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THE HEAT STRESS FOR WORKERS EMPLOYED IN GREENHOUSES FOR VEGETABLE GRAFTING

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1.INTRODUCTION

Vegetable grafting is widely distributed in Mediterranean horticulture for the production of plants with greater resistance to infections by soil-borne pathogens and increased tolerance against abiotic stresses. It is usually performed in greenhouses with shade cloth, where it is possible to control the main climatic factors (air temperature, humidity, solar radiation). The total automation of grafting operations is difficult because of the lack of uniformity of the plants, but some phases of grafting can be automated to increase work productivity. In this context, the presence of the worker cannot be eliminated and he is subject to some risk factors as heat stress and repetitive tasks. The risk of heat stress is evaluated using microclimatic indexes that take into account of climatic factors, work activity and worker's clothing.

The aim of this study is to evaluate the risk of heat stress for workers employed in vegetable grafting in Mediterranean greenhouses.

2. MATERIALS AND METHODS

The risk assessment of heat stress was performed using the following indexes:

1. The Predicted Mean Vote **PMV** and the Predicted Percentage of Dissatisfied **PPD** (UNI EN ISO 7730):

$$PMV = f\left(M, W, I_{cl}, f_{cl}, t_a, t_r, v_{ar}, p_a, h_c, t_{cl}\right) \qquad PPD = 100 - 95e^{-(0.03353PMV^4 + 0.2179PMV^2)}$$

where :

***M** is the metabolic rate (Wm^{-2}); **W** is the effective mechanical power (Wm^{-2}); I_{cl} is the clothing insulation (m^2 K W^{-1}); f_{cl} is the clothing surface area factor; t_a is the air temperature (°C); t_r is the mean radiant temperature (°C); v_{ar} is the relative air velocity (m s^{-1}); p_a is the water vapour partial pressure (Pa); h_c is the convective heat transfer coefficient [W (m^2 K)$^{-1}$]; t_{cl} is the clothing surface temperature (°C).The PMV scale of values is between +3 (very hot) to -3 (very cold) and the range between -0.5 and 0.5 corresponds to the thermal comfort.*

Fig.1 The instrument used for measure climatic parameters

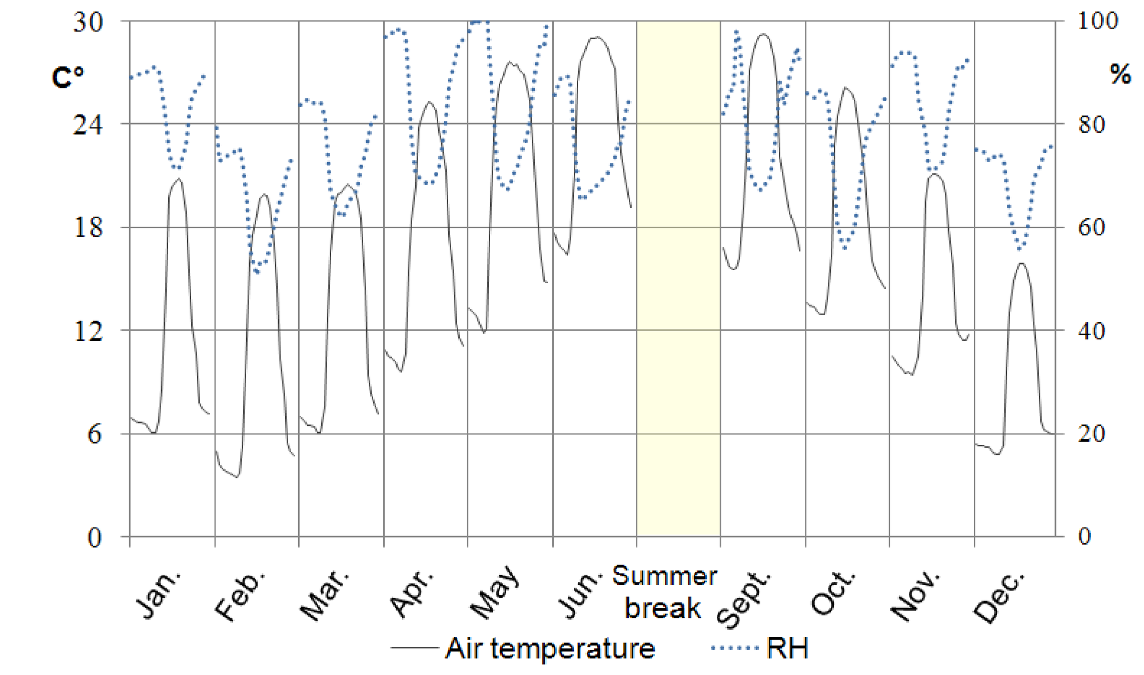

Fig.2 Monthly average values of air temperature and relative humidity

2. The wet bulb globe temperature **WBGT** (UNI EN 27243)

$$WBGT = 0.7t_{nw} + 0.3t_g$$ (for internal and external conditions, without exposure to sun)

$$WBGT = 0.7t_{nw} + 0.2t_g + 0.1t_a$$ (for external conditions with exposure to sun)

where:

t_{nw} is the natural wet-bulb temperature (°C), t_g is the globethermometer temperature (°C) and t_a is the dry-bulb temperature (°C).

3. The Environmental Stress Index **ESI**

$$ESI = 0.63T_a + 0.03RH + 0.002SR + 0.0054(T_a * RH) - 0.073(0.1 + SR^{-1})$$

where:

*T_a is the air temperature (°C), **RH** is the relative humidity (%) and **SR** is the solar radiation (W m^{-2}).*

The climatic parameters required by these indexes were measured (Fig. 1) in a Mediterranean greenhouse used for vegetable grafting, during working period (from January to June and from September to December). The work was done between 8.00 a.m. and 6.00 p.m. and included lunch break.

3. RESULTS

Figure 2 shows the monthly average values of air temperature and relative humidity measured in the greenhouse during the grafting period. Maximum air temperature was between about 16°C in December and 29°C in June and September, with a break in July and August. The relative humidity measured in the greenhouse was almost always over 60%.

From the monthly mean data collected in the greenhouse were calculated the indexes PMV (Fig. 3) and PPD, WBGT and ESI (Fig. 5). From April to October, the PMV takes values greater than +2 and the working environment from "warm" becomes "hot". Fig. 4 shows the working hours for different classes of PMV: -0.5 <PMV <0.5 (thermal comfort), -2 <PMV <-0.5 and 0.5 <PMV <2 (moderate thermal environments), PMV<-2 and PMV>+2 (severe thermal environments).

The hot environment is the worst condition for workers and it occurs from April to October for at least 8 hours per day (Fig. 4). Fig. 5 shows that WBGT index exceeds the threshold of 26.7°C for acclimated individuals since April. This limit is exceeded in April at 12 o'clock for about an hour, during the months of May and June in all the worked hours and in September and October respectively for 9 and 7 hours. The ESI index shows a trend similar to the WBGT data.

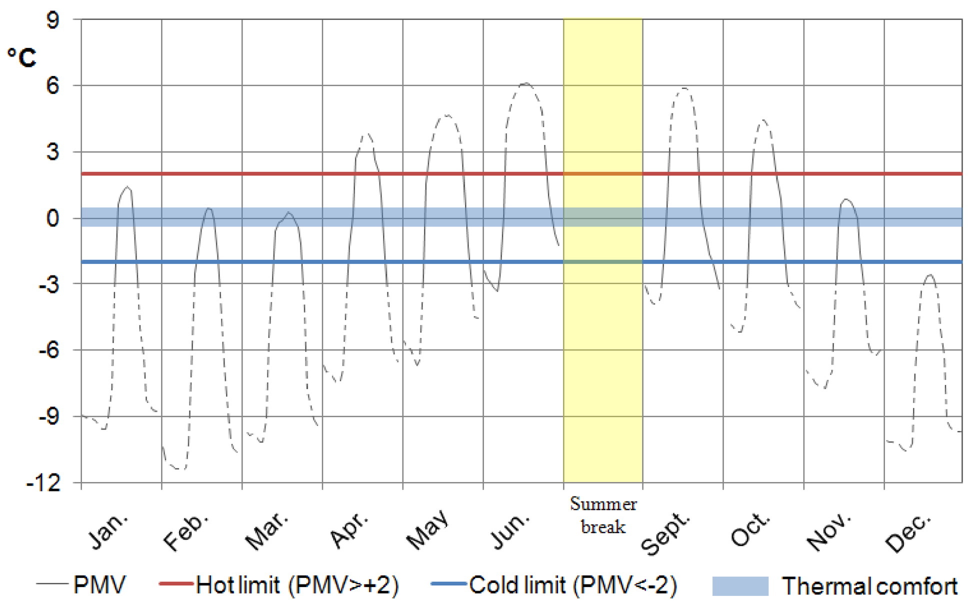

*Fig.3 Predicted Mean Vote **PMV***

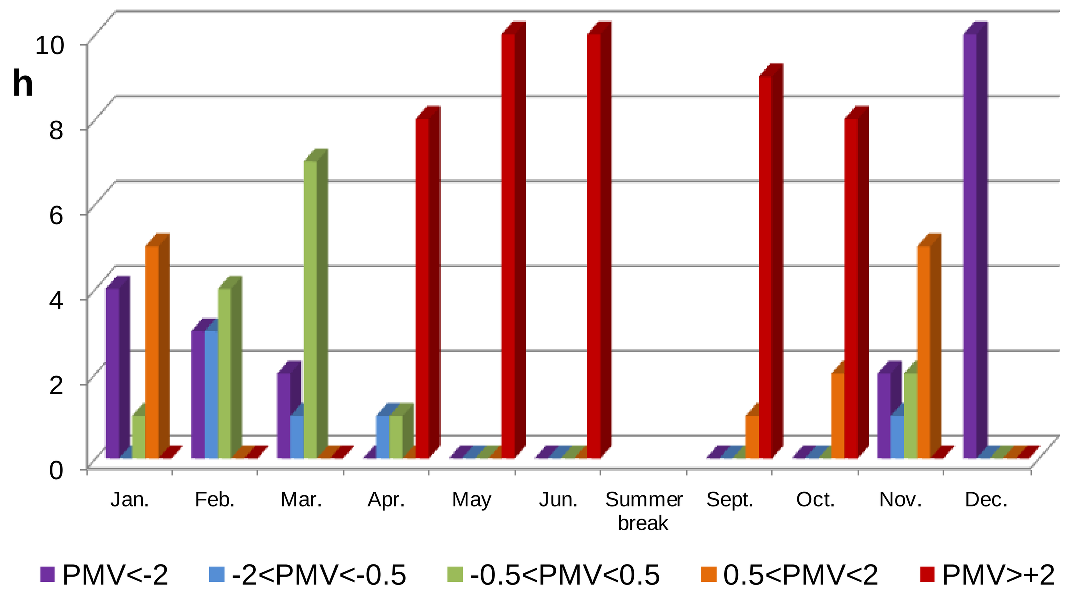

Fig.4 Number of working hours for PMV classes.

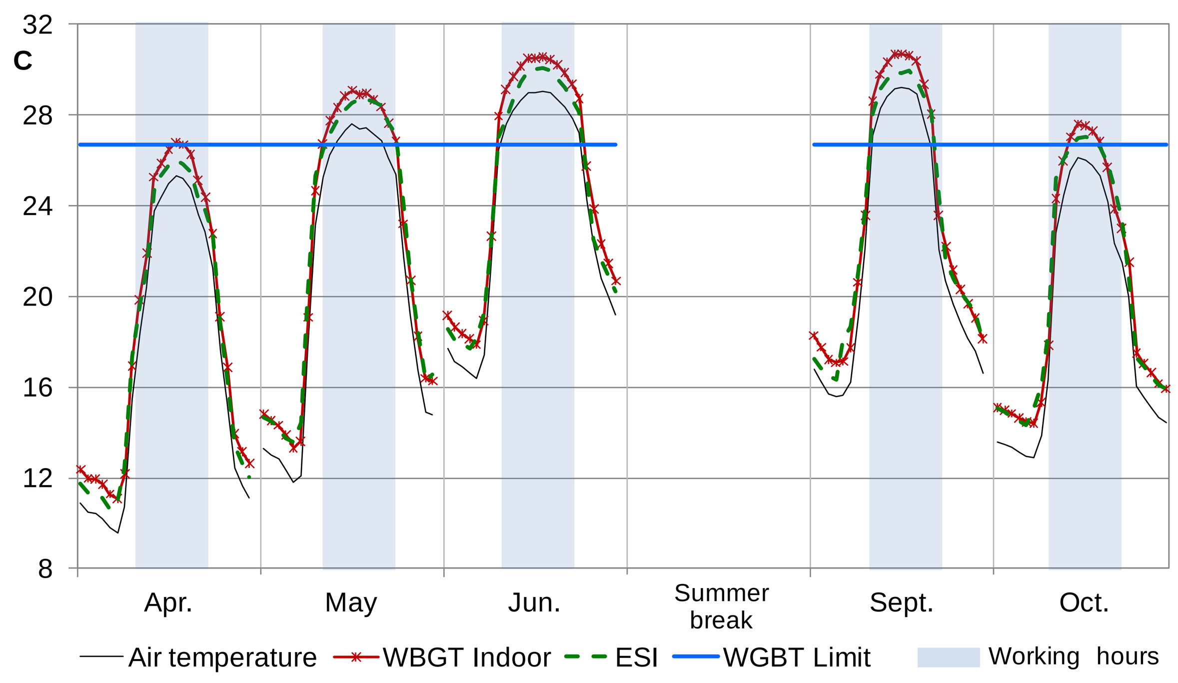

Fig.5 Air Temperature, WBGT and ESI comparison

4. DISCUSSION

The results show that in the months where the maximum daily temperature exceeds 25°C the PMV is over +2 and the environment becomes "hot" with potential risk of heat stress for workers.

To reduce the risk it is possible to modify the different factors that characterize the PMV, for example the clothing insulation (I_{cl}), but the possible reduction of this parameter does not decrease significantly the PMV. Indeed the parameter that affects more the PMV is the air temperature. An air temperature decrease of 5°C can reduces the PMV by 75%. Similar effects can be obtained on the WBGT index: an air temperature decrease of 4°C allows to obtain values of less than 26.7°C even during the hottest hours of the day. These air temperature reductions can not be obtained simply by natural ventilation but through the adoption of special cooling systems in greenhouse. Alternatively, the heat stress conditions can be alleviated reducing the exposure times by increasing the number of pauses, possibly in neighboring areas with favorable climatic conditions.

5. CONCLUSIONS

The assessments of thermal discomfort by the PMV index and of thermal stress by the WBGT index showed that the workers employed for vegetable grafting in Mediterranean greenhouses are subject to significant risks of heat stress despite the widespread use of shade cloths on the roofing. The months in which risk of heat stress was higher were April, May, June, September and October (with a work break on July and August).