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TECHNICAL REPORT

D3.6: Report on solutions to mitigate heat stress for workers of the agricultural sector

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SUMMARY (overview of identified issues and screened solutions)

European workers in the agricultural sector are seasonally exposed to heat stress that affects productivity (with ~ 0.7% lost efficiency per degree increase in air temperature above 21°C) **and potentially threatens individual health if appropriate precaution procedures are not adopted. This report is dedicated to providing guidelines with screened (effective, feasible and sustainable) solutions and strategies to mitigate or minimize negative effects of excessive heat exposure.**

Occupational heat strain (OHS) in the agricultural sector involve high body internal heat production associated with physically demanding tasks, seasonal exposure to outdoor conditions with high ambient temperature, humidity and solar radiation levels or indoor settings with limited ability to lower the environmental heat load (i.e. traditional cooling solutions are not applicable). Furthermore, specific settings (e.g. greenhouse work) or task with safety requirements such as wearing protective clothing may hamper heat loss and worsen heat stress.

It is advisable that agricultural firms, from large industrial operations to small family farms, consider/develop an appropriate heat response plan as it will benefit both employer and employee perspectives. Single or combined heat resilience methods appropriate/applicable for the specific work setting should be identified and translated into feasible actions and habits that workers can adopt during hot periods – with timely information at the beginning of the summer and regular follow-up reminders.

Importantly, workers must be allowed time to adapt to the heat. Workers will acclimatize to heat during the first days, however depending on the initial fitness and previous exposure it will take at least one week before workers get used (physiological adapted) to the increased heat.

Staying hydrated is critical for maintaining productivity and health; but workers routinely fail to rehydrate from day-to-day. Thus, more than 50% of agricultural workers arrive at work with inadequate/low hydration status, which is problematic, because heat-exposure combined with dehydration markedly impairs cognitive and physical performance and increase physiological strain. **This means they start the day at an elevated risk of heat intolerance and reduced performance.** To best correct this problem, workers should drink at least 500-750 ml (two cups of water) before work, during a mid-day break and after work, in addition to drinking water regularly throughout the day whenever thirsty. To ensure adequate hydration status, workers can self-monitor by ensuring they are drinking sufficiently to need to urinate approximately once every two-three hours and that their urine remains clear or slightly yellow. During periods where workers are sweating profusely, healthy workers should add a larger amount of salt (electrolytes) to their diet, however, this advice should only be followed by doctor's recommendations in those with heart, blood pressure, or other medical conditions.

Additional breaks can be planned and included without compromising the net/effective working time (e.g. 1-2 min, every 30 min)**.** Adding, preplanned work breaks during periods of hot weather has been demonstrated to improve worker health, wellbeing and comfort without reducing net worker productivity. This is because when workers overheat, they begin to work slower and take more frequent unplanned breaks, whereas taking preplanned breaks allows the workers to cool down and limit becoming overheated. These preplanned breaks should be undertaken in **shaded areas with plenty of ventilation**. Although air conditioning is the most effective method for reducing environmental heat stress, it is often prohibitively expensive, cannot be employed in the field, and detrimental to the environment. However, it can be employed more efficiently by cooling specific "cooling oases" such as small rooms or utilizing the air conditioning of workers' cars. The efficiency of air conditioning can be further improved by using it with ventilation and by limiting the amount and/or thickness of clothing worn while in the cooling spaces, in which case the air temperature need only to be lowered to ~26-28°C to be highly effective.

Cooling interventions can be applied during breaks to further lower physiological strain and improve worker performance. Several interventions have been identified which have been demonstrated to be effective at lowering physiological strain and improving performance during periodic breaks. These include immersing the arms up to the elbow in tubs of cool water, ingesting cool water or slush ice, applying ice wrapped in wet towels to the neck, wetting the skin while sitting in front of a fan or wearing a phase change material cooling vest (i.e. vests filled with cooling gel packs or ice). It should be noted, each of these interventions vary in effectiveness, cost and feasibility (discussed below) and employers should consider which interventions make the most sense for their given work environment.

Some interventions can be used during work as well. For workers that have to undertake very thermally demanding tasks (such as spraying pesticides in chemical protection suits) pre and intermittent cooling with more effective but less feasible and more costly methods, such as consuming large volumes of slush ice, wearing phase change material cooling vests, or precooling limbs through water immersion may be warranted. Additionally, if a task requires the person to be somewhat immobile in very hot environments for extended periods of time, liquid and air-cooled garments are available and are very effective, however, they are also very costly. For the majority of farmers who do not wear special chemical protective clothing, but need great mobility during work, clothing incorporated with ventilation fans is beneficial and is a preferred solution.

Appropriate clothing can lower the thermal stress. Some tasks require special protective clothing and clothing is also beneficial for protecting the agricultural worker from excessive sun exposure, but clothing can also limit heat loss as it provides a boundary layer that limits evaporation and convective and radiative heat loss from the skin**.** To facilitate heat loss, clothing worn during the work shift should be selected based upon promoting air flow across the skin and improving sweat evaporation (reducing clothing evaporative resistance). This can be accomplished by reducing the total amount of skin covered by clothing via wearing a t-shirt vs long sleeve (if indoors), wearing looser fitting clothing which allows for greater air flow underneath the clothing, and wearing clothing with a wider knitting pattern which allows for more air flow to pass through the clothing. Otherwise, novel ventilated garments can be worn which provide an elevated amount of cooling relative to standard clothing, facilitated by air flow underneath the clothing. Additionally, in outdoor environments on sunny days, hats should be worn to protect the head from solar radiation but designed and made of materials that allow for adequate air flow. In situations where long, rigid clothing must be worn (e.g. coveralls), ventilation patches can be incorporated into more protected areas such as under the arms and between the legs to help promote air flow through the garment. Finally, recent research suggests a cooling benefitted from using new generations of synthetic “sweat wicking” fabrics in lieu of natural fabrics, however, compression garments should be avoided.

1. Introduction

Agriculture is one of the oldest industries of the EU representing a considerable fraction of GDP, employing a large number of workers and central for stable food prices and supply. Despite increasing mechanization, the agricultural industry is still characterized by an array of manual labour tasks, which elevate the workers' metabolic rate and consequently the body produce large amounts of internal heat. Furthermore, workers are exposed to the open environment and hence high levels of external heat stress during hot parts of the year. Many agricultural tasks need to be performed on a fixed schedule, sometimes requiring the most physically demanding tasks to take place either during the hottest part of the day (around noon) or the hottest time of year (e.g. harvesting during the summer).
In this context, it is quite clear that occupational heat stress can negatively affect the agricultural workers health and their performance capacity, which subsequently may lower productivity and income for the individual and/or company costs directly related to lost working efficiency or indirectly via illness/sickness. The present report is part of a series of five industry-specific reports on each of the key EU sectors (manufacturing, construction, transportation, tourism and agriculture). Overall the reports focused on defining, screening and optimizing appropriate technical and biophysical solutions to counter the negative impact of high thermal stress imposed by the combination of adverse environmental conditions, industrial heat production, the workers own/internal metabolic heat production, conditions and confounding factors such as protective clothing or other work-related factors that may conflict with heat dissipation.

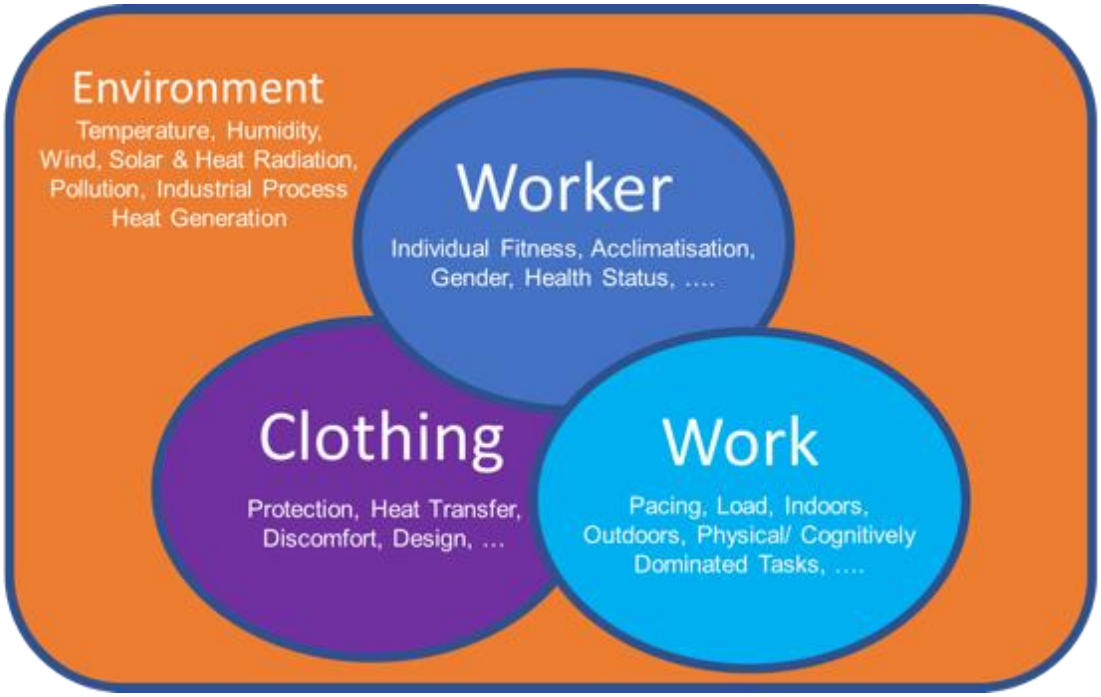


Figure 1 Overview on occupational aspect of human heat balance

Human function depends on a balance between internal (metabolic) heat production and heat-exchange with the environment (Kenny & Jay, 2013). When a worker is physically active, the metabolic energy release will increase in proportion to the work intensity and hence increase heat production in the body. If not released to the environment, this heat will warm up the worker, increase heat strain, impair both physical and cognitive function and potentially provoke fatal overheating. Therefore, to keep workers safe and avoid decrements in functionality, the produced heat must be balanced by heat lost from the body (skin) to the environment, which can be by dry heat loss (primarily air convection and radiation) and/or by sweat evaporation. For occupational settings, it is characteristic that in addition to climatic conditions (with air temperature, solar radiation, humidity and wind speed as the factors of importance) the local environment may also be highly influenced by the industrial settings (Malchaire *et al.*, 2001) (see figure 1). The warmer and more humid the environment (micro-climate around the worker), the more difficult it is to lose the heat. In addition, solar radiation or radiation from industrial processes, will further add to the heat

load while wind/ventilation can benefit dry heat loss as long as the air temperature is below ~ 35 degrees. In addition, wind can facilitate evaporation and hence benefit the overall heat balance even at higher environmental temperatures.

When considering solutions to lower heat stress, any practice that may either lower workers internal heat production (e.g. optimizing the work procedures), facilitate heat dissipation (including lessening of the constraining effects that e.g. clothing may impose) or directly cool the body (e.g. ingestion of cold drinks or ice) can be beneficial. This can range from behavioural and biological interventions/adaptations to technical solutions that may assist heat dissipation (e.g. increasing air flow, cooling vests or air conditioning) or lower the environmental heat load (e.g. reducing solar radiation). In accordance with this overall context, the present report will consider the specific solutions screened and identified as both effective and feasible to implement for workers in the agricultural sector.

This report on solutions for the agricultural sector focus on the industry specific issues, needs and exposure characteristics of workers from the agricultural sector in order to identify ways to mitigate the corresponding heat stress. The focus is in proposing adaptation measures including rescheduling work times, adding short preplanned rest breaks, advanced hydration strategies, shading alternatives, smart clothing solutions (i.e. ventilated garments), given the particular exposure of agricultural workers to both indoor and outdoor conditions. While assessing the capacity and potential of these adaptation measures to mitigate workers' heat stress, the report will also put special attention on determining the specific requirements of the different solutions, and their compatibility with the intended application environment. The cost, feasibility and sustainability of the proposed interventions will also be discussed as it is important to ensure the proposed measures can actually be used by potential employers, cost benefit decisions can be made, and it is critical the use of these interventions do not further contribute to climate change in significant ways.

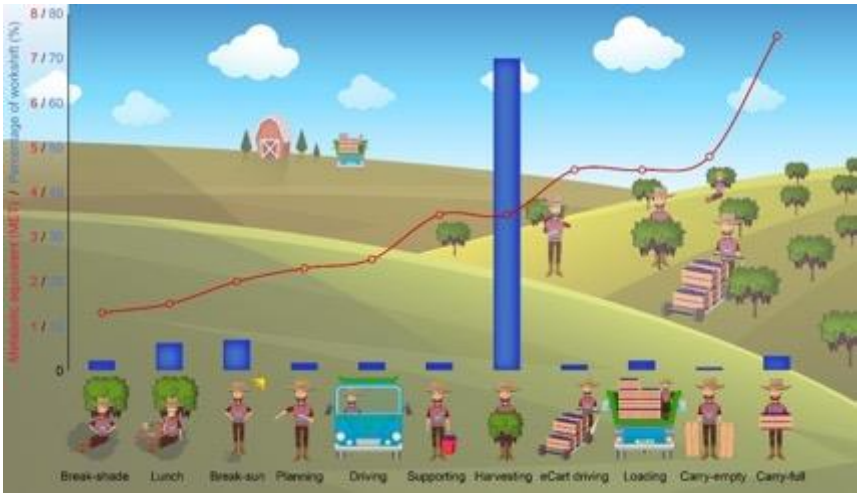


Figure 2. Metabolic equivalent (red line) and percentage of time spent (blue bars) on 11 different activities observed during a field study at a vineyard. Two activities involved work breaks (i.e., unprescribed irregular work breaks determined by workers' own judgment) and were considered as labour loss indicators, one activity involved a lunch break that was administered by management, and the remaining eight activities were directly related with the job tasks of the workers (from Heat-Shield work currently under review).

2. Industry specific issues for agricultural workers

As highlighted above, physically demanding tasks implies that the workers increase their metabolic rate to supply their working muscles with enough energy to complete their work. This will subsequently increase internal heat production and contribute to the overall heat stress. Figure 2 (from yet-unpublished Heat-Shield findings) depicts an example of the amount of time spent performing various agricultural related tasks verses the metabolic cost of those tasks.

In addition to large metabolic demands, much of the work performed in the agricultural industry occurs outdoors at the mercy of the elements. Specifically, high ambient temperatures and humidity levels impairs the amount and rate at which heat is lost from the body to the environment, which can allow for heat to accumulate within the body, leading to heat stress (Kenny & Jay, 2013).

Of particular importance for the agricultural industry is field work in which many workers are exposed to the sky with limited protection from solar radiation on sunny days. On clear sunny summer days, black-globe temperature, an indication of the amount of radiative load is present in a given environment can be

between 10 and 16°C higher than air temperature recorded in the shade, contributing to a substantially greater environmental heat load. In order to combat this heat load, workers may wish to remove clothing in order to limit the amount of thermal insulation, thereby facilitating greater heat loss. However, by exposing greater amounts of skin to the sun, this puts the agricultural workers at an elevated risk of skin cancer. Indeed, multiple studies have demonstrated in elevated skin cancer risk in outdoor workers (Radespiel-Tröger *et al.*, 2008).
Another aspect of field work which puts the workers at elevated risk is that water availability can be limited. Indeed, in a recent study we observed that while between 30-70% of workers from agricultural, police, tourism, construction and manufacturing industries arrived to work in a dehydrated state, agriculture was the only industry in which workers became progressively more dehydrated throughout the day (Piil *et al.*, 2018). One method that has been employed to counteract this issue is to store water in caches around the field (personal observation from Heat-Shield occupational hygienists and stakeholders; more on this in the hydration section). However, a major concern with this method, especially if the water is being stored in plastic containers as these could be ideal growth areas for harmful bacteria (Watanabe *et al.*, 2014).
Another frequent setting of agricultural work takes place within greenhouses. Because of this, the warm temperatures and high humidity levels can cause occupational heat stress to be an issue throughout the year and not just during the hot/summer periods (Cecchini *et al.*, 2010).
Finally, agricultural work often entails the spraying of chemicals which can be harmful for the health of the workers. Because of the highly insulative properties of the chemical suits, workers can become heat stressed rapidly if having to wear such a suit in warm conditions for extended periods of time (VAN WELY, 2017).

3. Identified/screened solutions

Those who are at higher risk

It is important to stress that **everyone** will be affected by heat stress (Ioannou *et al.*, 2017). However, certain characteristics have been identified as strong predictors for those who may be more susceptible to heat stress than others. In particular, elderly workers, women and those with chronic illnesses such as heart disease (Casa *et al.*, 2015; Flouris *et al.*, 2018).
Also, of note, the cultural background and previous work experience/experience with heat stress can play an important role as well. Foreign workers may be better equipped to deal with heat stress than local workers if they come from hotter countries (presently unpublished Heat-Shield work). Conversely, foreign workers who come from cooler countries may be at greater risk for heat illness.
Those who are currently ill, especially with conditions as flu or gastroenteritis or who have known infections of any variety will be at an elevated risk level for occupational heat stress, as these conditions are known to interfere with body's central thermoregulatory control centers (Casa *et al.*, 2015).

Trained personnel and information

It is important that every agricultural operation, no matter the size, has a designated person or persons responsible for the safety of the workers during heatwaves. In larger industrial operations, this could be staff physicians or medical officers. For smaller family operations, this role will most likely be filled by the owner. It is **critically important** that this person has a heat response plan in place **before** the occurrence of a bout of hot weather.
The first line of defence against heat stress is knowing when periods of hot weather are coming. Weather forecasts, especially during summer months should be checked regularly to be aware of impending bouts of hot weather. Additionally, recent advancements in technology have made it possible for individuals to sign up for advanced warning notifications. Indeed, the Heat-Shield affiliated website http://heatshield.zonalab.it/ is a weather notification website which not only gives alerts for impending hot weather, but also gives personalised recommendations based upon workers body morphology, age, the type of work they perform and the clothing that they have to wear at work and be accessed free of charge either by individual workers or by company representative in charge of the heat response plan for the company.

For operations which have a regular staff who are employed year after year, keeping medical records which document any workers who had difficulties with hot weather in previous years can be beneficial for knowing which workers may have greater sensitivities towards the heat and may need to be paid closer attention to. Additionally, to prevent catastrophe, instituting a "buddy system" in which workers are paired to ensure a worker does not collapse in a field or become unaware of their own poor state of health due to heat illness. When possible, ensuring that the work "buddies" check in with each other on a half-hourly bases (this can be facilitated more readily if the recommended 1.5 min breaks every 30 min policy is put in place).

Breaks

A major concern for many employers is effective working time considering that additional breaks may cost money due to reduced performance/productivity. In relation to heat stress, lowering the work intensity either by reducing the working pace or including more frequent breaks will diminish heat stress by lowering the amount of internal heat produced. It is important to note that if workers are not provided with breaks, they will as part of their thermo-regulatory behaviour slow down or take more frequent and longer breaks (Figure 3, Panel A; from (Ioannou *et al.*, 2017)) or ultimately be exhausted or ill and hence forced to stop.

Importantly, we demonstrate that pre-planned 1.5 min breaks (every 30 min throughout the working day) will not result in a decrease in work productivity compared to if workers are left alone, even without any additional cooling interventions are applied (Figure 3, Panel B; from presently un-published Heat-Shield work). Therefore, employers can be confident that giving their employees regular periodic breaks to rest and rehydrate will not reduce but will in fact likely enhance their workers' health and the overall work productivity during extended bouts of heat stress when negative physiological responses to the heat can accumulate.

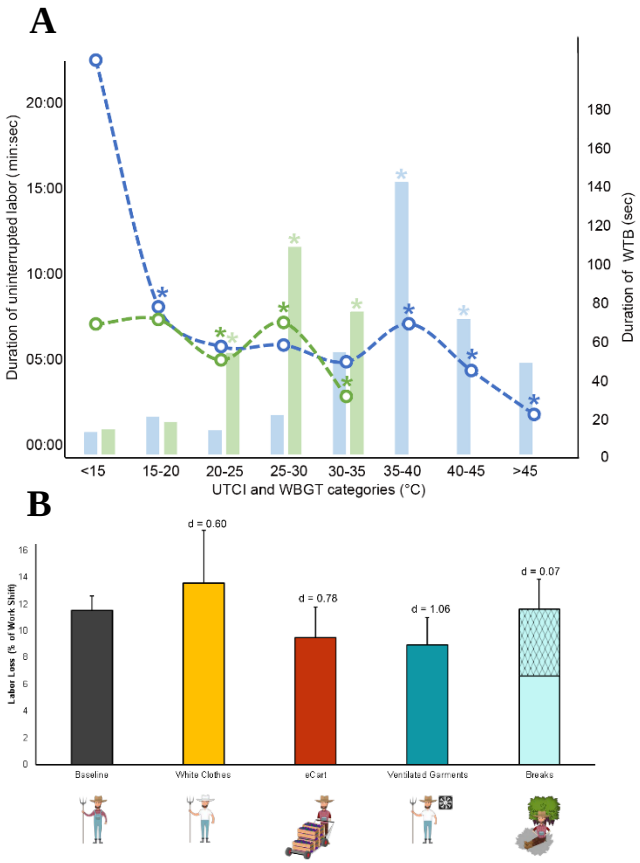


Figure 3. Panel A (from Ioannou *et al.*, 2017): Worker productivity denoted by the duration agricultural workers spent taking unplanned breaks as a function of rising environmental heat stress. Panel B (presently un-published Heat-Shield work): Reductions in worker productivity throughout the day during four different

To improve the effectiveness of the cooling breaks, refuges such as "cooling oases", i.e. areas that have been specifically designed to provide respite from hot working conditions should be created. This can be accomplished by have an air-conditioned shack or room if located in a building complex area or else by having a field kit which includes an insulated box filled with cooled water and a portable parasol or sun tent which could be set up in a field and transported around to provide shade on sunny days.

It may be interesting to note that in many countries, it is well accepted that construction sites must provide cooling stations, such as the ones described above, for their employees, yet these types of policies often, for some reason, are not legislated as strictly for agricultural workers. Further in other countries such as the United States and Canada, work rest cycles (such as those exhibited in Figure 4; (Anon, n.d.)) are mandated by law and are often recommended by workers unions as the gold standard work rest ratio model to follow. It is, however, important to note that these models were originally produced by the military as guidelines for soldiers marching in the heat and the transferability of these tasks to agricultural work is not well established. It is also worth noting that the work rest cycles go from no rest to resting 15 minutes out of every hour. This much rest is unacceptable in the eyes of many employers and this can diminish the likelihood of the employers adopting such guidelines. We therefore suggest employing the short frequent breaks we described above will be both effective and will be more likely to be adopted as common practise by employers.

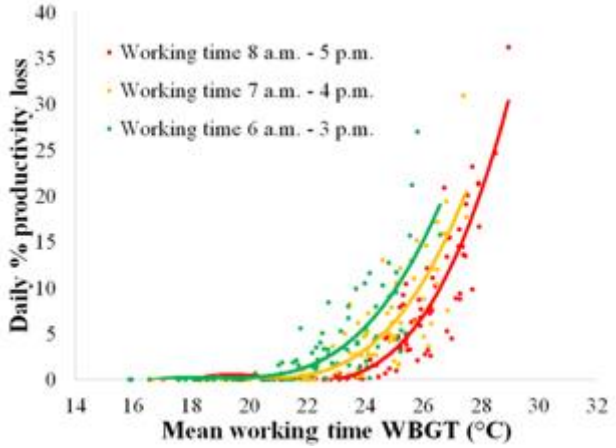
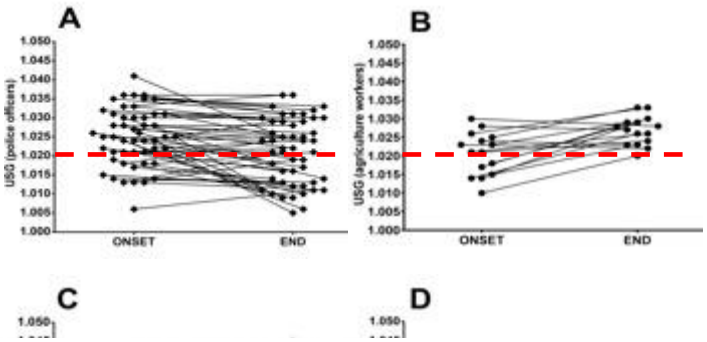


Figure 5. Changes in work productivity loss as a function of WBGT values for three different modelled work days (currently unpublished Heat-Shield work).

Timing of work

As mentioned initially some tasks in the agricultural sector are dictated by the season or daily timing requirement, however, when possible a feasible, easy and low-cost way to help mitigate heat stress is by changing the working hours or reschedule tasks. This can be accomplished in several ways. First of all, reorganising the itinerary of the day so that the most physically demanding tasks are performed early or late in the day when ambient temperatures are cooler. Additionally, when possible, temporary adjustments to when working hours take place can be employed. As demonstrated by figure 5, the loss in worker productivity can be mitigated by ~10% by starting the work shift 2 hours earlier (currently unpublished Heat-Shield work). Alternatively, work hours can be transferred to later in the day (to avoid the peak hours around noon), however, for European setting the morning hours are ideal as these are the coolest hours in the day as temperatures will typically descend more throughout the night. Other options may involve a break in the middle of the day when temperatures are at their highest and return to work later in the day once ambient temperature has cooled a bit. Finally, the concept of timing tasks around hot times of days can be extended to incorporate the year as well. Clearly, certain tasks (e.g. harvesting or urgent reparations) cannot be rescheduled, but physical demanding/manual work (overall infrastructure items) that can be planned with a prolonged perspective should be scheduled to times of the year when the environmental heat load is low.



WBGT °C			Light Work		Moderate Work		Heavy Work		Very Heavy Work	
DPCU	Body Armour	MOPP4	Work/Rest (min)	Water (L/h)	Work/Rest (min)	Water (L/h)	Work/Rest (min)	Water (L/h)	Work/Rest (min)	Water (L/h)
<25	<22	<19	NL	¾	NL	¾	50/10	¾	30/30	¾
25-26	22-23	19-20	NL	¾	NL	¾	40/20	¾	20/40	¾
27-28	24-25	21-22	NL	¾	50/10	1	30/30	1	20/40	1
29-30	26-27	23-24	NL	¾	40/20	1	30/30	1	10/50	1
31	28	25	NL	¾	30/30	1	20/40	1	5/55	1
32	29	26	50/10	1	20/40	1¼	10/50	1¼	5/55	1¼
33	30	27	40/20	1¼	10/50	1¼	10/50	1¼	CM	1¼
34	31	28	30/30	1¼	10/50	1¼	CM	1¼	CM	1¼
35	32	29	20/40	1¼	CM	1¼	CM	1¼	CM	1¼
36	33	30	10/50	1¼	CM	1¼	CM	1¼	CM	1¼
≥37	≥34	≥31	CM	1¼	CM	1¼	CM	1¼	CM	1¼

Figure 4. NIOSH work-rest cycles based upon WBGT values (Anon, n.d.).

Hydration options

Due to the frequent exposure to heat stress, ensuring agricultural workers maintain adequate hydration status is a major concern. As demonstrated in Figure 6, approximately 50% of agricultural workers arrive to work in what would be considered a dehydrated state (Piil *et al.*, 2018). What is worse, in contrast to multiple other industries such as manufacturing and transport, agricultural workers will become progressively more dehydrated throughout the day. This is largely due to agricultural workers having very elevated sweat losses in order to maintain heat balance in the face of heightened metabolic rates and hot working environment. Further complicating the issue, accessibility to drinking water, particularly for those workers who spend most of their time out in the field, can be very limited. Suggested methods to combat the lack of availability of water, is to establish "water caches" or locations in which drinkable water is stored which the workers can access when needed. This can be accomplished via water bottles in insulated boxes such as ice boxes, coolers, etc. Additionally, these water caches can be part of designated rest and cooling oases and equipped with portable tents in order for the workers to take a brief reprieve from the sun (once again, workers should follow the recommended 1.5 min break every 30 min protocol discussed above).

An important note on hygiene, plastic water bottles have been demonstrated to be worse carriers for bacteria compared to glass and metal bottles. There is a particular risk for bacteria in plastic when the plastic water bottles are heated (Watanabe *et al.*, 2014). To avoid risks of water contamination, workers should have their own metal or glass drinking containers when possible. Also, these drinking containers should ideally be replaced and or cleaned daily. The ideal recommendation would be for workers to establish water caches daily, with ice in insulated boxes to keep the water cool, and for the water to be stored in glass or metal containers.

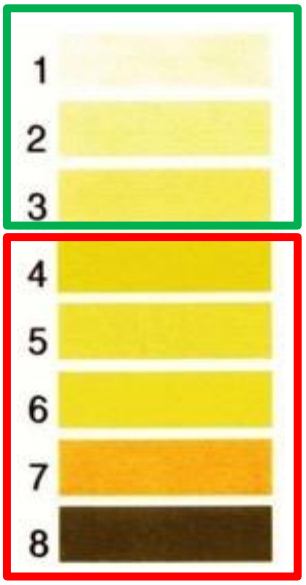


Figure 7. Urine colour as a marker for hydration status chart. Colours 1-3 are indicative of a well hydrated worker. Colours 4-7 are indicative of a dehydrated worker. Colour 8 may be indicative of kidney damage and the worker should see a physician.

As stated above, ~50% of workers arrive to work in a dehydrated (Piil *et al.*, 2018). This implies that hydration strategies before and after work are as important as hydration strategies during the work day and are often a better option as workers will typically have better access to drinking water before or after their work shift. Regardless of thirst, workers should ingest adequate water before their work shift (with ~ 500-750 ml as operational guideline), in the middle of the day, and after their work shift. Additionally, for healthy workers who sweat heavily on a regular basis, reestablishment of electrolyte balance by adding additional salt to the diet will help better maintain hydration status. Many physiological markers are often too complicated/inasive to be monitored in an occupational environment, but hydration status can be monitored relatively easily by inspecting one's own urine. First of all, workers should be instructed that they should be urinating approximately once every 2-3 hours. Urinating less frequently than this is likely a good indicator that the worker is drinking insufficient amounts of water. Secondly, the colour of the urine can be used as a strong indicator for hydration status. Figure 7 is a urine colour chart depicting the ideal urine colours for hydration status. The top three colours highlighted are indicative of an individual who is sufficiently hydrated. The darker colours are indicative of an individual who needs to drink more water. Additionally, should a worker find that they are peeing brown such as in colour sample 8, this could be indicative of kidney damage as a result of dehydration and the individual should be instructed to visit a doctor.

Cooling interventions during breaks

Brief regular cooling breaks (as described above) are the best opportunity for delivering small targeted interventions to help reduce physiological strain and maintain performance (Lee *et al.*, 2013). A vast array of cooling interventions exists and we have summarized those that were found in the literature and evaluated them based upon the strength of the evidence supporting or refuting their effectiveness, as well as their potency, cost, feasibility (within an agricultural setting) and environmental sustainability

Figure 6. Hydration status of workers from five different industries before and after the work shift (from Piil *et al.*, 2018).

(Table 1.0 from yet unpublished Heat-Shield research; see appendix 1). While this list is provided for the reader to peruse for ideas, the following highlighted interventions are those that we feel have the greatest all-around values for the prementioned criteria and the interventions that we feel are the best to be used in an agricultural setting:

Ice slurry ingestion: Ice slurries/slushies/crushed ice take advantage of the disproportionately large amount of heat used up in the melting of ice (334 J/g) compared to the warming of water (4.3 J/g/°C). Ice slurries have been demonstrated to be highly effective at lowering physiological strain when consumed at rest and improving subsequent work performance in the heat (Bongers *et al.*, 2015; Tan & Lee, 2015). Ice machines, ice shavers or slushy machines are all relatively inexpensive for the amount of cooling provided.

Arm immersion: Cold water immersion has been demonstrated to be the most effective acute cooling method for improving subsequent physical work in the heat (Casa *et al.*, 2007), however, whole-body immersion is generally unfeasible in most agricultural setting due to the loss of time while workers cool and change in dry clothes. Alternatively, limb immersion, in particular forearm immersion in cold water can result in a moderate lowering of physiological strain over a relatively short amount of time (McEntire *et al.*, 2013). Additionally, multiple workers can cool at the same time, improving the time efficiency of this intervention. Submersion of the arms in any water cooler than the arms themselves (~32°C) will result in some cooling, but for best results 15-20°C water should be employed (Casa *et al.*, 2007).

Cooling vests: Cooling vests, while not as effective as ice slurry or cold water immersion have been demonstrated to be effective at lowering physiological strain as well as improving physical performance in the heat (Bongers *et al.*, 2015; Chan *et al.*, 2015). These vests typically contain a phase change material such as ice or gel which absorbs heat from the body in order to melt the chosen material inside. Modern day cooling vests are highly customizable, with the amount of phase change gel being able to vary from vest to vest by about 1-2 kg.

Further, the chemical composition of the gels can be changed so that their melting point differs, in order to better account for individual needs, with cooler melting points being typically less comfortable but possess greater cooling potential. A common inconvenience with cooling vests is that, once the phase change material is melted and warmed to body temperature, the cooling benefits of the vests have been exhausted and the vests will now limit heat loss, as the workers will be carrying extra weight and the vest itself may contribute to thermal insulation and limit heat loss. As such, this cooling method is best used for short-duration work that is very thermally stressful such as greenhouse work or using chemical suits, or else to be used during cooling breaks.

Ice towels: This method is a cheaper alternative to cooling vests and can be a good solution during periods with very high heat stress (for cooling during breaks) or in emergency situations with acute need to lower skin temperature (and if used over prolonged periods lower deep core temperature as well) (Casa *et al.*, 2015; Schranner *et al.*, 2017; Lynch *et al.*, 2017). This method essentially consists of wetting towels with water and then filling the towels with ice.

Stationary Ventilation: increased airflow is always beneficial at 34°C air temperature or below (at any relative humidity). Based on currently unpublished Heat-Shield work, increased airflow is never recommended at 43°C air temperature or above (at any relative humidity). Between 34 and 43°C, increased airflow is only recommended below 60% relative humidity. However, below 40% relative humidity in this temperature range, increasing airflow will only have benefit when the skin is visibly wet. For this the skin needs to be wetted artificially from the outside (e.g. sprays) in addition to the person's sweat. In cases of moderate to heavy work levels with protective clothing covering legs, torso and arms (e.g. coveralls), increased airflow is always beneficial at 34°C air temperature or below (at any relative humidity). Increased airflow is never recommended at 43°C air temperature or above (at any relative humidity). Between 34 and 43°C benefit is unlikely. For internally ventilated clothing, the activation of the ventilator component will always be beneficial in ambient temperatures below 34°C. However, importantly benefit is only expected when the skin is wet. Other considerations: Where the task allows, reducing clothing coverage will increase the impact of the stationary fan. When fans are used for an extended period, efforts should be made to ensure hydration status is maintained. Regular fluid consumption is recommended to replace sweat losses. Externally applied water to the skin (e.g. spray; instead of only relying on sweating) will reduce the risk of dehydration in all "recommended" conditions, and potentially enhance the fan benefit. In direct solar radiation, UV protection needs to be considered.

Table 1. Assessment of different cooling interventions identified from the literature

Intervention	Strength of evidence	Productivity/ Performance/ Physiological impact	Economic Cost	Feasibility/ Implementation (indoor/outside)	Environmental sustainability
Environmental manipulation					
Air conditioning		+++	$$$		
Ventilation		- to ++	$		
Shading		0 to ++	$		
External cooling					
Cold water immersion		+ to ++	$$		
Phase change garments		+ to +++	$$		
Cooling packs		0 to ++	$$		
Ice towels		+++	$$		
Skin wetting		- to +++	$		
Menthol application		0 to +++	$		
Vacuum glove		0 to +	$$$		
Internal cooling					
Ice slurry ingestion		+ to +++	$		
Mixed method cooling					
External and internal cooling		++ to +++	$ to $$		
Hydration					
Hyperhydration		++	$		
Maintenance		++ to +++	$		
Rehydration		++ to +++	$		
Clothing					
Liquid & air-cooled		+++	$$$		
Compression		- to +	$$		
Elevated design		++	$$		
Ventilator-incorporated clothing		++	$$		
Heat acclimation					
Long term		+++	$ to $$$		
Medium		++ to +++	$ to $$$		
Short		+ to ++	$ to $$$		
Nutrition					
Carbohydrate		0 to +	$		
Amino acids		0 to ++	$		
Electrolytes		++	$		
Pacing strategies					
Breaks		0 to +++	$	to	
Pacing		0 to +++	$	to	
Scheduling		?	$	to	

Table 1 is a summary table of a Heat-Shield-conducted systematic review of systematic reviews on all available interventions that have been employed to improve physical and cognitive performance as well as physiological and perceptual responses to heat stress (see appendix 1). Pages (📄) denote strength of evidence, with 📄📄📄 denoting meta-analyzed data, 📄📄 denoting systematically analyzed data and 📄 denoting first level evidence only. Summative scores (-,0,+) denote effect on performance ranging from detrimental (-), neutral (0) to various levels of effectiveness (+=mildly beneficial, ++=moderately beneficial and +++= very beneficial). Approval signs (👎, 👍) denote how feasible the given intervention would be to employ in a standard agricultural environment ranging from nearly impossible to employ (👎👎👎) to essentially no additional effort to employ required (👍👍👍). Finally leaves (🍃) denote environmental sustainability ranging from not sustainable (🍃) to essentially no additional burdon on the environment (🍃🍃).

Cooling interventions during work

Cooling during work can be difficult, however there are several methods that can be employed at a low cost.

Skin wetting: By applying water to the skin will help facilitate evaporative cooling, lowering skin temperature, improving thermal comfort and lowering the workers' sweat rates, thereby slowing the rate of dehydration (Schranner *et al.*, 2017; Lynch *et al.*, 2017). This can also be achieved by wetting clothing (if the workers do not find this uncomfortable) or wetting rags that are subsequently wrapped around the head. As this type of cooling depends on the evaporation of water from the skin surface, it is more effective in dry environments, conversely, in humid environments, the water may remain on the skin or clothing and will likely cause greater worker discomfort.

Figure 8. Demonstration of novel ventilation shirt with built-in ventilator.

Ventilation shirts: Novel types of clothing such as "ventilation shirts" (Figure 8; from currently unpublished Heat-Shield work) shirts that have a miniature fan built into it to provide a consistent air flow through the clothing to help facilitate convective and evaporative cooling and maintain mobility in contrast to the use of a stationary fan.

Cooling vests: As stated above, cooling vests can be worn during breaks or during work and are effective at limiting physiological strain and improving work performance. However, care must be taken that the vests can be removed, or the phase change materials are replaced with a new one, once the phase change material inside has been completely melted. This method is best used for short term very thermally demanding work.

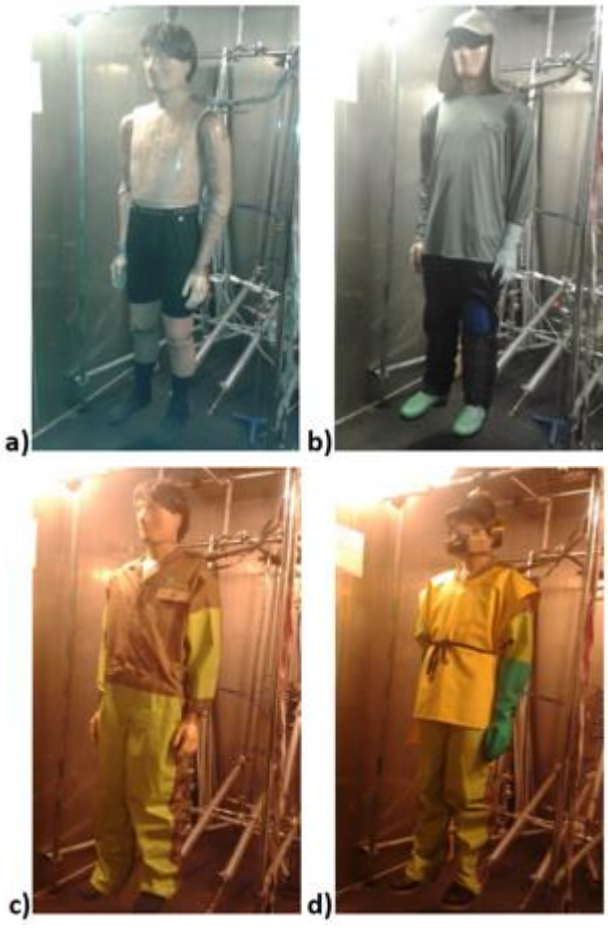


Figure 9. Depiction of different chemical protection suits which possess different levels of thermal insulation, weight, breathability, and maneuverability, all factors affecting the thermal qualities of the clothing

Clothing

Clothing should be selected in order to facilitate heat loss. Specifically, loose fitting clothing with a wider knitting pattern should be worn to help facilitate evaporative and convective heat transfer. Additionally, limiting the amount of clothing covering the skin surface will help facilitate cooling. This is especially relevant for indoor environments such as greenhouses, if the risk of pesticide exposure is low. However, in outdoor situations the risk of damage to the skin via UV radiation. In this instance, if workers prefer wearing short sleeves, they should ensure to use sun screen especially on clear, sunny days. It should be noted that in general clothing will be more effective at blocking UV radiation. If workers choose

long sleeved clothing, they should ensure that the shirts are light and loose fitting. Furthermore, light coloured clothing is better at limiting the solar load compared to darker coloured clothes. Also, in situations where workers are sweating heavily, clothing made of synthetic fabric (polyester) typically will allow for the sweat to be moved away from the skin more rapidly, improving thermal comfort, however, this type of clothing can have a negative smell.

Novel types of clothing such as "ventilation shirts" that have miniature fans built into it to provide a consistent air flow through the clothing to help facilitate convective and evaporative cooling. Importantly, for many agricultural operations, protection from chemicals when spraying is a major concern. By design, these articles of protective clothing are generally very impermeable and therefore the amount of heat that can be lost from the body while wearing this type of protective wear is limited. Some alterations can be made to the clothing to the protective suits to improve their thermoregulatory abilities such as fabrics which move more easily and are lighter, which thereby improve work efficiency and reduce metabolic heat production, the feel of the garment on the skin to improve comfort and the breathability of the garment to allow for slightly improved heat loss (VAN WELY, 2017). However, for more effective cooling, it is appropriate to use phase change materials or ice vest under the chemical protective clothing.

Physiological adaptation to heat stress

Common statements by both employers and employees, especially in countries in which hot weather is commonplace include "It's a hot country", "I'm used to the heat", and "Heat doesn't affect me". It is true that the human body does adapt to environmental heat stress, however, this process takes time. The classic ways in which the body adapts to heat stress includes a lower core temperature and heart rate at rest and for a given task, improved comfort in the heat, a greater sweating response (to allow for greater personal cooling, at the expense of greater water loss i.e. may put the worker at a greater risk of dehydration) and greater work capacity (Périard *et al.*, 2015). The initial phase of heat acclimatization takes approximately four days before physiological adaptations such as lowered heart rate and resting core temperature occur and 7 days until the majority of the process has occurred (see Figure 10). Further, full acclimatization to the heat will only occur after approximately 14 days of physical work during elevated environmental heat stress.

Employers and advisors may want to take advantage of the acclimatization process and time course for adaptations when work schedules are planned. For example, if employers can identify which tasks are the most thermally-demanding, they can assign more seasoned workers to these tasks and give new employees lighter tasks in the beginning to allow for their bodies to adapt to the heat stress of the environment prior to assigning them to more physically and thermally demanding tasks. A similar strategy can be taken for those who may have a more difficult time with the heat, such as older workers, those with pre-existing health conditions and workers who previously had great difficulty with the heat in previous years, in order to provide them with more time to adapt to the heat.

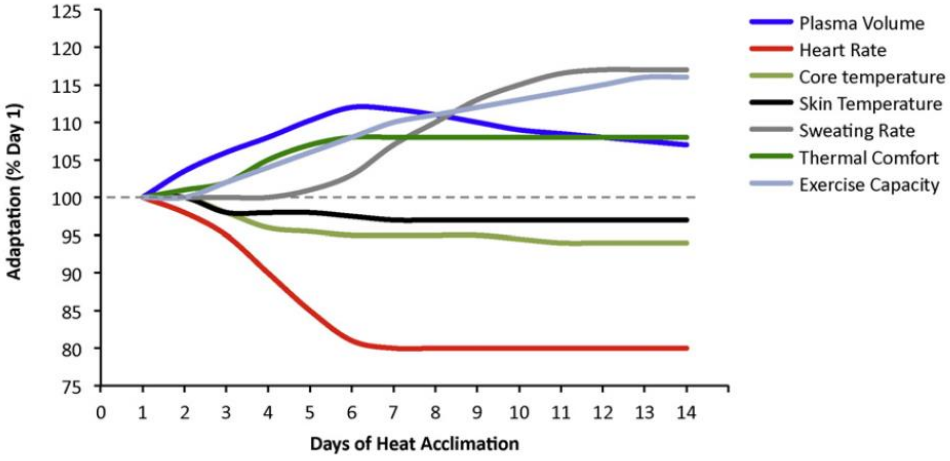


Figure 10. Depiction of typical physiological responses to heat acclimatisation as a function of the typical time required to attain these adaptations (from Périard *et al.*, 2015)

In extreme cases, where the ambient heat stress levels are so high during certain tasks that workers can only work for short periods of time without taking a break, purposeful heat acclimatization periods can be undertaken to better prepare the workers' bodies for heat stress (Strydom *et al.*, 1966). Recent scientific

studies have demonstrated that this can be done by having individuals exercise with extra layers of clothing to impede heat loss and build up heat in the body.

4. Identifying and treating heat illness

Despite best efforts to attempt to protect workers from heat stress, overheating and consequent heat illness and injury may arise as such, it is important to know the signs and symptoms of heat illness as well as the best methods for treatment. It is important to note that all forms of heat illness are most likely to occur at the onset of elevated weather conditions when workers are acclimatized to weather conditions. It is therefore important to reiterate that staff should be briefed on the signs, symptoms and treatments for heat illness ***before*** hot weather occurs in order to not be caught unaware. The following section is based on recommendations from the Israeli and American Militaries, the Korey Stringer Institute (an organisation whose purpose is to study and prevent exertional heat illness), the American College of Sports Medicine (American College of Sports Medicine *et al.*, 2007) and the National Athletic Trainers' Association position statement on exertional heat illness (Casa *et al.*, 2015).

Exercise-Associated Muscle Cramps

Especially following multiple days of physical labour in the heat, sudden or progressive involuntary and painful muscle contractions can occur during or after the work shift. This muscle soreness is associated with excessive sweating and are believed to be cause by some combination of dehydration, electrolyte imbalances, altered neuromuscular control and general fatigue. Early signs and symptoms include visible cramping, localized pain, dehydration, thirst, sweating or fatigue.

Heat Syncope

In order to combat the high levels of heat stress the body redistributes relatively large volumes towards the skin in order to dissipate excess heat to the environment. Especially, if a worker remains immobile in an upright period for several minutes at a time and especially following bouts of intense work, this blood can pool in the skin, especially in the lower limbs without having an avenue to return to the body's central circulation. This causes a drop in blood pressure and the consequent lack of blood returning to the brain and may result in a person fainting. This is more likely to happen if the worker is dehydrated, and some individuals will be more susceptible to heat syncope than others (Brothers *et al.*, 2011). Early signs and symptoms include dizziness, tunnel vision, pale or sweaty skin, and a decreased pulse rate while standing in the heat.

Heat Exhaustion

As previously discussed, work output in the heat will decrease over time. Indeed, while this may be due at first, at least to some degree because of voluntary reduction due to discomfort, overtime, even if an individual tries their hardest, the level of effort they are able to produce will be diminished. This is primarily due to reductions in cardiovascular output and central fatigue. This typically occurs at core temperatures above 40°C. While heat exhaustion is more common in hot and humid environments, it can occur in milder environments if workers are working at high intensities. At this stage, the symptoms (decreased voluntary work output) is largely a protective to inhibit the body from heating up further, and no permanent damage has occurred. Early signs and symptoms include excessive fatigue, faints, or collapses with minor cognitive changes (e.g. headache, dizziness, confusion) while performing physical activity, yet the athletic trainer should assess the patient's central nervous system function by noting any bizarre behavior, hallucinations, altered mental status, confusion, disorientation, or coma that may indicate a more serious condition such as EHS. Other signs and symptoms of exertional heat exhaustion may include fatigue, weakness, dizziness, headache, vomiting, nausea, lightheadedness, low blood pressure, and impaired muscle coordination. For workers experiencing heat exhaustion, any excess clothing should be removed. If the worker is working with chemical protective clothing, they should be removed from any area where dangerous chemicals may be present and then have the chemical suit removed. The worker should then be moved to a cool shaded area and be cooled by fanning, cold water ingestion, skin wetting, application of cooling pack or ice towels. The worker should rest lying down with their legs raised above their body in order to promote the return of blood towards the heart. If the worker has not recovered within 30 minutes, their rectal temperature should be measured (if possible) and emergency services should be contacted. If the worker's symptoms are alleviated within 30 min, it is advised that the worker not return to work, be sent home and then careful watched the following day.

Exertional heat stroke

Damage to the internal organs may occur when the body is subjected to elevated core temperature, especially during physical work, and is typically initiated from damage to the intestine due to reduced blood flow which allows for contamination of the blood supply by bacteria from the colon. This contamination leads to immune response cascades which may in turn result in damage to the liver and kidneys. Advanced signs that exertional heat injury may be occurring include very dark (especially brown) urine colour.

Figure 11. Illustration of an individual undergoing cold water immersion, the best-practise method for cooling down individual experiencing exertional heat illness.

The worst form of heat injury and of particular concern is exertional heat stroke. This condition is characterized by neuropsychiatric impairment and can result in death or permanent brain damage if not treated early and correctly. Signs and symptoms typically are central (pertaining to thought processes) in origin and may include collapse, aggressiveness, irritability, delirium, confusion, seizures, altered consciousness as well as changes in normal physiological processes such as lack of sweating in a hot environment, flushed red, hot skin, rapid breathing, racing heart rate, headache.

In the event of suspected heatstroke, cooling treatment needs to be delivered immediately with goal of reducing the worker's body temperature to below 40°C within 30 minutes. Importantly, the length of time that the core temperature remains above 40°C is strongly correlated with the risk for death and permanent injury. If no trained medical staff are present on site-when a suspected heat-stroke occurs (i.e. the worker has collapsed or exhibits signs of severe psychological impairment) emergency medical services should be called. The gold-standard method for reducing core temperature following exertional heat stroke is through immersing the body in cold water and should be started immediately. If the worker has excess clothing on but has collapsed, the worker should be first placed in the cooling bath and then have excess clothing removed to start the cooling as soon as possible. The water temperature should be as cool as possible and stirred regularly to prevent a layer of warmer water immediately beside the person to form, thereby reducing cooling efficiency. The worker's entire body up to the neck should be submerged however, especially if the worker has lost consciousness, another employee should remain close to the worker to ensure their head does not accidentally become submerged. Cooling should continue until the worker's core temperature has been reduced below 39°C. If medical staff are present, the worker should be cooled to below 39 first before being moved to the hospital. If no medical staff is present on site, the worker should continue to be cooled until emergency medical services have arrived.

A treated worker who was sent to the hospital for heatstroke should not return to work until they have rested for seven days and are asymptomatic. Once they do return to work, they should be treated as an unnacclimatized, at-risk worker and be given light tasks in cooler and slowly reintroduced to more intense work gradually, rather than having them return to full duties immediately. Additionally, if they start to show the early signs of heat illness, they should be halted from work immediately.

Core temperature measurement for safety

Of note for larger agricultural firms who may have certified medical staff on site, the gold standard method for assessing core temperature in case of expected exertional heat illness is via rectal temperature. This is both because it is a gold-standard method for assessing the core temperature due to its accuracy and low variability stemming from being measured from within the body in a well-insulated area and also due to the importance of that specific tissue temperature, for as discussed above, heat illness typically is initiated from damage to intestinal tissue during activity in the heat due to the high temperatures and low perfusion of these tissues. In the event of suspected severe heat illness (i.e. loss of consciousness, severe confusion) rectal temperature should be taken, if possible. Also, important to note, it is recommended best policy for a worker to be cooled to normothermic temperature i.e. below 38°C, before being transported

to a hospital by emergency medical personnel as the longer time spent at heightened core temperatures increases the risk of prolonged and severe damage occurring.

5. Summary

In summary, heat stress is a major issue for the agricultural industry due to the nature of the physically demanding work, exposure to hot, humid and sunny conditions, and having to sometimes wear protective clothing which limits heat loss to the environment. Without proper attention, the resulting heat stress experienced by agricultural workers can have negative effects on their health and work productivity. In order to ensure workers, remain healthy and productive the following steps should be followed:

1) Have a plan in place for how to deal with heat stress **before** bouts of hot weather where heat stress is an issue.
2) Pay attention to weather forecasts to be aware of impending periods of elevated heat stress.
3) When hot weather strikes, give workers time to physiologically adapt (at least for the first 4-7 days) to the hot weather conditions.
4) Reschedule the most physically demanding work tasks to the coolest time of day.
5) During periods of hot weather, provide 1.5-minute breaks every 30 minutes – ***this will not reduce overall worker productivity and will help maintain the wellbeing of the workers.***
6) Improve the effectiveness of these break periods by having the workers rest in well-ventilated shaded areas, drink cold water, immerse their arms in cool water and wet their skin.
7) Hydration is incredibly important. Try to make sure workers drink 500 ml (2 glasses) of water before the work shift starts and when the work shift end, further encouraging them to drink plenty in the evenings. Also, make sure workers have access to water throughout the day.
8) Ensure workers wear light, breathable, light-coloured, loose fitting clothing. If working outdoors, cover skin with loose fitting clothing and wear a breathable hat to protect from solar radiation. When indoors, consider wearing clothing that exposes as much skin to the open air as possible.
9) Make sure workers are aware of the signs and symptoms of heat illness and ensure a proper plan is in place to deal with these symptoms if they develop.

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7. Appendix of yet-to-be published Heat-Shield research

1.1 Sustainable solutions to mitigate environmental heat stress – occupational and global health perspectives

Introduction: Occupational heat stress influences the well-being and productivity of billions of people. As climate change will aggravate these conditions, identifying effective solutions is of critical concern. However, implementation in industrial settings, economic viability and ecological sustainability from a global health perspective are of equally important consideration. The present umbrella-review was therefore conducted to identify methods that relieve thermal stress and/or improve performance in the heat and evaluate the "implementation potential" of the procedure.
Methods: A systematic review of systematic reviews was conducted in PUBMED, Web of Science and SPORTdiscus, employing the following eligibility criteria: 1) ambient temperature above 28°C or hypohydrated participants, 2) healthy adults, 3) reported outcomes for physical or cognitive performance, thermal comfort or core temperature, 4) written in English, 5) and published before July 2018.
Results: 45 reviews fulfilled the criteria (36 were exercise-oriented, 6 were occupationally-oriented and 3 included both aspects) including 19 papers with meta-analyses. Lowering environmental heat stress was most effective for maintaining performance in the heat, it was also most expensive and least feasible, correspondingly necessitating more personalised interventions. The most effective interventions in the literature were phase-change and liquid-cooled garments, cold water immersion, heat acclimation, cold fluid ingestion and maintaining hydration status. Albeit effective, cold water immersion and liquid perfused garments are unfeasible under most occupational settings. On the other hand, highly feasible and sustainable methods such as taking periodic breaks, providing shade and using electric fans currently lack experimental and meta-analytical evidence in the literature.
Conclusions: Presently, the literature is overwhelmingly dominated by exercise-oriented studies conducted in laboratory settings and disregard whether the method is feasible to implement in real-life settings (occupational or recreational) or suitable and sustainable for mass application. Future studies are needed which are occupationally-oriented, useable in the field and are scalable.