Behaviour of honey bees and bumble bees beneath three different greenhouse claddings

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Several new cladding materials for greenhouses are tested and some already introduced in greenhouse horticulture, aiming at maximizing the transmission of photosynthetic radiation and reducing the loss of heat. As a part of the evaluation this research focuses on the suitability of different claddings for use in combination with pollinators. Pollinators, honeybees and bumblebees, are applied in a number of greenhouse vegetable and floricultural crops.
In a commercial nursery and in small experimental greenhouses with glass, polymethylmethacrylate and polycarbonate claddings, honey bees and bumble bees were introduced. Their orientation behaviour was studied shortly after introduction. The spectral photon distribution inside the greenhouses was determined.
In the glass greenhouse the sun was visible as a circular strong light source, in the double layered polymer (polymethylmethacrylate and polycarbonate) greenhouses the sun looked like an arc along the whole length of the roof. All claddings showed good transmission of light for photosynthesis (400-700 nm wavelength). Ultraviolet was hardly transmitted by polycarbonate, partly by glass and fully by polymethacrylate.
After introduction honey bees and bumble bees showed normal orientation behaviour beneath glass and polymethylmethacrylate, but not beneath polycarbonate. Beneath polycarbonate the bees did not return to their hives, neither beneath double layered (zigzag) nor single plane covers. The results indicate that polycarbonate should not be used for crops which need pollination.

Keywords: honeybee, bumblebee, greenhouse, ultraviolet transmission, orientation

The aim of greenhouse claddings is to transmit as much irradiance from the sun as possible for plant growth, and simultaneously insulate the greenhouse atmosphere from the outside against losses of convection heath. This insulation can be improved by choice of the material and by improving the construction, for instance double layers filled with insulating stagnant air or empty (vacuum) spaces. For plant growth the photosynthetic active photons (400-700 nm wavelengths, PPF (photosynthetic photon flux)) are the most important, supplemented with some ultraviolet and far-red for photomorphogenetic processes (Kendrick & Kronenberg 1994). Far-red (700-800 nm) is transmitted by all cladding materials used, but ultraviolet is absorbed by some of them (Hoffmann 1999). Although this generally does not cause problems for plant growth and morphogenesis, there may be problems for pollinating insects.

Bees largely rely on vision, and seeing ultraviolet is covered by one of the three photosensory pigments in the retinal cells of the units of the compound eyes (Goodman 2003). Without ultraviolet only the blue and green pigment regions are excited, resulting in a reduced ability to recognize flowers and the environment. In addition ultraviolet plays a role in the bees' use of the sun compass: when the sun is not directly visible because of overcast conditions, the position of the sun is determined by the relative amount of ultraviolet in the light perceived, and by the polarization patterns which are also perceived in the ultraviolet range (Goodman 2003, Gould & Gould 1988). Ultraviolet, detected by the three small dorsal simple eyes (ocelli) also plays a role in the perception of up and down in order to maintain a correct horizontal position during flight. Bees have no labyrinth to sense gravity during flight. Much of the available information in the literature about honey bees may also hold for bumble bees and vice versa, although not everything necessarily has to be similar.

One of the highly promising greenhouse claddings has a zigzag structure to ensure that a higher proportion of the incident light is transmitted, especially with small angles of incidence of the sun light in winter periods. This might also cause problems for bees, since it scatters the light and reduces the bees' sight on the sun.

Problems with bees, especially bumble bees, have been reported (horticultural practice and scientific literature) when they needed to forage beneath some plastic greenhouse foils (Morandin *et al.* 2001). These foils contain chemicals that absorb most of the ultraviolet in order to avoid fast deterioration of the polymer.

Before introducing new claddings in horticulture it is necessary to determine whether they are compatible with the use of honey bees and bumble bees for pollination. The use of bumble bees in tomato growing is common practice, and honey bees are used in the cultivation of sweet peppers, courgette, strawberries, aubergine and other.

In this research we compare the orientation behaviour of honey bees and bumble bees beneath two polymer greenhouse claddings (polymethylmethacrylate (PMMA) and polycarbonate (PC)) and the standard glass cover.

MATERIAL AND METHODS

Research locations

On a commercial nursery, producing young plants of several *Bromelia* species and cultivars, the three different claddings were present on different compartments: standard glass cover, double layered PMMA and double layered zigzag PC. In the glass and PC compartment sun screens were available (I LS 60 revolux and open revolux (in the vents), screening percentage 75%). The screens were closed during the observations. Screens were absent in the PMMA compartment. Observations were carried out on August 24, 31 and September 7, 2005.

Three small experimental greenhouses (3 x 4 m) with single layered plane coverings of glass, PMMA and PC in Wageningen were used additionally for one day (10 November 2005).

Introduction of honey bees and bumble bees

Honey bee colonies, kept in small polystyrene two storey hives (Minibeuten), containing about 5000-6000 bees were introduced in the greenhouse compartments (one per compartment), together with bumble bee (*Bombus terrestris*) colonies obtained from a commercial breeder (one per compartment). The compartments had an area of about 2500 m^2 (glass) and 3500 m^2 (PMMA and PC). After the observations the hives were closed and removed from the greenhouse.

In the experiment in the small experimental greenhouses only honey bees were introduced in single storey hives, containing about 2500 bees. In this case the hives were removed from the greenhouses the next morning before the bee activity started, giving bees that had left the hive the opportunity to return to their hive before dark.

Observations

Since there was no suitable crop available to forage on in the greenhouses, it was only possible to observe the orientation flights of the bees. A few times we offered a comb with fresh honey as a kind of forage.

About 10 minutes after introduction the hive entrances were opened, and the behaviour of the bees leaving the hive was observed qualitatively. During the day a few times the number of bees leaving the hive and the number returning to the hive was counted during a half hour. In the observations of September 7 the same colony was used first in the PC compartment, and then moved to the PMMA compartment. The reference colony stayed in the glass compartment.

In the small greenhouse experiment the day after the observations all bee workers that had not returned to their hives were collected and counted. During the observations (15 minutes periods) the temperature and air relative humidity was determined inside the greenhouses.

Spectral photon distribution

With a Li-Cor 1800 portable spectroradiometer the spectral photon distribution was measured in the different compartments in the range from 300 through 800 nm. Since the incident radiation is not constant during the day, the spectra were made comparable by setting the highest point of the spectra to 100%. The measurements were made between 11.30 and 13.30 hr on September 7.

Statistics

Since it was not possible to observe more than one honey bee and one bumble bee colony simultaneously it was not possible to do statistical analyses. Subsequent observation periods during the day were with the same colonies, and therefore not independent.

RESULTS

Light beneath the different claddings

The appearance of the sun, as seen from inside the greenhouse from the position of the bee hives is shown in the photographs of Fig. 1: behind the sun screen the sun is still visible as a light spot in the glass house, but it appears as a light arc in the PC house. In both compartments the screens may hamper the bees' vision of the sun, since narrow and long strips of light remain visible between the screens. In the PMMA compartment the sun appears as a dim arc, with some scattering of light around it at the position of the sun.

The ultraviolet part of the spectral photon distribution of the incident light on the level of the bee hives is shown in Fig. 2. To make the spectra comparable the highest measured peak of each spectrum (around 510 nm) was set to 100, and the rest of the spectrum was adjusted to this. Although the spectra partly reflect the availability of ultraviolet in the sun spectrum on the 7^{th} of September, the differences between the spectra represent the differences in transmission of ultraviolet between the greenhouse covers. PMMA transmits ultraviolet over the total wavelength band from 300-400 nm, glass from 320-400, and PC only from 375-400 nm.

Figure 1. Photographs of the sun as it appeared in three compartments: glass (left), PC (middle) and PMMA (right). Note that screens are present in glass and PC, but absent in PMMA

Behaviour of honey bees and bumble bees

As soon as the flight entrance of a honey bee colony was opened in nurseries covered with glass and PMMA, the bees appeared in the entrance, and started to fly small horizontal circles around the hives. The circles increased in width, and after a few circles the bees disappeared in a horizontal direction. After a few minutes some bees started to return to their hives. Almost the same was seen with bumble bees, although they made fewer circles, and flew away more rapidly. Under PC the bees came out of the hives, flew one circle at most and then disappeared while flying loops in the direction of the top of the greenhouse, where they remained trapped against the insect gauze in the open vents. Again, the behaviour of the bumble bees was similar to that of the honey bees. Only a few bees returned to the hives.

A honey comb with fresh honey, where bees could forage on, placed about 2 meters from the hives on the growing tablets of the greenhouse was easily found and used under PMMA, less under glass, and not under PC. Bees under PC that tried to land on the comb often failed and landed some decimetres beside the comb.

Bee activity: number of bees leaving and returning to the hive

Observations were made in the commercial nursery on August 24 and 31 and September 7. On 31 August it was very hot in the greenhouse, and there was hardly any activity of the bees. The other days the temperatures were moderate (20-25°C). By accident part of the data (measurement in glass compartment) of

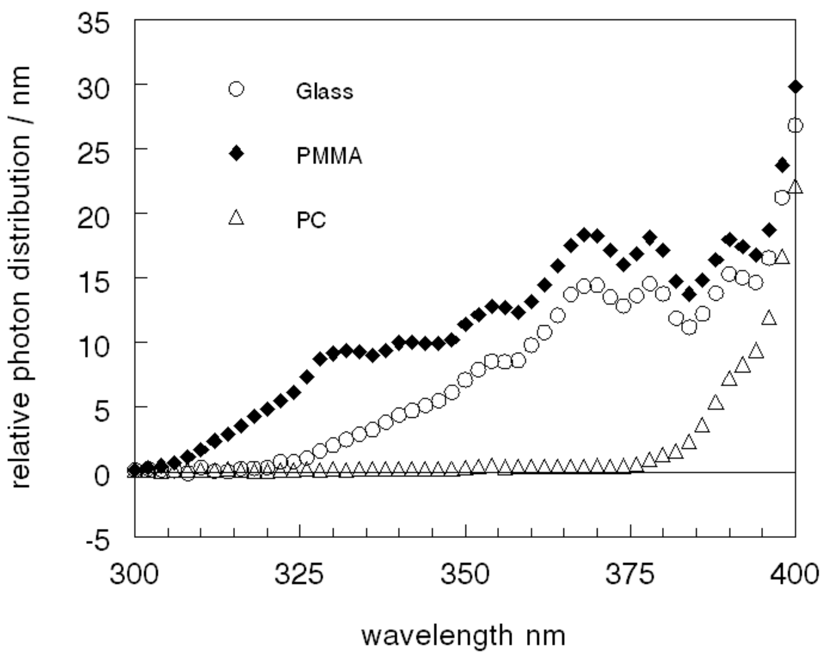

Figure 2. Spectra of incident light in the greenhouse beneath glass, PC and PMMA on 7 September 2005. Only the wavelengths 300-400 nm are shown. Y-axis relative values.

September 7 2005 were lost. The data are listed in Fig. 3. Generally the number of bees returning to the hive was slightly lower or equalled the number of leaving bees beneath glass and PMMA, but beneath PC hardly any bees returned. Observing more bees returning than leaving (7-9 III, PMMA) is explained by returning bees during the observation period that had left before the observation

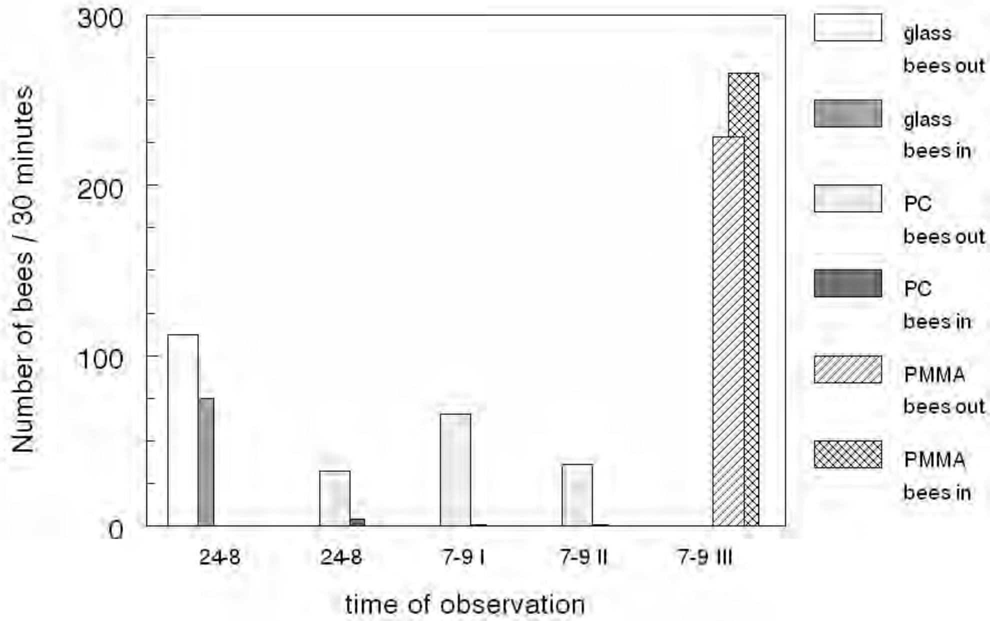

Figure 3. Numbers of bees leaving the hive (every first column) and returning to the hive (every second column, partly hidden) during observation periods of 0.5 hr. 24-8: simultaneous observations beneath glass and PC; 7-9: subsequent observations with one colony: I: beneath PC, 11 hr; II: beneath PC, 13 hr; III: beneath PMMA, 13.30 hr. Simultaneous data of 7-9 beneath glass were lost.

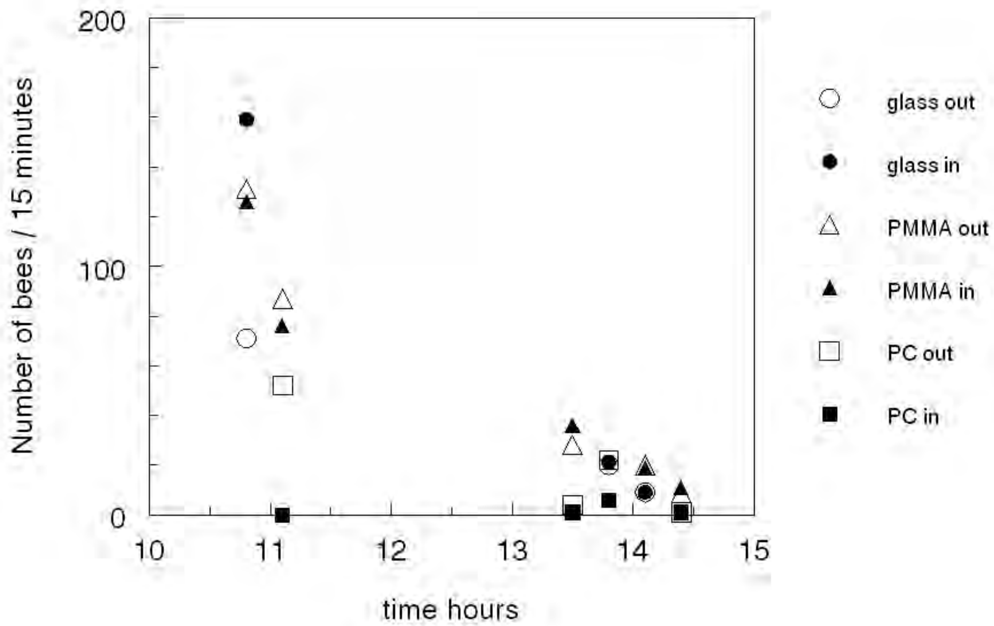

Figure 4. Observations on the number of bees leaving (=out) the hive and returning to it (=in) on 10 November 2005 in the experimental greenhouses.

Table 1. The number of bees found in the three experimental greenhouses the morning after the day of the observations.

Greenhouse cover	Living bees	Dead bees	Total bees
Glass	137	46	183
PMMA	33	22	55
PC	168	53	221

period. On 7-9 11 hr also bumblebees were observed beneath PC: sixteen workers left, one returned. On September 7 beneath glass many bees only returned much later to the hive, after the screen automatically opened because incident light from the sun decreased (numbers not shown). Until then they had been trapped between the glass cover and the screen.

The observations made on November 10, 2005, during periods of 15 minutes, are presented in Fig. 4. Honey bee activity was high around 11 h, but decreased during the day. There was a good match between the numbers of leaving and returning bees beneath PMMA, a rather good match beneath glass, but no match beneath PC, since hardly any honey bee returned. The greenhouses were not heated but by the sun. The inside temperatures differed between the houses during the first observations around 11 h (glass: 24°C, PMMA: 23°C, PC: 19°C), later the temperatures were the same in different houses: observations around 13.30 h: 20°C, after 14 h: 17°C. A lower temperature at 11 hr beneath PC might partially explain a lower activity beneath PC.

After the bees' activity had stopped, the hives were left in the greenhouse until the next morning. Before the bees' activity started the hives were closed and removed from the greenhouses. The bees that had not succeeded in returning to their hives the day before were collected from the greenhouses. Some were dead, some still alive. The numbers are listed in Table 1. High numbers were found beneath glass and PC, low numbers beneath PMMA.

DISCUSSION

Since there was no crop to forage on present in the commercial nursery, and no crop at all in the experimental greenhouses, we had to confine the research to the initial orientation behaviour of the bees. This forms only a limited basis to evaluate greenhouse claddings regarding their suitability for pollinators. Bees may be able to learn and adapt when for a longer period under conditions with limited vision due to lack of ultraviolet. Dyer & Chittka (2004) showed that bumblebees experienced difficulties when they had to forage without ultraviolet light available; they sacrificed handling speed. However, after a few flowers they showed to learn quickly, and regained the normal speed. After they had adapted to forage without ultraviolet, they encountered similar problems when ultraviolet availability was restored, and again they learned quickly. Nevertheless, despite bumble bees' and honey bees' learning abilities, it is unlikely that the bees that flew directly to the insect gauze in the top of the PC greenhouse would have got the ability to learn and return to the hive. Also in the experimental small greenhouses many bees had not returned at the end of the day, and thus lost the opportunity to learn. Under normal conditions bees always return to the hive before the evening, bees that do not return are lost. The activity of bees not so much represents the number of bees available in the hive, but is determined by the available reward and area to survey. So in the small greenhouses only a low activity may be expected with an area of 12 m^2 and no forage crop available. The bees that were found dead in the greenhouse may partly represent normal mortality of bees in the hive, since dead bees are removed from the hive and dismissed in the field. The number of bees that were found alive in the greenhouses (Table 1) did not correspond to the observed flight activity (Fig. 4) which would have been the case when it was equally difficult to return home beneath different coverings. This suggests that the high number of bees found alive beneath PC is caused by a low number of returning bees, not by a higher flight activity. The highest flight activities were found beneath PMMA, where the number of bees found alive in the greenhouse was the lowest.

Since we did our observations on only one colony per greenhouse compartment, differences between colonies may have interfered with the effects of the different claddings: one colony may be inherently more active than another. It was however striking to see how a colony when transmitted from the PC house to the PMMA house (7-9 II to 7-9 III in Fig. 3), strongly increased its activity, probably explained by the increase in light (no screen present in the PMMA house), including ultraviolet. The bees also started immediately to behave normal (flying horizontal circles, flying away horizontally and returning to the hive).

Not so many (especially quantitative) observations were made on bumble bees. This is because bumble bee colonies contain far less workers than honeybee colonies, when losing about 10-20 workers in the first half hour after introduction, one cannot expect unaffected activity in the next hours. However, qualitatively the observations on bumble bees corresponded fully with those on honey bees.

The problems that the bees experience beneath PC are likely not caused by the breaking of the light of the sun, which is a circular, narrow and bright light source in the perception of bees (Gould & Gould 1988), into a bright arc, of a length of the full sky. This breaking was to a great extent also present in the PMMA house, where no problems were encountered. Also beneath the single layered plane cover of PC of the experimental greenhouses, which allowed normal sight on the sun, the problems were still present. Absorption of the ultraviolet by the covering material therefore is the most likely cause; honey bees and bumble bees experience problems with orientation beneath PC greenhouse covers. Morandin *et al.* (2001) showed that in plastic foil tomato greenhouses bee losses from colonies were lower when the cover transmitted ultraviolet light (from 315 nm onward), and that the activity of the colonies was higher than beneath covers that absorb most of the ultraviolet (below 350 nm). Researching the interaction flower-pollinator from the rear side, by pointing cameras on individual flowers in a greenhouse with an ultraviolet absorbing cover revealed similar results: none of the starring flowers was intimately addressed by a bee (B. Vaissière, lecture at Apimondia congress Dublin, 2005).

Would the losses have been lower when there would have been an attractive forage crop in the commercial nursery greenhouses? Birmingham & Winston (2004) showed that mounting big landmarks in a commercial tomato greenhouse increased the foraging speed and net pollen input into the colonies of bumblebees, obviously it helped the workers learning to find their way with greater speed. It did however not influence the number of drifting workers and potential losses from the colonies, suggesting that initial orientation performance in a greenhouse was not improved by learning. Whether bees would have learned better with a rewarding crop available remains questionable, especially for those bees that were already trapped against the insect gauze in the vents. Olfaction might have played a role under such circumstances. This question remains as an objective for further research.

The sketchy observations presented here tend to point to the conclusion that polycarbonate as a material is not suitable for use as a greenhouse cladding for crops that need pollination by insect pollinators such as honey bees and bumble bees. To which extent the bees can cope with ultraviolet deficient conditions through learning has to be elucidated in more elaborate studies.

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