value table of Oxygen consumption rates with WBGT is given in Table 3.

Table 3: Mean values of oxygen consumption rates with WBGT

S. No.	Treatment	Resting OCR (ml/min)	Working OCR (ml/min)	Delta OCR (ml/min)
1	28 ºC WBGT	191.29	718.25	527.75
2	30 ºC WBGT	204.89	759.49	557.12
3	32 ºC WBGT	217.69	821.46	609.95
	Mean	204.62	766.40	564.94
	CD at 1 per cent level of significance	62.44	62.44	194.35
	CV	24.61	24.61	27.23

It can be seen that Resting OCR varied from 191.29 ml/min at WBGT of 28 °C to 217.69 ml/min at WBGT of 32 °C. Working OCR varied from 724.43 ml/min at WBGT of 28 °C to 778.65 ml/min at WBGT of 32 °C. The resting OCR of subjects significantly increase with every 2 ºC increase in WBGT at 1 per cent level of significance while working OCR of subjects significantly increase with every 2 ºC increase in WBGT at 1 per cent level of significance. The increase in working OCR was more than the resting OCR with increase in WBGT condition. It also signifies the effect of heat load on working condition is higher.

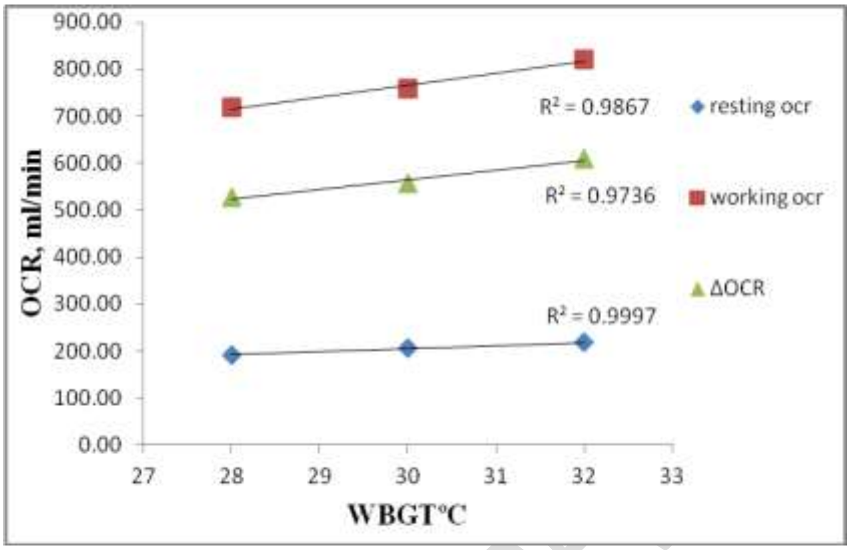

Fig. 3 Effect of WBGT on OCR

In Fig. 3, resting and working oxygen consumption rates were observed to increase with increase in WBGT. This increase was due to heat stress which was induced due to increase in WBGT. As the heart rate increased, oxygen consumption rate also increased. There was a linear relationship between WBGT and OCR and R^2 values were 0.99995 and 0.9997 for working and resting OCR respectively in all cases of variance of heart rates with WBGT showing high degree of correlation. Resting and working oxygen consumption rates exhibited a positive linear trend with increase in WBGT. Hori et al (1978), Al-Haboubi (1996) and Singh (2013) also reported similar increase in oxygen consumption rate with increase in environmental temperature.

4.4.3 Effect of WBGT on physical discomfort

Overall Discomfort Rate of the ten subjects were measured at different WBGT. Mean value table of overall discomfort rate with WBGT is given in table 4.

Table 4: Mean Values of Overall Discomfort Rate with WBGT

S. No.	Treatment	ODR
1	28 ºC WBGT	5.2
2	30 ºC WBGT	7.2
3	32 ºC WBGT	8
	Mean	6.8

	CD at 1 per cent level of significance	0.58
	CV	6.87

It can be seen from the ANOVA table in Appendix – I that ODR of subjects significantly increase with increase in WBGT at 1 per cent level of significance. The difference of CD at 1 per cent level of significance is observed in the mean values of ODR with increase in WBGT.

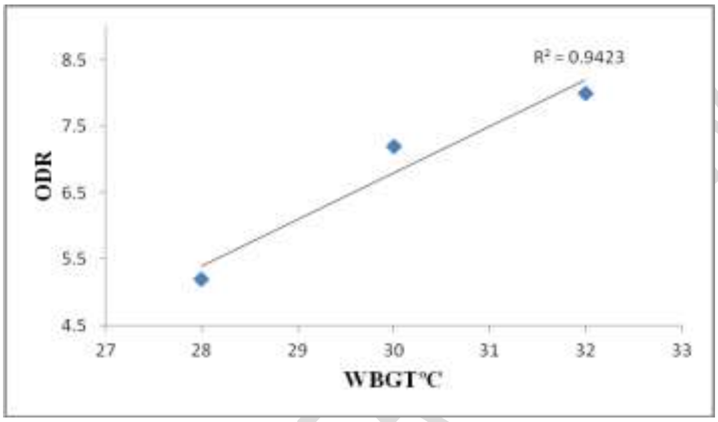

Fig. 4. Effect of WBGT on ODR

In Fig. 4, overall discomfort rates were observed to increase with increase in WBGT. This increase was due to heat stress which was induced due to increase in WBGT. There was a linear relationship between WBGT and ODR and R^2 value was higher than 0.942 which is very high showing high degree of correlation between ODR and WBGT. Overall Discomfort Rate exhibited a positive linear trend with increase in WBGT. Singh (2013) and Dharaiya (2015) also reported similar increase in ODR with increase in environmental temperature.

CONCLUSION

Commented [WU6]: The conclusion of the manuscript requires further updating to better summarize the findings, address potential implications for mitigation strategies, and provide clearer recommendations for future research on heat stress management for farm workers.

Thermal parameters like oral, head, left lower hand, middle left hand, upper right hand, left upper chest, right scapula, left calf, right anterior thigh, mean skin temperatures of farm workers increased with increase in WBGT due to heat stress. However, forehead temperatures decreased with increase in WBGT due to perspiration and evaporative cooling. Physiological parameters like resting and working heart rate as well as resting and working oxygen consumption rate increased with increase in WBGT. Overall Discomfort Rate (ODR) increased with increase in WBGT due to heat stress.

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