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Climatized packing house with evaporative coolers - part 1: Occupational heat exposure[1]

Packing house climatizado com resfriadores evaporativos - parte 1: Exposição ocupacional ao calor

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HIGHLIGHTS:
Evaporative coolers effectively reduced the temperature to levels of thermal comfort.
Occupational heat exposure limit was not reached in any production period, regardless of using evaporative coolers.
Without evaporative coolers, the relative humidity reached critical values in the afternoon during the dry period.

ABSTRACT: Agribusiness workers are regularly exposed to high temperatures, even in covered environments such as packing houses. This study aimed to assess the effect of evaporative coolers on reducing occupational heat exposure for workers and consequently improving the thermal comfort of the selection and packaging areas in a table grape packing house. The evaluation was conducted as per the criteria of the Brazilian legislation, based on the Regulatory Norms (NR's) 15 and 17 of the Department of Labor. The study was conducted during two climatic production periods, dry and rainy, with the evaporative coolers on and off. With the coolers on, the workers' occupational exposure to heat was reduced without exceeding the wet bulb globe temperature index tolerance limit for the activities carried out according to the NR 15. However, it did not provide adequate thermal comfort indices according to NR 17. Under semiarid conditions, coolers rendered the environment thermally comfortable for local workers. To reduce the risks to workers' health, it is suggested that they take breaks in case of discomfort from the heat and provide workers with water and mineral salts to replenish sweat loss.

Key words: ambiance, conditioners, thermal comfort, fruit processing unit

RESUMO: Os trabalhadores do agronegócio são expostos a condições de trabalho com altas temperaturas regularmente, mesmo em ambientes cobertos, como os packing houses. O objetivo deste estudo foi avaliar o efeito do uso de resfriadores evaporativos na redução da exposição ocupacional de trabalhadores ao calor e na melhoria do conforto térmico da área de seleção e embalagem de um packing house de uvas de mesa. A avaliação ocorreu de acordo com os critérios da legislação brasileira, aplicando-se as Normas Regulamentadoras (NR's) 15 e 17, do Ministério do Trabalho. O estudo ocorreu durante dois períodos climáticos de produção: seco e chuvoso, com os resfriadores evaporativos ligados e desligados. Com os resfriadores evaporativos ligados, houve redução da exposição ocupacional dos trabalhadores ao calor, sem ultrapassar o limite de tolerância da temperatura de bulbo úmido para as atividades desenvolvidas, de acordo com a NR 15. Contudo, não apresentou índices adequados de conforto térmico, segundo a NR 17. Para as condições de semiárido, os resfriadores tornaram o ambiente termicamente confortável para os trabalhadores locais. Para reduzir os riscos à saúde do trabalhador, sugere-se adotar pausas quando houver desconforto por calor e fornecer água e sais minerais aos trabalhadores para reposição das perdas por suor.

Palavras-chave: ambiência, climatizador, conforto térmico, unidade de beneficiamento de frutas

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Introduction

Processing units for agricultural products play a significant role in Brazilian agribusiness. Moreover, owing to the increasing demand for market quality and competitiveness, the resulting labor intensification has created unfavorable conditions for workers (Pinto et al., 2017). Therefore, owing to specific occupational risks, such as heat exposure, issues related to the health and safety of workers have become prominent elements in business management (Rosa & Lima, 2019). However, in Brazil, daily monitoring of heat exposure in rural areas has not been conducted, and research focusing on occupational health issues at these locations is scarce (Martins et al., 2017; Roscani et al., 2019).

Oliveira et al. (2020) emphasized that thermal discomfort can be exacerbated by continuous physical exertion, fatigue, dehydration, and poor nutrition. Increasing the risk of heat stress, even under moderately warm conditions, can result in reduced labor productivity (Orlov et al., 2021). Therefore, limiting heat exposure is of great interest to employers and their employees.

The use of evaporative cooling techniques for thermal adjustment of the environment is an energy-efficient method that is widely employed (Yang et al., 2019). However, it is grounded in several factors; the primary one being the health of facility users. This is because unlike air conditioning, air renewal, ease of operation, low maintenance requirements, and the need for technological alternatives consistent with the climate of each region are important factors (Chaudhari et al., 2015; Krüger et al., 2016).

Thus, this study assessed the effect of evaporative coolers on reducing occupational heat exposure for workers and improving the thermal comfort of the selection and packaging areas in a table grape packing house. Further, the study aimed to propose corrective measures to address the identified need to provide a thermally comfortable environment.

Material and Methods

The study was conducted within the selection and packaging area of a table grape packing house on a commercial farm located in Casa Nova, BA, Brazil (9° 12’ 55” S and 41° 12’ 05” W, with 405 m altitude). The local climate, classified as BSh according to Köppen, is semi-arid, characterized by being very hot and dry, with an average annual temperature of 27 °C and relative humidity of 50.63% (Alvares et al., 2013). The region has a low average annual precipitation that is unevenly distributed and concentrated in only three or four months. The highest amount of precipitation (298 mm) occurred between January and March. The months with the lowest precipitation were August and September, with a total precipitation of 6 mm.

The packing house was constructed using a reinforced concrete structure, metal roofing, and masonry in the external enclosures and internal divisions. It featured doors and openings to facilitate airflow into the environment. The roof had three divisions, one in an arch (central) and two in a waterfall design for the sides, with a ceiling height of 4.0 m and a total internal area of 640.20 m². It included 12 wind-driven roof ventilators with dimensions of 0.63 m in height, 0.90 m at its widest part, and 0.57 m at its end. In addition, there were 2 evaporative coolers, both with a power of 1.3 kW h^{-1}, an air flow rate of 36,000 m^3 h^{-1}, and an effective coverage area ranging as 180-280 m².

The methodology and procedures employed followed the criteria specified in regulatory standard (NR) No. 15 (BRASIL, 2019) and occupational hygiene standard (NHO) 06 (BRASIL, 2017). To collect data under real working conditions, the study was conducted during working hours from 8 am to 5 pm. Two production periods with different climatic conditions were considered: November 2019 (dry season) and March 2020 (rainy season).

Microclimatic data were recorded at 18 different points, one at each workbench, distributed along the processing line and spaced every 3.5 m. The analysis considered the averages of the points within three sectors: the start, middle, and end, as illustrated in Figure 1.

Four employees were positioned on each workbench, with two on each side working continuously, standing, and performing moderate arm and hand movements. These movements involved picking containers arriving from the field with approximately 8 kg of grapes from a conveyor at a height of 0.80 m and placing them on a bench at a height of 0.90 m. Subsequently, they selected, classified, and packed the fruits, and finally, placed the ready box for sale with 5 kg of grapes on the upper part of the conveyor at a height of 1.15 m.

Sensors were installed near the workers at a height of 1.5 m above the ground on metal structures specific to the facility. Tripods were not used (as is commonly done) to clear physical space and preserve routine work activities.

Hobo U12-013 data loggers (Onset Computer Corporation, Pocasset, MA, USA) were installed, with a temperature measurement range between -20 and 70 °C and an accuracy of +/- 0.35 °C, coupled with a relative humidity between 5-95%, with an accuracy of +/- 2.5%. A thermocouple model TMCx-HD (Onset Computer Corporation, Pocasset, MA, USA) was also installed with a measurement range of -40 to 100 °C, coupled with black globes. Temperature, relative humidity, and black-globe temperature data were collected every 15 min and averaged hourly.

Wind speed data were collected using a hot-wire anemometer model tafr-190 (Instrutherm Instrumentos de Medição Ltda, São Paulo, SP, Brazil) with a measurement range

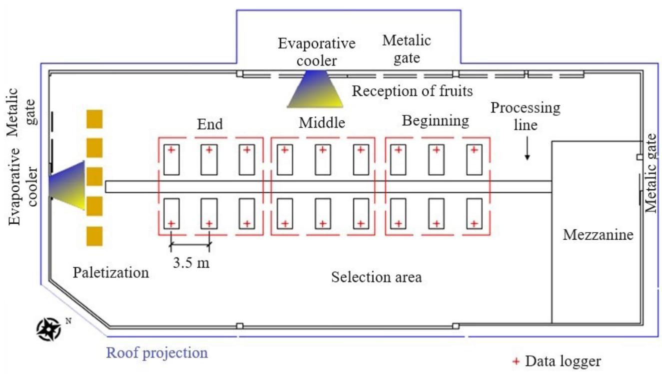

Figure 1. Layout of the selection area in the packing house with the location of the analyzed sectors

between 0.1-25.0 m s^{-1}. Further, wet bulb temperature data were collected using a psychrometer model pol31-D (Politerm Instrumentos de Medição Ltda, São Paulo, SP, Brazil) with a measurement range of 0-80 °C, both recorded every 1 hour.

Measurements were conducted under two different scenarios: three days with the evaporative coolers turned on and three days with them turned off for each production period. The wet bulb globe temperature (WBGT) was determined from the collected data using Eq. 1, which is suitable for assessing indoor environments (without solar load), as established in NR 15 (BRASIL, 2019).

$$WBGT = 0.7tbn + 0.3tg \quad (1)$$

Where:

tbn - natural wet bulb temperature (°C); and,

tg - black globe temperature (°C).

Subsequently, the metabolic rate was estimated by comparing the performed activity with the conditions presented in NR 15 (BRASIL, 2019). The activity performed by employees in the selection and packaging area was classified as moderate standing work using both arms, with a metabolic rate of 279 W. Consequently, the occupational heat exposure limit was examined based on the metabolic rate previously determined by following the same regulations.

To analyze the thermal comfort conditions, guidance from NR 17 (BRASIL, 1978) was followed, which utilized the effective temperature index (ETI), relative humidity (RH), and wind speed as variables. This index correlates the dry and wet bulb temperature values with wind speed using a nomogram, where the effective temperature to which an individual is exposed can be determined, as illustrated in Figure 2.

According to item 17.5.2 of NR 17, for the environment to be thermally comfortable, the ITE should range between 20-23 °C, wind speed should not exceed 0.75 m s^{-1}, and air RH should not be lower than 40%. The values collected during the experimental period were compared with the reference values.

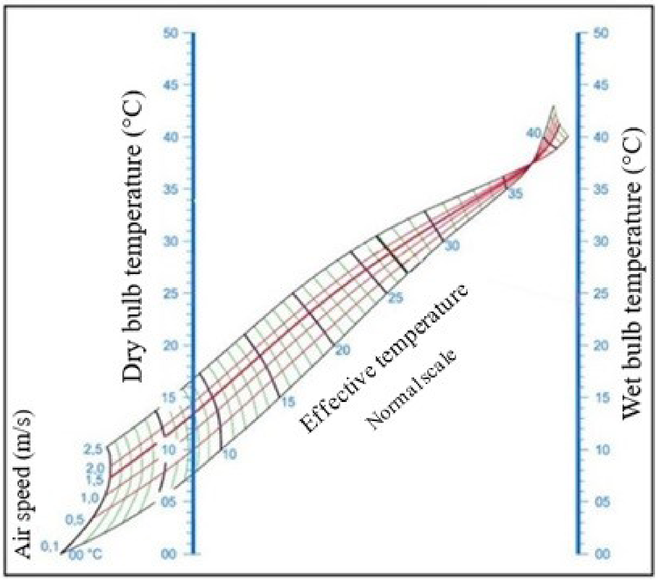

Figure 2. Effective temperature nomogram (Houghten & Yaglou, 1923)

Results and Discussion

The occupational heat exposure limit corresponds to a maximum wet bulb globe temperature index (WBGT) of 28.5 °C (NR 15), as depicted in Figure 3. This limit was not reached in any production period regardless of the use of evaporative coolers across the three studied sectors. Therefore, activities performed in the selection and packaging area of the packing house did not qualify as unhealthy.

Despite not being an unhealthy environment in terms of heat, during the dry period (Figures 3A, B, and C), a progressive variation in WBGT values was observed throughout the day. Without the use of coolers, the lowest value was observed at the beginning of the processing line at 8 am (21.93 °C) (Figure 2C), whereas the highest observed value was 26.86 °C at the end of the line at 1 pm (Figure 3A). With the coolers on, the lowest value was 22.71 °C in the middle sector at 8 am, whereas the highest value was 26.14 °C in the starting sector at 3 pm.

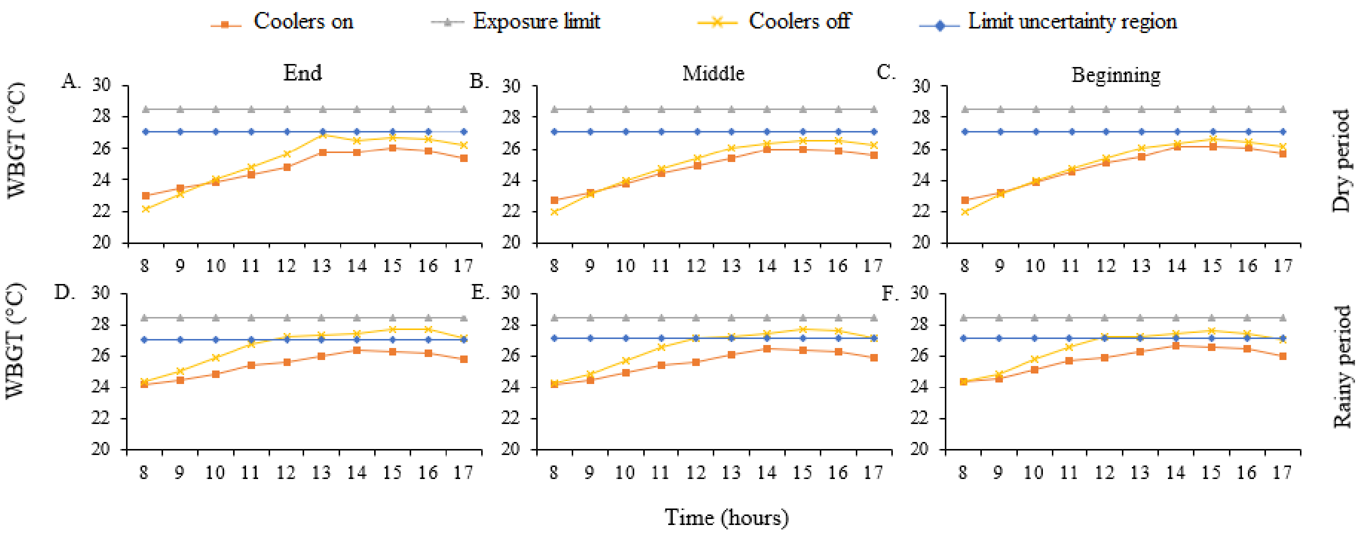

Figure 3. Average hourly wet bulb globe temperature (WBGT): A, B, and C represent he end, middle, and beginning of the processing line, respectively, during the dry period. D, E, and F represent the end, middle, and beginning of the processing line, respectively, during the rainy period

The end sector was located in front of one of the installed evaporative coolers, presenting a higher relative humidity, and consequently, a higher wet bulb temperature. A heat source was observed: a meshed metal gate that facilitated solar radiation incidence on the packaging sector floor near the end of the line in the afternoon. This increased the black globe temperature values. All these factors contributed to the higher WBGT values.

During the rainy period (Figures 3D-F), a progressive increase in the WBGT values was observed. Without the use of coolers, the lowest value was 24.30 °C in the middle sector at 8 am, and the highest value was 27.77 °C in the end sector at 3 pm. Using the coolers, the lowest value was 24.17 °C in the middle sector at 8 am, whereas the highest value was 26.65 °C in the starting sector at 2 pm. Notably, the environment came quire close to the exposure limit without the use of coolers, with a difference of only 0.73 °C at 3 pm in the end sector.

However, the same coolers caused a reduction of up to 1.5 °C during critical hours (between 12 pm and 4 pm). Carvalho et al. (2012) assessed occupational heat exposure in broiler chicken sheds during winter in the semi-arid region of Minas Gerais and found greater thermal overload between 11 am and 3 pm, thus recommending rest breaks. Similarly, Ramirio et al. (2021) found a comparable situation when evaluating occupational heat exposure during manual coffee harvesting in the Minas Gerais.

According to Table 4 of NHO 06 (BRASIL, 2017), an adjustment was made to calculate exposure limits considering uncertainties attributed to metabolic rates and temperature sensor accuracy. Therefore, for the specific metabolic rate being considered (279 W), the maximum WBGT values varied between 27.1-28.5 °C (Figure 3), which would render the environment unhealthy during the rainy period from 12 pm without the use of evaporative coolers (Figures 3D-F).

Body temperature and environmental conditions directly influence the thermal exchange between the human body and environment (Wang & Hu, 2018; Zhang et al., 2019). Therefore, preventive and corrective measures are recommended to reduce occupational heat exposure and minimize health risks to workers. Measures that should be adopted include providing water and minerals for sweat replenishment, introducing breaks in case of discomfort owing to heat, and adjusting ventilation. The latter can be achieved by installing additional evaporative cooling units to satisfy the requirements of all sectors.

Sunshades (eaves, canopies, and hedges) can also be designed to prevent direct sunlight from reaching walls, gates, and the inside of the packing area. In addition, vegetation can be an important tool for reducing heat flow in building envelopes and passive thermal control inside buildings. According to Wong et al. (2021), the use of vegetation is an effective strategy for heat mitigation.

Matheus et al. (2016) evaluated the thermal performance of buildings that used vegetative barriers as protection for roofs and façades and concluded that vegetation can be an important tool for the reduction of heat flows in building envelopes and passive thermal control inside buildings.

An analysis of the ETI values in Figure 4 revealed that in all the studied situations, the environment was outside the thermal comfort zone determined by NR 17, with the most critical situation in the afternoon. As observed for the WBGT, during the dry period (Figures 4A-C), the coolers were insufficient to reduce the values. However, during the rainy period (Figures 4D, E, and F), a greater reduction was observed, particularly at the end of the processing line.

However, the parameters defined in the standard were based on international values, with different climatic conditions. Rural workers in the northeastern semi-arid region were adapted to the hot and dry climate, as the annual temperature averages exceeded 26 °C. They further noted that producers reported many packing house employees who complained of cold and falling ill easily when the ambient temperature varied

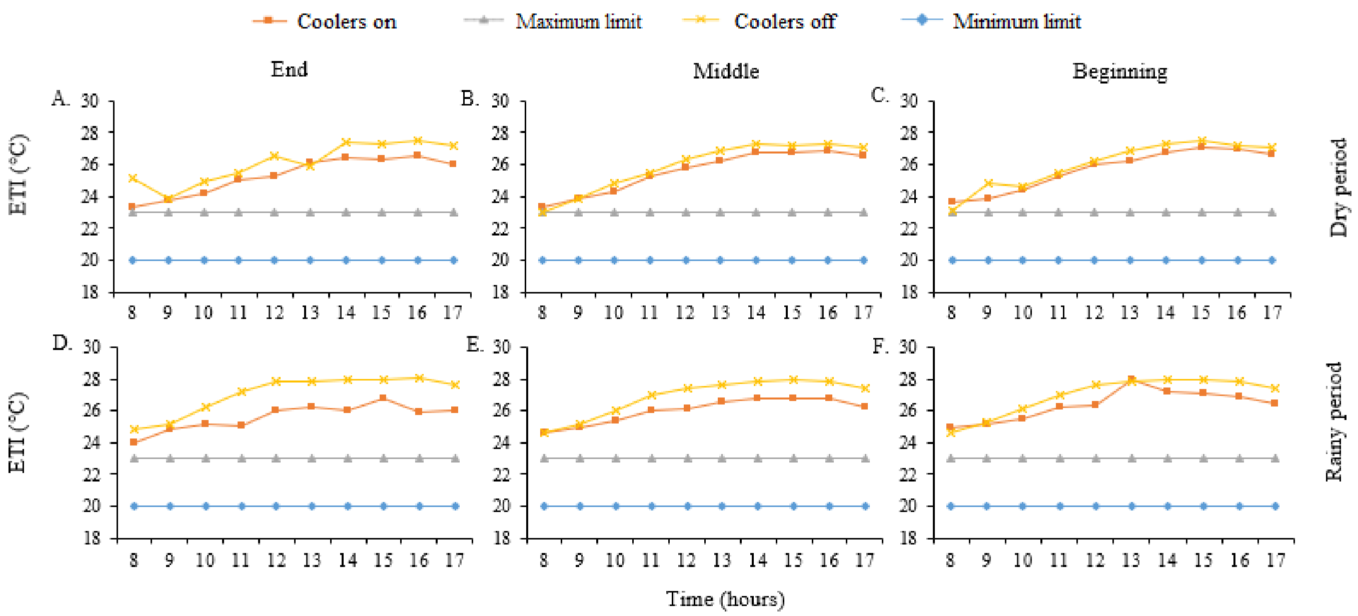

Figure 4. Average hourly effective temperature index (ETI): A, B, and C represent the end, middle, and beginning of the processing line, respectively, during the dry period. D, E, and F represent the end, middle, and beginning of the processing line, respectively, during the rainy period

between 20-25 °C.

Jowkar et al. (2020) confirmed that people's long-term thermal history influences their comfort temperature preferences, thermal sensations, and thermal comfort zones. Individuals with a warmer history considered 24 °C as the optimal acceptable temperature. Djamila (2017) observed that the temperature range between 24-25 °C, regardless of whether the environment had natural or artificial ventilation, was ideal for neutral temperature. Epstein & Moran (2006) considered the range of environmental thermal comfort to be between 20-27 °C.

With the use of evaporative coolers, the effective temperature values ranged from 24-26 °C. Thus, the environment became comfortable for local workers in semi-arid conditions during both dry and rainy periods. This can be considered a positive result because thermal stress significantly affected the efficiency of the work performed by an operator, resulting in a reduction in worker enthusiasm and an increase in incident rates, which can escalate to workplace accidents (Rosa & Lima, 2019).

The relative humidity levels are shown in Figure 5. During the dry period (Figures 5A-C), there was a sharp decline throughout the day. A reduction from 70 to 40% between 8 am and 5 pm without coolers, and a reduction from 70 to 49% with coolers were observed.

With the use of evaporative coolers, the minimum limit proposed in NR17 was not reached in any sector. Without coolers, starting at 2 pm, the relative humidity levels became critical, and reached a minimum of 40% at 3 pm in all sectors.

During the rainy period (Figures 5D-F), the relative humidity indices were higher, averaging 70%, both with and without coolers. Because the external air was already humid owing to the rainy season, no significant change was observed in the indoor environment when using the coolers. The highest values (> 80 %) were observed during the first two hours of the day.

According to Gonçalves et al. (2012), air relative humidity has been linked to health problems when its content is either too high or too low and should ideally be maintained between 40-70%. Outside of these limitations, one should be alert to the worsening of respiratory diseases. Therefore, during the rainy period, there was an alert regarding the relative humidity levels owing to the high values.

In case of the thermal stress, in addition to evaluating temperature, it is crucial to measure the relative humidity levels of the air, as this parameter regulates the rate of evaporation of human sweat. At high levels, the evaporative capacity of sweat released by the skin decreased, thereby increasing the sensation of thermal discomfort. When the values were lower, in very hot environments, the evaporative capacity increased, and consequently, the thermal sensation improved (Yan et al., 2020).

Thus, with the use of evaporative coolers, the thermal environment of the packing house proved to be thermally comfortable during the dry period, as it was responsible for increasing the humidity levels and maintaining them within the comfort zone mentioned in the literature (Gonçalves et al., 2012). However, during the rainy period, the use of evaporative coolers maintained an environment with high relative humidity levels, which was characteristic of the season, thereby causing a sensation of thermal discomfort.

The wind speed data are shown in Figure 6. In both evaluated periods, it was observed that the starting sector was the least ventilated, with an average of 0.30 m s^{-1} in the dry period and 0.21 m s^{-1} in the rainy period, even with the coolers on. This was expected because the coolers were installed closer to the middle and end sectors.

The middle sector (Figures 6B and E) exhibited better ventilation conditions, both naturally and when using coolers, with values within the limits established in NR 17 (maximum of 0.75 m s^{-1}).

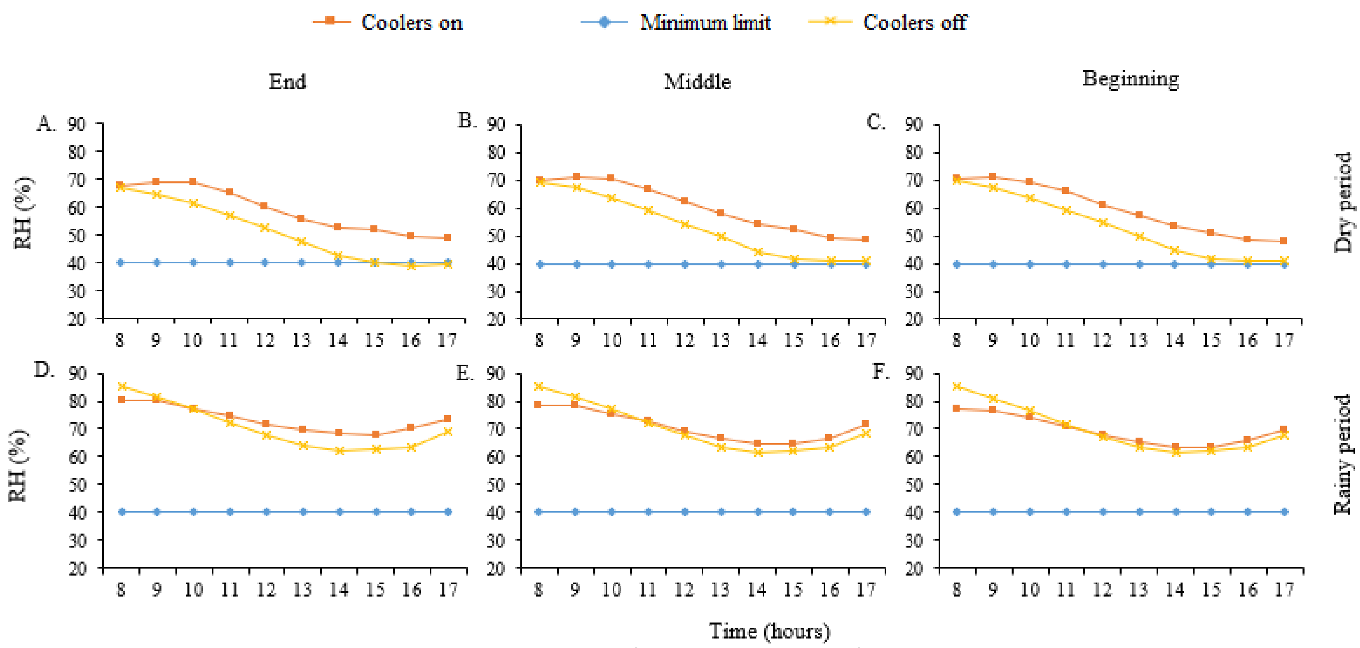

Figure 5. Hourly average relative air humidity (RH): A, B, and C represent the end, middle, and beginning of the processing line, respectively, during the dry period. D, E, and F represent the end, middle, and beginning of the processing line, respectively, during the rainy period

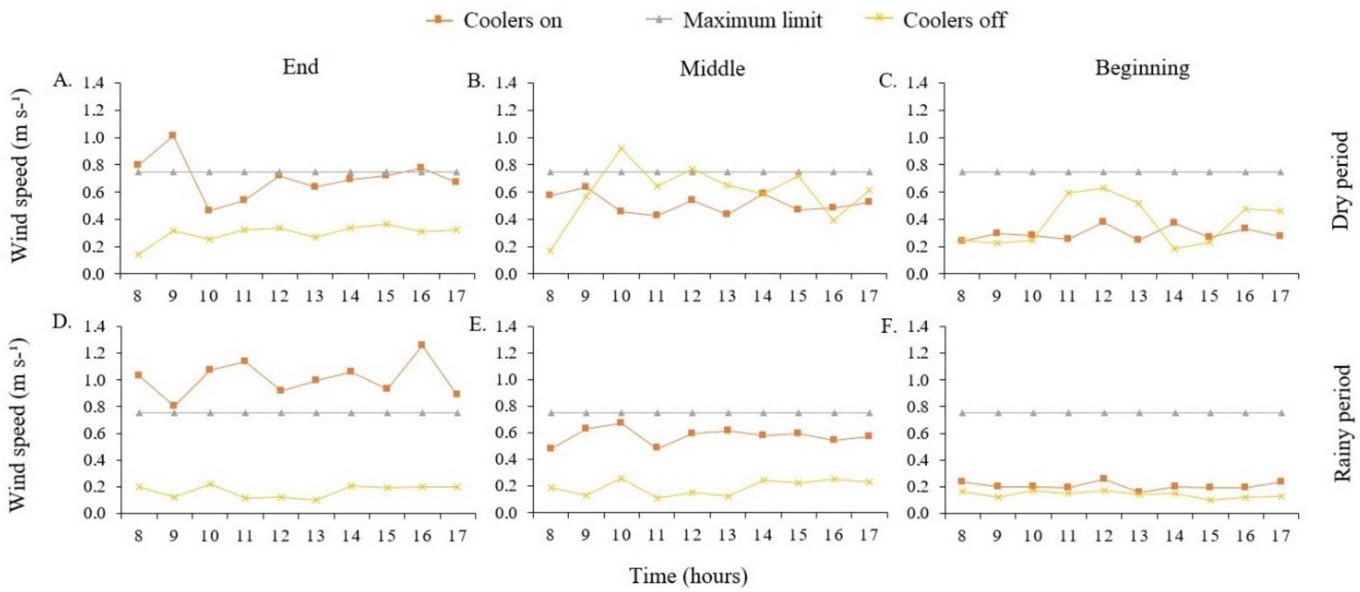

Figure 6. Average hourly wind speed: A, B, and C represent the end, middle, and beginning of the processing line, respectively, during the dry period. D, E, and F represent the end, middle, and beginning of the processing line, respectively, during the rainy period

The end sector (Figures 6A and D) yielded the highest values, reaching averages of 0.70 and 1 m s^{-1} during the dry and rainy periods, respectively. These values were very close to or even exceeding the limit proposed in NR 17, most of the time, in both periods. In this regard, it is recommended to adjust the fins that direct the air from the evaporative cooler and install fans to create an exhaust effect and standardize the ventilation.

Wind can cause both a feeling of freshness and discomfort, as it becomes stronger than the need to eliminate sweat. Ventilation projects in facilities facilitate the correction of humidity conditions that are incompatible with indoor environments. Even at moderate speeds, wind can create problems for people with respiratory illnesses, as it transports dust, pollutants, and other allergens (Gobo et al., 2017).

Similar to this study, Barkokébas Junior et al. (2019) investigated the risks related to thermal stress to which tropical rural workers were exposed and observed higher temperatures and reduced relative humidity in the afternoon. These factors, combined with air movement, facilitated sweat evaporation, and contributed to the removal of excess thermal energy from the body. Thus, activities could be performed continuously in the morning; however, breaks were required in the afternoon.

Unfavorable conditions, such as high temperatures combined with the physical effort of labor activities and inappropriate clothing, can result in reactions in the human body, such as increased internal temperature, activation of sweat glands, vasodilation, dehydration, cramps, heat shock, or sunstroke (Amorim et al., 2020). Mood and behavioral changes can also occur, which become more unsafe in hot environments, increasing the risk of accidents.

Thus, providing water and minerals for sweat replacement and introducing breaks when discomfort owing to heat arises are measures that should be implemented to reduce health risks for workers.

It is essential to engage rural workers in discussions regarding their health and safety at work. The identification of occupational risks and understanding exposure to these risks are the first steps towards preventive action. Considering the relevance of this sector to the economy, there is a clear need for educational, research, and extension initiatives to reduce or eliminate occupational risks and their consequences (Kolln et al., 2022).

Conclusions

1. The use of evaporative coolers reduced occupational heat exposure for workers, remaining within the established wet bulb globe temperature tolerance limit according to the reference norm (NR) 15. However, it did not provide adequate thermal comfort indices according to NR 17.

2. In semi-arid conditions, the evaporative coolers improved the thermal comfort of local workers

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