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Application of NIR-lasers for the control of aphids and whiteflies

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1. Introduction, Knowledge, Objectives

Insecticides are often used for pest control in horticultural crops. Increasing concerns about potential residues on the produce, contamination of non-target areas, and the rising problems with respect to resistance demand new strategies. Alternative methods for pest control focus on biological methods (Schmutterer & Huber 2005, van Lenteren 2012) or biotechnical measures (Welter et al. 2005, Kumar & Poehling 2006, Diaz & Fereres 2007). The main advantage of these methods is an increase of the selectivity leading to a reduced impact on non-target insects and the environment. The approach of using lasers to directly damage treated pests is even more selective. Conconi (1983) investigated laser-based pest control of beetle species in stored foods (laser wavelengths: 488 nm and 632.8 nm, total applied energy: 3 to 480 J). Shulman (1990) discussed the control of swarms of locusts in general. Yao et al. (2008, 2009) used a laser (808 nm, 2 to 6 J) to kill up to 80 % of *Locusta migratoria* in different growth stages, while the host plants (green bristle grass, *Setaria viridis*) remained rather unharmed. Zhang (1997) and Ren et al. (2006) used the effect of laser irradiation (632.8 nm, 4 J; and 650 nm, 4 to 30 J respectively) for the control of fruit flies (*Drosophila melanogaster*).
The objective of this study was to analyze the spectral characteristics of aphids and whiteflies in order to examine the suitability of high power NIR laser systems for lethally damaging pests while sparing the host plants at short irradiation times.

2. Material and Methods

2.1 Pests and host plants

The host plants (Brussels sprout, common wheat, and common bean) were grown in greenhouse at 18/10 °C and were infected with small pest colonies (7 aphids per cage), which were derived from stock cultures. After a growth period of four weeks the pest densities reached high levels. The cabbage aphid (*Brevicoryne brassicae*), the black bean aphid (*Aphis fabae*), and grain aphids (*Sitobion avenae*) settled in all developmental stages from L1 larvae to adults (which were mostly wingless morphs) on Brussels sprout (*Brassica oleracea* var. *gemmifera*), common bean (*Phaseolus vulgaris*), or wheat plants (*Triticum aestivum* L.), respectively. For the cabbage whitefly (*Aleyrodes proletella*), only the winged adults were considered for treatments. However, the developmental stages of the pests were not differentiated in the laser irradiation tests.

2.2 Spectral measurements

In order to determine the most efficient laser wavelengths, the reflectance spectra of the pests as well as of the plant leaves were measured using a spectrometer equipped with an integrating sphere (Lambda 900, PerkinElmer Inc.). The leaf size exceeded the aperture (8 x 15 mm^2) of the spectrometer, while the living pests had to be fixed on adhesive strips. Due to their diverse sizes, shapes, and urge to escape, a gapless layer of pest bodies could not be arranged. The reflectance spectra of three different pest densities were averaged.

2.3 Laser applications

The pests on the bottom side of the leaves were placed in the center of the working area of the laser scanner. An area of 50 mm^2 was irradiated by unidirectional line-by-line scanning. Four different laser systems, each of them at 5 kHz pulse-width modulation mode, were tested. In order to achieve best test situations, each laser system was driven individually considering spot diameter, speed of the guided beam, and laser beam intensities (Tab. 1). The test series focused on the determination of effective laser powers to lethally damage the pests at given spot diameters and reasonable irradiation times as well as on the influence of laser spot diameter and irradiation time at constant laser energy densities.

Tab. 1: Overview of the laser systems and parameter sets which were used for the irradiation tests of pest and plant species

laser type	**wavelength**	**focus ø**	**used spot ø**	**max. output**	**feed rate**	**energy density**
(-)	**(nm)**	**(µm)**	**(mm)**	**(W)**	**(mm s^{-1})**	**(J mm^{-2})**
solid state laser (Nd:YAG)	1064	250	0.25 … 0.39	100	20 … 30	3.55 … 12.00
fiber laser (Tm)	1908	25	1.20	50	50	0.09 … 0.16
gas laser (CO_2)	10600	250	2.25 … 3.50	50	5 … 15	0.05 … 0.20

2.4 Analysis after laser irradiation

Each laser treatment was captured with a microscope camera (DigiMicro 2.0 Scale, DNT GmbH, Germany). Additionally, a stereo microscope (Stemi 2000-C, Carl Zeiss GmbH, Germany) and two SEMs (Series 2, CamScan and Quanta 400 F, FEI Comp., USA) were used. The images before and after laser irradiation were rated visually using four levels of quality according to the extent of visible damages.

3. Results

The spectral characteristics of the pests used were evaluated qualitatively. The most suitable laser wavelength should primarily achieve pest damage rather than wounding of the plant material. As both pest and plant tissue contain high amounts of water, the specific water dependent local minima showed at 976, 1200, 1450 and 1930 nm (Fig. 1). The reflectance of all host plants was similar (max. 13 % difference). The pests showed low reflectance in the VIS range, increasing values in the NIR range before the reflectance decreased again at about 1250 nm. But the increase of reflectance in the range from 700 to 1250 nm was always less than that of the host plant leaves. Hence, the spectral differences between the pest and the plant spectra were reasonably high.

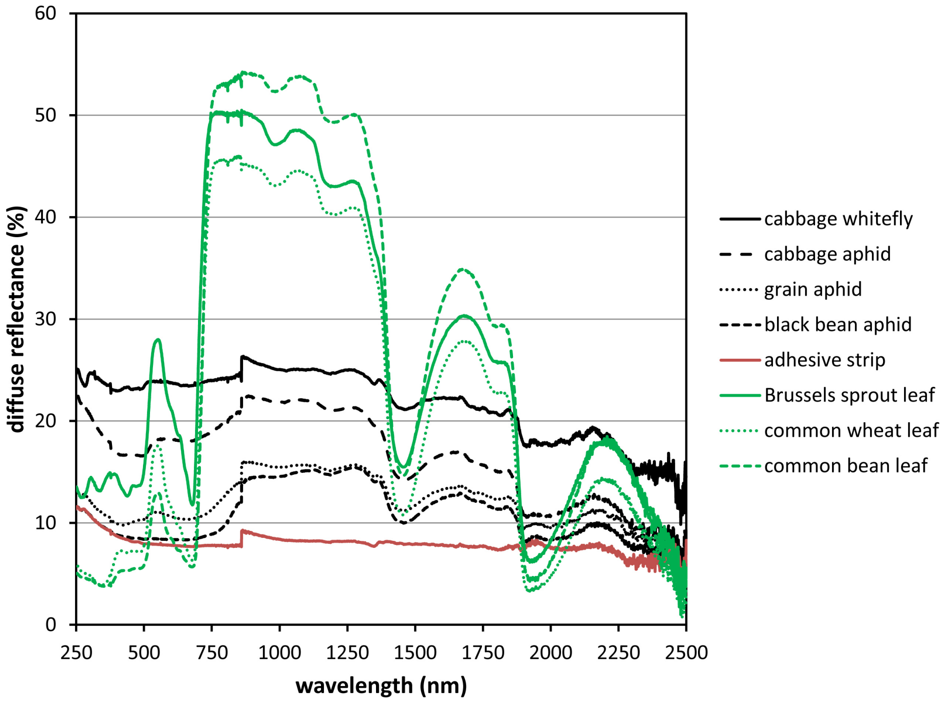

Fig. 1: Mean reflectance spectra of different pests (grain aphid, black bean aphid, cabbage aphid, and cabbage whitefly), the adhesive strips used for the fixation of aphids during spectral measurements, and different leaves (wheat, bean, Brussels sprout) (n = 3)

The laser irradiation led to a deformation of the pests mainly due to the loss of the haemolymph. The legs were stunted and spread. In particular, the head area was sensitive as it changed to a dark brown color. The SEM images illustrate the selective damage of whiteflies and aphids showing roughened surfaces due to tissue degradation (Fig. 2).

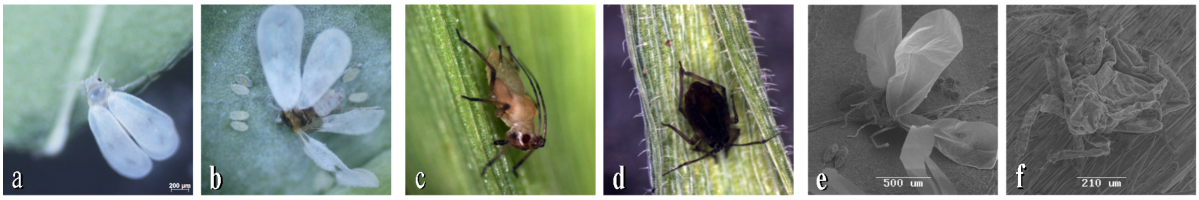

Fig. 2: The effect of laser treatment on different pests. Images of a cabbage whitefly (*Aleyrodes proletella*) and a grain aphid (*Sitobion avenae*) on the one hand untreated (a, c) and on the other hand lethally damaged (b, d) as well as corresponding SEM images (e, f)

Depending on the laser energy density applied, the pests and the leaves were increasingly damaged (Fig. 3). A differentiation with respect to the damageability of pests and leaves only appeared at 1064 nm (also compare Fig. 1).
The lethal energy densities (LD_{90}) for each pest were determined using the linear regressions shown in Fig. 3 (Tab. 2). The CO_2 laser application showed the lowest energy demand. The fiber laser (Tm) radiation caused comparable damages to pests and plant leaves. Meanwhile, with Nd:YAG laser application higher energies were needed to damage the pests prior to the plant leaves.

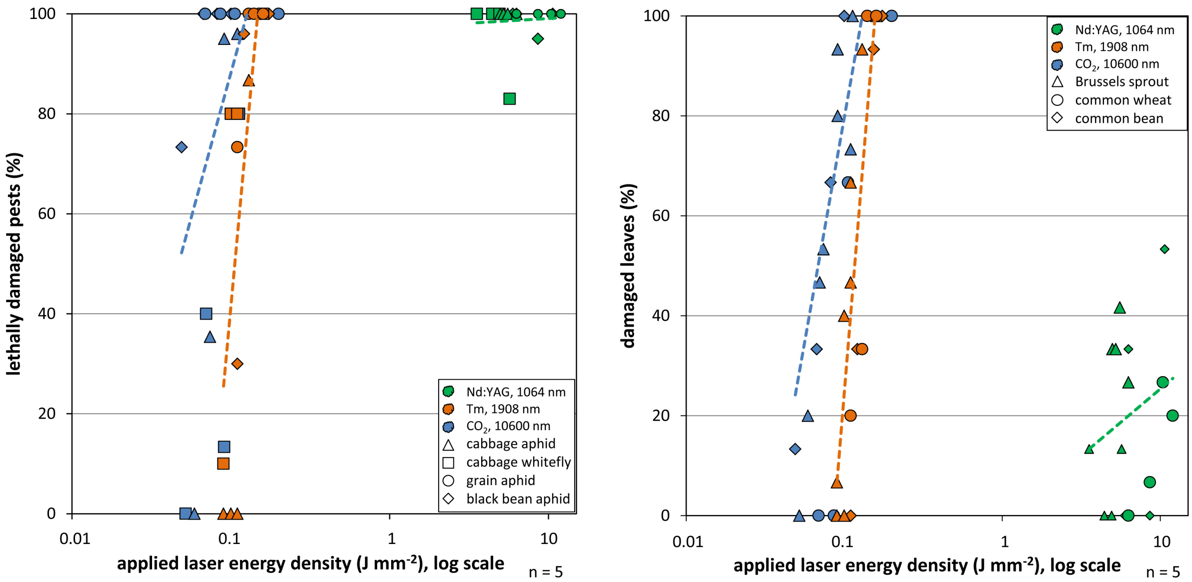

Fig. 3: Mean damage levels depending on the laser wavelength, the energy density, and the pest species (left) or the plant species (right) (n = 5)

Tab. 2: Overview of calculated lethal laser energy densities (in J mm^{-2}); LD_{90} for pests and LD_{10} for plant leaves

laser (wavelength)	**pest species, LD_{90} (J mm^{-2})**				**plant species, LD_{10} (J mm^{-2})**		
	cabbage aphid	cabbage whitefly	grain aphid	black bean aphid	Brussels sprout	common wheat	common bean
Nd:YAG (1064 nm)	< 4.98	< 3.55	< 6.29	< 5.97	3.87	8.54	6.12
Tm (1908 nm)	0.14	0.14	0.13	0.15	0.09	0.11	0.11
CO_2 (10600 nm)	0.10	0.14	< 0.07	0.07	0.05	0.07	0.05

4. Discussion

For the spectra of pests, it was assumed that low reflectance correspond to high absorption. Hence, the maximum absorption of the pests and the plants was observed in the UV range as well as in the transition range towards mid-infrared. With respect to the patchy distribution of pest bodies, parts of the laser radiation would directly hit and damage the leaf material. Laser wavelengths that fit to high spectral differences could be effectively used. The spectra were qualitatively analyzed, yielding noticeably high spectral differences especially within the range of 720 to 800 nm (Fig. 1), where the increase of the reflectance values of pests was lower than that of the plant leaves. An alexandrite laser would fit to that wavelength range. However, UV, NIR, or MIR lasers combined with an accurate beam positioning would be appropriate for the selective irradiation of single pests. It appeared that the laser radiation at 1064 nm led to the damage of pests before the plant leaves were affected (Fig. 3). Since the total absorption was low (see Fig. 1), high energy densities would be needed for any lethal damage of pests. The laser radiation at 1908 nm or 10600 nm showed lower reflectance values because of the high absorption of water (compare Wieliczka et al., 1989). Hence, any treated leaf would nearly absorb 95 % of the radiation and would be damaged by any two-dimensional irradiation. Therefore a selective laser application would enhance the treatment success. The experiments performed showed that the exposure time had no effect on the damage to leaves but a significant effect on the pests (the faster the lesser damage). It is assumed that the higher thermal conductivity as well as the higher mass inertia of the leaves allows for more resistance against short thermal loads. Larger spot diameters had a negative influence on the leaves as more radiation did not reach the pests. In addition, the total energy input at comparable energy density was higher than using small spots, so that local damages became more likely. Across from other investigations on laser based pest control (see above), the use of high power NIR/MIR laser systems allows selective and fast treatments.

5. Conclusions

Due to the spectral analyses, a NIR lasers with a wavelength between 720 and 800 nm was best suited to lethally damage soft-bodied pests. Lasers at 1064 nm could be used for large area applications as the damage of leaves could be neglected. In order to use single shot applications, lasers at 1908 nm and 10600 nm would require less energy due to higher absorption of the insect bodies. The effective doses depended on the pest species and on its developmental stage, too. Future work will focus on long-term studies regarding the effect of sub-lethal laser radiation on behavioral changes (orientation, feeding, and reproduction) as well as on the effect of lethal damages on population dynamics.

6. Literature

Conconi R.E.J. de (1983). Laser light as a new potential method for pest control in preserved foods. Biodeterioration 5 Conference Proceedings, pp. 592-608 **Diaz B.M., Fereres A. (2007).** Ultraviolet-blocking materials as a physical barrier to control insect pests and plant pathogens in protected crops. Pest Technology 1 (2), pp. 85-95 **Kumar P., Poehling H.M. (2006).** UV-blocking plastic films and nets influence vectors and virus transmission on greenhouse tomatoes in the humid tropics. Environmental Entomology 35 (4), pp. 1069-1082 **Ren K., Tu K., Li H.W. (2006).** Control effects of semiconductor laser on *Drosophila melanogaster*. Zhongguo Jiguang/Chinese Journal of Lasers 33(8), pp. 1148-1152 **Schmutterer H., Huber H. (2005).** Natürliche Schädlingsbekämpfungsmittel. Ulmer Verlag **Shulman S. (1990).** Star warriors seek new foes. Nature 344, p. 802 **van Lenteren J.C. (2012).** IOBC Internet Book of Biological Control. *www.iobc-global.org* **Welter S.C., Pickel C., Millar J., Cave F., van Steenwyk R.A., Dunley J. (2005).** Pheromone mating disruption offers selective management options for key pest. California Agriculture 58, 16-22 **Wieliczka D.M., Weng S., Querry M.R. (1989).** Wedge shaped cell for highly absorbent liquids: infrared optical constants of water. Appl. Opt. 28, pp. 1714-1719 **Yao M., Zhou Q., Liu M., Zhao J. (2008).** Preliminary study of the application of semiconductor diode laser in controlling locusts. Proceedings of 2nd Int. Symp. on Intelligent Information Technology Application. Vol. 3, pp. 426-429 **Yao M., Zhou Q., Liu M., Zhao J. (2009).** Effect on locusts and Green Bristle Grass by 808 nm laser irradiation. Proceedings of Int. Conf. on Energy and Environment Technology. Vol. 3, pp. 298-301 **Zhang J. (1997).** Biologic effects on the *Drosophila melanogaster* by laser radiation. Yingyong Jiguang/Applied Laser Technology 17(6), pp. 273-275