Title
Occupational and off-work recovery predictors of heat-related illness among farmworkers in California: Insights including gender-related differences

Journal
International Journal of Hygiene and Environmental Health, 277

ISSN
1438-4639

Authors
van Selm, Lena
Ciborowski, Haley
Wagoner, Rietta
et al.

Publication Date
2026-08-01

DOI
10.1016/j.ijheh.2026.114885

International Journal of Hygiene and Environmental Health 277 (2026) 114885

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

Occupational and off-work recovery predictors of heat-related illness among farmworkers in California: Insights including gender-related differences

Lena van Selm [a,b], Haley Ciborowski [c], Rietta Wagoner [d,e], Brandon Toji-Ruiz [f], Michelle Solorio [f], Briana Toji [f,g], Ana Solorio [g], Trent Biggs [c], Penelope J.E. Quintana [f], Linda Lara-Jacobo [f], Nicolas Lopez-Galvez [f,*]

[a] Barcelona Institute for Global Health (ISGlobal), Barcelona, Spain
[b] Faculty of Medicine and Health Sciences, University of Barcelona, Barcelona, Spain
[c] Geography, San Diego State University, San Diego, CA, 92182, United States
[d] San Diego State University Research Foundation, San Diego, CA, United States
[e] University of Arizona Environmental Health Sciences, Tucson, AZ, United States
[f] School of Public Health, San Diego State University, San Diego, CA, 92182, United States
[g] Organization Lideres Campesinas de California, Oxnard, CA, 93036, United States

A R T I C L E I N F O

Keywords:
Heat
Heat-related illnesses
Occupational health
Farmworkers
Outdoor workers

A B S T R A C T

Background: Farmworkers in the United States are exposed to extreme heat and demanding physical labor, placing them at increased risk for heat-related illnesses (HRI). This study examined individual, occupational, and household factors associated with self-reported HRI among men and women farmworkers in Imperial Valley, California.

Methods: This cross-sectional study used a convenience and snowball sampling approach to recruit agricultural workers through a local community organization. Participants were administered an in-person interview on their experience with HRI and potential risk factors. A multivariate regression analysis was conducted to identify variables related to HRI.

Results: From 300 participants, 119 (39.7%) experienced HRI, defined as reporting at least three HRI symptoms. In the multivariate regression analysis, HRI odds were significantly increased in women (aOR: 2.36, 95%CI: 1.35-4.15), in those reporting heat-related sleep problems (aOR: 3.25, 95%CI: 1.50-7.02), face covering use (aOR: 1.94, 95%CI: 1.09-3.45) and those working more than 5 days per week (aOR: 2.19, 95%CI: 1.23-3.91). Older age had a modest association with lower odds of HRI (aOR: 0.98, 95%CI: 0.96-0.99) and more than one break per day (aOR: 0.59, 95%CI: 0.35-1.00, p = 0.053) was associated with marginally lower HRI odds.

Conclusions: As climate change continues to intensify occupational heat exposure among agricultural workers, interventions should extend beyond purely workplace-focused efforts and address cumulative exposure, non-occupational factors and structural constraints. Report of heat-related sleep problems has been associated with HRI relatively recently. Future research should establish the occupational, structural, and biological pathways contributing to the increased HRI odds for women farmworkers.

1. Introduction

Extreme heat represents a growing occupational hazard for farmworkers in the United States, particularly in desert and semi-arid regions, where climate change is intensifying already dangerous working conditions (Arnold et al., 2020; Hulley et al., 2020; National Weather Service, 2024). Heat has emerged as the leading cause of weather-related mortality throughout the United States, and climate projections indicate continued increases in the frequency, duration, and severity of extreme heat events (Pierce et al., 2013; Thompson et al., 2025). Because agricultural labor is predominantly performed outdoors and involves sustained physical exertion, farmworkers experience

* Corresponding author.
E-mail address: nilopez@sdsu.edu (N. Lopez-Galvez).

https://doi.org/10.1016/j.ijheh.2026.114885
Received 22 April 2026; Received in revised form 5 August 2026; Accepted 5 August 2026
Available online 6 August 2026

disproportionate exposure to hazardous heat.

Physiological heat stress develops when internal heat production and external environmental heat overwhelm the body's thermoregulatory capacity. This process is influenced by ambient temperature, humidity, radiant heat, wind conditions, physical workload, and clothing (Jackson and Rosenberg, 2010; National Institute for Occupational Safety and Health, 2016). When heat stress is not adequately mitigated, workers may experience heat-related illnesses (HRI) ranging from dehydration and muscle cramps to heat exhaustion or heatstroke. Beyond acute illness, repeated heat exposure contributes to cumulative physiological strain and can exacerbate chronic conditions including cardiovascular disease, diabetes, hypertension, and kidney disease (Glaser et al., 2016; Johnson et al., 2019). Farmworkers in the United States report substantial levels of HRI and, in California, over 10% suffered from acute kidney injury (AKI) (Bethel and Harger, 2014; Mirabelli et al., 2010; Moyce et al., 2016). In addition, studies consistently demonstrate elevated rates of heat-related mortality compared to the general working population (Edgerly et al., 2024; Gubernot et al., 2014; Jackson and Rosenberg, 2010).

Heat-related health risk among farmworkers is shaped not only by environmental conditions but also by social, economic, and institutional factors that influence exposure, prevention, and response (Arcury and Quandt, 2020; Courville et al., 2016; Quesada et al., 2011). Farmworkers face intersecting vulnerabilities including low wages, limited labor protections, immigration-related concerns, language barriers, and constrained access to healthcare (Holmes, 2013). Economic insecurity can incentivize workers to continue laboring through hazardous conditions, delay rest or hydration, and avoid reporting symptoms of heat strain (Lam et al., 2013; Tigchelaar et al., 2020), while fear of job loss or immigration consequences further limits use of formal protections (Edgerly et al., 2024; Gubernot et al., 2014). Although regulatory standards exist to reduce occupational heat risk, their effectiveness depends heavily on implementation and enforcement. Access to water, shade, and rest remains uneven across agricultural worksites and is often mediated by supervisory discretion rather than enforceable thresholds (Cal/OSHA, 2005; Heinzerling et al., 2020). In complaint-driven enforcement systems, workers' structural vulnerabilities limit the protective potential of administrative controls, even when formal policies are in place.

Occupational heat exposure is also closely intertwined with non-workplace conditions and personal characteristics that influence recovery and resilience. Adequate physiological recovery from heat stress requires access to cool environments and sufficient sleep, yet many farmworkers reside in housing with limited insulation, overcrowding, or inadequate air conditioning leading to elevated nighttime temperatures (Arcury and Quandt, 2020). In addition, although heat illness has historically been framed as a predominantly men occupational risk, emerging evidence suggests that women farmworkers may experience comparable or elevated vulnerability under certain working and social conditions (Arnold et al., 2020; Courville et al., 2016; Edgerly et al., 2024). Therefore, gender differences and non-workplace related conditions should be taken into account when assessing risk factors for HRI.

California's Imperial Valley represents one of the most extreme agricultural heat environments in the United States. Summer temperatures frequently exceed 43°C (109 °F) and direct solar exposure and high humidity associated with irrigation further increase the risk of heat stress (Parajuli et al., 2024). Between 2000 and 2017, Imperial County experienced the highest rates of heat-related injuries and diseases in California (Heinzerling et al., 2020). Recent analyses demonstrate that heat thresholds associated with elevated HRI risk are routinely exceeded during the growing season and are projected to worsen under future climate scenarios (Parajuli et al., 2024; Thompson et al., 2025).

Despite extensive documentation of occupational heat exposure among farmworkers, important gaps remain in understanding how structural, occupational, and non-workplace factors jointly shape heat-related illness risk, particularly across gender. The objective of this study was therefore to identify individual, occupational, and household factors associated with self-reported HRI among men and women farmworkers in Imperial Valley, California, with the aim of informing more effective and equitable HRI prevention strategies needed under intensifying climatic conditions.

2. Methods

2.1. Study design & setting

This cross-sectional study took place in the Imperial Valley, California, an area that is a major contributor to the U.S. winter vegetable supply and which relies on a predominantly immigrant agricultural workforce. This study was designed, reviewed, and implemented with assistance from a women-led community organization, Líderes Campesinas of California.

2.2. Participant recruitment and data collection

Participants were eligible for inclusion in the study if they were 18 years of age or older, employed in agriculture, and planned on working and living in the Imperial Valley region for at least 6 months. Recruitment followed a non-probability convenience and snowball sampling approach for two years, across eight agricultural seasons, spanning Spring 2024 through Winter 2025, and was facilitated through Líderes Campesinas' established community networks. A bilingual, English/Spanish, questionnaire was developed by the research team and reviewed by Líderes Campesinas to ensure cultural appropriateness, regional language relevance, and overall clarity. The questionnaire incorporates items adapted from previously validated surveys assessing occupational heat stress and heat strain symptoms, including instruments developed through the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) Program (Kjellstrom et al., 2009; National Institute for Occupational Safety and Health, 2016). The questionnaire was administered in person at each participant's home and participants were asked to sign an informed consent form before starting. Questions covered sociodemographic information, living conditions, and working activities and conditions, including those related to occupational heat. For example, workers were asked about work intensity, clothing and hydration practices at work, and heat and cooling practices at home. Participants were also asked if they had suffered from any of the following heat-related symptoms since they started working at their current job: muscle cramps, headache, dizziness, nausea, high body temperature, fainting, dry skin, fatigue, and dry mouth or lips. Research staff recorded questionnaire responses electronically on tablets using REDCap software (Harris et al., 2009). All protocols were reviewed and approved by the San Diego Human Research Protection Program prior to implementation (Protocol #HS-2024-0081).

2.3. Data analysis

Data were exported from REDCap into R for data analysis (R Core Team, 2025). Participants with missing data on more than 20% of the items were excluded from the analysis (8 out of 308 participants). A total of 19 surveys were missing data but for fewer than 20% of questions. In line with previous studies, Heat-Related Illness (HRI) was defined as reporting at least three heat related symptoms (Fleischer et al., 2013; Mutic et al., 2018; Riccò et al., 2019). Differences in baseline characteristics by gender were evaluated using the Pearson's Chi-Square Test or the Wilcoxon Rank-Sum Test ("gtsummary" package). Linearity of the age-HRI association was assessed by comparing linear and restricted cubic spline models using a likelihood ratio test ("mice" package). Univariate logistic regression models were run for each of the 30 pre-selected variables identified as potential risk factors based on the existing literature, biological plausibility, and their potential associations with heat-related illness or the primary exposures of interest. Age, gender, and smoking status were considered core covariates and were retained in all multivariable models regardless of their univariable associations. Variables meeting the $p < 0.20$ threshold during univariate screening were considered for inclusion in the multivariable models. We fitted three models. Model 1 included a priory variables plus candidate predictors that met a $p < 0.20$ screening threshold. Model 2 included the a priori variables plus candidate predictors meeting $p < 0.05$ threshold. Model 3 comprised the a priori covariates and the final predictor set retained after applying a change-in-estimate rule and comparing nested models using the Akaike information criterion (AIC). Considering the selected variables, 9 surveys had missing data. These missing values were filled using Multivariate Imputation by Chained Equations (MICE), using predictive mean matching (PMM) with the "mice" package, generating m = 5 imputed data sets. Estimates from each imputed dataset were pooled using Rubin's rules and three different multivariate logistic regression models were created using the imputed data. Adjusted prevalence odds ratios with 95% confidence intervals are reported. As a sensitivity analysis, results from the imputed data were compared to a complete-case analysis (n = 291), comparing the odds ratios, confidence intervals, and p-values. The sensitivity analysis demonstrated strong concordance between the two approaches. Odds ratios differed by less than 10% for the vast majority of variables across all models (range: −6.6% to 8.7%). Confidence intervals showed substantial overlap, and the direction and statistical significance of effects remained consistent. We evaluated three nested logistic regression models to identify factors associated with HRI. Performance of each of the three models was assessed using the Akaike Information Criterion (AIC), and calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test ("ResourceSelection") and one final model was selected. More information on the initial models and evaluation criteria is included in the supplementary information. Collinearity among predictors was assessed using variance inflation factors (VIF) calculated on the complete-case models ("car" package); all values were below 5, indicating no problematic collinearity. Influential observations were assessed using Cook's distance and residuals-versus-leverage plots; while a small number of observations exceeded the conventional Cook's distance threshold, all values remained well below 1 and no observations combined high leverage with poor model fit. To explore potential effect modification by gender, we tested interaction terms between gender and each variable selected for the final model, using likelihood ratio tests (via the D1() function from the "mice" package). All data analysis was completed in R Studio version 4.5.1.

3. Results

A total of 300 participants were included for analysis. In the final sample, 175 (58%) were men, and 125 (42%) were women. Women workers were older than men workers with a median age of 49 years versus 40 years (Table 1). Women reported chronic disease more often (35% versus 15%), but reported less smoking (12% versus 30%) and alcohol consumption (15% versus 49%). Men workers were more often born in the United States (n = 58; 33%) compared to women (14%). Of the total sample, 119 workers (39.7%) reported experiencing HRI (Table 1). The most frequently reported symptoms were headache (n = 140, 45%), muscle cramps (n = 138, 45%), fatigue (n = 119, 39%) and having a very dry mouth (n = 111, 36%) (Table S1).

Women and men showed significant differences in employment patterns, workload, and heat-related exposures. Plant work (referred as crop production tasks involving direct plant contact) was the most common task among women (94%), while men farmworkers were more evenly distributed across maintenance work (47%), plant work (34%), and other tasks (19%) (Table 2). Men reported working more often under extreme heat conditions (90% versus 66%, $p < 0.001$) and were more likely to consume more than three water bottles per shift (93% versus 65%, $p < 0.001$), work more than five days per week (35% versus 20%, p = 0.005), and be employed full-time (79% versus 64%, p = 0.004). Moreover, men were markedly more likely to be employed year-round (48%), compared with only 4% of women ($p < 0.001$), but men were less likely to use face coverings (59% versus 78%, $p < 0.001$). Despite these differences, both groups reported similar rates of heat-related training (p = 0.700), physically demanding work (p = 0.800), glove use (p = 0.600), and job tenure (p = 0.100), though women generally took more breaks during the workday (p = 0.010) (Table 2).

Table 1
Sociodemographic characteristics of farmworkers stratified by sex.

	Total (n = 300)	Women (n = 125)	Men (n = 175)	p-value
	n (%)	n (%)	n (%)	
Age, median (IQR)	45 (32, 56)	49 (37, 58)	40 (29, 53)	<0.001
Missing	1	0	1	
Diagnosed with a chronic disease	70 (23%)	44 (35%)	26 (15%)	<0.001
Smoking	68 (23%)	15 (12%)	53 (30%)	<0.001
Education level				
Less than high school	169 (57%)	80 (65%)	89 (52%)	0.028
High school or above	127 (43%)	44 (35%)	83 (48%)	
Country of birth				
US	76 (25%)	18 (14%)	58 (33%)	<0.001
Mexico	211 (71%)	103 (82%)	108 (62%)	
Central America/ Caribbean	12 (4%)	4 (3%)	8 (5%)	
Recent use of pain medication	101 (34%)	53 (43%)	48 (28%)	0.007
Missing	3	1	2	
Alcohol consumption	104 (35%)	19 (15%)	85 (49%)	<0.001
Missing	1	1	0	
Air conditioning use (at home)				
Always	235 (79%)	94 (76%)	141 (81%)	0.300
Not always	64 (21%)	30 (24%)	34 (19%)	
Missing	1	1	0	
Sleep problems due to heat	37 (12%)	11 (8.9%)	26 (15%)	0.120
Missing	1	1	0	
HRI*				
No	181 (60.3%)	67 (53.6%)	114 (65.1%)	0.058
Yes	119 (39.7%)	58 (46.4%)	61 (34.9%)	

IQR: inter-quartile range; HRI*: heat related illnesses referring to farmworkers who experienced three or more heat related symptoms (summarized in Table S1).

In the univariate analysis (Supplementary Table S5), higher odds of HRI were associated with women (n = 58; 46.4%, OR: 1.62, 95%CI: 1.01, 2.59), heat-related sleeping problems (n = 22, 59.5%, OR: 2.54, 95%CI: 1.27, 5.21) and using face covering (n = 106, 41.6%, OR: 2.27, 95%CI: 1.36, 3.88). Older age (OR: 0.98, 95%CI: 0.97, 1), working in the northern Imperial Valley (n = 37, 31.9%, OR: 0.58, 95%CI: 0.36, 0.94), drinking more than three bottles of water per shift (n = 89, 36.5%, OR: 0.5, 95%CI: 0.28, 0.89) and having more than one break per day (n = 68, 35.4%, OR: 0.6, 95%CI: 0.37, 0.98) were associated with lower HRI-odds.

In the final multivariable logistic regression model (Fig. 1), participants who reported sleep problems due to heat had over three times the odds of experiencing HRI (adjusted odds ratio (aOR): 3.21, 95%CI: 1.49-6.94). HRI odds were more than twice as high among women (aOR: 2.37, 95%CI: 1.35-4.16) and participants working more than five days per week (aOR: 2.19, 95%CI: 1.23-3.91) and almost doubled for workers using face covering during work (aOR: 1.94, 95%CI: 1.09-3.45). Both each additional year of age (aOR: 0.97, 95%CI: 0.96-0.99) and taking more than one break per day (aOR: 0.59, 95%CI: 0.35-1.01) were

Table 2
Occupational activities and factors of farmworkers stratified by sex.

	Total (n = 300)	Women (n = 125)	Men (n = 175)	p-value
	n (%)	n (%)	n (%)	
Type of employment				
All year	89 (30%)	5 (4.0%)	84 (48%)	<0.001
Seasonal	211 (70%)	120 (96%)	91 (52%)	
Working schedule				
Fulltime	218 (73%)	80 (64%)	138 (79%)	0.004
Part time	82 (27%)	45 (36%)	37 (21%)	
Working days per week				
5 or less	213 (71%)	100 (80%)	113 (65%)	0.005
More than 5	86 (29%)	25 (20%)	61 (35%)	
Working hours per day				
8 or less	210 (70%)	87 (70%)	123 (71%)	0.800
More than 8	89 (30%)	38 (30%)	51 (29%)	
Main Work tasks				
Maintenance work	87 (29%)	5 (4.0%)	82 (47%)	<0.001
Plant work[a]	178 (59%)	118 (94%)	60 (34%)	
Vehicle, supervisors, pesticide applicators	35 (12%)	2 (1.6%)	33 (19%)	
Time with current employer				
1 year or less	93 (31%)	46 (37%)	47 (27%)	0.100
More than one year	206 (69%)	79 (63%)	127 (73%)	
Time in current task				
1 year or less	112 (37%)	55 (44%)	57 (33%)	0.068
More than one year	187 (62%)	70 (56%)	117 (67%)	
Recently worked in extreme heat	241 (80%)	83 (66%)	158 (90%)	<0.001
Received Heat Related Training	248 (83%)	105 (84%)	143 (82%)	0.700
Very physically demanding work	139 (46%)	57 (46%)	82 (47%)	0.800
Personal protective equipment				
No Use of PPE	56 (19%)	32 (26%)	24 (14%)	0.008
PPE and does not increase heat	111 (37%)	49 (39%)	62 (36%)	
PPE and increases heat	132 (44%)	44 (35%)	88 (51%)	
Face covering use	200 (67%)	97 (78%)	103 (59%)	<0.001
Using protective gloves at work	255 (85%)	108 (86%)	147 (84%)	0.600
Water consumption at work				
Always	239 (80%)	93 (74%)	146 (84%)	0.043
Not always	60 (20%)	32 (26%)	28 (16%)	
Water bottles consumed per work shift				
3 or less	56 (19%)	44 (35%)	12 (6.9%)	<0.001
More than 3	244 (81%)	81 (65%)	163 (93%)	
Energy drink consumption at work or prior	175 (59%)	66 (53%)	109 (63%)	0.100
Number of breaks per work shift				
1 or less	105 (35%)	33 (27%)	72 (41%)	0.010
More than 1	192 (65%)	90 (73%)	102 (59%)	

[a] Crop production tasks involving direct plant contact; Abbreviations: PPE: personnel protective equipment | P-values were calculated through the Pearson's Chi-Square Test.

associated with marginally reduced odds of HRI. Region, glove use, and smoking status were not significantly associated with HRI in the final adjusted model (Fig. 1). No interactions were found between gender and the other statistically significant (or marginally significant) variables (age, working days per week, face covering use, sleep problems due to heat, and number of breaks) in models adjusted for all covariates, indicating that the associations between these predictors and HRI did not differ meaningfully between men and women. It is important to note that all odds ratios reported are prevalence odds ratios.

4. Discussion

This study examined individual, occupational, and household factors associated with heat-related illness (HRI) among men and women farmworkers in Imperial Valley, California. Consistent with a growing body of occupational heat research, our findings demonstrate that HRI is not driven by environmental exposure alone, but is shaped by work organization, recovery conditions, and structural constraints that govern workers' ability to prevent or respond to heat strain (Arcury and Quandt, 2020; Edgerly et al., 2024; Gubernot et al., 2014). By integrating indicators of work intensity, protective practices, and heat-related sleep problems, this analysis contributes quantitative evidence to support conceptual frameworks that position heat illness as a cumulative and structurally mediated occupational health outcome.

A central finding of this study is that women farmworkers had more than twice the odds of HRI compared to men. While the existing evidence is sparse and somewhat mixed, several studies have documented gendered patterns of heat-related vulnerability in agricultural labor, including reports of higher HRI levels among women (Arnold et al., 2020; Courville et al., 2016; Edgerly et al., 2024). Several mechanisms may help explain this elevated risk. Physiological differences may contribute, as women generally have higher percentages of body fat and higher resting core temperatures (Williams, 2021). However, non-biological factors could also play a role. For example, women farmworkers are often concentrated in specific tasks, such as plant or packing work, that involve sustained postures, repetitive motion, limited airflow, and prolonged exposure with fewer opportunities for self-pacing (Arcury and Quandt, 2020; Handal et al., 2025). Differences could also be related to reporting, as women may be more likely to recognize and report heat-related symptoms, whereas men may normalize or minimize illness due to workplace or gender norms (Courville et al., 2016). Finally, women in our study had a higher prevalence of chronic disease, which could impair thermoregulation or increase the risk of dehydration (Flouris et al., 2024). These findings reinforce the importance of conceptualizing gender as a structural and occupational determinant of HRI risk rather than a simple biological modifier.

The strongest predictor of HRI in this study was reporting sleep problems due to heat, which was associated with more than threefold increased odds of HRI symptoms. Elevated nighttime temperatures delay sleep onset, impair sleep duration and quality, disrupt thermoregulation, and exacerbate cardiovascular and metabolic strain (Buguet et al., 2023; Meade et al., 2020; Minor et al., 2022). In occupational contexts, insufficient sleep and circadian disruption are associated with increased fatigue, reduced cognitive performance, and elevated injury risk (Kecklund and Axelsson, 2016; Wright et al., 2013). Notably, in the current study, all workers reported having air-conditioning at home, and the majority reported always using it. Moreover, only a relatively small proportion of participants reported heat-related sleep problems overall (8.3% among those without HRI and 19.0% among those with HRI), suggesting that nighttime heat exposure may be impact HRI odds among a vulnerable subset of workers. Why some workers with access to air-conditioning still experienced heat-related sleep disruption warrants further investigation, but potential explanations could include inadequate capacity of air conditioning units given extreme high outdoor temperatures (Easton-Calabria et al., 2026) or underutilization of air conditioning due to concerns about electricity costs (Obradovich et al., 2017). Taken together, these results highlight the critical role of nighttime recovery in shaping cumulative heat strain and underscore the need to move beyond worksite-focused interventions to address the full exposure environment of farmworkers.

Other recovery-related factors also showed associations with HRI. Working more than five days per week was associated with significantly increased odds of HRI, suggesting that cumulative heat exposure and

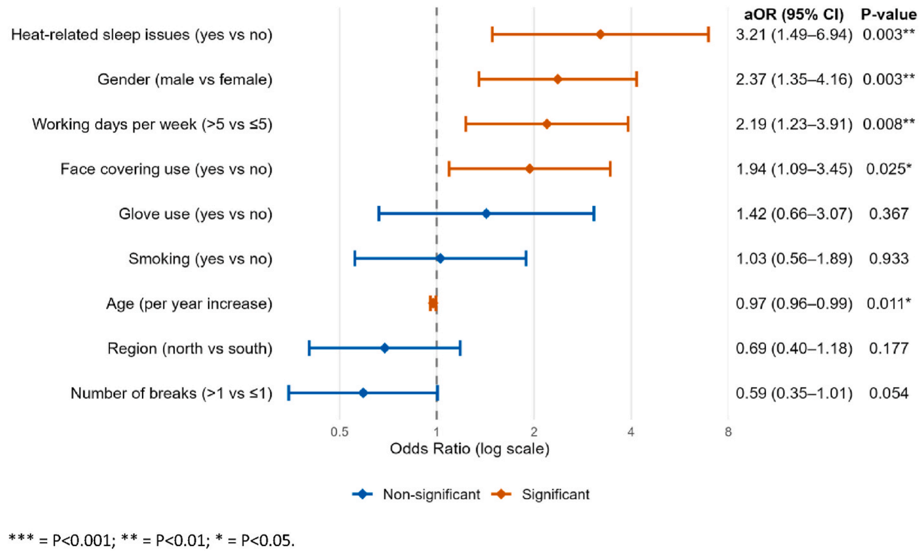

Fig. 1. Forest plot with adjusted odds ratios for heat-related illness
*** = P < 0.001; ** = P < 0.01; * = P < 0.05.

limited inter-day recovery may impact HRI levels. While much of the heat-health literature focuses on daily maximum temperatures or within-shift exposure, repeated heat exposure across consecutive workdays may impose cumulative physiological strain. A meta-analysis showed that among workers who were frequently exposed to occupational heat (defined as at least 6 h per day, 5 days per week, for 2 months), 15% suffered from kidney disease or acute kidney injury, demonstrating the health risks of cumulative heat exposure (Flouris et al., 2018). In contrast, taking more than one break per day demonstrated marginally lower odds of HRI, consistent with the well-established evidence that rest breaks reduce heat strain (Fleischer et al., 2013; Riccò et al., 2019; Spector et al., 2015). However, break access is often mediated by supervisory discretion and production pressures rather than objective heat metrics. This undermines the protective potential of rest, as farmworkers may forego breaks to avoid retaliation or wage loss associated with reduced productivity (Courville et al., 2016; Edgerly et al., 2024). These findings show how both work organization and structural constraints shape recovery opportunities and, therefore, HRI odds among farmworkers.

Face covering use was associated with increased odds of HRI in the adjusted model, illustrating a critical tradeoff between protection from other environmental and occupational hazards and heat stress. While face coverings and other personal protective equipment (PPE) are essential for reducing exposure to sun, dust, and pesticides, occupational health research consistently shows that clothing and equipment that restrict airflow or evaporative cooling can increase core body temperature and perceived exertion under hot conditions (National Institute for Occupational Safety and Health, 2016). This finding should not be interpreted as discouraging PPE use, but rather as evidence of the need for integrated protection strategies that minimize heat stress while maintaining safety from other hazards. Such strategies may include improved fabric design, task-specific PPE selection, additional rest or cooling periods for workers using heat-retaining equipment, and engineering controls that reduce reliance on personal protective measures alone (Cheveldayoff et al., 2023; Watson et al., 2019).

Each additional year of age was modestly associated with decreased odds of HRI. Although older age is often linked to greater physiological vulnerability to heat in the general population (Tony Wolf et al., 2023), occupational studies among farmworkers have reported mixed patterns (El Khayat et al., 2022). While slower metabolisms, weaker immune systems and an increased disease burden might increase older workers' HRI risk, younger workers may be at increased risk due to a lack of maturity, training, skills, and experience (International Labour Organization, 2024). One potential explanation for the potentially protective effect of age is the "healthy worker survivor effect", whereby workers who remain in physically demanding agricultural labor at older ages may represent a subgroup with greater heat tolerance, experience, or adaptive strategies (Meade et al., 2020; Spector et al., 2015). Older workers may also have greater autonomy over pacing or task selection, although such dynamics warrant further investigation.

4.1. Implications for prevention and policy

Together, these findings suggest that effective HRI prevention must extend beyond workplace-based technical controls, and address recovery, housing conditions, and structural constraints that limit workers' ability to protect themselves from HRI. Policies that focus solely on water, shade, and rest during work hours may be insufficient in regions where nighttime heat, high electricity costs, and overcrowded housing undermine recovery. Integrating housing and energy assistance, strengthening enforcement mechanisms, and incorporating workload- and metric-based rest standards may be necessary to meaningfully reduce HRI risk. As climate change accelerates, identifying and addressing cumulative and structurally mediated pathways to HRI will be essential for protecting farmworker health. By quantifying associations between gender, recovery, work intensity, and HRI, this study provides evidence to inform more comprehensive and equitable heat prevention strategies in agricultural settings.

5. Limitations

Several limitations should be considered when interpreting the findings of this study. First, this study relied on self-reported HRI symptoms rather than clinical diagnoses, which may introduce recall or reporting bias. However, symptom-based definitions of HRI are widely used in farmworker research (Fleischer et al., 2013; Mutic et al., 2018; Riccò et al., 2019) and capture a broader spectrum of heat-related morbidity that is often missed in administrative or clinical data. Given well-documented underreporting of occupational illness due to fear of retaliation or immigration-related concerns, self-reported symptoms may represent a conservative estimate of true burden. Second, exposure measures also relied on participants' self-reported working and living conditions rather than direct environmental or physiological monitoring. Although we examined a broad range of individual and occupational factors, some relevant variables could not be fully assessed, including information on specific crop types, exact task demands, employer-level heat prevention practices, housing quality, and energy affordability. As a result, residual confounding by variation in environmental heat, workload intensity, or housing characteristics is possible. Third, the cross-sectional study design limits the ability to draw causal inferences about the relationships between identified associated factors and HRI. Specifically, assessing HRI symptoms since the start of current employment alongside current exposure practices may introduce temporal misalignment and reverse-causation associations. Nevertheless, these current practices could serve as serve as reasonable proxies for persistent (occupational) conditions, offering valuable insight into co-occurring hazards even if exact temporal sequence cannot be verified. In addition, the observed associations are consistent with prior literature. Additionally, with an HRI prevalence of 39.7%, the prevalence odds ratios reported from the logistic models may overstate the corresponding prevalence ratios, so effect sizes should be interpreted with caution. Future studies integrating survey data with environmental monitoring and wearable sensors would strengthen causal inference and exposure assessment. Fourth, the study sample was recruited using non-probability convenience and snowball sampling methods through a trusted community organization. While this approach facilitated participation among a population that is often difficult to reach through traditional sampling strategies, it may limit generalizability beyond the study population. Finally, although we tested for effect modification by gender, the study may have been underpowered to detect more subtle interaction effects; therefore, null findings for interaction terms should be interpreted with caution.

6. Conclusion

In this study of farmworkers in Imperial Valley, California, we identified occupational, recovery-related, and individual factors associated with reporting HRI symptoms, highlighting heat as a cumulative and structurally mediated occupational health risk. The finding that women farmworkers faced more than twice the HRI odds compared to men underscores the need for future research to disentangle the occupational, structural, and biological pathways contributing to this disparity and to evaluate gender-sensitive approaches to heat illness prevention. Our findings demonstrating that impaired recovery plays a central role in shaping HRI odds, underscores the importance of examining how labor organization and non-workplace conditions interact to influence vulnerability. Effective prevention must extend beyond the worksite to include recovery environments, housing conditions, and access to cooling. As climate change continues to intensify heat exposure in agricultural regions, interventions focused solely on workplace water, shade, and rest are unlikely to be sufficient without parallel efforts to address cumulative exposure, enforcement, and structural constraints. By quantifying pathways identified in prior qualitative research, this study contributes evidence to support more comprehensive and equitable approaches to HRI prevention for farmworkers under a warming climate.

Data sharing statement

De-identified data that support the findings of this study are available from the corresponding author upon reasonable request and with permission from the authors' institution.

Funding source

This study was funded by the University of California Office of the President (UCOP) Climate Action Grant award R02CP7521 & R02CP7565. This study was supported and monitored in part by The National Oceanic and Atmospheric Administration – Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies under the Cooperative Agreement Grant #: NA22SEC4810016. NOAA Office of Education, The Educational Partnership Program (NOAA-EPP) and the NOAA-CESSRST-II provided full fellowship support for survey team member Stephanie Hurtado Gonzalez. The statements, findings, conclusions and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA.

CRediT authorship contribution statement

Lena van Selm: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Haley Ciborowski:** Conceptualization, Investigation, Project administration, Writing – original draft, Writing – review & editing. **Rietta Wagoner:** Conceptualization, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Brandon Toji-Ruiz:** Data curation, Investigation, Methodology, Project administration, Validation, Writing – review & editing. **Michelle Solorio:** Data curation, Methodology, Validation, Writing – review & editing. **Briana Toji:** Investigation, Methodology, Validation, Writing – review & editing. **Ana Solorio:** Investigation, Validation, Writing – review & editing. **Trent Biggs:** Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing. **Penelope J.E. Quintana:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Visualization, Writing – review & editing. **Linda Lara-Jacobo:** Conceptualization, Investigation, Methodology, Resources, Supervision, Writing – review & editing. **Nicolas Lopez-Galvez:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

Conflict of interest

The authors have no competing interests to declare.

Acknowledgements

We are grateful to the farmworkers who participated in this study for sharing their time and experiences. We also acknowledge the contributions of the field research team members, Ofelia Cruz, Stephanie Hurtado-Gonzalez, Alejandra Early, and Eduardo Arreola, for their dedication to data collection and project implementation. We thank the entire Rural Heat Island research team for their valuable input and discussions that informed this work, as well as Líderes Campesinas for their continued partnership and support. As an ISGlobal researcher, Lena van Selm acknowledges support from the grant CEX2023-0001290-S funded by MCIN/AEI/10.13039/501100011033, and support from the Generalitat de Catalunya through the CERCA Program.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2026.114885.

References

Arcury, T.A., Quandt, S.A., 2020. Latinx Farmworkers in the Eastern United States: Health, Safety, and Justice, second ed.

Arnold, T.J., Arcury, T.A., Sandberg, J.C., Quandt, S.A., Talton, J.W., Mora, D.C., Kearney, G.D., Chen, H., Wiggins, M.F., Daniel, S.S., 2020. Heat-related illness among latinx child farmworkers in North Carolina: a mixed-methods study. New Solut. J. Environ. Occup. Health Policy 30, 111–126. https://doi.org/10.1177/1048291120920571.

Bethel, J.W., Harger, R., 2014. Heat-related illness among Oregon farmworkers. Int. J. Environ. Res. Publ. Health 11, 9273–9285. https://doi.org/10.3390/ijerph110909273.

Buguet, A., Radomski, M.W., Reis, J., Spencer, P.S., 2023. Heatwaves and human sleep: stress response versus adaptation. J. Neurol. Sci. 454, 120862. https://doi.org/10.1016/j.jns.2023.120862.

Cal/OSHA, 2005. Heat Illness Prevention in Outdoor Places of Employment, California Code of Regulations. Title 8, Section 3395.
Cheveldayoff, P., Chowdhury, F., Shah, N., Burow, C., Figueiredo, M., Nguyen, N., Talbo, M., Jamasi, R., Katz, A., Pasquale, C., Hill, L., 2023. Considerations for occupational heat exposure: a scoping review. PLOS Clim. 2, e0000202. https://doi.org/10.1371/journal.pclm.0000202.
Courville, M.D., Wadsworth, G., Schenker, M., 2016. "we just have to continue working": farmworker self-care and heat-related illness. J. Agric. Food Sys. Community Dev. 6, 143–164.
Easton-Calabria, L., Reed, C., Ruder, T., Mychal, J., Scazzosi, J., Chari, R., Vant-Hull, B., Drapkin, J.K., Madrigano, J., 2026. Indoor thermal environments, cooling access, and energy burden in New Orleans, LA: challenges and opportunities for heat adaptation. J. Urban Health 103, 469–483. https://doi.org/10.1007/s11524-026-01096-w.
Edgerly, A., Gillespie, G.L., Hittle, B.M., Bhattacharya, A., 2024. US farmworkers' barriers to preventing heat-related illness: an integrative review. Publ. Health Chall 3, e222. https://doi.org/10.1002/puh2.222.
El Khayat, M., Halwani, D.A., Hneiny, L., Alameddine, I., Haidar, M.A., Habib, R.R., 2022. Impacts of climate change and heat stress on farmworkers' health: a scoping review. Front. Public Health 10, 782811. https://doi.org/10.3389/fpubh.2022.782811.
Fleischer, N.L., Tiesman, H.M., Sumitani, J., Mize, T., Amarnath, K.K., Bayakly, A.R., Murphy, M.W., 2013. Public health impact of heat-related illness among migrant farmworkers. Am. J. Prev. Med. 44, 199–206. https://doi.org/10.1016/j.amepre.2012.10.020.
Flouris, A., Azzi, M., Graczyk, H., Nafradi, B., 2024. Heat at Work: Implications for Safety and Health. International Labour Organization.
Flouris, A.D., Dinas, P.C., Ioannou, L.G., Nybo, L., Havenith, G., Kenny, G.P., Kjellstrom, T., 2018. Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. Lancet Planet. Health 2, e521–e531. https://doi.org/10.1016/S2542-5196(18)30237-7.
Glaser, J., Lemery, J., Rajagopalan, B., Diaz, H.F., García-Trabanino, R., Taduri, G., Madero, M., Amarasinghe, M., Abraham, G., Anutrakulchai, S., Jha, V., Stenvinkel, P., Roncal-Jimenez, C., Lanaspa, M.A., Correa-Rotter, R., Sheikh-Hamad, D., Burdmann, E.A., Andres-Hernando, A., Milagres, T., Weiss, I., Kanbay, M., Wesseling, C., Sánchez-Lozada, L.G., Johnson, R.J., 2016. Climate change and the emergent epidemic of CKD from heat stress in rural communities: the case for heat stress nephropathy. Clin. J. Am. Soc. Nephrol. 11, 1472. https://doi.org/10.2215/CJN.13841215.
Gubernot, D.M., Anderson, G.B., Hunting, K.L., 2014. The epidemiology of occupational heat exposure in the United States: a review of the literature and assessment of research needs in a changing climate. Int. J. Biometeorol. 58, 1779–1788. https://doi.org/10.1007/s00484-013-0752-x.
Handal, A.J., Iglesias-Rios, L., Valentín-Cortés, M.A., O'Neill, M.S., 2025. Experiences of women farmworkers in Michigan: perspectives from the Michigan farmworker project. Am. J. Community Psychol. 75, 292–304. https://doi.org/10.1002/ajcp.12792.
Harris, P.A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., Conde, J.G., 2009. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. J. Biomed. Inf. 42, 377–381. https://doi.org/10.1016/j.jbi.2008.08.010.
Heinzerling, A., Laws, R.L., Frederick, M., Jackson, R., Windham, G., Materna, B., Harrison, R., 2020. Risk factors for occupational heat-related illness among California workers, 2000–2017. Am. J. Ind. Med. 63, 1145–1154. https://doi.org/10.1002/ajim.23191.
Holmes, S.M., 2013. Fresh Fruit, Broken Bodies: Migrant Farmworkers in the United States, first ed. University of California Press.
Hulley, G.C., Dousset, B., Kahn, B.H., 2020. Rising trends in heatwave metrics across Southern California. Earths Future 8. https://doi.org/10.1029/2020EF001480 e2020EF001480.
International Labour Organization, 2024. Ensuring Safety and Health at Work in a Changing Climate.
Jackson, L.L., Rosenberg, H.R., 2010. Preventing heat-related illness among agricultural workers. J. Agromed. 15, 200–215. https://doi.org/10.1080/1059924X.2010.487021.
Johnson, R.J., Wesseling, C., Newman, L.S., 2019. Chronic kidney disease of unknown cause in agricultural communities. N. Engl. J. Med. 380, 1843–1852. https://doi.org/10.1056/NEJMra1813869.
Kecklund, G., Axelsson, J., 2016. Health consequences of shift work and insufficient sleep. Br. Med. J. 355, i5210. https://doi.org/10.1136/bmj.i5210.
Kjellstrom, T., Gabrysch, S., Lemke, B., Dear, K., 2009. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. Glob. Health Action 2, 2082. https://doi.org/10.3402/gha.v2i0.2082.
Lam, M., Krenz, J., Palmández, P., Negrete, M., Perla, M., Murphy-Robinson, H., Spector, J.T., 2013. Identification of barriers to the prevention and treatment of heat-related illness in Latino farmworkers using activity-oriented, participatory rural appraisal focus group methods. BMC Public Health 13, 1004. https://doi.org/10.1186/1471-2458-13-1004.
Meade, R.D., Akerman, A.P., Notley, S.R., McGinn, R., Poirier, P., Gosselin, P., Kenny, G. P., 2020. Physiological factors characterizing heat-vulnerable older adults: a narrative review. Environ. Int. 144, 105909. https://doi.org/10.1016/j.envint.2020.105909.
Minor, K., Bjerre-Nielsen, A., Jonasdottir, S.S., Lehmann, S., Obradovich, N., 2022. Rising temperatures erode human sleep globally. One Earth 5, 534–549. https://doi.org/10.1016/j.oneear.2022.04.008.
Mirabelli, M.C., Quandt, S.A., Crain, R., Grzywacz, J.G., Robinson, E.N., Vallejos, Q.M., Arcury, T.A., 2010. Symptoms of heat illness among Latino farm workers in North Carolina. Am. J. Prev. Med. 39, 468–471. https://doi.org/10.1016/j.amepre.2010.07.008.
Moyce, S., Joseph, J., Tancredi, D., Mitchell, D., Schenker, M., 2016. Cumulative incidence of acute kidney injury in California's agricultural workers. J. Occup. Environ. Med. 58, 391–397. https://doi.org/10.1097/JOM.0000000000000668.
Mutic, A.D., Mix, J.M., Elon, L., Mutic, N.J., Economos, J., Flocks, J., Tovar-Aguilar, A.J., McCauley, L.A., 2018. Classification of heat-related illness symptoms among Florida farmworkers. J. Nurs. Scholarsh. 50, 74–82. https://doi.org/10.1111/jnu.12355.
National Institute for Occupational Safety and Health, 2016. Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. https://doi.org/10.26616/NIOSHPUB2016106.
National Weather Service, 2024. Weather Related Fatality and Injury Statistics.
Obradovich, N., Migliorini, R., Mednick, S.C., Fowler, J.H., 2017. Nighttime temperature and human sleep loss in a changing climate. Sci. Adv. 3, e1601555. https://doi.org/10.1126/sciadv.1601555.
Parajuli, S.P., Biggs, T., De Sales, F., Zavala Perez, M.A., He, C., Jones, C., Thompson, C., Galvez, N.L., Ciborowski, H., Quintino, T., Di Napoli, C., Montazar, A., Yazdi, T.H., Soucier, M., 2024. Impact of irrigation on farmworkers' heat stress in California differs by season and during the day and night. Commun. Earth Environ. 5, 787. https://doi.org/10.1038/s43247-024-01959-7.
Pierce, D.W., Das, T., Cayan, D.R., Maurer, E.P., Miller, N.L., Bao, Y., Kanamitsu, M., Yoshimura, K., Snyder, M.A., Sloan, L.C., Franco, G., Tyree, M., 2013. Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling. Clim. Dyn. 40, 839–856. https://doi.org/10.1007/s00382-012-1337-9.
Quesada, J., Hart, L.K., Bourgois, P., 2011. Structural vulnerability and health: latino migrant laborers in the United States. Med. Anthropol. 30, 339–362. https://doi.org/10.1080/01459740.2011.576725.
R Core Team, 2025. R: a Language and Environment for Statistical Computing.
Riccò, M., Vezzosi, L., Bragazzi, N.L., Balzarini, F., 2019. Heat-related illnesses among pesticide applicators in North-Eastern Italy (2017). J. Agromed. 25, 52–64. https://doi.org/10.1080/1059924X.2019.1606745.
Spector, J., Krenz, J., Blank, K.N., 2015. Risk factors for heat-related illness in Washington crop workers. J. Agromed. 2, 1–17. https://doi.org/10.1080/1059924X.2015.1047107.
Thompson, C.F., Jones, C., Biggs, T., Quintana, P.J.E., Perez, M.A.Z., Sales, F.D., Roberts, D., Parajuli, S., Ciborowski, H., McMahon, C., 2025. A climatology of summertime wet-bulb globe temperature in California's imperial valley. J. Appl. Meteorol. Climatol. 64, 911–932. https://doi.org/10.1175/JAMC-D-24-0199.1.
Tigchelaar, M., Battisti, D.S., Spector, J.T., 2020. Work adaptations insufficient to address growing heat risk for U.S. agricultural workers. Environ. Res. Lett. 15, 094035. https://doi.org/10.1088/1748-9326/ab86f4.
Tony Wolf, S., Cottle, R.M., Fisher, K.G., Vecellio, D.J., Larry Kenney, W., 2023. Heat stress vulnerability and critical environmental limits for older adults. Commun. Earth Environ. 4, 486. https://doi.org/10.1038/s43247-023-01159-9.
Watson, C., Troynikov, O., Lingard, H., 2019. Design considerations for low-level risk personal protective clothing: a review. Ind. Health 57, 306–325. https://doi.org/10.2486/indhealth.2018-0040.
Williams, M.L., 2021. Global warming, heat-related illnesses, and the dermatologist. Int. J. Womens Dermatol. 7, 70–84. https://doi.org/10.1016/j.ijwd.2020.08.007.
Wright, K.P., Bogan, R.K., Wyatt, J.K., 2013. Shift work and the assessment and management of shift work disorder (SWD). Sleep Med. Rev. 17, 41–54. https://doi.org/10.1016/j.smrv.2012.02.002.