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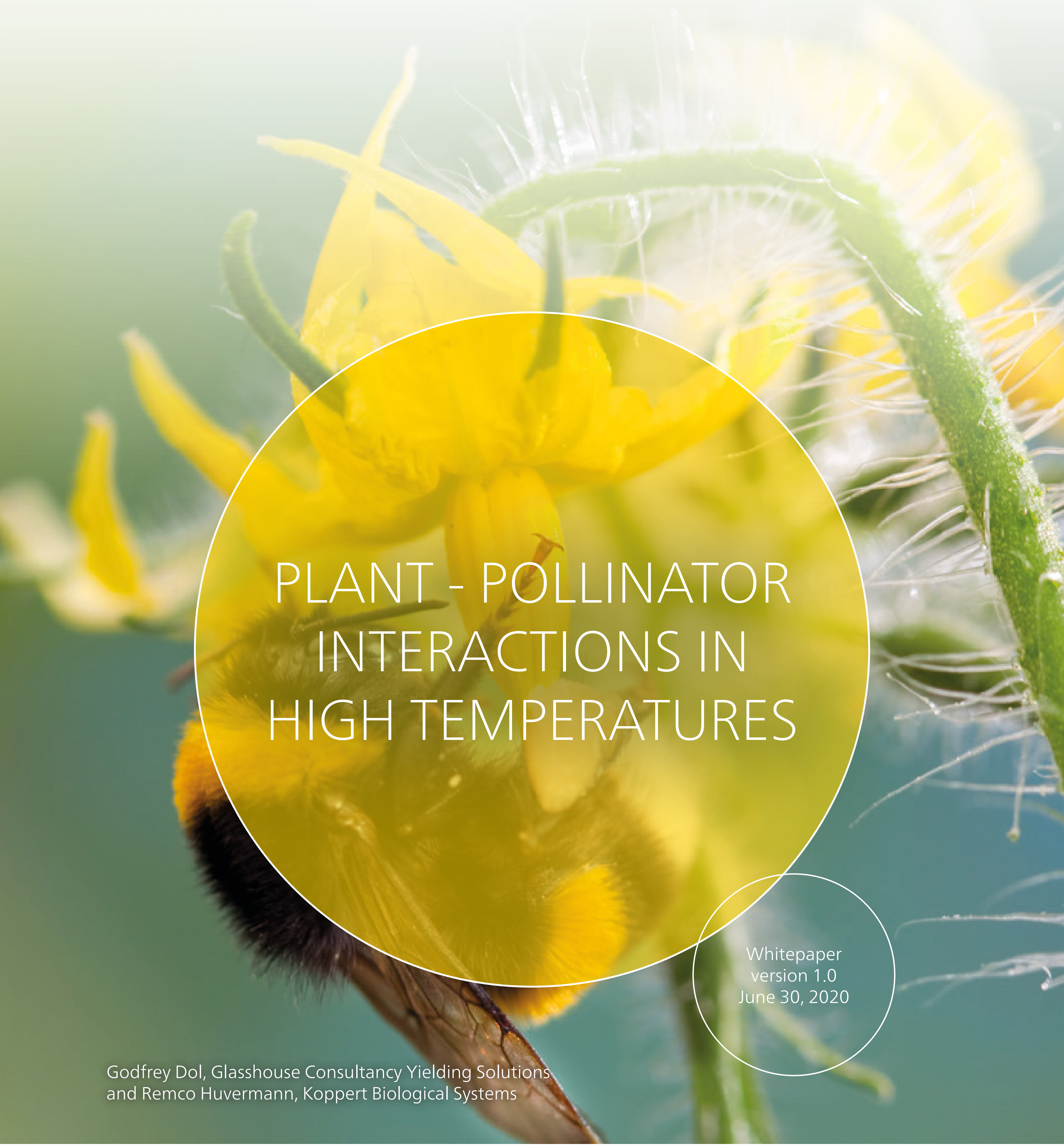

PLANT - POLLINATOR INTERACTIONS IN HIGH TEMPERATURES

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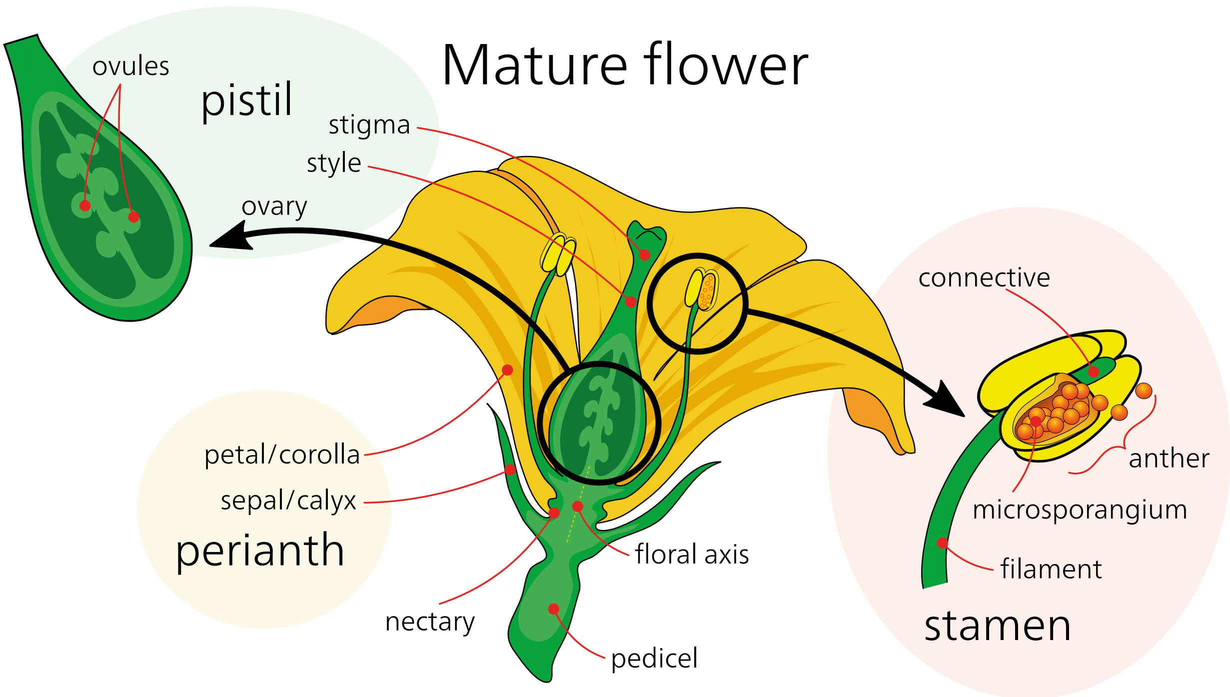
Plant - pollinator interactions in high temperatures

This paper focuses on the impact of climate (temperature, radiation, humidity) on plants, pollination and bumblebees. Proper pollination of a tomato flower is the most critical process related to fruit set, yield, and quality. Poorly pollinated flowers never become premium fruit, no matter how perfect a climate the grower creates. Pollination therefore deserves the utmost attention. Many aspects need to be considered for good pollination. Pollinating insects, the strength of plants, and environmental conditions all play an important role. It is crucial to recognize the direct and longer-term impact of hot climate conditions affecting both the plants/flowers and pollinating insects such as bumblebees.



What is the best climate for a Tomato?

Without proper pollination, the investment of a greenhouse, heating, fertilizer, and labour, is practically wasted. One of the most clearly defined guidelines in the greenhouse industry is the optimum temperature range for pollination. Growers want to keep the greenhouse temperature below 30° C. It is one of the main reasons why greenhouses have flourished in cold climates, and why others are built at high altitude. Cold climates allow for the maximum temperature in the greenhouse to be reduced below the danger levels for pollination. Pollination also has a minimum day time temperature limit of 16° C, below which the pollen is not viable.

What is considered hot?

At temperatures of more than 30° C, the pollination degrades, and above 32° C, there are severe implications for yield and quality. It is essential to point out that exposure to maximum temperatures of more than 30° C for a couple of hours has a negligible effect on pollination. However, a full day above 30° C has an immediate effect on pollination. If the temperature reaches 40° C for one hour, there is also an immediate effect. For a high 24-hour temperature to affect pollination takes at least one to two weeks. Similarly, it takes two weeks of cold weather for pollination to return to normal.

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The plants, flowers, and pollination

Flower quality can also be reduced by factors other than hot climate conditions. Pollination demands energy from the plant, and it is one of the first processes to fall by the wayside if the plant cannot produce enough assimilates. In the act of self-protection, the plant aborts the fruit to reduce fruit load on the plant and directs the assimilates to the vegetative growth of the plant. This is undesirable as it creates fluctuating yields that result in overall lower production.

Differences in cultivars

There are also upper limits for the 24-hour temperature, above which pollination is compromised, regardless of light levels. For beefsteak and truss tomatoes on the vine, an average 24-hour temperature of more than 21° C has adverse effects on the setting. Cherry and snack tomatoes suffer at temperatures above 23° C. Individual varieties can have a different 24-hour temperature above which the pollination is compromised. When temperatures are above these thresholds, any means to reduce the day or night temperature must be used. This includes using cooling at night.

Figure 2: The Stigma is protruding through the protective flower cone because of high 24 hour temperature

Hot is more than just the environmental temperature: Impact of radiant heat and humidity

A glasshouse air temperature of 30° C at a humidity of 80% can still results in good pollination. At 30° C and 60% humidity, the pollination suffers. Add to this the knowledge that flower temperature might also play a role; the influence of radiation also needs to be considered. A flower can turn into a marketable fruit when it is pollinated at 30° C and 80% humidity, but only if the radiation is at an intensity of no more than 400 watts. The table in figure 3 gives a representation of what the best conditions are for pollination. Of course, these are approximations and should only serve as a guideline. There are differences between varieties. Radiant heat affects the plant differently. Figure 4 shows the thermal imaging of a tomato plant. Observations confirm that the flowers become much warmer than their environment or other parts of the plants. Leaves can cool themselves through transpiration, while flowers cannot.

For this reason, better pollination is achieved through shading in certain situations. Shading reduces flower temperature (and thus pollen). If a shade curtain is not available, whitewash or heat reducing paints can be used to reduce the amount of heat coming into the greenhouse.

An infrared thermometer can help to gain certainty about the effect of temperature on pollination. A flower temperature of more than 35° C impedes pollination. The maximum temperature in the greenhouse must be kept below 30° C to maintain a lower flower temperature. Even at 28° C, pollination can be reduced if the humidity is too low or radiation is too high. Staying outside the gray and yellow areas in the table in figure 3 ensures that pollination and setting issues due to temperature and humidity are eliminated. At the same time, the grower must make sure the plants have enough strength but are not too strong, and the climate in the greenhouse is consistent. No easy feat, but the payback is more than worth the effort.

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Relative Humidity

The second guideline for tomato plants is humidity. At low humidity (below 50-55%), the pollen is too dry and does not stick to the stigma. At high humidity, the pollen sticks to the stamen and does not fall onto the stigma. In conventional greenhouses, the recommended humidity range is 60-75%. Due to better air movement, the range in a semi-closed greenhouse is 70-85%. Setting malfunction can be caused by a combination of high humidity deficit and elevated temperature. In conventional greenhouses in warm climates, this is typical of summer plantings. A combination of high light and low humidity forces the plant to work too hard, and as a result, the setting on the first fruit is skipped. The plant looks fine, strong,

% Relative Humidity

Temperature in °C	95	90	85	80	75	70	65	60	55	50	45
15											
16		<800	<800	<800	<800	<800	<800	<700	<700	<700	
17		<800	<800	<800	<800	<800	<800	<700	<700	<700	
18		<800	<800	<800	<800	<800	<800	<800	<700	<700	
19		<800	<800	<800	<800	<800	<800	<800	<700	<700	
20		<800	<800	<800	<800	<800	<800	<800	<700	<700	
21		<800	<800	<800	<800	<800	<800	<800	<700	<700	
22		<800	<800	<800	<800	<800	<800	<800	<700	<700	
23		<800	<800	<800	<800	<800	<800	<700	<700	<600	
24		<800	<800	<800	<800	<800	<800	<700	<600		
25		<800	<800	<800	<800	<800	<700	<600			
26		<800	<800	<800	<800	<800	<600				
27		<700	<600	<600	<600	<600	<500				
28		<600	<600	<600	<600	<500					
29		<500	<500	<500	<500	<400					
30		<500	<500	<400							
31		<500	<400								
32		<400									
33											

Poor Pollination
Pollination at Risk
Good Pollination

Figure 3: Pollination parameters for temperature, humidity, and radiation for large fruiting tomatoes. It includes temperature, humidity, and maximum radiation levels given in Watts.

and healthy. However, the conditions in the greenhouse give the plant the impulse to transpire excessively. The plant goes into self-protection mode by skipping the fruit and focusses the assimilates on building large leaves. It is also likely that flower temperature plays a role in this process (figure 4). Leaves can cool themselves, but flowers do not have stomata or any other means to cool themselves. In low humidity, bumblebees are also less active and do not find flowers attractive. The lack of fruit causes the plant to become more vegetative to which the grower often responds by removing a head leaf. In this case, removing the head leaf may worsen the problem as it allows direct radiation to increase the flower temperature. In a semi-closed greenhouse, this type of poor setting can be found near the climate chamber because of hot, dry air movements caused by momentum. This exhaustion related type of poor setting is typified by the first fruits not setting. In this case, the solution lies in a combination of reducing fan speed, more shading, more use of the cooling wall, and increasing humidity. Often high humidity is blamed for the poor setting. A semi-closed greenhouse can sustain higher humidity and still have perfect pollination compared to a conventional greenhouse, even if pollination occurs by hand. A humidity of 85% is fine for pollination in a semi-closed greenhouse, while a humidity of more than 80% starts to impede pollination in a conventional greenhouse.

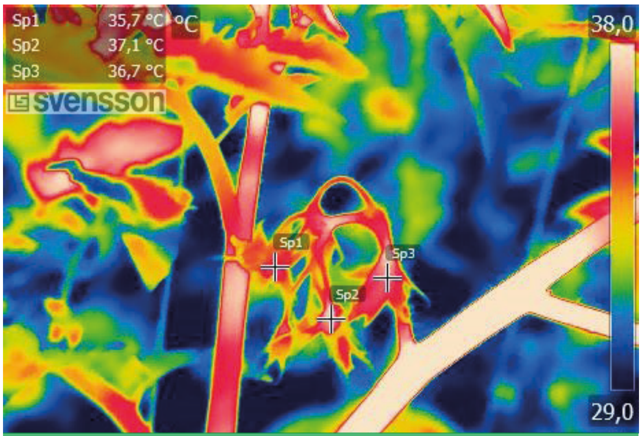


Figure 4: Thermal image of a tomato flower in the direct sunlight in April

Photo : © Svensson Climate Screens

Impact of heat on bumblebee

With increasing temperatures, the behavioural responses have the potential to reduce pollination services significantly. Such responses to heat may be important for flower visitation. The time taken for thermoregulation at higher temperatures comes at the cost of foraging, with negative consequences for pollination. Once temperatures pass the 30° C mark, more and more bees stay in the hive to ventilate it, reducing their pollination activity. When temperatures exceed 33° C, workers go into survival mode, eliminating larva and halting any pollination. Direct sunlight can increase the temperatures within the hive by 2 to 15° C, which can cause damage to the hive.

In conventional greenhouses, the recommended humidity range is 60-75%. Due to better air movement, the range in a semi-closed greenhouse is 70-85%.

Bumblebees are particularly prone to overheating if temperatures increase because of their large size, dark colour, and hairy bodies.

Keep your bumblebees cool during hot weather

Correct placement of the hive can reduce heat stress of pollinators. Position the hive about 20-60 cm above the ground on the south-side (in the Northern Hemisphere) of a path to obtain maximum shade from the crop. If needed, provide additional shading of the walkways. Protecting the hives from direct sunlight can make a difference of 2-15° C in the hive. It encourages longer pollination hours and prevents damage to the hive. Direct light can be diffused by using diffuse glass, plastic films, moveable screens, or by applying a coating on the covering. Whitewash is particularly used on greenhouses in Mediterranean regions to keep out thermal radiation and to diffuse the light. Other cooling methods include: protective shading, diffused glass, wind ventilation, use of air-cooling systems, use of evaporation systems.

During periods of hot weather, when the temperature exceeds 30° C for large parts of the day, the bees will work fewer hours. It is recommended to increase the amount of hives when warm weather is forecasted, to make sure more bees can complete the pollination task in fewer hours.

Monitoring pollination efficiency

During pollination, a bumblebee bites onto the flower and makes the flower vibrate. This is known as buzz pollination. The imprints of the bumblebee's jaw on the flower (bite marks) turn brown within one to four hours and make it possible to check the bumblebees' work. These brown marks can be used to help determine how many hives must be ordered.

A single visit results in the transfer of enough pollen for pollination. To see whether a bee pollinated the flower, peel back the dried-up flower petals to see if bruising is visible (figure 5 - first picture on the right). About 18-20 flowers per hectare must be checked per variety. Covering a representative area of the greenhouse.

Figure 6 shows the recommendation to growers to make sure optimum pollination is assured.

Most tomato types have a recommended introduction of hives per hectare per week. The brown colour intensity, or number of bitemarks, determines, whether more or fewer bees should be ordered. The bite mark on the right-hand side in figure 5 has very light bruising and should be classified as a Score 1 in the outlined scorecard.

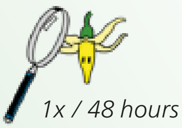
Figure 5: Bumblebee bite marks on a tomato flower

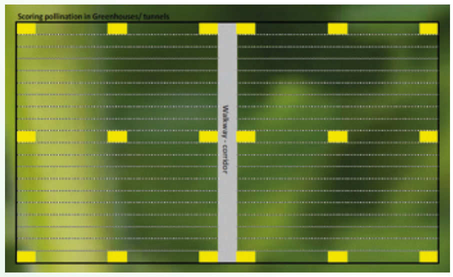
Conclusion

In cold climates, it is assumed that the proper management of bees is sufficient to ensure good pollination. The single biggest problem is that if there is not enough strength in the plant, the setting may be poor. Growing in warm climates opens up a whole new set of challenges that can affect yield and quality. Management of temperature, humidity, and radiation is essential. Under challenging circumstances, proper monitoring of whether pollination is taking place, and whether the setting is 100% is vital to ensure the maximum yield is achieved. Monitoring also provides a feedback loop to help the grower determine the cause when pollination is not perfect.

Pollination scorecard

I = 1-3 biting marks
II = 3-6 biting marls
III = more than 7 marks





Score I = good pollination but increase schedule
Score II = goal, maintain schedule
Score III = good pollination but decrease schedule

Note: never skip an introduction! Order more hives if hot weather is forecasted to achieve sufficient pollination.

Figure 6: Pollination scorecard

Summary of actions to protect both plants and pollinators in high temperatures

Use protective shading, diffuse glass, whitewash, heat-reflecting paint, plastic film or similar, wind ventilation, air cooling systems or evaporation systems, etc. to maintain optimal temperature (below 30° C) to avoid heat radiation, enhance plant strength, and maintain pollination efficiency

Protect bumblebee hives from direct sunlight. Position the hive about 20-60 cm above the ground on the south-side of a path to obtain maximum shade from the crop. If needed, provide additional shading

Maintain humidity between 60 - 75% in a conventional greenhouse, and 70 - 85% in semi-closed greenhouses

Monitor bite marks on flowers and order hives accordingly

Order more hives if hot weather is forecasted to achieve sufficient pollination

For a balanced plant vigor always maintain the correct temperature and light balance

Watch our short animation: Bumblebee pollination in high temperatures

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