



# Photo Protection of Pesticides by UV Absorbers- A Useful Strategy for Reducing Loss: A Review

Kahar Nidhi<sup>1</sup>, Bhatt Gaurang<sup>1</sup>, Purohit Ashish<sup>1</sup>, Deota Pradeep T.<sup>1</sup>

10.18805/ag.R-2783

## ABSTRACT

Pesticide residues are often exposed to sunlight before they diffuse into plants. Many pesticides undergo photodegradation and break down into various photoproducts that may pose risks to living organisms if accidentally ingested. One promising strategy to mitigate pesticide photodegradation is the incorporation of UV light absorbers into their formulations. Significant advancements have been made in protecting both bio-based and synthetic pesticides from ultraviolet (UV) radiation. One of the major limitations in the application of pesticides is their susceptibility to photodegradation, which leads to a significant reduction in their efficacy. The incorporation of UV absorbers into pesticide formulations offers a promising strategy to enhance both their stability and effectiveness. The use of UV absorbers can substantially prolong the environmental persistence and performance of pesticides. As part of this review, we present herein case studies on three representative insecticides, namely Azadirachtin, Chlorpyrifos and Disulfoton. The case studies revealed that UV absorbers play a crucial role in minimizing the photodegradation of pesticides. Specifically, water-soluble quaternary ammonium UV absorbers (QAUVAs) led to a 22-26% increase in the recovery of the insecticide disulfoton compared to samples without UV protection. Similarly, the use of suitable UV absorbers enhanced the post-exposure recovery of azadirachtin and chlorpyrifos by 24% and 30%, respectively. This method not only reduces the need for frequent pesticide applications, thereby lowering associated costs, but also supports environmental sustainability and boosts agricultural efficiency. This review highlights our contributions to advancing pesticide photostabilization through the use of UV Absorbers.

**Key words:** Azadirachtin, Chlorpyrifos, Disulfoton, Pesticides, Photostabilization, UV absorbers.

This literature review provides scientific insights into strategies for preventing pesticide loss caused by photodegradation using suitable UV light absorbers. This review primarily focuses on enhancing the cost-effectiveness of pesticide applications by minimizing losses due to photolysis, thereby improving their overall efficiency and sustainability in agricultural practices.

The Sun serves as the primary source of light for all the life on Earth and ultraviolet (UV) radiation constitutes less than 10 % of total sunlight (Fig 1) (Hilfiker *et al.*, 1996). UV rays are high-energy, invisible light with wavelengths ranging from 400 to 100 nm. They are classified into three categories based on their wavelength: UV-A (400–320 nm), UV-B (320–280 nm) and UV-C (280–100 nm) (Rohatgi-Mukherjee, 1978; Turro *et al.*, 2009). Certain small atmospheric molecules, such as ozone, oxygen and water vapor, effectively filter a substantial portion of UV-B radiation and completely block UV-C radiation. However, UV-A, along with the remaining fraction of UV-B, can penetrate the atmosphere and reach the Earth's surface (Parwaiz *et al.*, 2019).

Numerous reactions occur when insecticides are exposed to the external environment, including hydrolysis, microbial degradation, photolysis and volatilization. Pesticides are photodegraded by sunlight, which reduces their effectiveness. When a molecule is exposed to sunlight, it undergoes a variety of basic processes, such as decarboxylation, dealkylation, rearrangement, cyclization, dehalogenation, oxidation, isomerization, *etc.*, which typically result in the

<sup>1</sup>Department of Applied Chemistry, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara-390 001, Gujarat, India.

**Corresponding Author:** Deota Pradeep T., Department of Applied Chemistry, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara-390 001, Gujarat, India. Email: ptdeota-appchem@msubaroda.ac.in

ORCID: <https://orcid.org/0009-0002-5888-0007>, <https://orcid.org/0000-0002-1691-0805>, <https://orcid.org/0009-0001-9024-0440>, <https://orcid.org/0000-0002-9325-4717>

**How to cite this article:** Kahar, N., Bhatt, G., Purohit, A., Deota, P.T. (2025). Photo Protection of Pesticides by UV Absorbers- A Useful Strategy for Reducing Loss: A Review. *Agricultural Reviews*. 1-12. doi: 10.18805/ag.R-2783.

**Submitted:** 30-01-2025    **Accepted:** 05-08-2025    **Online:** 30-08-2025

degradation of the pesticide molecule and some of which might be harmful to living organisms if mistakenly consumed (Lakshmipathy *et al.*, 2024; Morillo and Villaverde, 2017; Nishant and Upadhyay, 2016). There are several methods to reduce the effect of photodegradation on pesticides. These include introducing UV resistant materials as pesticide formulation additives, using organo-clay formulations, mixing clays with chromophores and altering the chemical structure of pesticides (Nguyen *et al.*, 2012). Despite the fact that chemical pest control methods are extensively used worldwide, they are considered

unsustainable from an environmental perspective. In recent years, interest in agricultural pest management has shifted from the use of traditional synthetic insecticides to more specialized, ecologically acceptable bio-pesticides in both developed and developing nations. Biopesticides are generally produced from natural resources such as microbes, minerals, plants and animals (Kannan *et al.*, 2023). In 1998, the global pesticide market was projected to be worth approximately USD 32 billion. The biopesticide share of this sector, excluding genetically modified crops, is variably estimated to be up to USD 350 million, or less than 1% of the global pesticide market (Boyetchko *et al.*, 1999). Biopesticides provide developing nations with great opportunities to research and develop their own natural biopesticide resources for crop protection. Although most biopesticides provide little risk to non-target species, they are not necessarily safe because something is natural. Biopesticides have been employed in the past for various applications, which include Blasticidin-S 1, 6-Benzylaminopurine

2, Milbemycin 3, Nicotine 4, Zeatin 5 and many more (Corpping and Menn, 2000; Nguyen *et al.*, 2012; Thakore and Srivastava, 2017) (Fig 2).

However, many biopesticides are difficult to use because of their instability under ultraviolet (UV) radiation. This problem can be solved by covering the membrane. Cellulose is one of the most abundant natural biomass materials. Modified cellulose is commonly utilized for membranes because it has more possible applications and qualities than unmodified cellulose. A crosslinker derived from diisocyanate and benzophenone derivative such as 6 would offer cellulose with better mechanical and chemical stability and anti-UV characteristics for the controlled-release agrochemical formulations (CRFs) in membrane biopesticide (Pang *et al.*, 2016) (Scheme 1).

Avermectin (AVM) is a biodegradable and highly effective biopesticide with lower toxicity. AVM molecules may be photolyzed during use. Electrostatic interactions result

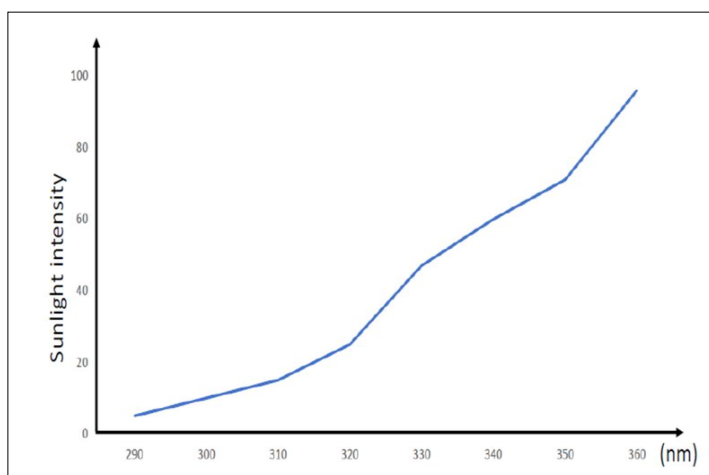


Fig 1: Distribution of wavelength in solar radiation.

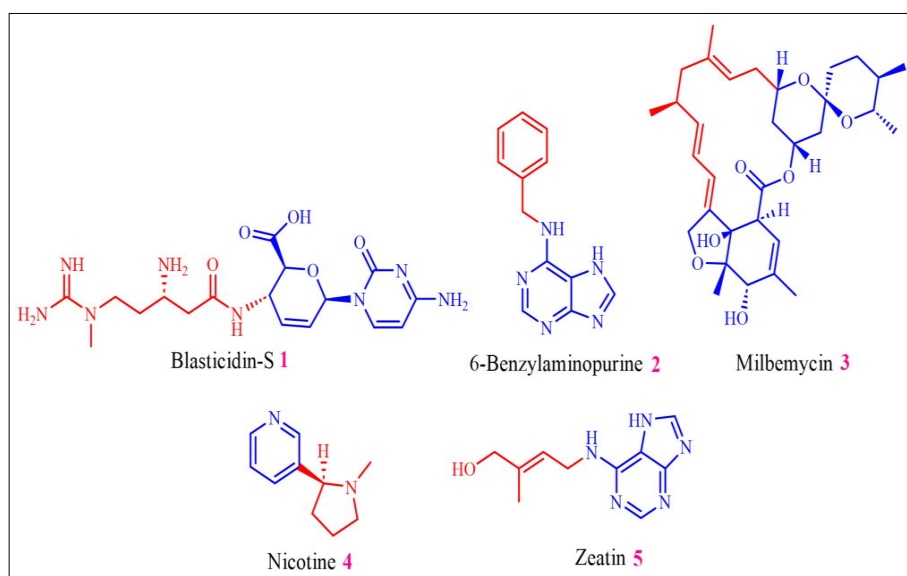
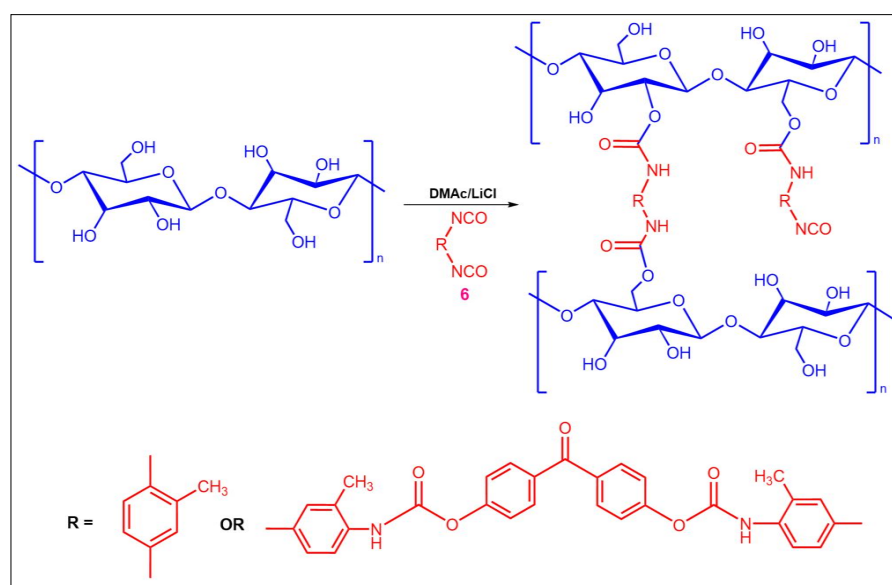


Fig 2: Structure of some biopesticides.

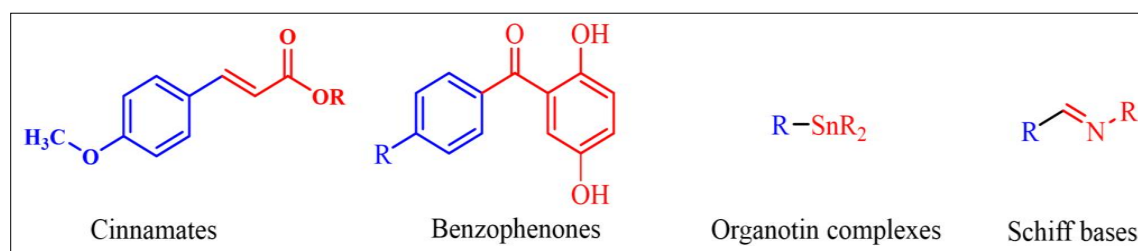
in the formation of a complex between isolated soya protein (ISP) and carboxymethyl chitosan (CMCS), which may enhance the pesticide loading ability to load pesticides. The encapsulation can provide efficient UV protection for AVM, delay its photolysis and provide insecticides a sustained-release characteristic (Chen *et al.*, 2019). Many UV filters such as benzophenone-1 (BP-1), benzophenone-2 (BP-2), benzophenone-3 (BP-3), benzophenone-4 (BP-4), 4,4-dihydroxy benzophenone (4-DHB), ethyl-4-aminobenzoate (Et-PABA), 2-ethyl-hexyl-4-trimethoxycinnamate (EHMC), p-aminobenzoic acid have been employed for the protection of biopesticides (Zenker *et al.*, 2008).

Any substance that can mitigate the harmful effects of UV radiation on the material may be regarded as a UV absorber/ UV blocker/ photostabilizer/ photoprotecting agent/ light screen/ ultraviolet filter. An interesting method was developed to prevent pesticide photodegradation using UV light absorbers in their formulations. UV absorbers are generally categorized into two main types: organic ultraviolet light absorbers and inorganic particulates. These compounds play a crucial role in reducing or preventing UV radiation-induced degradation. Organic materials that

dissolve in the oil phase can serve as soluble UV absorbers for various applications. In contrast, inorganic materials, such as microfine  $\text{TiO}_2$  particles, function as insoluble UV absorbers, effectively shielding substances from UV radiation (Araki and Baby, 2025; Parwaiz *et al.*, 2019). Lignin composites have been widely utilized for UV shielding in various applications, including food packaging, solar panel protection and healthcare products. As a naturally occurring antioxygenic macromolecular system, lignin-based UV absorbers offer an environmentally friendly alternative to synthetic UV stabilizers. Due to their biodegradability and low toxicity, they have a minimal impact on both the environment and human health, making them a sustainable choice for UV protection (Ugartondo *et al.*, 2008). UV light induces photooxidative degradation of substances, leading to crosslinking, bond breakage, free radical formation, volatile emissions and reduction in molecular weight. A highly effective way to enhance the UV resistance and aging durability of substances is by incorporating UV absorbers into their formulation (Qiao *et al.*, 2022). In the pursuit of effective strategies to prevent photochemical degradation, the photostabilization of



**Scheme 1:** Modified cellulose with diisocyanate and benzophenone derivative 6.



**Fig 3:** Some common UV absorbers.

polymers has recently garnered significant attention. UV absorbers play a crucial role in this process by absorbing harmful UV radiation and converting it into harmless thermal energy, thereby enhancing the durability and longevity of the products (Larché *et al.*, 2012). Additionally, UV absorbers inhibit the formation of free radicals, that emerge during the initial stages of degradation. With the growing emphasis on environmental sustainability, researchers have shown increasing interest in the application of different classes of molecules for photostabilisation. Carbon black, titanium oxide, benzotriazoles and benzophenones are among the most widely used UV absorbers in industrial applications. Some common UV absorbers are shown in Fig 3.

It is challenging to obtain photostable formulations of organic sunscreen containing avobenzone because they suffer from photofragmentation (Scheme 2).

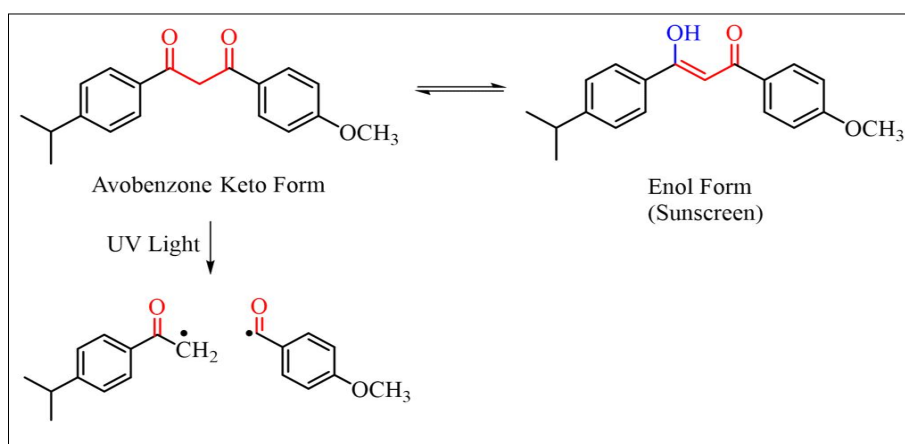
The most important factor in maintaining the criteria of an effective UV filter is photochemical stability because light-induced degradation of sunscreen agent may increase phototoxic / photoallergic contact dermatitis as well as impair photo-protective efficiency (Damiani *et al.*, 1999).

Photostability studies in sunscreen formulations demonstrated that the photostable compound Diethyl Syringylidene Malonate (DESM) 9 significantly improves avobenzone's stability. The photostabilizer DESM 9 was

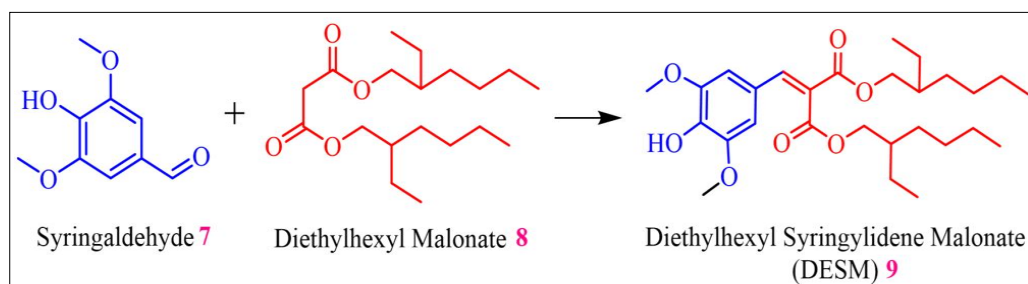
synthesized from Syringaldehyde 7 and Diethylhexyl Malonate 8 (Scheme 3). Research revealed that DESM 9 effectively quenches singlet oxygen, thereby reducing the photodegradation of avobenzone. The stabilization of avobenzone is attributed to the triplet state energy transfer from avobenzone to DESM 9 and scavenging of reactive species (Chaudhuri *et al.*, 2006).

Literature reports various examples of a number of additives employed in small amounts can effectively minimize photodegradation of various materials including pesticides. Schiff bases (Yousif *et al.*, 2015; Yousif, Hasan, *et al.*, 2016), organic molecules (Balakit *et al.*, 2015; Sabaa *et al.*, 2005), metal complexes (Martins *et al.*, 2016; Yousif, Salimon, *et al.*, 2016) and such other compounds (Chen *et al.*, 2004; Mohammed *et al.*, 2017) are among the most remarkable additives. As they are electron-rich, they serve as UV absorbers and shield various materials from photodegradation by absorbing UV light. Five such Schiff bases with thiadiazole moiety have been employed as photostabilizers at low concentrations. (Shaalan *et al.*, 2018) (Fig 4).

The type of functional group and the level of aromaticity influenced the effectiveness of the Schiff bases in stabilizing the photosensitive molecules. The hydroxyl group in the Schiff base **10** is vital for photostabilization. The proton



**Scheme 2:** Photofragmentation of avobenzone under UV light.



**Scheme 3:** Synthesis of DESM.

transfer (PT) and intersystem crossing (ISC) between excited states are easily accomplished by the presence of the hydroxyl group. (Starnes *et al.*, 2006) (Scheme 4)

Herein, we present some of our contributions in the form of case studies showing the usefulness of known photostabilizers, as well as developing new model systems that have been found to be effective as photostabilizers in the photoprotection of some of the representative pesticides. It is worth mentioning here that our photoprotection strategies described below have yielded excellent results. (*vide infra*).

### Case Study-1, Azadirachtin

Azadirachtin is a promising biopesticide derived from the Indian neem tree (*Azadirachta indica*, A. Juss). Azadirachtin-A (Aza-A,  $C_{35}H_{44}O_{16}$ ) is the predominant component if neem seed extracts, comprising approximately 85% of the total content. Additionally, Aza-A is recognized for being biodegradable, low in toxicity and non-mutagenic to animals and humans (Stark and Walter, 1995). It exhibits multiple biological activities, including acting as a potent

insect repellent, antimalarial agent and insect growth regulator (Mordue and Blackwell, 1993). However, owing to the presence of reactive functionalities such as  $\pi$ -electrons, ester linkages and epoxide rings, Aza-A is highly photoreactive and undergoes degradation or isomerization upon exposure to sunlight. To ensure its effective application, UV stabilizers must be incorporated to enhance the photostability of the Aza-A molecule.

Our group has studied the effect of four different UV stabilizers on azadirachtin-A 15 namely 2,4-dihydroxybenzophenone 16, p-aminobenzoic acid 17, 4,4'-dihydroxybenzophenone 18 and phenyl salicylate 19. (Fig 5).

The percent degradation of Aza-A was recorded at various time intervals for each UV absorber in the solution phase. The percent degradation of Aza-A in the absence of any photostabilizer was 56% and the same was found to be 32 % in the presence of phenyl salicylate after 30 hours of UV exposure. Our findings clearly revealed that 24% of Aza-A could be saved from photodegradation in the case of phenyl salicylate, which was found to be the most efficient among the four photostabilizers studied. Better results

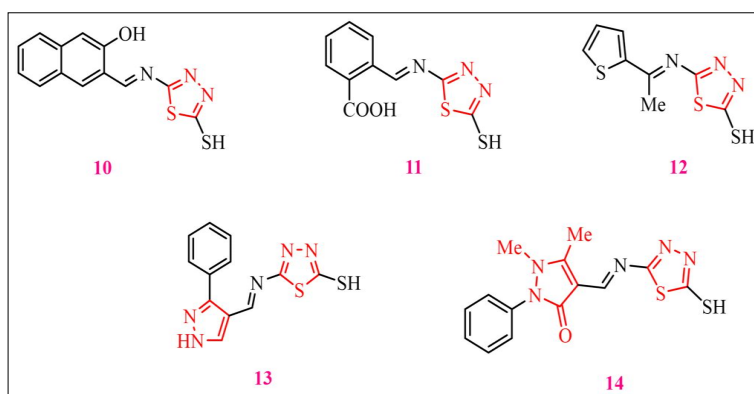
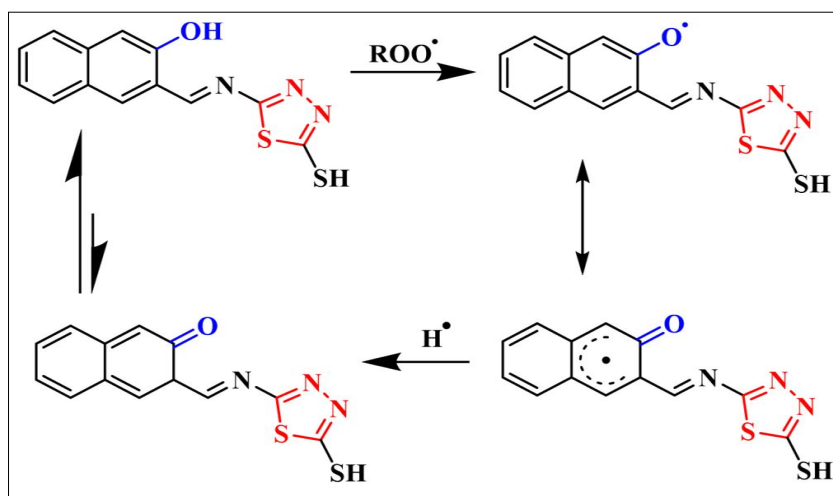


Fig 4: Some common Schiff bases with thiadiazole moiety.



Scheme 4: Mechanism of Photostabilization of 10.

were obtained when Aza-A was irradiated under sunlight in the presence and absence of photostabilizers. Thus the percent degradation of Aza-A in the absence of any photostabilizer was 80 % which was substantially reduced to only 46 % in the presence of phenyl salicylate amounting a net saving of 34 % of the precious biopesticide (Deota *et al.*, 2002).

Encouraged by these results, our group studied the photostabilization effect of the solid-phase radiation of the above four UV absorbers on Aza-A. It is found that adding phenyl salicylate to Aza-A in a molar ratio of 1:1 resulted in the greatest photostabilization of the Aza-A molecule in both the solid and solution phase among all the UV absorbers examined (Deota *et al.*, 2003).

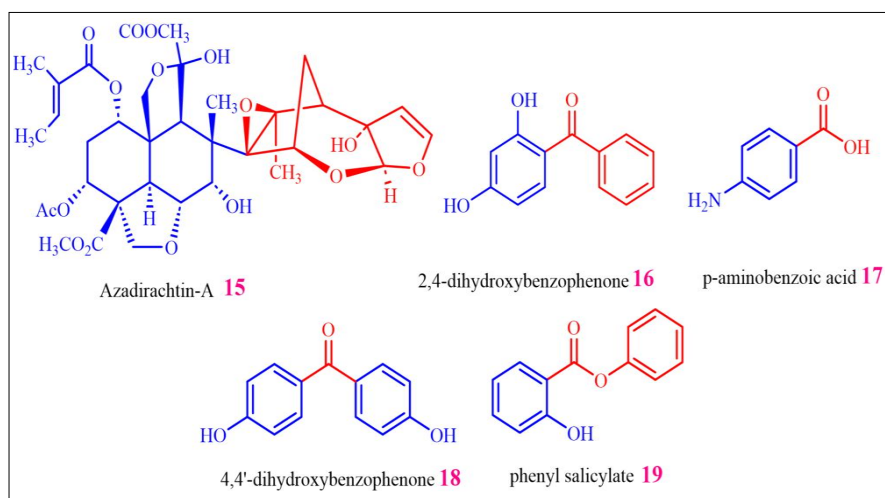
As per the estimate, the total consumption of azadirachtin worldwide was USD 105 million in 2022 means roughly USD 35.7 million can be saved annually and thus, a huge loss of this invaluable material can be avoided. It is evident that substantial savings can be achieved by selecting an appropriate photostabilizer to prevent the loss of expensive pesticides in field applications.

Phenyl salicylate 19 does not directly absorb UV light when exposed to it; instead, it undergoes a photo-Fries

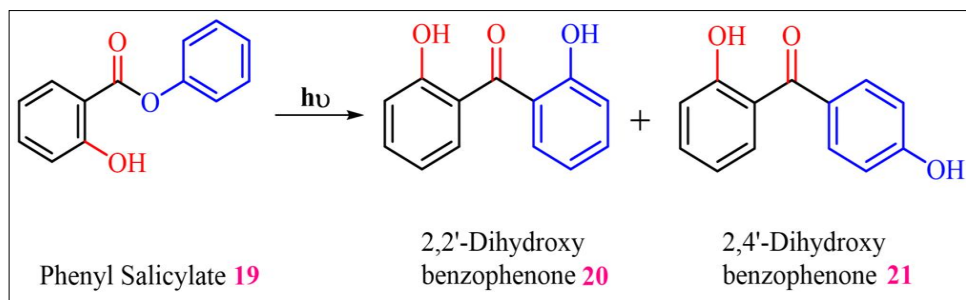
type rearrangement to produce highly absorbing 20 and 21 (Scheme 5). The absorbed energy is subsequently released by these two molecules through Excited-State Intramolecular Proton Transfer (ESIPT).

2-Hydroxybenzophenones function as photostabilizers by dissipating the absorbed light energy via non-photochemical mechanisms. The photostabilizer  $PS_0$  is returned to its initial state through a reverse proton transfer mechanism (Ghiggino *et al.*, 1986; Woessner *et al.*, 1984) (Scheme 6). This photostabilization is thought to be caused by the hydroxyl and keto groups present in the 2-hydroxybenzophenone structure. Our group is currently developing an interesting method for avoiding pesticide photodegradation using UV light absorbers in pesticide formulations.

The formation of harmful photoproducts may be reduced by prolonging the life of pesticides. To safeguard photosensitive insecticides, the addition of UV-absorbing chemicals to formulations is often appealing. The insecticide is photostabilized either by the photostabilizer preferentially absorbing light, which prevents photoexcitation of the insecticide molecules, or by the excited insecticide molecules transferring excess energy to the photostabilizers



**Fig 5:** Structures of Aza-A along with the UV absorbers.



**Scheme 5:** Photo-Fries type rearrangement of phenyl salicylate.

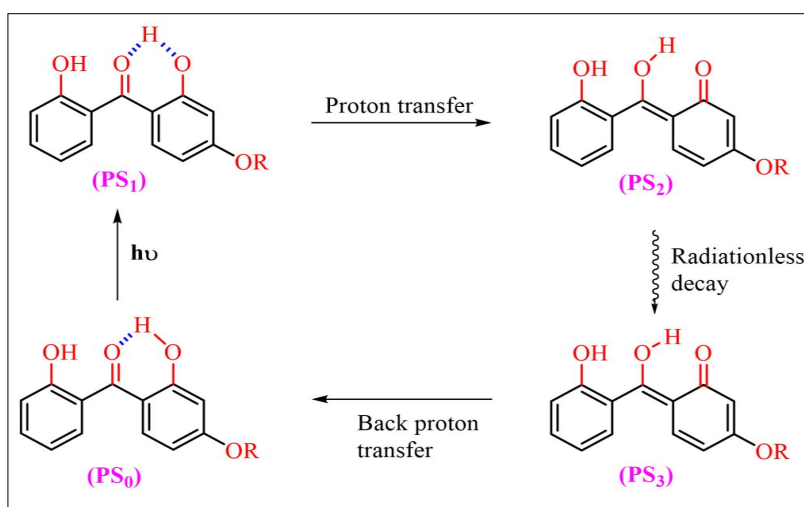
via a number of energy transfer mechanisms, such as excited-state intramolecular proton transfer (ESIPT) or keto-enol tautomerism (Wasielewski, 1992). Several compounds have been protected against photodegradation by intramolecularly hydrogen bonded photostabilizers, such as 2-(2-hydroxyaryl)-1,3,5-triazines, 2-(2-hydroxyaryl)-benzotriazoles, 2-hydroxybenzophenones and oxanilides (Waiblinger *et al.*, 2000).

### Case Study-2, Chlorpyrifos

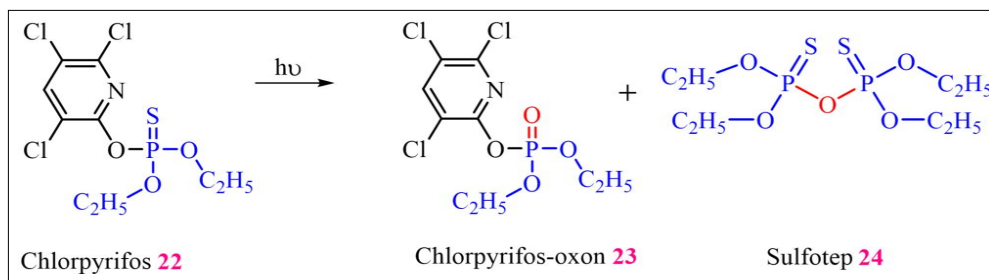
A popular organophosphate pesticide used in both agricultural and nonagricultural areas is O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) phosphorothioate (Kamel *et al.*, 2009). The main crops on which 22 is used include cotton, tree nuts, soybeans, peaches, cereals, alfalfa, citrus fruits, vegetables, corn and tobacco. Although accurate information about the existence of pesticides in groundwater is uncommon, the Roorkee area of India's Haridwar district has experienced soil and groundwater pollution as a result of intensive agricultural production. Some regions of Karnataka, Haryana, Maharashtra, West Bengal and Delhi were found to get contaminated with mainly 17 organochlorine and 7 organophosphate pesticides (Mutiya *et al.*, 2011; Kumar *et al.*, 2016). When 22 is exposed to

sunlight, it breaks down and forms a number of photoproducts that are more resistant to UV rays than 22 itself. One such photoproduct, chlorpyrifos-oxon 23, is more lasting and approximately 3000 times more hazardous to humans than 22. Sulfotep 24, a very hazardous byproduct of 22 that often coexists with it as an impurity, is also produced upon exposure to UV rays (Allender and Keegan, 1991) (Scheme 7).

Considering that the 2-hydroxybenzophenone moiety effectively functions in the photoprotection of pesticides via ESIPT, we envisaged the construction of a dimeric hydroxy keto functionality, which is the key component in the photostabilization process. Our group then envisioned, retrosynthetically planned and executed the synthesis of benzil type of molecules 26 (a-h) as shown in scheme 8. We then proceeded with their proposed application as photostabilizers for Chlorpyrifos 22. We hypothesized that benzil derivatives contain structures of type 26, which integrate two hydroxy and keto pairs into a single system. These benzil derivatives are thought to be more efficient and advantageous photostabilizers because of their embedded structural features. The results of this study are presented hereinunder (Deota *et al.*, 2019).



**Scheme 6:** ESIPT mechanism of o-hydroxy benzophenone.



**Scheme 7:** Chlorpyrifos Photodegradation led to various oxidized product.

When 22 was exposed to UV radiation without photostabilizers, its recovery was only 66.12 %; however, it was 78.80 % in the presence of the well-known photostabilizer 2,4-dihydroxybenzophenone. The photostabilizing effect of benzil derivatives (26a) was also found to be up to 30.51% in our case. According to our study, a 1:1 mol ratio of 22 to benzil derivative 26h resulted in the greatest photostabilization; up to 96.63% of 22 was recovered after the exposure trials when compared to bare 22 exposed to UV irradiation. It is possible to decrease the generation of hazardous impurities caused by the photodegradation of 22 in crops by using benzil derivatives (Scheme 8).

### Case study-3, Disulfoton

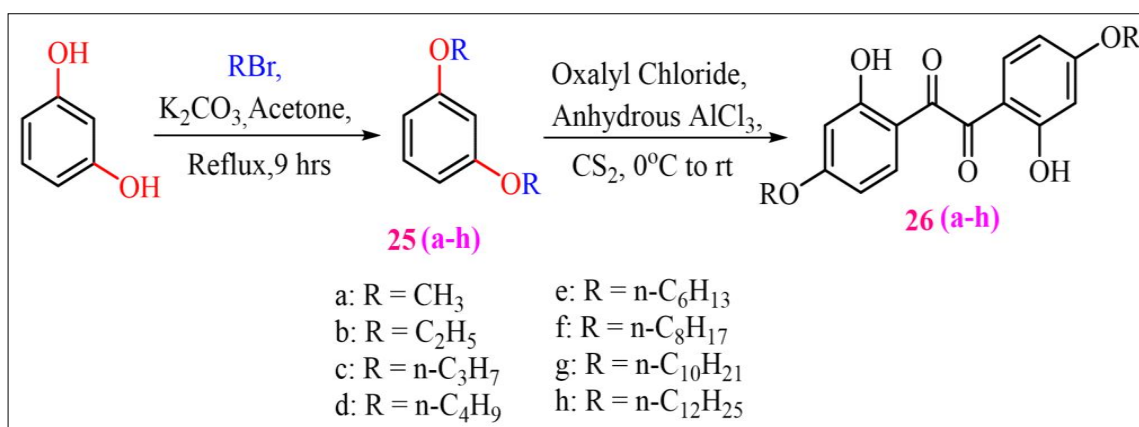
The organophosphate pesticide disulfoton 27 has been shown to be a systemic toxin that works against insects by sucking mouthparts. It is effective against various insects, including leafhoppers, aphids and worms. It is also suitable for a variety of fruits and vegetables. Disulfoton 27 is one of the most photosensitive of the seventynine pesticides that are widely used globally (Padalkar *et al.*, 2014). According to literature, roughly 40 % of 27 photodegrades quickly to its sulfoxide 28 on the soil, resulting in significant economic losses (Hirahara *et al.*, 2001; Katagi, 2004) (Fig 6).

In commercial preparations, many a times emulsifiers are often employed to solubilize the organic content in

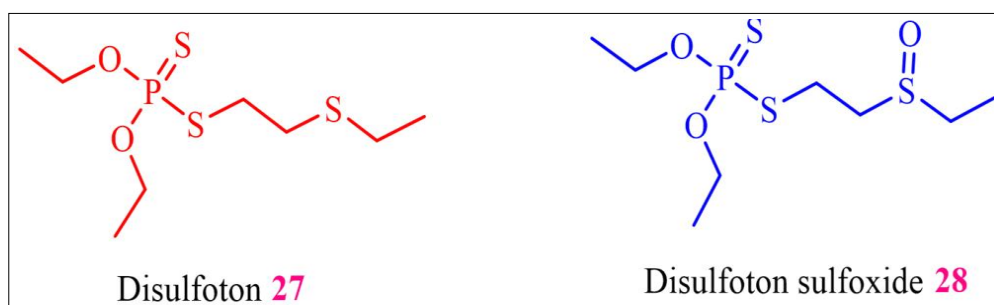
water. It was envisioned that the emulsifier component from the formulations of pesticides could be removed by the incorporation of a quaternary ammonium functionality to make the pesticide molecule water-soluble. In this context, 2,4-dihydroxybenzophenone was considered as a model substrate, which has a hydroxy keto system with a suitably disposed hydroxyl group that can be transformed into the quaternary ammonium group in a few steps.

Accordingly, the water-soluble quaternary ammonium ultraviolet light absorbers (QAUVA) of the type 31 were synthesized from 2,4-dihydroxybenzophenone and then they were examined for their photostabilization effect to protect the organophosphate pesticide that is 27 (O,O-diethyl S-(2-(ethylthio)ethyl) phosphorodithioate) (Deota *et al.*, 2022) (Fig 7).

When 27 was irradiated without any Quaternary Ammonium UltraViolet light Absorbers (QAUVA), 39.2 % of it was found to degrade, in accordance with the report of Hirahara *et al.* 2001. In this investigation, when the pesticide was exposed to UV irradiation while being protected by QAUVAs (n= 2, 4, 6, 12), the degradation of the insecticide was significantly lower (~25.64 %), indicating effective photoprotection provided by the QAUVAs (Scheme 9) QAUVAs preferentially absorb UV radiation, preventing the photodegradation of the pesticide molecules. The absorbed UV light is then released by the ESIPT mechanism



**Scheme 8:** Preparation of benzil derivatives (a-h).



**Fig 6:** Structures of Disulfoton and its oxidative product.

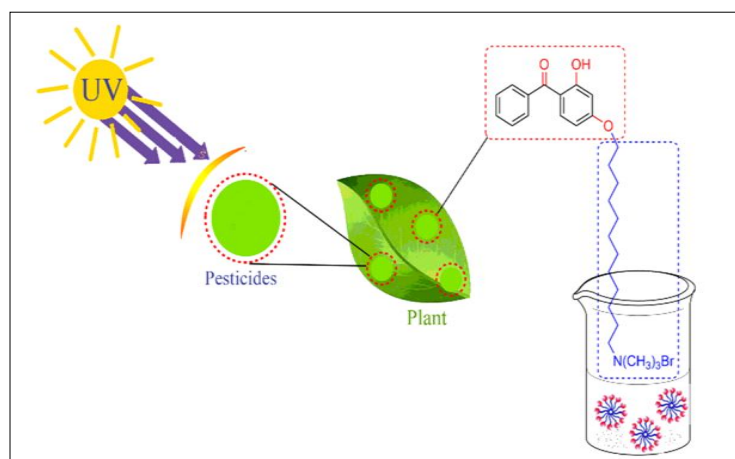
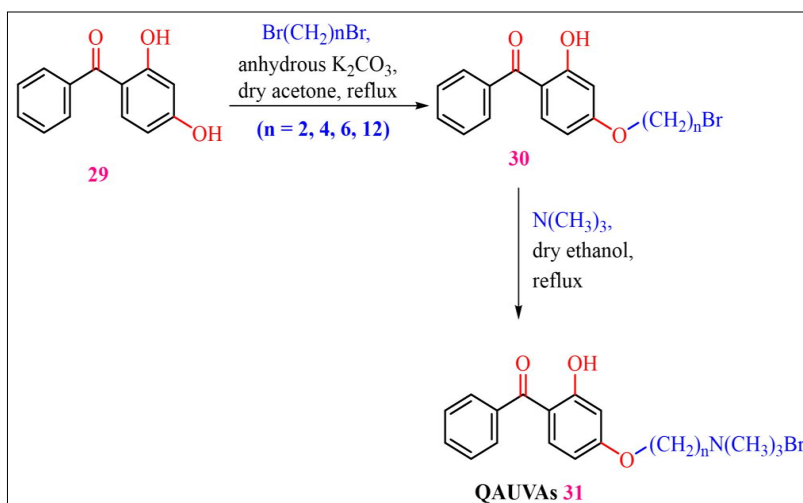


Fig 7: Graphical representation of Photoprotection of pesticides.



Scheme 9: Synthesis of QAUVAs.

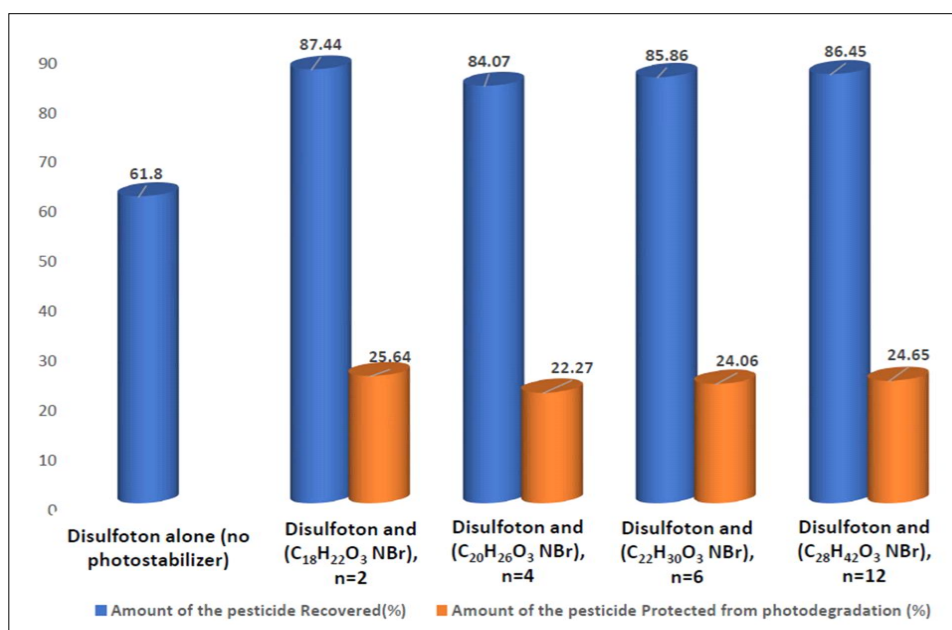


Fig 8: % Recovery of disulfoton in the presence and absence of QAUVAs.

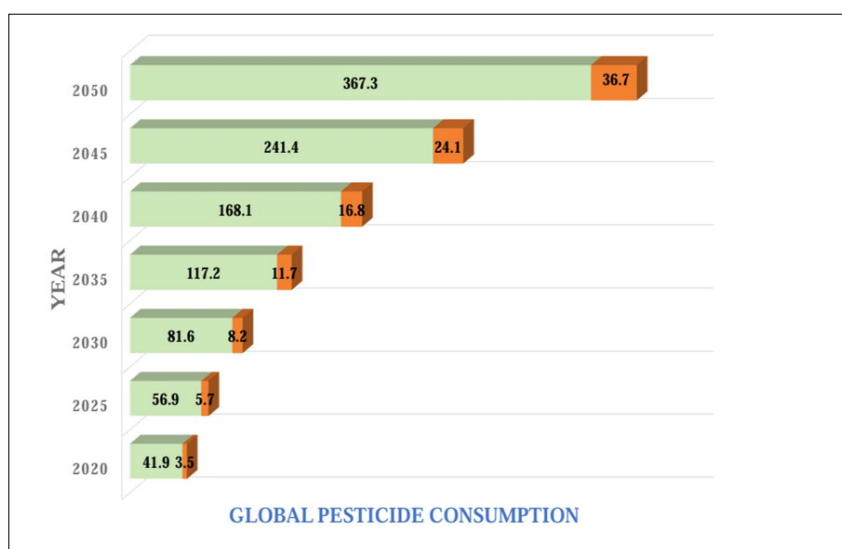


Fig 9: Projected pesticide consumption and savings in Billion USD globally.

through radiationless decay. A photostabilization study of 27 using water-soluble QAUUVAs was performed under UV illumination.

The photoprotection of the pesticide 27 using the synthesized QAUUVAs is depicted in Scheme 9. Even when placed close to the UV source, all four QAUUVAs exhibited a significant UV screening effect. The best photostabilization of 27 (~25.64%) was found to be given by one of the quaternary salts ( $n=2$ ) (Fig 8).

The susceptibility of pesticides to photodegradation, which results in loss of their efficiency, is one of the major limitations in their application. The use of UV absorbers such as presented in this study may form a strong basis as a component of Integrated Pest Management (IPM) programs and may significantly increase their environmental life and performance (Lalruatsangi, 2022; Swati Sachdev and Singh, 2016).

In summary we have found that UV absorbers can significantly reduce the photodegradation of pesticides. Our results on water-soluble quaternary ammonium UV absorbers (QAUUVAs) demonstrated 22–26 % higher recovery of the insecticide disulfoton compared to controls without UV absorbers (Zhang *et al.*, 2024). Similarly, incorporation of appropriate UV absorbers provided 24 % and 30 % higher recovery in case of Azadirachtin and Chlorpyrifos respectively post-exposure.

The global pesticides market was valued at USD 45.7 billion in 2022 and is anticipated to reach around USD 92.6 billion by 2032, growing at a compound annual growth rate of 7.5%.

If we conservatively estimate that incorporating UV absorbers can reduce pesticide degradation by 10 %, this could translate to a potential global saving of whopping USD 4.57 billion annually.

Based on these projections, the total potential savings in global pesticide usage over the next 28 years could reach approximately USD 107.84 billion (Fig 9).

## CONCLUSION

The global use of synthetic pesticides and biopesticides for pest control is on the rise. However, a major challenge in their application is their susceptibility to photodegradation caused by sunlight or UV radiation, which limits their effectiveness over longer durations.

In this review, we attempted to demonstrate the effectiveness of UV absorbers in the photoprotection of pesticides. We have demonstrated the usefulness of a photoprotection strategy using UV absorbers through case studies of a biopesticide and two synthetic pesticides. Our findings suggest that a major chunk of pesticides can be saved from photodegradation and thus can boost the economy on a larger scale.

Future research should focus on understanding how various photochemical processes affect the electronic states of pesticide molecules on soil and plant surfaces, as well as how these molecules interact with reactive oxygen species. Additionally, the soil diffusion of pesticides can follow a degradation pathway dependent on soil moisture and microbial activity, although this aspect is beyond the scope of this review. The concept of anti-photolysis is not only relevant to pesticide protection but can also be applied to various other fields, including the preservation of fabrics, polymers, rubber, paper and other materials sensitive to sunlight.

## ACKNOWLEDGEMENT

We gratefully acknowledge The Maharaja Sayajirao University of Baroda for providing access to library resources and research infrastructure essential to the preparation of this review.

## Disclaimers

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated institutions.

**Informed consent**

This study does not involve animal or human participants and informed consent is not applicable.

**Conflict of interest**

The authors declare no conflict of interest related to the content of this publication.

**REFERENCES**

- Araki, S.M. and Baby, A.R. (2025). New perspectives on titanium dioxide and zinc oxide as inorganic UV filters: Advances, safety, challenges and environmental considerations. *Cosmetics*. **12**(2): 77.
- Allender, W.J. and Keegan, J. (1991). Determination of chlorpyrifos and its major breakdown products in technical formulations. *Bulletin of Environmental Contamination and Toxicology*. **46**(2): 313-319. <https://doi.org/10.1007/BF01691954>.
- Balakit, A.A., Ahmed, A., El-Hiti, G.A., Smith, K. and Yousif, E. (2015). Synthesis of new thiophene derivatives and their use as photostabilizers for rigid poly (vinyl chloride). *International Journal of Polymer Science*. **2015**: 510390. <https://doi.org/10.1155/2015/510390>.
- Boyetchko, S., Pedersen, E., Punja, Z. and Reddy, M. (1999). Biopesticides: Present status and future prospects. *Biopesticides: Use and Delivery*. Ed. FR Hall and JJ Menn. Humana Press. Totowa, NJ. 487-507.
- Chaudhuri, R.K., Lascu, Z., Puccetti, G., Deshpande, A.A. and Paknikar, S.K. (2006). Design of a photostabilizer having built-in antioxidant functionality and its utility in obtaining broad-spectrum sunscreen formulations† [<https://doi.org/10.1562/2005-07-15-RA-612>]. *Photochemistry and Photobiology*. **82**(3): 823-828. <https://doi.org/https://doi.org/10.1562/2005-07-15-RA-612>.
- Chen, L., Zhou, H., Hao, L., Chen, H. and Zhou, X. (2019). Soy protein isolate-carboxymethyl cellulose conjugates with pH sensitivity for sustained avermectin release. *Royal Society Open Science*. **6**(7): 190685. <https://doi.org/10.1098/rsos.190685>.
- Chen, X., Li, C., Zhang, L., Xu, S., Zhou, Q., Zhu, Y. and Qu, X. (2004). Main factors in preparation of antibacterial particles/ PVC composite. *China Particuology*. **2**(5): 226-229. [https://doi.org/https://doi.org/10.1016/S1672-2515\(07\)60063-3](https://doi.org/https://doi.org/10.1016/S1672-2515(07)60063-3).
- Corpping, L.G. and Menn, J. J. (2000). Biopesticides: A review of their action, application and efficacy. *Pest Manage. Sci*. **56**: 651-676.
- Damiani, E., Greci, L., Parsons, R. and Knowland, J. (1999). Nitroxide radicals protect DNA from damage when illuminated *in vitro* in the presence of dibenzoylmethane and a common sunscreen ingredient. *Free Radical Biology and Medicine*. **26**(7): 809-816. [https://doi.org/https://doi.org/10.1016/S0891-5849\(98\)00292-5](https://doi.org/https://doi.org/10.1016/S0891-5849(98)00292-5).
- Deota, P.T., Parmar, H.S., Patel, G.M. and Bhatt, G.J. (2022). Impact of ultraviolet-absorbing 2-hydroxy-4-quaternary ammonium koxo benzophenone motif on photodegradation of disulfoton: A case study. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-022-21247-1>.
- Deota, P.T., Upadhyay, P.R., Patel, K.B., Mehta, K.J., Varshney, A.K. and Mehta, M.H. (2002). Effect of some ultraviolet lightabsorbers on photo-stabilization of azadirachtin-A. *Natural Product Letters*. **16**(5): 329-334. <https://doi.org/10.1080/10575630290031981>.
- Deota, P.T., Upadhyay, P.R. and Valodkar, V.B. (2003). Effect of ultraviolet light absorbers on photostabilization of azadirachtin-A in solution (Part: II). *Natural Product Research*. **17**(1): 21-26. <https://doi.org/10.1080/10575630210028019>.
- Deota, P.T., Patel, G.M. and Parmar, H.S. (2019). Improved Photostabilization of chlorpyrifos insecticide with novel benzil derivatives. *Chemical Methodologies*. **3**(4): 481-493. <https://doi.org/10.22034/chemm.2018.151723.1101>.
- Ghiggino, K.P., Scully, A.D. and Leaver, I.H. (1986). Effect of solvent on excited-state intramolecular proton transfer in benzotriazole photostabilizers. *The Journal of Physical Chemistry*. **90**(21): 5089-5093. <https://doi.org/10.1021/j100412a042>.
- Hilfiker, R., Kaufmann, W., Reinert, G. and Schmidt, E. (1996). Improving sun protection factors of fabrics by applying UV-absorbers. *Textile Research Journal*. **66**(2): 61-70.
- Hirahara, Y., Ueno, H. and Nakamuro, K. (2001). Comparative photodegradation study of fenthion and disulfoton under irradiation of different light sources in liquid- and solid-phases. *Journal of Health Science*. **47**(2): 129-135. <https://doi.org/10.1248/jhs.47.129>.
- Kamel, A., Byrne, C., Vigo, C., Ferrario, J., Stafford, C., Verdin, G., Siegelman, F., Knizner, S. and Hetrick, J. (2009). Oxidation of selected organophosphate pesticides during chlorination of simulated drinking water. *Water Research*. **43**(2): 522-534. <https://doi.org/https://doi.org/10.1016/j.watres.2008.10.038>.
- Kannan, R., Dhivya, V. and Sakamuthu, V. (2023). Promoting rhizosphere microorganisms and biopesticides: A review. *Agricultural Reviews*. **44**(4): 485-492.
- Katagi, T. (2004). Photodegradation of Pesticides on Plant and Soil Surfaces. In G.W. Ware (Ed.), *Reviews of Environmental Contamination and Toxicology: Continuation of Residue Reviews* Springer New York. (pp. 1-78). [https://doi.org/10.1007/978-1-4419-9098-3\\_1](https://doi.org/10.1007/978-1-4419-9098-3_1).
- Kumar, S., Kaushik, G. and Villarreal-Chiu, J.F. (2016). Scenario of organophosphate pollution and toxicity in India: A review. *Environmental Science and Pollution Research*. **23**: 9480-9491. <https://doi.org/10.1007/s11356-016-6294-0>.
- Lakshmipathy, K., Sindhu, S., Singh, A., Chikkaballapur Krishnappa, S. and Duggonahally Veeresh, C. (2024). A review on pesticides degradation by using ultraviolet light treatment in agricultural commodities. *eFood*. **5**(1): e129.
- Lalruatsangi, K. (2022). Botanicals as selective pesticides for the integrated pest management in vegetables: A review. *Agricultural Reviews*. **43**(2): 239-242. doi: 10.18805/ag.R-2102.
- Larché, J.-F., Bussière, P.-O., Therias, S. and Gardette, J.-L. (2012). Photooxidation of polymers: Relating material properties to chemical changes. *Polymer Degradation and Stability*. **97**(1): 25-34.
- Morillo, E. and Villaverde, J. (2017). Advanced technologies for the remediation of pesticide-contaminated soils. *Science of the Total Environment*. **586**: 576-597.

- Martins, L.M.D.R.S., Hazra, S., Guedes da Silva, M.F.C. and Pombeiro, A.J.L. (2016). A sulfonated Schiff base dimethyltin (iv) coordination polymer: Synthesis, characterization and application as a catalyst for ultrasound- or microwave-assisted Baeyer–Villiger oxidation under solvent-free conditions [10.1039/C6RA14689A]. *RSC Advances*. **6(81)**: 78225-78233. <https://doi.org/10.1039/C6RA14689A>.
- Mohammed, R., El-Hiti, G. A., Ahmed, A. and Yousif, E. (2017). Poly (Vinyl Chloride) Doped by 2-(4-Isobutylphenyl) Propanoate Metal Complexes: Enhanced Resistance to UV Irradiation. *Arabian Journal for Science and Engineering*. **42(10)**: 4307-4315. <https://doi.org/10.1007/s13369-016-2323-z>.
- Mordue, A. and Blackwell, A. (1993). Azadirachtin: An update. *Journal of Insect Physiology*. **39(11)**: 903-924.
- Mutiyar, P., Mittal, A. and Pekdeger, A. (2011). Status of organochlorine pesticides in the drinking water well-field located in the Delhi region of the flood plains of river Yamuna. *Drinking Water Engineering and Science*. **4(1)**: 51-60.
- Narayanan, D.L., Saladi, R.N. and Fox, J.L. (2010). Review: Ultraviolet radiation and skin cancer [https://doi.org/10.1111/j.1365-4632.2010.04474.x]. *International Journal of Dermatology*. **49(9)**: 978-986. <https://doi.org/https://doi.org/10.1111/j.1365-4632.2010.04474.x>
- Nguyen, H.M., Hwang, I.C., Park, J.W. and Park, H.J. (2012). Enhanced payload and photo-protection for pesticides using nanostructured lipid carriers with corn oil as liquid lipid. *Journal of Microencapsulation*. **29(6)**: 596-604. <https://doi.org/10.3109/02652048.2012.668960>.
- Nishant, N. and Upadhyay, R. (2016). Presence of pesticide residue in vegetable crops: A review. *Agricultural Reviews*. **37(3)**: 173-185. doi: 10.18805/ag.v37i3.3533.
- Parwaiz, S., Khan, M.M. and Pradhan, D. (2019). CeO<sub>2</sub>-based nanocomposites: An advanced alternative to TiO<sub>2</sub> and ZnO in sunscreens. *Materials Express*. **9(3)**: 185-202.
- Padalkar, V.S., Ramasami, P. and Sekar, N. (2014). A comprehensive spectroscopic and computational investigation of intramolecular proton transfer in the excited states of 2-(22 - hydroxyphenyl) benzoxazole and its derivatives. *Journal of Luminescence*. **146**: 527-538. <https://doi.org/https://doi.org/10.1016/j.jlumin.2013.09.007>.
- Pang, L., Gao, Z., Zhang, S., Li, Y., Hu, S. and Ren, X. (2016). Preparation and anti-UV property of modified cellulose membranes for biopesticides controlled release. *Industrial Crops and Products*. **89**: 176-181. <https://doi.org/https://doi.org/10.1016/j.indcrop.2016.05.014>.
- Qiao, R.M., Zhao, C.P., Liu, J.L., Zhang, M.L. and He, W.Q. (2022). Synthesis of novel ultraviolet absorbers and preparation and field application of anti-ultraviolet aging PBAT/UVA films. *Polymers*. **14(7)**: 1434.
- Rohatgi-Mukherjee, K. (1978). *Fundamentals of photochemistry*. New Age International. pp. 96.
- Sabaa, M.W., Oraby, E.H., Abdel Naby, A.S. and Mohamed, R.R. (2005). Anthraquinone derivatives as organic stabilizers for rigid poly (vinyl chloride) against photo-degradation. *European Polymer Journal*. **41(11)**: 2530-2543. <https://doi.org/https://doi.org/10.1016/j.eurpolymj.2005.05.015>.
- Shalan, N., Laftah, N., El-Hiti, G.A., Alotaibi, M.H., Muslih, R., Ahmed, D.S. and Yousif, E. (2018). Poly (vinyl Chloride) Photostabilization in the Presence of Schiff Bases Containing a Thiadiazole Moiety. *Molecules*. **23(4)**.
- Stark, J.D. and Walter, J.F. (1995). Neem oil and neem oil components affect the efficacy of commercial neem insecticides. *Journal of Agricultural and Food Chemistry*. **43(2)**: 507-512.
- Starnes, W.H., Du, B., Kim, S., Zaikov, V.G., Ge, X. and Culyba, E.K. (2006). Thermal stabilization and plasticization of poly (vinyl chloride) by ester thiols: Update and current status. *Thermochimica Acta*. **442(1)**: 78-80. <https://doi.org/https://doi.org/10.1016/j.tca.2006.01.018>.
- Swati Sachdev, S.S. and Singh, R. (2016). Current challenges, constraints and future strategies for development of successful market for biopesticides.
- Thakore, D. and Srivastava, A.K. (2017). Production of biopesticide azadirachtin using plant cell and hairy root cultures. *Engineering in Life Sciences*. **17(9)**: 997-1005.
- Turro, N.J., Ramamurthy, V. and Scaiano, J.C. (2009). Principles of molecular photochemistry: An introduction. University science books, pp. 30.
- Ugartondo, V., Mitjans, M. and Vinardell, M. P. (2008). Comparative antioxidant and cytotoxic effects of lignins from different sources. *Bioresource Technology*. **99(14)**: 6683-6687. <https://doi.org/https://doi.org/10.1016/j.biortech.2007.11.038>.
- Waiblinger, F., Keck, J., Stein, M., Fluegge, A.P., Kramer, H.E.A. and Leppard, D. (2000). Light-induced opening of the intramolecular hydrogen bond of UV absorbers of the 2-(2-Hydroxyphenyl)-1,3,5-triazine and the 2-(2-Hydroxyphenyl) benzotriazole Type. *The Journal of Physical Chemistry A*. **104(6)**: 1100-1106. <https://doi.org/10.1021/jp993349l>.
- Wasielowski, M.R. (1992). Photoinduced electron transfer in supramolecular systems for artificial photosynthesis. *Chemical Reviews*. **92(3)**: 435-461. <https://doi.org/10.1021/cr00011a005>.
- Woessner, G., Goeller, G., Kollat, P., Stezowski, J.J., Hauser, M., Klein, U.K.A. and Kramer, H.E.A. (1984). Photophysical and photochemical deactivation processes of ultraviolet stabilizers of the (2-hydroxyphenyl)benzotriazole class. *The Journal of Physical Chemistry*. **88(23)**: 5544-5550. <https://doi.org/10.1021/j150667a017>.
- Yousif, E., El-Hiti, G.A., Hussain, Z. and Altaie, A. (2015). Viscoelastic, spectroscopic and microscopic study of the photo irradiation effect on the stability of PVC in the presence of sulfamethoxazole schiff's bases. *Polymers*. **7(11)**: 2190-2204.
- Yousif, E., Hasan, A. and El-Hiti, G.A. (2016). Spectroscopic, physical and topography of photochemical process of PVC films in the presence of schiff base metal complexes. *Polymers*. **8(6)**.
- Yousif, E., Salimon, J., Salih, N., Jawad, A. and Win, Y.F. (2016). New stabilizers for PVC based on some diorganotin (IV) complexes with benzamidoleucine. *Arabian Journal of Chemistry*. **9**: S1394-S1401. <https://doi.org/https://doi.org/10.1016/j.arabjc.2012.03.004>.
- Zenker, A., Schmutz, H. and Fent, K. (2008). Simultaneous trace determination of nine organic UV-absorbing compounds (UV filters) in environmental samples. *Journal of Chromatography A*. **1202(1)**: 64-74. <https://doi.org/https://doi.org/10.1016/j.chroma.2008.06.041>.
- Zhang, N., Xiao, Y., Hu, S., Chen, Q., Huang, Y., Li, M., Jin, Z., Chen, H., Wu, W. and Wang, J. (2024). Improving UV protection and retention of photosensitive agrochemicals: Innovative polyurethane-CeO<sub>2</sub> hybrid pesticide microcapsules. *Chemical Engineering Journal*. **500**: 157351.