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Laser Technology for Parasite Control: A Physics-Based, Eco-Friendly, and Non-Invasive Approach

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Abstract:

Laser-based technologies may represent a non-invasive alternative to traditional pharmacological treatments for parasite elimination, as they can deliver targeted high-energy beams with minimal contact and high specificity. Laser-based technologies in biology are growing, and there are opportunities for applications in pest control. Conventional chemical treatments are widely used to manage parasitic infections in humans, animals, and plants. However, these methods present significant limitations, such as toxicity, the accumulation of chemical residues in food, and the development of resistant parasite strains. These challenges highlight the urgent need for alternative control strategies. Consequently, searching for alternatives is essential. An emerging alternative involves bio-ecological approaches. Strategies grounded in physics are gaining increasing attention. These approaches that integrate physics-based methods offer a promising direction. In particular, laser technology has gained attention as a non-invasive, eco-friendly, and highly specific tool for targeted parasite control. Continued research and development in this field may pave the way for effective, and needs to be apply in the real-world testing.

Key words: Laser-based technologies, parasite control, insect pest control,

laser

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1. Introduction

The best way to manage parasite diseases in people, animals, and plants is to use chemical products. These substances have several disadvantages, including toxicity, residues in plants and meat, byproducts, and the emergence of chemical resistance (Hamid et al., 2023). Therefore, it is crucial to look for substitutes for these chemical products. Bio-ecological approaches in pest control refer to sustainable methods that use natural biological and ecological principles to manage pest populations, aiming to reduce reliance on chemical pesticides. These approaches are environmentally friendly and often focus on long-term pest suppression rather than immediate eradication. Of these, solutions based on physics are currently being considered (Gaetani et al., 2021). Due to its ability to deliver potent high-energy beams without physical contact and its potential for high precision, laser technology is being explored as a promising non-pharmacological approach for parasite eradication (Musset et al., 2023). Laser-based technologies are increasingly being used in biology, and there are potential uses in pest management. For instance, fish lice and aphids were managed using the automation of laser therapy (Hernandez-Aguilar et al., 2024). Additionally, Arafa used it to combat oocysts of the Eimeria species (Arafa et al., 2023). Lasers are capable of emitting collimated, high-power beams over long distances, making them suitable for outdoor applications. Moreover, ultraviolet (UV) radiation, a component of some laser systems, is recognized for its ability to induce DNA damage (Gaetani et al., 2021). Furthermore, causing DNA mutations in insect populations has un-favorable long-term effects since it may result in genetically altered and adapted species (Perrot-Minnot et al., 2024). On the other hand, mosquitoes (Anopheles stephensi) were effectively killed with modest energy doses (approximately 1 J cm^{-2}) by using CO_2 IR laser (100.6 µm wavelength) or pulsed (~ 25 ms) green laser light (532 nm wavelength) (Keller et al., 2016).

2. Laser efficacy against different parasites

2.1. Efficacy against protozoa

Reducing the ability of *Eimeria* oocysts to undergo sporulation plays a crucial role in limiting the transmission of coccidial infections. In a recent investigation, Arafa et al. (2023) evaluated the impact of femtosecond laser pulses on the sporulation process of these oocysts, aiming to establish an effective photonic intervention for managing poultry coccidiosis. Unsporulated *Eimeria* oocysts were exposed to femtosecond laser radiation in 96-well microplates under varying wavelengths and exposure durations. Notably, irradiation with femtosecond pulses in the 360–390 nm range resulted in a marked suppression of sporulation and caused distinct morphological disruptions compared to non-irradiated controls. They discovered that treatment with a pulsed 370 nm wavelength was the most effective at reducing the oocyst sporulation rate, with decreases of 17%, 15%, and 11% after exposures of 5, 10, and 15 minutes, respectively. In contrast, irradiation with infrared wavelengths of 720 and 800 nm had no significant effect on oocyst sporulation. Thus, irradiating unsporulated oocysts with a pulsed 370 nm femtosecond laser efficiently lowers the sporulation of *Eimeria species* oocysts, which may aid in control of poultry coccidiosis (Table 1).

2.2. Efficacy against helminths

Musset et al. (2023) demonstrated the use of laser-based methods to selectively eliminate internal parasites while preserving host viability. They targeted the acanthocephalan parasite *Polymorphus minutus* using a 450 nm Blue Diode Laser (Table 1), which specifically interacts with carotenoid pigments in the parasite. By delivering 5 laser pulses (50 ms each) at 1.4 W, they achieved 80% parasite mortality within the host. Additionally, 60% of infected gammarid hosts survived 11 days after treatment.

They also performed preliminary experiments using a Nanosecond-Green Laser to target lipid structures in another acanthocephalan, *Pomphorhynchus tereticollis*, as an exploratory approach for broader parasite targeting strategies.

2.3. Efficacy against insects

Gaetani investigated the effectiveness of laser irradiation in targeting insects by using three distinct wavelengths: 532 nm, 1070 nm, and 10.6 µm. These wavelengths were selected to test two different mechanisms of laser-tissue interaction. The first mechanism involves the absorption of laser energy by pigments in the insect exoskeleton, such as melanin and chitin, which is a species-dependent process due to variation in pigment composition. This was explored using the 532 nm and 1070 nm lasers. The second mechanism relies on the absorption of infrared radiation by intracellular water, a species-independent process, as water is universally present in cells. This was specifically targeted using the 10.6 µm wavelength, corresponding to the infrared range typically used by CO_2 lasers (Gaetani et al., 2021).

Rakhmatulin and Andreasen (2020) developed a prototype for a cost-effective laser-based weeding system and tested it on couch grass (*Elytrigia repens*) growing alongside tomato plants (Table 1). They evaluated three laser power levels—0.3 W, 1 W, and 5 W. The 1 W laser proved ineffective for complete weed eradication and required prolonged exposure, making it impractical. In contrast, the 5 W laser showed greater efficacy in eliminating the weeds but carried a risk of damaging the crop, especially if the beam scattered or split during operation (Gaetani et al., 2021; Rakhmatulin & Andreasen, 2020). Additionally, laser lights, particularly short-wavelength visible light, as well as green and infrared wavelengths, have been shown to lethally affect various insect pests. These include aphids (Gaetani et al., 2021), mosquitoes (Keller et al., 2016), and salmon lice, a type of ectoparasitic copepod (Stingray® patent EP2531022; Stingray Marine Solutions AS, Norway; Musset et al., 2023). In such cases, the pests are located in open environments, allowing for direct and efficient laser targeting.

3. Specific criteria of laser-based parasite control

For laser-based pest control to be viable, several critical criteria must be met. First, the laser radiation must effectively eliminate the targeted parasite with high precision. Second, the system should operate with high energy efficiency to ensure practicality in large-scale applications. Lastly, the overall approach must be ecologically sustainable, minimizing harm to non-target organisms and the surrounding environment.

4. How laser beam induces its action

Pulsed femtosecond laser irradiation in the visible spectrum can induce DNA damage, disrupt cellular metabolism and leading to the inactivation of microorganisms such as *Salmonella typhimurium* (Tsen et al., 2012) and *Pseudomonas aeruginosa*. Similarly, infrared femtosecond lasers at 800 nm have been shown to inactivate *P. aeruginosa* by denaturing nucleic acids, membrane lipids, and proteins (Musset et al., 2023). When laser energy is directed at a material, it is rapidly converted into heat, which then spreads temporally and spatially according to the material's thermal properties. The resulting thermal effects may include heating, melting, or vaporization, while additional outcomes can include photochemical (e.g., molecular denaturation) and photomechanical effects (e.g., rapid ablation). These thermal responses are categorized into rapid effects, where energy deposition and heat transfer occur nearly simultaneously, and slow effects, where heat generation and diffusion are comparable in duration. In biological tissues, light propagation is also influenced by diffusion properties unique to each tissue. To minimize collateral damage from light diffusion, laser wavelengths should be carefully selected to match the specific absorption characteristics of the target tissue (Musset et al., 2023).

Table 1. Laser Efficacy: Suggest adding a summary table (laser type, target, outcome)

Laser type	**Target**	**Outcome**
Femtosecond laser efficiently	Protozoa (*Eimeria tenella* oocysts)	lowers the sporulation of *Eimeria* species oocysts
Blue Diode Laser	Acanthocephalan parasite *Polymorphus minutus*	achieved 80% parasite mortality

Laser irradiation, laser lights, short-wavelength visible light, green and infrared wavelengths,	Insects	laser-tissue interaction lethally affect various insect pests

5. Conclusion

The growing limitations of conventional chemical treatments-including toxicity, environmental contamination, and the emergence of resistant parasite strains-underscore the urgent need for innovative and sustainable alternatives. Laser-based technologies offer a promising non-invasive approach to parasite control, providing high specificity and minimal ecological impact. As part of broader bio-ecological strategies that extend beyond traditional chemistry and biology, physics-based methods such as laser applications represent a novel and eco-friendly avenue for managing parasitic infections. Continued research and development in this field may pave the way for effective, and needs to be apply in the real-world testing.

Conflict of interest: none

Data availability: all data in this review are available from the authors

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