**Supporting Material**

**Fungicide and insecticide exposure adversely impact bumblebees under semi-field conditions**

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**Supplementary Table S1** Results of the linear models testing for differences in plant cover (%) and average number of closed inflorescences per enclosure estimated before the start of the experiment across assigned pesticide treatments (Closer, Amistar, Closer + Amistar and control).

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Sum Sq** | ***F*-value** | ***P*-value** |
| ***Plant cover (%)*** | | |  |  |
| Closer | 1.98 | 0.03 | 0.869 |  |
| Amistar | 1.75 | 0.02 | 0.877 |  |
| Closer x Amistar | 1.83 | 0.03 | 0.874 |  |
| ***Number of closed inflorescences per m2*** | | | |  |
| Closer | 1.30 | 0.02 | 0.877 |  |
| Amistar | 1.02 | 0.02 | 0.891 |  |
| Closer x Amistar | 2.40 | 0.05 | 0.833 |  |

**Supplementary Table S2** Results of the linear (mixed) models including the four colonies excluded in the main analyses, testing the effects of Closer (sulfoxaflor) and Amistar (azoxystrobin) application, flower abundance (flowers, average number of flowers m-2 per enclosure) and their interactions on individual foraging performance (number of visited flowers by one worker bumblebee (*B. terrestris*), flower visitation (number of bumblebees visiting flowers), number of daily foraging flights, colony growth (colony weight Day15 – initial colony weight Day-1) and on per-visit pollen deposition (number of pollen grains deposited during one visit on virgin stigmas of *Phacelia tanacetifolia*). Models also include air temperature (temperature) and the initial colony weight (initial colony weight Day-1) as covariates. Analyses on foraging performance were split and performed on data collected before and after Amistar application (Fig. S2).

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Sum Sq** | ***F*-value** | ***P*-value** |
| ***Colony growth*** | | |  |
| Closer | 492.2 | 3.63 | 0.066 |
| Amistar | 518.8 | 3.82 | 0.060 |
| **flowers** | **2274.9** | **16.77** | **<0.001** |
| Closer x Amistar | 268.9 | 1.98 | 0.169 |
| Closer x flowers | 240.5 | 1.77 | 0.193 |
| Amistar x flowers | 69.2 | 0.51 | 0.481 |
| Closer x Amistar x flowers | 17.3 | 0.13 | 0.724 |
| **initial weight** | **5976.0** | **44.06** | **<0.001** |

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Sum Sq** | ***F*-value** | ***P*-value** |
| ***Colony size*** | | |  |
| Closer | 1375.0 | 3.20 | 0.084 |
| Amistar | 82.8 | 0.19 | 0.664 |
| flowers | 937.4 | 2.18 | 0.150 |
| Closer x Amistar | 309.6 | 0.72 | 0.403 |
| Closer x flowers | 13.2 | 0.03 | 0.862 |
| Amistar x flowers | 69.0 | 0.16 | 0.692 |
| Closer x Amistar x flowers | 42.4 | 0.10 | 0.756 |
| initial weight | 79.9 | 0.19 | 0.670 |

*(Supplementary Table continues below)*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** | **Variables** | **χ2** | ***P*-value** |
| day 1-4 (before Amistar application) | | | day 5-18 (after Amistar application) | | |
| ***Individual foraging performance*** | | | | | |
| **Closer** | **9.16** | **0.002** | **Closer** | **8.61** | **0.003** |
| **flowers** | **5.07** | **0.024** | **Amistar** | **12.34** | **<0.001** |
| Closer x flowers | 0.01 | 0.932 | flowers | 1.29 | 0.256 |
| temperature | 3.49 | 0.062 | Closer x Amistar | 2.24 | 0.134 |
| initial weight | 0.03 | 0.861 | Closer x flowers | 1.54 | 0.215 |
|  |  |  | Amistar x flowers | 3.60 | 0.058 |
|  |  |  | Closer x Amistar x flowers | 1.16 | 0.281 |
|  |  |  | temperature | 0.14 | 0.710 |
|  |  |  | initial weight | 0.94 | 0.332 |
| ***Flower visitation*** | | | | | |
| Closer | 0.15 | 0.694 | Closer | 0.48 | 0.488 |
| flowers | 1.00 | 0.317 | Amistar | 2.71 | 0.100 |
| Closer x flowers | 1.09 | 0.297 | **flowers** | **8.95** | **0.003** |
| **temperature** | **8.58** | **0.003** | Closer x Amistar | 0.69 | 0.406 |
| initial weight | 1.42 | 0.234 | Closer x flowers | 0.01 | 0.932 |
|  |  |  | Amistar x flowers | 1.69 | 0.193 |
|  |  |  | Closer x Amistar x flowers | 3.35 | 0.067 |
|  |  |  | temperature | 2.57 | 0.109 |
|  |  |  | initial weight | 0.00 | 0.970 |
| ***Number of flights*** | | | | | |
| Closer | 0.15 | 0.696 | Closer | 0.13 | 0.720 |
| **flowers** | **7.92** | **0.005** | Amistar | 0.60 | 0.440 |
| Closer x flowers | 1.48 | 0.224 | **flowers** | **6.87** | **0.009** |
| temperature | 1.24 | 0.265 | Closer x Amistar | 0.14 | 0.704 |
| initial weight | 3.81 | 0.051 | Closer x flowers | 0.18 | 0.673 |
|  |  |  | Amistar x flowers | 0.46 | 0.500 |
|  |  |  | Closer x Amistar x flowers | 0.53 | 0.465 |
|  |  |  | temperature | 0.29 | 0.588 |
|  |  |  | initial weight | 1.03 | 0.311 |

*(Supplementary Table continues below)*

|  |  |  |
| --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** |
| ***Pollen deposition on stigmas*** | |
| Closer | 0.65 | 0.419 |
| Amistar | 2.20 | 0.138 |
| flowers | 0.03 | 0.868 |
| Closer x Amistar | 1.83 | 0.176 |
| Closer x flowers | 0.06 | 0.813 |
| Amistar x flowers | 0.17 | 0.676 |
| Closer x Amistar x flowers | 0.63 | 0.428 |
| temperature | 0.75 | 0.385 |
| initial weight | 0.05 | 0.830 |
| ***Pollen deposition on stigmas and styles*** | |
| Closer | 0.34 | 0.560 |
| Amistar | 3.46 | 0.063 |
| flowers | 2.62 | 0.106 |
| Closer x Amistar | 1.88 | 0.171 |
| Closer x flowers | 1.62 | 0.203 |
| Amistar x flowers | 0.35 | 0.554 |
| Closer x Amistar x flowers | 0.21 | 0.646 |
| temperature | 0.03 | 0.873 |
| initial weight | 0.01 | 0.904 |

**Supplementary Table S3** Results of the LMMs testing the effects of Closer (sulfoxaflor) and Amistar (azoxystrobin) application, flower abundance (flowers, average number of flowers m-2 per enclosure) and their interactions between day 5 and day 7 on individual foraging performance, flower visitation, number of daily foraging flights, colony growth and on per-visit pollen deposition. Models also include air temperature (temperature) and the initial colony weight (initial colony weight Day-1) as covariates.

|  |  |  |
| --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** |
| day 5-18 (after Amistar application) | | |
| ***Individual foraging performance*** | | |
| **Closer** | **4.65** | **0.031** |
| **Amistar** | **10.87** | **0.001** |
| flowers | 0.86 | 0.353 |
| Closer x Amistar | 1.14 | 0.285 |
| Closer x flowers | 0.01 | 0.914 |
| Amistar x flowers | 0.05 | 0.823 |
| Closer x Amistar x flowers | 1.91 | 0.167 |
| temperature | 0.09 | 0.765 |
| initial weight | 0.01 | 0.937 |
| ***Flower visitation*** |  |  |
| Closer | 0.22 | 0.638 |
| Amistar | 1.07 | 0.302 |
| flowers | 3.07 | 0.080 |
| Closer x Amistar | 3.77 | 0.052 |
| Closer x flowers | 0.00 | 0.945 |
| Amistar x flowers | 2.07 | 0.151 |
| Closer x Amistar x flowers | 0.00 | 0.966 |
| temperature | 1.77 | 0.183 |
| initial weight | 0.13 | 0.722 |
| ***Number of flights*** |  |  |
| Closer | 2.81 | 0.093 |
| Amistar | 2.49 | 0.115 |
| **flowers** | **5.35** | **0.021** |
| Closer x Amistar | 0.09 | 0.770 |
| Closer x flowers | 0.04 | 0.852 |
| Amistar x flowers | 0.20 | 0.653 |
| Closer x Amistar x flowers | 0.00 | 0.982 |
| **temperature** | **50.04** | **<0.001** |
| initial weight | 0.05 | 0.815 |

*(Supplementary Table continues below)*

|  |  |  |
| --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** |
| ***Pollen deposition on stigmas*** | |
| Closer | 1.36 | 0.244 |
| Amistar | 1.96 | 0.162 |
| flowers | 0.00 | 0.988 |
| Closer x Amistar | 0.56 | 0.453 |
| Closer x flowers | 1.40 | 0.237 |
| Amistar x flowers | 0.71 | 0.399 |
| Closer x Amistar x flowers | 1.76 | 0.185 |
| temperature | 0.16 | 0.692 |
| initial weight | 1.37 | 0.243 |
| ***Pollen deposition on stigmas and styles*** | |
| Closer | 0.05 | 0.820 |
| Amistar | 3.63 | 0.057 |
| flowers | 0.88 | 0.349 |
| Closer x Amistar | 0.07 | 0.797 |
| Closer x flowers | 0.37 | 0.545 |
| Amistar x flowers | 2.00 | 0.158 |
| Closer x Amistar x flowers | 0.10 | 0.754 |
| temperature | 0.00 | 0.971 |
| initial weight | 2.25 | 0.133 |

**Supplementary Table S4** Results of the linear (mixed) models testing the effects of treatments (categorical, 4 levels: Closer, Amistar, Closer + Amistar and control), flower abundance (flowers, average number of flowers m-2 per enclosure) and their interactions after Amistar application on colony growth, individual foraging performance, flower visitation, number of daily foraging flights and on per-visit pollen deposition. Models also include air temperature (temperature) and the initial colony weight (initial colony weight Day-1) as covariates.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Sum Sq** | ***F*-value** | ***P*-value** |
| ***Colony growth*** | | |  |
| **treatment** | **1176.0** | **3.52** | **0.028** |
| **flowers** | **2245.9** | **20.15** | **<0.001** |
| treatment x flowers | 362.9 | 1.09 | 0.372 |
| **initial weight** | **6176.2** | **55.40** | **<0.001** |

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Sum Sq** | ***F*-value** | ***P*-value** |
| ***Colony size*** | | |  |
| treatment | 2798.4 | 2.64 | 0.070 |
| flowers | 1300.1 | 3.68 | 0.066 |
| treatment x flowers | 293.5 | 0.28 | 0.842 |
| initial weight | 35.1 | 0.10 | 0.755 |

|  |  |  |
| --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** |
| day 5-18 (after Amistar application) | | |
| ***Individual foraging performance*** | | |
| **treatment** | **19.19** | **<0.001** |
| flowers | 1.95 | 0.162 |
| treatment x flowers | 5.43 | 0.143 |
| temperature | 0.01 | 0.908 |
| initial weight | 2.01 | 0.156 |
|  |  |  |
| ***Flower visitation*** |  |  |
| treatment | 2.40 | 0.494 |
| **flowers** | **4.52** | **0.034** |
| treatment x flowers | 3.81 | 0.283 |
| temperature | 1.71 | 0.191 |
| initial weight | 0.07 | 0.799 |
|  |  |  |
| ***Number of flights*** |  |  |
| treatment | 0.93 | 0.818 |
| **flowers** | **5.25** | **0.022** |
| treatment x flowers | 1.12 | 0.772 |
| temperature | 0.75 | 0.387 |
| initial weight | 0.30 | 0.582 |

*(Supplementary Table continues below)*

|  |  |  |
| --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** |
| ***Pollen deposition*** |  |
| treatment | 4.84 | 0.184 |
| flowers | 0.09 | 0.761 |
| treatment x flowers | 3.52 | 0.318 |
| temperature | 0.95 | 0.331 |
| initial weight | 0.34 | 0.558 |
| ***Pollen deposition*** |  |
| **treatment** | **9.19** | **0.027** |
| flowers | 1.29 | 0.256 |
| treatment x flowers | 5.41 | 0.144 |
| temperature | 0.05 | 0.825 |
| initial weight | 0.61 | 0.435 |

**Supplementary Table S5** Results of the linear (mixed) models testing the effects of Closer (sulfoxaflor) and Amistar (azoxystrobin) application, flower abundance (flowers, average number of flowers m-2 per enclosure) and their interactions on colony growth (colony weight Day15 – initial colony weight Day-1), individual foraging performance (number of visited flowers by one worker bumblebee (*B. terrestris*), flower visitation (number of bumblebees visiting flowers), number of daily foraging flights and on per-visit pollen deposition (number of pollen grains deposited during one visit on virgin stigmas of *Phacelia tanacetifolia*). Models also include air temperature (temperature) and the initial colony weight (initial colony weight Day-1) as covariates. Analyses on foraging performance were split and performed on data collected before and after Amistar application (Fig. S2).

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Sum Sq** | ***F*-value** | ***P*-value** |
| ***Colony growth*** | | |  |
| **Closer** | **679.3** | **6.09** | **0.020** |
| Amistar | 217.2 | 1.95 | 0.174 |
| **flowers** | **2245.9** | **20.15** | **<0.001** |
| Closer x Amistar | 168.2 | 1.51 | 0.230 |
| Closer x flowers | 279.5 | 2.51 | 0.125 |
| Amistar x flowers | 29.2 | 0.26 | 0.613 |
| Closer x Amistar x flowers | 79.2 | 0.71 | 0.407 |
| **initial weight** | **6176.2** | **55.40** | **<0.001** |

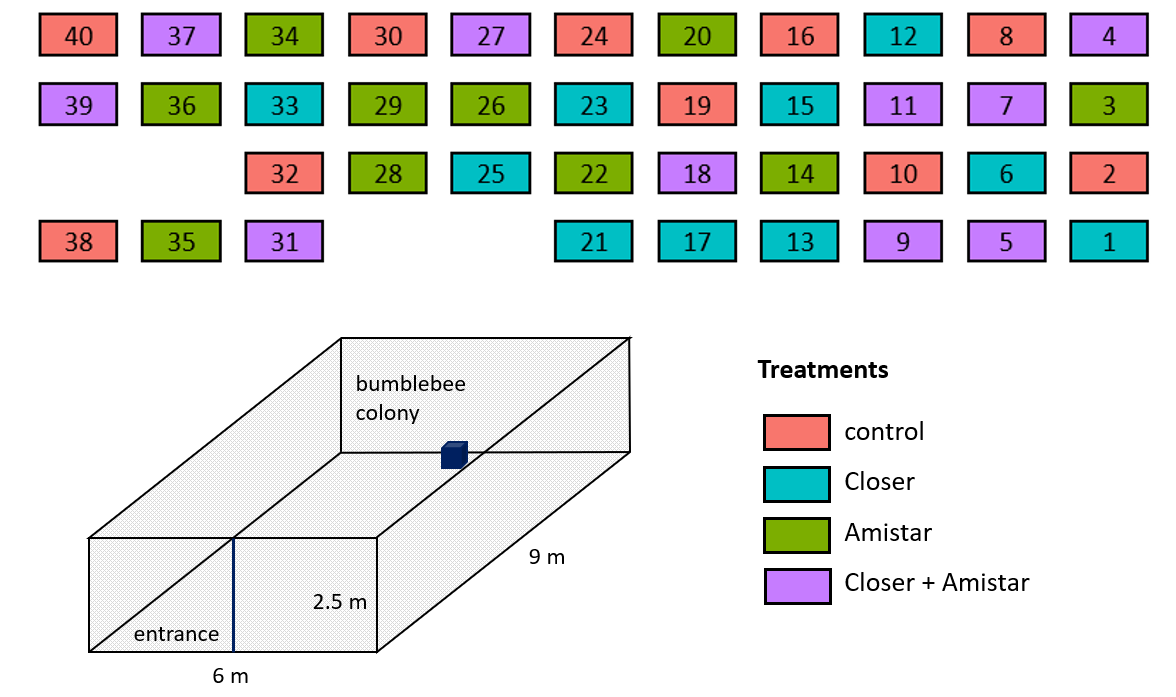
|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Sum Sq** | ***F*-value** | ***P*-value** |
| ***Colony size*** | | |  |
| **Closer** | **2451.2** | **6.94** | **0.014** |
| Amistar | 15.7 | 0.04 | 0.835 |
| flowers | 1300.1 | 3.68 | 0.066 |
| Closer x Amistar | 5.1 | 0.01 | 0.906 |
| Closer x flowers | 118.1 | 0.33 | 0.568 |
| Amistar x flowers | 107.2 | 0.30 | 0.586 |
| Closer x Amistar x flowers | 10.9 | 0.03 | 0.862 |
| initial weight | 35.1 | 0.10 | 0.755 |

*(Supplementary Table continues below)*

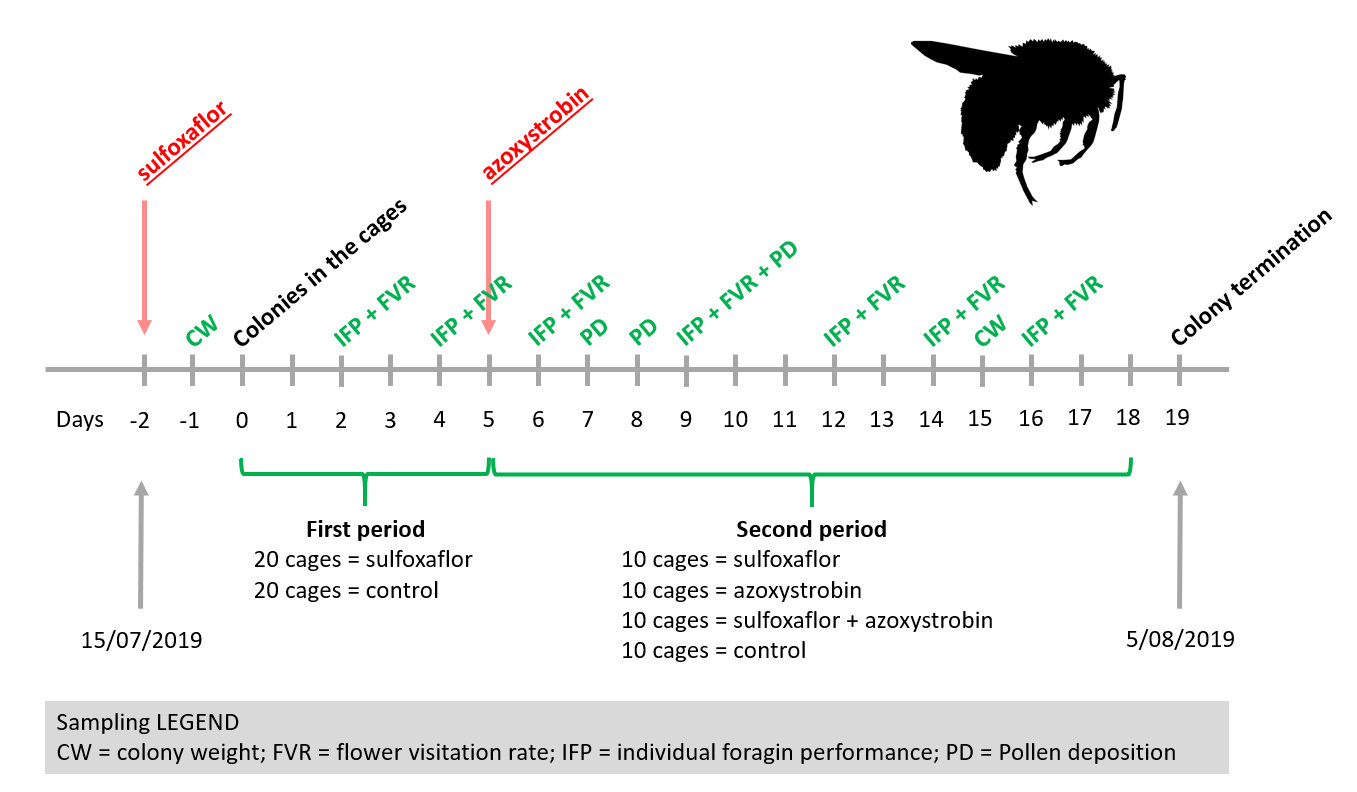
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** | **Variables** | **χ2** | ***P*-value** |
| day 1-4 (before Amistar application) | | | day 5-18 (after Amistar application) | | |
| ***Individual foraging performance*** | | | | | |
| **Closer** | **7.67** | **0.006** | **Closer** | **9.49** | **0.002** |
| **flowers** | **5.74** | **0.017** | **Amistar** | **8.64** | **0.003** |
| Closer x flowers | 0.15 | 0.697 | flowers | 1.95 | 0.162 |
| **temperature** | **4.05** | **0.044** | Closer x Amistar | 2.43 | 0.119 |
| initial weight | 0.04 | 0.845 | Closer x flowers | 2.30 | 0.129 |
|  |  |  | Amistar x flowers | 2.14 | 0.144 |
|  |  |  | Closer x Amistar x flowers | 0.53 | 0.466 |
|  |  |  | temperature | 0.01 | 0.908 |
|  |  |  | initial weight | 2.01 | 0.156 |
| ***Flower visitation*** | | | | | |
| Closer | 0.44 | 0.509 | Closer | 0.11 | 0.735 |
| flowers | 0.73 | 0.393 | Amistar | 1.71 | 0.190 |
| Closer x flowers | 1.24 | 0.265 | **flowers** | **4.52** | **0.034** |
| **temperature** | **7.38** | **0.007** | Closer x Amistar | 0.67 | 0.413 |
| initial weight | 1.54 | 0.214 | Closer x flowers | 0.25 | 0.617 |
|  |  |  | Amistar x flowers | 1.00 | 0.317 |
|  |  |  | Closer x Amistar x flowers | 2.64 | 0.104 |
|  |  |  | temperature | 1.71 | 0.191 |
|  |  |  | initial weight | 0.07 | 0.799 |
| *(Supplementary Table continues below)*  ***Number of flights*** | | | | | |
| Closer | 0.43 | 0.512 | Closer | 0.58 | 0.448 |
| **flowers** | **9.27** | **0.002** | Amistar | 0.01 | 0.944 |
| Closer x flowers | 2.36 | 0.124 | **flowers** | **5.25** | **0.022** |
| temperature | 0.58 | 0.445 | Closer x Amistar | 0.32 | 0.574 |
| **initial weight** | **4.68** | **0.031** | Closer x flowers | 0.03 | 0.863 |
|  |  |  | Amistar x flowers | 0.99 | 0.319 |
|  |  |  | Closer x Amistar x flowers | 0.13 | 0.723 |
|  |  |  | temperature | 0.75 | 0.387 |
|  |  |  | initial weight | 0.30 | 0.582 |

*(Supplementary Table continues below)*

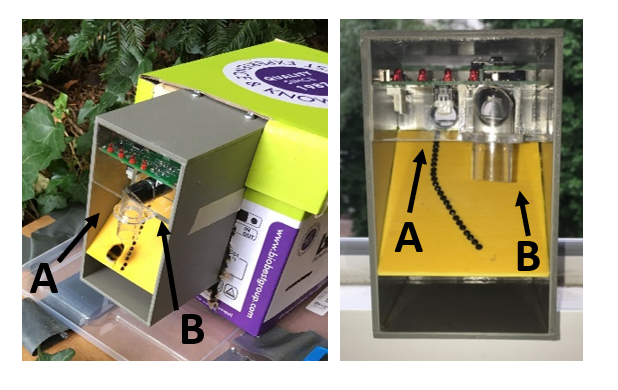
|  |  |  |
| --- | --- | --- |
| **Variables** | **χ2** | ***P*-value** |
| ***Pollen deposition on stigmas*** | |
| Closer | 0.49 | 0.482 |
| Amistar | 3.23 | 0.072 |
| flowers | 0.09 | 0.761 |
| Closer x Amistar | 1.37 | 0.242 |
| Closer x flowers | 0.56 | 0.456 |
| Amistar x flowers | 0.67 | 0.415 |
| Closer x Amistar x flowers | 2.50 | 0.114 |
| temperature | 0.95 | 0.331 |
| initial weight | 0.34 | 0.558 |
| ***Pollen deposition on stigmas and styles*** | |
| Closer | 1.08 | 0.298 |
| **Amistar** | **5.44** | **0.020** |
| flowers | 1.29 | 0.256 |
| Closer x Amistar | 1.38 | 0.239 |
| Closer x flowers | 0.07 | 0.797 |
| Amistar x flowers | 2.15 | 0.142 |
| Closer x Amistar x flowers | 3.26 | 0.071 |
| temperature | 0.05 | 0.825 |
| initial weight | 0.61 | 0.435 |



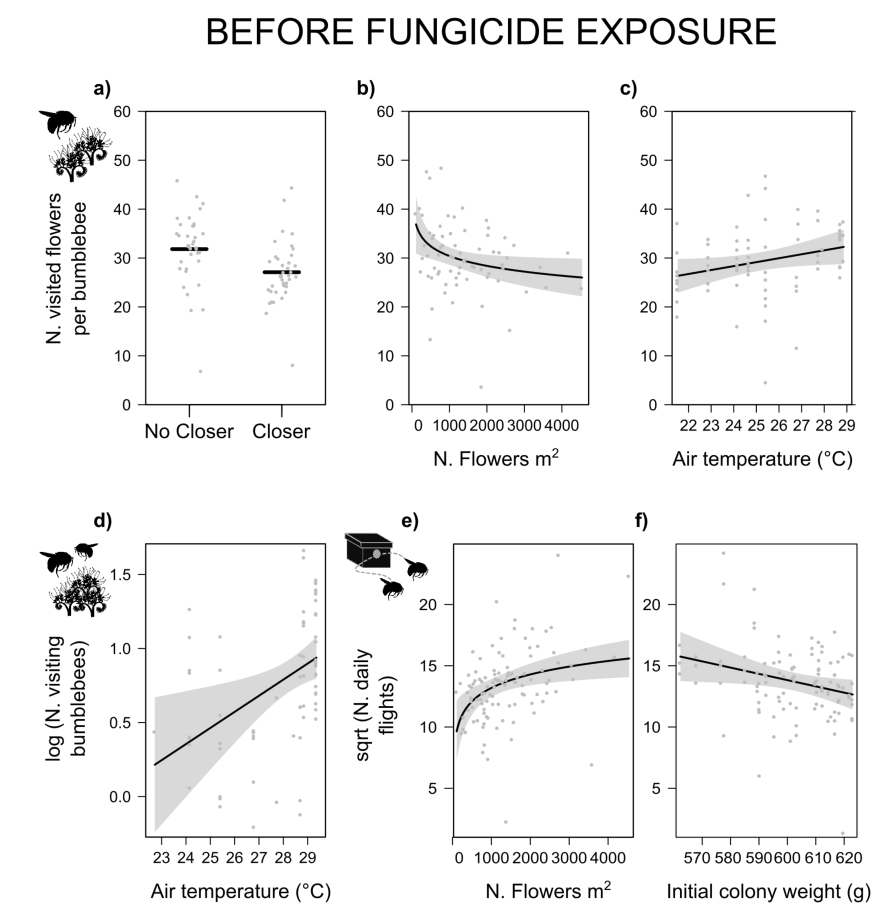
**Supplementary Figure S1.** Scheme of the 40 enclosures with the distribution of the treatments. Cages were made of metallic tubes (each 6 x 9 m, height: 2.5 m; Howitec) and positioned at least 4 m from the field boundaries (>1000 m from the nearest crop) and at least 4 m apart from each other.



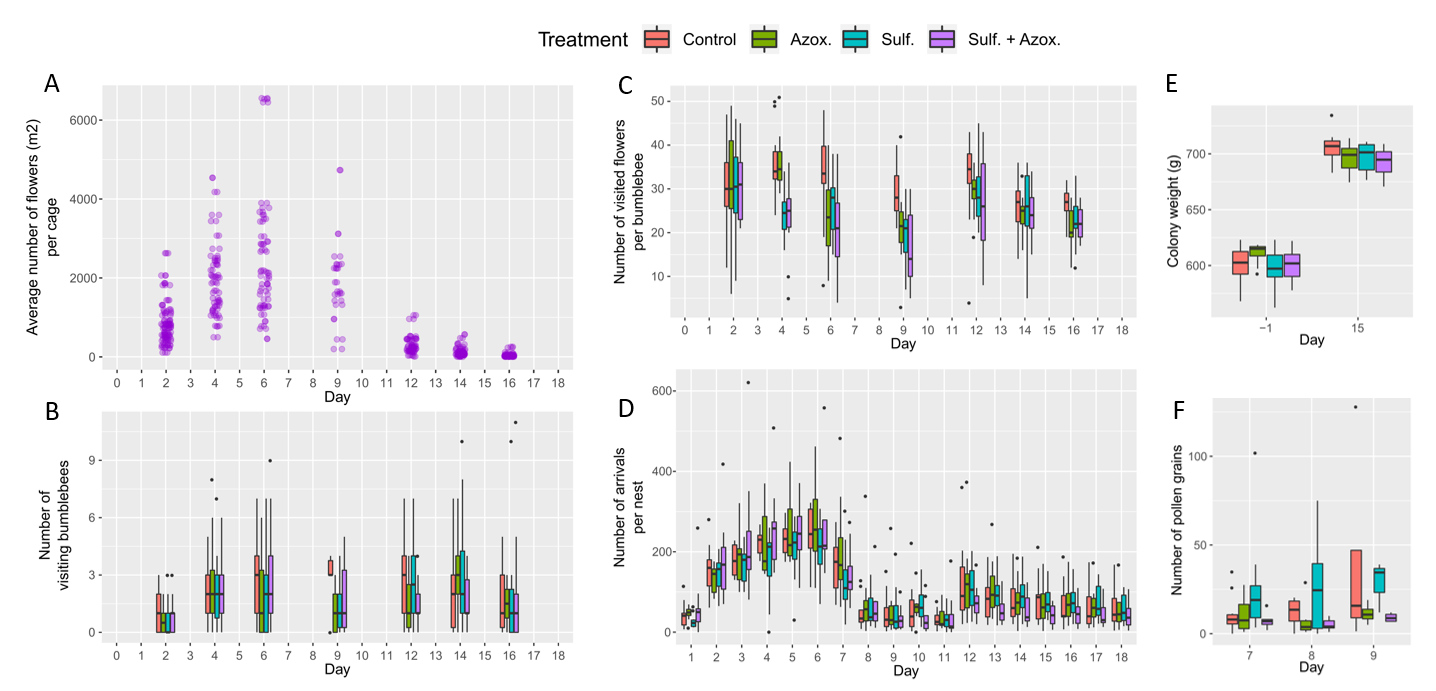
**Supplementary Figure S2.** Experiment timeline. Red, pesticide applications; black, start and end of the study; green, different type of sampling (see legend). The study is divided in two different periods in order to properly analyse the data.



**Supplementary Figure S3.** Bumblebee monitoring device provided by Atlantic Pollination Ltd. **A**, arrival opening; **B**, departure opening. Departure opening is formed by an “L” shape plastic tube to discourage bumblebee to use it to access the nest. The line of black dots on yellow background facilitate bumblebee to locate the “Arrival” opening. Because the entrance passage is accessible, visible and convenient, returning bees enter the nest rapidly without hesitation, compared with the difficulty of climbing vertically up the exit passage. The bumblebee monitoring units use infrared light which is produced by a combined emitter/sensor. The infrared beam is directed into the passage through which the bumble bees travel. The sensor detects the infrared light which is reflected either (a) from the empty passage or (b) from a bee in the passage. By utilising a pair of emitter/sensor units in the passageway, not only the presence of a bee but also the direction of its motion is detected.



**Supplementary Figure S4.** Responses of the studied variables to various tested factors before the application of the fungicide. Effects of (*a*)exposure to the insecticide Closer (sulfoxaflor), (*b*) flower abundance (average number of flowers m-2 per enclosure) and (*c*) air temperature on individual foraging performance (number of visited flowers per bumblebee). Effects of (*d*) air temperature on flower visitation (number of bumblebees visiting flowers). Effects of (*e*) flower abundance and (*f*) initial colony weight on bumblebee colony growth (colony weight Day15 – initial colony weight Day-1). Plots display prediction lines, partial residuals and confidence bands (95%).



**Supplementary Figure S5.** Raw data. (a) average number of *Phacelia tanacetifolia* flowers per square meter as measured during seven assessments; (b) number of bumblebees visiting *Phacelia tanacetifolia* flowers in an area of nine square meters in a time period of three minutes;(c) number of Phacelia tanacetifolia flowers visited by an individual bumblebee over a two-minute period; (d) number of arrivals per colony measured daily by the bumblebee monitoring units;(e) Colony weight at the beginning and at the end of the experiment; (f) average number of pollen grains per inflorescence deposited during one visit on stigmas.