Joshlyn Stover
James Madison High School
San Antonio, TX, USA
Costa Rica, Pesticides

Costa Rica: Tackling A Pesticide Problem

Costa Rica, a vibrant and ecologically diverse nation in Central America, is home to a population of approximately 5 million people. About two-thirds of Costa Ricans reside in urban areas, while the remaining third live in rural communities, highlighting the country's modernization and urbanization trends. Costa Rica is a stable and progressive democratic republic with a history of peace and political stability. It operates under a presidential system of government, where the President serves as both the head of state and government.

Costa Rica's lush landscape is characterized by tropical rainforests, rugged mountains, and pristine beaches. Around 25% of the land is cultivated, with coffee, bananas, and pineapples being among the major crops. The country is renowned for its commitment to environmental conservation and sustainable agriculture practices. The average farm size in Costa Rica is relatively small, typically ranging from 1 to 5 hectares, emphasizing the prevalence of small-scale family farming. This stands in contrast to some larger agricultural operations seen in neighboring countries.

The climate in Costa Rica varies widely due to its diverse geography, ranging from tropical rainforests to high-altitude cloud forests. The country experiences a distinct wet season from May to November and a dry season from December to April, making it a year-round destination for eco-tourism. However, this picturesque image belies a significant environmental and health concern: the excessive use of pesticides. A distressing reality emerges as Costa Rica claims one of the highest percentages of pesticide usage globally, with an average of approximately 25 kilograms of pesticides applied per hectare of agricultural land, dwarfing the meager 2.5 kilograms per hectare found in the United States. This staggering statistic underscores the pressing need to address the consequences of this pesticide-intensive approach.

One cannot overlook the inherent irony of this situation. Costa Rica, often revered for its commitment to environmental conservation and sustainability, is marred by a dilemma that poses a profound threat to its natural beauty and the well-being of its people. The insidious effects of such widespread pesticide use cannot be understated. While these chemicals promise enhanced crop yields and pest control, the reality is detrimental to human health and the environment.

The regulatory framework surrounding pesticide use in Costa Rica has long been criticized for its inadequacy. The country's relatively lax regulations have allowed the rampant application of pesticides, which, in turn, has unleashed a barrage of toxic substances into the environment. The most commonly employed pesticides in Costa Rica include the fungicide chlorothalonil, the herbicides paraquat and glyphosate, and the pyrethroid insecticide cypermethrin. The concerning issue is that these substances are not exclusive to the fields; they seep into the soil, water bodies, and the air we breathe. Consequently, both the people and the fragile ecosystems are facing grave risks.

It's not just the pervasive presence of pesticides that should give us pause. The concentration of these harmful substances has far-reaching consequences. A study conducted in 2019 on fruits and vegetables grown in Costa Rica revealed that nearly one-fifth (19.5%) of the samples exceeded the maximum allowable pesticide content. This implies that these chemical residues are not merely an isolated concern but a pervasive threat to the food chain. Consumers, whether in Costa Rica or beyond its borders, are inadvertently exposed to the harmful effects of these chemicals.

Perhaps even more distressing is the human toll of this pesticide reliance. In 2010, Costa Rica witnessed the treatment of 146 individuals for "accidental poisoning from pesticide exposure," tragically resulting in 12 deaths. These numbers starkly illustrate the hidden dangers faced by farmers and laborers who toil in the fields to provide the world with its sustenance. Their sacrifice should not equate to a compromise of their health.

Addressing this complex issue requires a delicate balance between agricultural productivity and ecological preservation. For Costa Rican farmers, abandoning pesticide-intensive practices is a challenging endeavor. Economic pressures, fluctuating market demands, and the inherent risk of reduced yields often force them into this perilous cycle. Many of these farmers face the daunting task of maintaining profitability while minimizing their environmental impact, necessitating comprehensive support and innovative solutions. One solution that can be used to solve this issue is using nanotechnology, such as carbon quantum dots.

Nanotechnology is a research and development aimed at understanding and working with seeing, measuring, and manipulating matter at the atomic, molecular, and supramolecular levels. At this scale, materials' physical, chemical, and biological properties differ fundamentally (National Nanotechnology Initiative, 2019). Combining this technology with areas of animal health can increase the effectiveness and quality of disease treatment. Carbon quantum dots have unique properties, such as their inherent fluorescent property, high resistance to photobleaching, high surface area, ease of synthesis, flexible choice of precursor, and surface tunability, enabling CQDs for promising application in biosensing. When the surfaces of carbon quantum dots receive UV light irradiation, some of their electrons are excited into higher energy states. When electrons return to their ground, a photon is emitted as a glowing blue color.

Carbon dots can bond with certain pesticides (fungicides, herbicides, and insecticides), which is helpful as pesticides are commonly used in medical and agricultural fields and can affect humans and their environment. Using the fluorescent properties due to UV light of carbon dots combined with pesticides such as atrazine, glyphosate, and neonicotinoids can give insight into the imaging properties of quantum dots. These pesticides are considered hazardous in countries in the EU but are still used in the US (Capik, 2014). Based on outside research, the researcher hypothesized that the carbon quantum dots would change their degree of fluorescence in the presence of atrazine, glyphosate, and pyrethroids. Specific crops and animal feeds can contain these pesticides and be harmful to those who eat them. Detecting large amounts of these pesticides using the imaging capabilities of quantum dots can create a simple way to prevent those crops from being ingested (Chu, Unnikrishnan et al. 2020).

In an experimental study, I investigated the effects of nanotechnology, specifically quantum dots, on six different pesticides. I observed the natural ability of carbon quantum dots to fluoresce under ultraviolet light. Also, I watched this ability in the presence of glyphosate (RoundUp QuickPro), imidacloprid (Dominion 2L), bifenthrin (bifen I/T), permethrin (Hi-Yield), pyrethroids (cypermethrin), and atrazine (Hi-Yield). Based on outside research, I hypothesized that the carbon quantum dots would change their degree of fluorescence in the presence of atrazine, glyphosate, and pyrethroids.

I synthesized quantum dots using vinegar, water, sugar, and baking soda. They were heated in a microwave for 10 minutes to speed up synthesis. Drops of the quantum dot solution were diluted into eight glass vials on a UV light. Each vial contained a different kind of diluted pesticide contained inside of it. Changes were observed every 10 minutes for 50 minutes. Carbon quantum dots can fluoresce in the presence of ultraviolet light; however, if the fluorescence is enhanced or quenched by certain pesticides, it can help detect these pesticides in specific animal feeds.

The experiment and findings supported the hypothesis. The fluorescence of glyphosate differed from the control solutions by either being less fluorescent in the first experiment or more fluorescent in the second experiment. The atrazine had an adverse reaction to the quantum dots in both experiments as it completely quenched the fluorescent property of the quantum dots, along with bifenthrin. The pyrethroids did not interact with the quantum dots as the fluorescent levels of the pyrethroid stayed consistent with the solution with only quantum dots. The reaction was the same as if the pyrethroid had not been added. The hypothesis did not account for the imidacloprid, which positively responded to the quantum dots. The pesticide increased in fluorescence significantly in the first experiment. However, in the second experiment, the imidacloprid did not increase in fluorescence as considerably. The imidacloprid did have a consistently brighter fluorescence than the control solutions.

The experiment results indicate that carbon quantum dots could detect the presence of glyphosate and imidacloprid in animal feed and other substances. The results coincide with outside research on the imaging capabilities of quantum dots on pesticides. Mandal, Sahoo, et al. (2019) experimented with carbon quantum dots and pesticides such as imidacloprid. They were successful in being able to detect the carbon dots as it was able to bond with imidacloprid. This study also showed the ability of imidacloprid to bond with carbon quantum dots. Imidacloprid fluoresced brighter than the quantum dots on their own, indicating the pesticide could react with the quantum dots and react, increasing in fluorescence. In the same study, atrazine was also tested with the quantum dots. Atrazine quenched the fluorescence of the carbon quantum dots along with chlorpyrifos, lindane, and tetradifon.

The results for glyphosate are mixed, however, as the fluorescence for the glyphosate changed drastically from experiment one to experiment two. In the first experiment, fluorescence from glyphosate was almost entirely quenched by 50 minutes; however, in the second experiment, the fluorescence was significantly brighter and even more fluorescent than the quantum dots (Tafreshi, Fatahi, et al. 2019) conducted a study showing the fluorescent quenching properties of three pesticides, diazinon, glyphosate, and amicarbazone. The glyphosate vial exhibited fluorescence quenching properties; however, it was not extreme unless a large concentration of glyphosate was added to the vial. The more glyphosate added, the less fluorescent light could be seen. This explains the apparent change in fluorescence for the glyphosate vial, as less was added in the second experiment to account for the visibility of the vials.

This experiment proved that it is indeed possible to detect the presence of pesticides using quantum dots. It is also straightforward to obtain the materials for the quantum dots as most of the materials I used in my experiment came from ingredients already in my home. More money would need to be invested if more accurate results are to be observed, such as a fluorescence spectrometer. A fluorescence spectrometer would have been able to see the wavelength frequencies in nanometers. This would have helped create more specific calculations on each solution's fluorescence changes and ultimately led to more precise observations and results. Some farmers may oppose having to pay extra to test their products for excessive pesticide content, but having an extra layer of regulation could help sell their products sell better to countries overseas. It could increase profit margins and overtake the small cost of testing the products.

These carbon quantum dots can be introduced into Costa Rica through multiple avenues. To fully crack down on excessive use of pesticides, the use of carbon quantum dots can be required by law for agricultural businesses to test their products before putting them into circulation in the market. This would have to be proposed as a bill for the Costa Rican legislature. Passing an agricultural law in Costa Rica requires a thoughtful and strategic approach that considers the country's unique agrarian landscape and the diverse needs of its stakeholders. To start, engaging in comprehensive research and analysis of the existing agricultural policies and practices is essential. This should involve collaboration with experts, farmers, and relevant government agencies to identify areas needing improvement or reform. Building a broad-based coalition of support, including farmers' associations, environmental groups, and other key stakeholders, is crucial for garnering political support. Public awareness campaigns and education efforts can inform the public about the proposed changes and their potential benefits. Additionally, involving lawmakers and policymakers knowledgeable about the intricacies of Costa Rica's agriculture sector is vital. Lastly, open and transparent communication throughout the legislative process, compromise, and flexibility in crafting the law will increase the chances of successfully passing agricultural legislation promoting sustainability, innovation, and the well-being of both farmers and the environment in Costa Rica.

In conclusion, the pesticide problem in Costa Rica is a critical issue that threatens both the environment and public health despite the country's reputation for environmental conservation and sustainability. The excessive use of pesticides has led to a pervasive presence of toxic substances in the soil, water, and air, affecting the people and the entire food chain. The tragic incidents of pesticide poisoning further emphasize the urgency of addressing this problem.

The regulatory framework surrounding pesticide use in Costa Rica must be revised, allowing for the uncontrolled application of harmful chemicals. To tackle this complex issue, a comprehensive approach is required to balance agricultural productivity with ecological preservation. The introduction of nanotechnology, specifically carbon quantum dots, offers a promising solution for detecting and monitoring pesticide contamination of farming products. The experimental results support the feasibility of this approach, providing a means to protect both consumers and the environment from the dangers of pesticide residues.

Implementing carbon quantum dots as a mandatory testing tool in the agricultural sector would require legislative action and a coordinated effort among stakeholders. Building a coalition of support, conducting thorough research, and ensuring transparent communication are crucial steps in this process. By taking these measures, Costa Rica can move toward a more sustainable and environmentally friendly agricultural system that aligns with its commitment to preserving its natural beauty and the well-being of its people. It's a challenging endeavor but essential for Costa Rica's future and its invaluable ecosystems.

Literature Cited

Amusing, S. (2019, March 27). DIY Quantum Dots(Nanotech in Your Kitchen). [Review of DIY Quantum Dots(Nanotech in Your Kitchen).]. Instructables. https://www.instructables.com/DIY-Quantum-DotsNanotech-in-Your-Kitchen/

Capik, C. (2014, June 13). Pesticides, Herbicides, & Chemicals Banned in Europe, Safe in U.S. [Review of Pesticides, Herbicides, & Chemicals Banned in Europe, Safe in U.S.]. AFN. https://agfundernews.com/chemicals-banned-europe-safe-u-s

Chu, H. W., Unnikrishnan, B., Anand, A., Lin, Y. W., & Huang, C. C. (2020). Carbon quantum dots for the detection of antibiotics and pesticides. Journal of food and drug analysis, 28(4), 539–557. https://doi.org/10.38212/2224-6614.1269

Chung, S., & Zhang, M. (2021). Microwave-Assisted Synthesis of Carbon Dot – Iron Oxide Nanoparticles for Fluorescence Imaging and Therapy. Frontiers in Bioengineering and Biotechnology, 9. https://doi.org/10.3389/fbioe.2021.711534

“Costa Rican Government Promises to Regulate Pesticide Use in the Pineapple Industry.” Banana Link, 6 Apr. 2021, www.bananalink.org.uk/news/costa-rican-government-promises-to-regulate-pesticide-use-in-the-pineapple-industry/#:~:text=Costa%20Rica%20has%20one%20of,important%20export%20crops%2C%20including%20pineapples.

Fernandez, Ileana. “Un Warns Costa Rica on the Use of Pesticides.” The Tico Times | Costa Rica News | Travel | Real Estate, 28 May 2022,ticotimes.net/2022/05/28/un-warns-costa-rica-on-the-use-of-pesticides.

Li, H., Sun, C., Vijayaraghavan, R., Zhou, F., Zhang, X., & MacFarlane, D. R. (2016). Long lifetime photoluminescence in N, S co-doped carbon quantum dots from an ionic liquid and their applications in ultrasensitive detection of pesticides. Carbon, 104, 33-39. https://doi.org/10.1016/j.carbon.2016.03.040

Mandal, P., Sahoo, D., Sarkar, P., Chakraborty, K., & Das, S. (2019). Fluorescence turn-on and turn-off sensing of pesticides by carbon dot-based sensor. New Journal of Chemistry, 43(30), 12137–12151. https://doi.org/10.1039/C9NJ03192H

National Nanotechnology Initiative. (2019). What is Nanotechnology? Nano.gov. https://www.nano.gov/nanotech-101/what/definition

“Pesticide Use by Country.” Worldometer, www.worldometers.info/food-agriculture/pesticides-by-country/. Accessed 7 Sept. 2023.

Tafreshi, F. A., Fatahi, Z., Ghasemi, S. F., Taherian, A., & Esfandiari, N. (2019). Ultrasensitive fluorescent detection of pesticides in real sample by using green carbon dots. PLoS ONE, 15(3). https://doi.org/10.1371/journal.pone.0230646

Tian, B., Fu, T., Wan, Y., Ma, Y., Wang, Y., Feng, Z., & Jiang, Z. (2021). B- and N-doped carbon dots by one-step microwave hydrothermal synthesis: tracking yeast status and imaging mechanism. Journal of Nanobiotechnology, 19(1). https://doi.org/10.1186/s12951-021-01211-w

Wang, J., Teng, X., Wang, Y., Si, S., Ju, J., Pan, W., Wang, J., Sun, X., & Wang, W. (2021). Carbon dots based fluorescence methods for the detections of pesticides and veterinary drugs: Response mechanism, selectivity improvement and application. TrAC Trends in Analytical Chemistry, 144, 116430. https://doi.org/10.1016/j.trac.2021.116430

Zúñiga, Alejandro. The Truth about Costa Rica’s Pesticide Use, The Costa Rica Daily: Costa Rica News & Travel, 22 Feb. 2021, www.crcdaily.com/p/costa-rica-pesticide-use.