Jurnal Serambi Engineering JSE Volume IX, No.2, April 2024 Hal 8733 - 8739
p-ISSN : 2528-3561
e-ISSN : 2541-1934

Review of Florpyrauxifen-Benzyl Herbicide: Bringing Current Global Knowledge for Environmental Impact Mitigation in the Indonesian Context

Mashudi[1*], Bieby Voijant Tangahu[2]

[1,2]Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember (ITS) Surabaya
*__Corresponding author__: mashudi1993@its.ac.id

Received: April 1, 2024 Approved: April 6, 2024

Abstract
Florpyrauxifen-benzyl, a synthetic auxin herbicide, has recently been introduced for weed control in rice cultivation in Indonesia. However, limited research has been conducted to investigate its environmental impacts, particularly in the Indonesian context. This review article aims to provide a comprehensive overview of the current understanding of florpyrauxifen-benzyl, based on scientific articles published by global scientists over the past six years. The article systematically reviews and categorises the development of studies on florpyrauxifen-benzyl into three main clusters: weed control efficacy, residue fate and environmental impact. The weed control cluster examines the efficacy, selectivity and potential resistance issues associated with the herbicide. The residue fate cluster focuses on method development, residue measurements in different matrices and degradation pathways. The environmental impact cluster will address the holistic ecological impact of florpyrauxifen-benzyl, including effects on environmental quality (water, sediment, soil), micro-organisms, non-target agricultural crops, fauna and humans. This compilation of current knowledge on florpyrauxifen-benzyl will serve to inform environmental mitigation strategies and identify knowledge gaps that require further investigation in the future to support sustainable agricultural practices in Indonesia.
Keywords: *florpyrauxifen-benzyl, herbicide, weed, environmental impact, sustainable agriculture.*

Abstrak
Florpyrauxifen-benzyl merupakan kolompok herbisida auksin sintesis yang baru-baru ini dikenalkan ke Indonesia tahun 2019 untuk mengendalikan gulma pada tanaman padi. Karena relatif baru, penelitian terkait dampak lingkungan dari herbisida ini masih sangat terbatas, khususnya untuk konteks di Indonesia. Artikel ini ditulis untuk memberikan gambaran komperhensif terkait herbisida ini berdasarkan publikasi akademisi dunia dalam kurun waktu enam tahun terakhir. Artikel ini menjelaskan pengetahuan terkait florpyrauxifen-benzyl dan membagi menjadi tiga bagian yang meliputi: efektivitas pengendalian gulma, residu herbisida, dan dampak lingkungan herbisida tersebut. Bagian efektivitas pengendalian akan memaparkan tingkat efektivitas, selektivitas, dan potensi masalah resistensi gulma terhadap herbisida ini. Kemudian, bagian residu herbisida akan membahas tentang pengembangan metode pengukuran senyawa herbisida beserta turunannya, pengukuran di beragam media, dan jalur degradasi herbisida tersebut. Terakhir, bagian dampak lingkungan akan melihat dampak ekologi secara holistik, termasuk dampak terhadap kualitas lingkungan (air, sedimen, dan tanah), dampak terhadap mikroba, tanaman pertanian non-target, hewan, dan manusia. Kumpulan pengetahuan ini diharapkan dapat memperbaiki strategi mitigasi kerusakan lingkungan yang muncul akibat herbisida ini sekaligus mengidentifikasi pengetahuan yang diperlukan untuk mendukung perwujudan pertanian berkelanjutan di Indonesia.
Kata Kunci: *florpyrauxifen-benzyl, herbisida, gulma, dampak lingkungan, pertanian berkelanjutan.*

1. Introduction

Florpyrauxifen-benzyl is an auxin synthetic herbicide that newly introduced to Indonesia in 2019 and its mainly use for weed control in rice plantation. This herbicide was released to Indonesian market by Corteva Agriscience in two distinct products namely Novlect and Loyant. Due to its excellent result in controlling variety of weeds and its selectivity to rice, the products were quickly favored by many Indonesian farmers. Florpyrauxifen-benzyl demonstrates a notable distinction from traditional synthetic herbicides as it exhibits a heightened affinity for receptor. This enhanced receptor binding improves the efficacy in managing herbicide-resistant weeds that employ diverse resistance mechanisms [1].

Florpyrauxifen-benzyl has a chemical formula of C20H14Cl2F2N2O3, with a molecular weight of 439.24. It is registered in the chemical database CAS with the registration number CAS: 1390661-72-9. The chemical structure of this herbicide closely resembles the natural auxin produced by plants [2]. The action mechanism remains incompletely elucidated; nevertheless, prior studies have indicated that their interaction with the TIR1/AFB auxin receptor plays a pivotal role in weed control [3]. Meanwhile, other study revealed that this herbicide functions as a molecular glue between the SCFTIR/AFB5 receptor protein complex and the auxin co-receptor, disrupting the balance of biosynthesis of other plant hormones such as ethylene and abscisic acid [4]. This imbalance leads to the accumulation of excessive ethylene and ABA within plant cells, ultimately resulting in plant death [5].

Despite its excellent performance in eradicating weeds, limited research has been conducted to elucidate crucial impacts from florpyrauxifen-benzyl application. Research topics encompassing dosage effectiveness, resistance potential, residue dynamics, and environmental impacts need to be undertaken especially in Indonesia. Europe, China, US, and several other countries have reportedly utilized this substance earlier and the academic communities from the respected countries have accumulated substantial knowledge regarding florpyrauxifen-benzyl. This article aims to bring that current knowledge published by academic around the world to Indonesian context. Ultimately, the acquired understanding will be employed to effectively mitigate any potential environmental impacts that may arise in the future.

2. Material and Methods

This article was developed by analyzing global academic publications on florpyrauxifen-benzyl. The existing publication topics were classified into three different clusters namely weed control effectivity, residue fate, and environmental impacts of florpyrauxifen-benzyl. Google scholar was employed to obtain published scientific articles in the past six years related to florpyrauxifen-benzyl which fall within previously defined clusters. A minimum of 10 highly relevant publications per category were selected, reviewed, and thoroughly discussed within this study. Total of more than 30 articles were then utilized to build new insights of florpyrauxifen-benzyl and brought the knowledge to Indonesian context. Finally, the newly acquired understanding were utilized to identify research gaps and develop impact mitigation strategies in Indonesia.

3. Results and Discussion

Weed Control Effectivity of Florpyrauxifen-Benzyl

Florpyrauxifen-benzyl has emerged as an alternative herbicide with several advantages, including its ability to effectively control various weeds that have developed resistance to long-used traditional herbicides. Numerous studies have been conducted to assess the effectiveness of florpyrauxifen-benzyl in weed management, particularly in rice crops and aquatic weeds. One of the key factors contributing to its effectiveness is its strong affinity to the auxin receptors [6]. This strong binding disrupts the biosynthesis of other plant hormones and leads to biochemical imbalances that interfere with the normal cell activities [1]. Study revealed that the presence of florpyrauxifen-benzyl stimulates the synthesis of ethylene and promotes the accumulation of ABA (abscisic acid) and ROS (reactive oxygen species). This accumulation eventually reaches toxic concentrations, leading to the demise of the targeted weeds [2].

Those action mechanisms in molecular level were then translated to effectiveness of the herbicide in the field application. Numerous field studies have been conducted to measure the efficacy of florpyrauxifen-benzyl in various setting. Research undertaken in greenhouse revealed that the herbicide provides effective control in wide variety of rice weeds which some of them also commonly found in Indonesia's rice plantation [7]. Other study emphasized that florpyrauxifen-benzyl can be applied in a mixture with other commonly used herbicides without producing negative impacts [8]. In field applications, this information is highly valuable as it allows farmers to combine florpyrauxifen-benzyl with other herbicides in a single spray, thereby enhancing operational efficiency. It is imperative to undertake experimental investigations to evaluate the impacts of mixing florpyrauxifen-benzyl with other frequently employed compounds in rice cultivation in Indonesia.

In addition to its effectiveness in controlling weeds in rice fields, florpyrauxifen-benzyl can also be utilized to eradicate invasive species in aquatic ecosystems. Field experiments conducted by [9] demonstrated that the 12-36 µg/L application of this herbicide reduced Hydrilla sp. population up to 85%. Other invasive species such as hybrid watermilfoil (*Myriophyllum spicatum*) have also been reported to be effectively eliminated, reaching 100% of eradication record. Furthermore, the compound exhibits favorable selectivity, allowing non-target species to grow normally [10]. This high efficiency and selectivity further define florpyrauxifen-benzyl as a new favorite herbicide to be used not only for paddy, but also aquatic environment in general.

Despite the numerous advantages attributed to florpyrauxifen-benzyl in weed control, alternative research findings have indicated the occurrence of rice damage resulting from its application. This damage occurred under specific environmental conditions characterized by reduced light and elevated temperatures. In such conditions, the utilization of florpyrauxifen-benzyl has been reported to induce rice damage of up to 80% [11]. Furthermore, the accidental exposure of non-target crops and the emergence of weed resistance to florpyrauxifen-benzyl necessitates careful consideration. A guideline on precise dosage application is essential to mitigate these potential impacts.

Herbicide resistance

Resistance level testing represents is crucial aspect in herbicide discourse, as historically all herbicides demonstrated notable efficacy but eventually faced the emergence of resistance due to factors such as improper dosage practices over long period of time. With regards to florpyrauxifen-benzyl, it is imperative to conduct resistance test against key weed species, particularly those prevalent in rice cultivation in Indonesia, as identified by [12]. The initial resistance studies have been conducted in Korea, using two weed species *Echinochloa crus-galli* and *E. oryzicola*, which also commonly found in Indonesia paddy fields. The findings of the study indicate that *E. oryzicola* poses a higher potential for resistance compared to other species, with a baseline sensitivity index (BSI) reaching 6.3. [13]. The resistance references will be valuable for future investigations and mitigation of potential emergence of weed resistance.

In USA, investigations of resistance mechanisms have been conducted on barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.). The research revealed that resistant biotypes exhibit reduced florpyrauxifen-benzyl uptake and enhanced translocation of florpyrauxifen acid, leading to its rapid degradation [14]. Another report suggested that plant's ability to hydrolyze the methoxy group, potentially facilitated by the cytochrome P450 monooxygenase C enzyme, contribute to build the resistance [15]. Interestingly, florpyrauxifen-benzyl has been reported to effectively control other herbicide-resistant barnyardgrass four years before the same species acquired the resistance capability against it [16]. This fact should be taken into consideration as resistance traits may emerge in a relatively short period of time.

Herbicide concentration in various matrices

The investigation of residue fate is imperative to estimate the environmental implications of novel compounds, including florpyrauxifen-benzyl. Research group [17] developed a liquid-liquid extraction with low temperature purification (LLE-LTP) methodology coupled with high performance liquid chromatography with diode array detection (HPLC-DAD) for this residue analysis purpose. They claimed that the method was effective, simple, and easy to use for the extraction and analysis of florpyrauxifen-benzyl residues in water matrices. Another notable publication by [18] summarized methods in broader medium such as soil, water, air, food, and animal feed. These proven methodologies should be followed by Indonesian researchers in the future to examine residue fate of the herbicide use in the country.

The residues of florpyrauxifen-benzyl have been found to persist in rice plants for up to 12 months, with the highest distribution observed in straw and young seeds. In contrast, the residue levels of florpyrauxifen-benzyl in rice grains are recorded to be very low, specifically at 0.061 mg/kg [18]. On the other hand, another study reported the absence of residues in the stems and grains of brown rice, leading to the conclusion that the application of florpyrauxifen-benzyl does not pose any food safety hazards. The same report confirmed that the dissipation dynamics of florpyrauxifen-benzyl in paddy water, paddy soil, and rice straw followed first-order kinetics, with half-lives of less than 3 days [19].

In aerobic conditions, it has been reported that florpyrauxifen-benzyl has a half-life of approximately 8 days in water-sediment medium. However, in a similar medium but under anaerobic condition, the half-life is shorter, less than 3 days. During this period, the parent compound of florpyrauxifen-benzyl undergoes gradual degradation and transforms into other derivative compounds with different properties and toxicities level. In shallow and clear water, the primary degradation process of florpyrauxifen-benzyl occurs through photolysis, with a very short half-life of approximately 0.16 days. On the other hand, degradation through hydrolysis is reported to require a much longer time, with a measured half-life of 111 days, occurring in deeper water and sediments [20]. Toxicity test of benthic fauna is essential to be measured considering the higher prevalence of florpyrauxifen-benzyl deposition.

Dissipation of parent compound

Following degradation, florpyrauxifen-benzyl undergoes transformation into various forms, including five known derivative compounds: florpyrauxifen, hydroxy-FPB, hydroxy-florpyrauxifen, dechloro-FPB, and dechloroflorpyrauxifen. Simultaneously, degradation processes such as hydrolysis, biodegradation, sorption, and photodegradation can occur concurrently. Abiotic processes and plant-mediated hydrolysis, followed by biodegradation, are considered the dominant mechanisms in aquatic lake environments [21] In the context of soil and water environments, it has been reported that biodegradation mediated by microorganisms is the primary degradation process for florpyrauxifen-benzyl. Furthermore, the application of florpyrauxifen-benzyl has been shown to induce significant changes in the composition of soil bacterial communities [1]. As soil bacteria contribute greatly to soil fertility, research on florpyrauxifen-benzyl impact in Indonesian soil is valuable.

The investigation of the absorption and translocation processes of florpyrauxifen-benzyl within plant organs is of utmost importance for assessing its potential deposition. A study conducted by [22] examined the absorption and translocation of florpyrauxifen-benzyl in ten aquatic plants. The results showed that all tested plants exhibited absorption, with Myriophyllum heterophyllum displaying the highest absorption rate of up to 40 µg/g. Moreover, translocation processes were also observed in all plant species, with Nymphoides cristata exhibiting the highest translocation rate. Notably, the translocation process was influenced not only by plant species but also by soil moisture content or growth media characteristics [23]. The simultaneous application of different herbicides can also influence the translocation process, as observed in the combination of florpyrauxifen-benzyl and endothall. It was found that the application of florpyrauxifen-benzyl with endothall significantly reduced the translocation rate from stems to roots of plants by 6-16 times [24].

Environmental Impacts Of Florpyrauxifen-Benzyl

The environmental impacts associated with the application of florpyrauxifen-benzyl can be assessed through various approaches, including its effects on environmental quality, indigenous microorganisms, non-target plants, fauna, and human health. Research investigating the effects on environmental parameters has been conducted by [25], which observed changes in water quality following the application of this herbicide. The researchers revealed an increase in biochemical oxygen demand (BOD) and a decrease in dissolved oxygen (DO) in the short time (3-10 days) after application. However, this trend gradually changed, and by day 42, the DO had exceeded the initial conditions. Another study conducted in Indonesia indicated that the application of florpyrauxifen-benzyl at a rate of 15 g/ha did not significantly alter water quality. It was reported that parameters such as pH, temperature, total dissolved solids (TDS), dissolved oxygen, and ammonia were changed but did not differ significantly from the control. The changes observed in these parameters also remained within the standard water quality guidelines based on regulatory requirements [26].

The application of florpyrauxifen-benzyl often leads to environmental changes, which in turn impact the living organisms. Among these organisms, bacteria are particularly sensitive, and their community structure tends to be influenced by small environmental alterations. A study conducted by [1] confirmed and revealed significant changes in the structure of soil bacterial communities within a few days after florpyrauxifen-benzyl application. The presence of the herbicide showed a positive correlation with the abundance of Luteimonas and five other genera, while Pseudolabrys and two other genera displayed a negative correlation. These changes in soil microbial composition raise important concerns as they have a significant impact on soil fertility [27].

Another important environmental impact that needs to be considered is related to the potential toxicity to non-target agricultural plants. When applying florpyrauxifen-benzyl, there is a risk of unintended effects on plant species other than the target weed. Selectivity is a vital attribute for herbicides, including florpyrauxifen-benzyl, particularly in the context of non-monoculture agricultural practices. Rice farmers in Indonesia, predominantly residing in Java, commonly adopt intercropping techniques where additional crops are grown alongside the primary crop, rice. Consequently, it becomes crucial to comprehend the potential damage that may occur to these row plants. Previous research endeavors have investigated the effects of florpyrauxifen-benzyl on non-rice crops to shed light on potential adverse consequences.

Soybean has been commonly utilized as a representative non-rice plant species for sensitivity assessments of florpyrauxifen-benzyl. Extensive research studies have consistently demonstrated the high susceptibility of soybean to the exposure of florpyrauxifen-benzyl. Notably, experiments conducted by [28] revealed that the application of florpyrauxifen-benzyl at a mere 10% of the recommended dosage induced visible damage symptoms in various crops, including corn, cotton, sunflower, and soybean. Among these crops, soybeans exhibited the most pronounced sensitivity, with damage percentages reaching as high as 96%. Other research investigating the volatility effects of florpyrauxifen-benzyl have also demonstrated the occurrence of injury, albeit minimal, to soybean plants located within approximately 31 cm of herbicide application [29].

Technological advancements in the agricultural have also contributed to mitigating the impacts of florpyrauxifen-benzyl. Research conducted by [30] investigated the effects of herbicide application using drones on pollination activities, showing a significant reduction in soybean reproductive structures. The damage to soybean flower diminished the food source for pollinators which then reduced the harvesting yield. However, research conducted by [31] has demonstrated that adjusting the drone speed, reducing the height, increasing droplet size, and adding non-ionic surfactants can significantly decrease soybean injury. Additionally, [32] conducted study assessing the potential effects of soil previously exposed to herbicides and florpyrauxifen-benzyl exhibited the lowest carry-over impact on soybean compared to other herbicides.

Furthermore, understanding the impact of florpyrauxifen-benzyl on fauna is crucial to assess its ecological implications. The United States Environmental Protection Agency (USEPA) reports that this compound is not classified as acutely or chronically toxic. These findings are based on toxicological tests conducted on birds, reptiles, mammals, and bees at concentrations above the maximum recommended usage. Regarding aquatic fauna such as clams, crayfish, catfish, and bluegill, it has been observed that a concentration of 0.15 mg/L can cause short-term bioaccumulation before degradation occurs on the third day [33]. Additionally, a study conducted by research group [34] confirms that the toxicity level of florpyrauxifen-benzyl in aquatic habitats remains low, as its toxicity test on juvenile mussels did not show any significant acute toxic effects.

Lastly, the assessment of environmental impact should encompass the potential effects of florpyrauxifen-benzyl on human health. In order to evaluate health risks, experimental studies utilizing animal models, such as mice, are commonly employed. Findings from European investigations have revealed that this compound can be absorbed greatly when applied in low levels, while absorption is limited at higher intake. The absorbed compound was then metabolized and secreted through urine within 24 hours, remaining florpyrauxifen which is known to have a longer persistence. Notably, the toxicity assessment indicates that florpyrauxifen demonstrates low toxicity levels when administered orally and dermally, with LD50 values exceeding 5g/kg and an inhalation LC50 value of 5.33 ppm per 4h [18]. Furthermore, United States Environmental Protection Agency asserts that florpyrauxifen-benzyl does not possess carcinogenic or genotoxic properties.

Impact Mitigation and Research Gap

Based on the aforementioned discussion, it can be generally concluded that florpyrauxifen-benzyl is believed to have a relatively low environmental impact compared to other herbicides. Nevertheless, the observed effects on environmental quality, such as the decline in dissolved oxygen levels and the increase in biochemical oxygen demand, serve as preliminary indicators necessitating mitigation measures. Although the measured water quality is reported to comply with regulatory standards, notable alterations in various environmental parameters have been detected. Additionally, it has been documented that the derivative compounds of florpyrauxifen-benzyl can persist for a significant duration in deep water and sediment. Furthermore, in soil media, the application of this compound has demonstrated significant alterations in soil quality, particularly concerning the structure of soil microorganisms.

The impact of florpyrauxifen-benzyl on non-target agricultural crops, particularly soybeans, has been extensively documented. Although its overall impact is relatively smaller compared to other herbicides, several field studies have reported significant plant injury and ecological disruption for pollinator populations, consequently resulting in yield reduction. A study is needed to investigate the impact of florpyrauxifen-benzyl usage on row crops commonly planted alongside rice in Indonesia, such as legumes, corn, and chili peppers. The emerging use of drones for herbicide spraying in Indonesia further highlights the need to consider the potential spread of herbicides to non-target plants through wind drift. Therefore, the development of awareness programs and the establishment of guidelines for the application of florpyrauxifen-benzyl using drones are crucial to mitigate these impacts.

Based on the information of environmental impacts mitigation discussed above, future research is needed in Indonesia to address several issues. To accommodate diverse research topics, clustering of the research gap namely weed control, residue fate, and environmental impacts of florpyrauxifen-benzyl can be employed. The weed control cluster should focus on issues of herbicide effectiveness, selectivity, and potential resistance. The residue fate cluster should cover research of methodologies development, residue measurement in various matrices, and the processes of residue degradation in the environment. Meanwhile, environmental impacts cluster should investigate the comprehensive ecological effects of florpyrauxifen-benzyl, including the impacts on environmental quality (water, sediment, soil), microorganisms, non-target agricultural crops, fauna, and humans.

4. Conclusion

Florpyrauxifen-benzyl is novel herbicide that is increasingly being used in Indonesia due to its effectiveness and selectivity. Being a relatively new compound, its environmental impacts, particularly in the Indonesian context, remain poorly understood. In general, current scholars agreed that the environmental impact of florpyrauxifen-benzyl is considered minimal compared to other herbicides. Nevertheless, it is crucial to implement mitigation measures to address potential environmental impacts, given the emerging evidence of environmental quality change, soil microbial structure alteration, non-target agricultural plants injury, and fauna toxicity are reported associated with application of florpyrauxifen-benzyl. To better prepare the mitigation, research development in Indonesia should be directed towards clustered topics including weed control, residue fate, and environmental impacts.

5. Acknowledgment

The work on this article is funded by Institut Teknologi Sepuluh Nopember (ITS) Surabaya through competitive research grant (department/unit scheme) 2022/2023.

6. Abbreviations

FBP	Florpyrauxifen-benzyl
LC50	Lethal concentration 50
LD50	Lethal dosage 50

7. References

[1] Liu, C., et al., *Residue dynamics of florpyrauxifen-benzyl and its effects on bacterial community structure in paddy soil of Northeast China.* Ecotoxicology and Environmental Safety, 2023. 249: p. 114390.

[2] Wang, H., et al., *The phytotoxicity mechanism of florpyrauxifen-benzyl to Echinochloa crus-galli (L.) P. Beauv and weed control effect.* Pesticide Biochemistry and Physiology, 2021. 179: p. 104978.

[3] Guo, F., et al., *Functional analysis of auxin receptor OsTIR1/OsAFB family members in rice grain yield, tillering, plant height, root system, germination, and auxinic herbicide resistance.* New Phytologist, 2021. 229(5): p. 2676-2692.

[4] Velásquez, J.C., et al. *Florpyrauxifen-Benzyl Selectivity to Rice*. Agriculture, 2021. 11, DOI: 10.3390/agriculture11121270.

[5] Grossmann, K., *Auxin herbicides: current status of mechanism and mode of action.* Pest Management Science, 2010. 66(2): p. 113-120.

[6] Herrera, R., et al., *Chapter 35 - Rinskor active herbicide—A new environment-friendly tool for weed management in rice and aquatic environments*, in *Recent Highlights in the Discovery and Optimization of Crop Protection Products*, P. Maienfisch and S. Mangelinckx, Editors. 2021, Academic Press. p. 511-523.

[7] Miller, M.R. and J.K. Norsworthy, *Florpyrauxifen-benzyl Weed Control Spectrum and Tank-Mix Compatibility with other Commonly Applied Herbicides in Rice.* Weed Technology, 2018. 32(3): p. 319-325.

[8] Wright, H.E., et al., *Use of florpyrauxifen-benzyl in non-flooded rice production systems.* Crop, Forage & Turfgrass Management, 2021. 7(1): p. e20081.

[9] Mudge, C.R. and M.D. Netherland, *Evaluation of new endothall and florpyrauxifen-benzyl use patterns for controlling crested floating heart and giant salvinia.* 2020.

[10] Davidson, A., *Field application of florpyrauxifen-benzyl to treat hybrid Eurasian watermilfoil: initial effects on native and invasive aquatic vegetation.* Management of Biological Invasions, 2023. 14.

[11] Beesinger, J.W., et al., *Impact of environmental and agronomic conditions on rice injury caused by florpyrauxifen-benzyl.* Weed Technology, 2022. 36(1): p. 93-100.

[12] Caton, B., et al., *Panduan Lapang Praktis Untuk Gulma Padi di Asia*. 2011: IRRI.

[13] Lim, S.-H., et al., *Baseline Sensitivity of Echinochloa crus-gall and E. oryzicola to Florpyrauxifen-Benzyl, a New Synthetic Auxin Herbicide, in Korea.* Frontiers in Plant Science, 2021. 12.

[14] Hwang, J.-I., et al., *Absorption, translocation, and metabolism of florpyrauxifen-benzyl and cyhalofop-butyl in cyhalofop-butyl-resistant barnyardgrass [Echinochloa crus-galli (L.) P. Beauv.]*. Pesticide Biochemistry and Physiology, 2022. 180: p. 104999.

[15] Takano, H.K., et al., *Metabolic cross-resistance to florpyrauxifen-benzyl in barnyardgrass (Echinochloa crus-galli) evolved before the commercialization of Rinskor™.* Weed Science, 2023. 71(2): p. 77-83.
[16] Miller, M.R., J.K. Norsworthy, and R.C. Scott, *Evaluation of Florpyrauxifen-benzyl on Herbicide-Resistant and Herbicide-Susceptible Barnyardgrass Accessions.* Weed Technology, 2018. 32(2): p. 126-134.
[17] Vieira, L.H., et al., *Optimization and validation of LLE-LTP to determine florpyrauxifen-benzyl herbicide in water samples by HPLC-DAD.* Journal of Environmental Science and Health, Part B, 2022. 57(9): p. 697-709.
[18] European Food Safety, A., et al., *Peer review of the pesticide risk assessment of the active substance florpyrauxifen (variant assessed florpyrauxifen-benzyl).* EFSA Journal, 2018. 16(8): p. e05378.
[19] Zhou, R., et al., *Residue analysis, dissipation behavior, storage stability and dietary risk assessment of florpyrauxifen-benzyl in natural paddy field environment using UPLC-QTOF-MS/MS.* Journal of Food Composition and Analysis, 2022. 114: p. 104781.
[20] Massachusetts Department of Agriculture Division of Crop and Pest Services (MDAR) and Massachusetts Department of Environmental Protection Office of Research and Standards (MassDEP). *Review of Florpyrauxifen-benzyl for Application to Massachusetts Lakes and Ponds.* 2019.
[21] Van Frost, S., *Characterizing the Environmental Fate Of Aquatic Herbicides By Connecting Quantification In Lakes To Laboratory Studies*. 2023.
[22] Haug, E.J., et al., *Absorption and translocation of florpyrauxifen-benzyl in ten aquatic plant species.* Weed Science, 2021. 69(6): p. 624-630.
[23] Miller, M.R. and J.K. Norsworthy, *Influence of Soil Moisture on Absorption, Translocation, and Metabolism of Florpyrauxifen-benzyl.* Weed Science, 2018. 66(4): p. 418-423.
[24] Ortiz, M.F., et al., *Xenobiotics translocate in aquatic plants: a case study using three aquatic herbicides*. 2022, Colorado State University.
[25] Lamb, B.T., et al., *Monitoring and water quality impacts of an herbicide treatment on an aquatic invasive plant in a drinking water reservoir.* Journal of Environmental Management, 2021. 288: p. 112444.
[26] Kurniadie, D., et al. *Control of Aquatic Weed Eichhornia crassipes Using Florpyrauxifen-benzyl Herbicide—Case Study in Cangkuang Lake (Indonesia)*. Water, 2023. 15, DOI: 10.3390/w15101859.
[27] Mącik, M., A. Gryta, and M. Frąc, *Biofertilizers in agriculture: An overview on concepts, strategies and effects on soil microorganisms.* Advances in agronomy, 2020. 162: p. 31-87.
[28] Miller, M.R. and J.K. Norsworthy, *Row Crop Sensitivity to Low Rates of Foliar-Applied Florpyrauxifen-benzyl.* Weed Technology, 2018. 32(4): p. 398-403.
[29] Walker, D.C., *Impact of New Technologies on Weed Control in Louisiana Rice Production.* 2022.
[30] Butts, T.R., et al., *Herbicide spray drift from ground and aerial applications: Implications for potential pollinator foraging sources.* Scientific Reports, 2022. 12(1): p. 18017.
[31] Huang, Z., et al., *Field evaluation of spray drift and nontargeted soybean injury from unmanned aerial spraying system herbicide application under acceptable operation conditions.* Pest Management Science, 2023. 79(3): p. 1140-1153.
[32] Miller, M.R. and J.K. Norsworthy, *Assessment of Florpyrauxifen-benzyl Potential to Carryover to Subsequent Crops.* Weed Technology, 2018. 32(4): p. 404-409.
[33] Washington State Department of Ecology (WSDOE). *Final Supplemental Environmental Impact Statement for the State of Washington Aquatic Plant and Algae Management*. Prepared by TRC Environmental. 2017.
[34] Buczek, S.B., et al., *Evaluation of Juvenile Freshwater Mussel Sensitivity to Multiple Forms of Florpyrauxifen-Benzyl.* Bulletin of Environmental Contamination and Toxicology, 2020. 105(4): p. 588-594.