Mechanism of Action and Research on Amide Herbicide Safeners

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Abstract: Herbicides have been used for decades in a wide range of agricultural fields as a key tool to increase crop yields and maintain the ecological balance of farmland. Among many herbicides, amide herbicides stand out as the preferred solution for field management of various crops due to their excellent herbicidal efficacy and wide applicability. However, along with their wide application, how to ensure weed control and crop safety at the same time has become a major challenge in agricultural research. Against this background, amide herbicide safeners have emerged, which effectively protect crops from herbicides by virtue of their unique mechanism of action, adding new impetus to the sustainable development of agriculture. In this paper, the mechanism of action of amide herbicide safeners will be analysed in depth, revealing their intrinsic mysteries in ensuring crop safety and enhancing herbicide selectivity, with the aim of providing a more scientific and safer weed control strategy for agricultural production.

Keywords: Amide herbicide safener; Mechanism of action; Research

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In today's green revolution in agriculture, herbicides are becoming increasingly important as a core element in improving crop productivity. Amide herbicides, with their excellent herbicidal efficacy and stable efficacy performance, have become the leaders in the pesticide market. However, there are two sides of the coin. While amide herbicides show high weed control ability, they also carry the risk of crop damage[1] . To meet this challenge, researchers have worked tirelessly to develop safety agents for amide herbicides. These safeners are like the "guardians" of crops, which can enhance the tolerance of crops to herbicides without weakening their herbicidal activity, bringing new hope to agricultural production.

1. Overview of Amide Herbicide Safeners

(1) Definitions

Amide herbicide safeners, as a unique chemical in the field of agrochemistry, play a crucial role. Their core definition is that they fulfil the dual function of "safety" and "protection". Specifically, these safeners not only ensure that amide herbicides are effective against the target weed and do not weaken the weed control effect, but also selectively protect the crop from the potential harmful effects of the herbicide during application. This definition profoundly reflects the art of balance in the use of chemical pesticides, i.e. effective weed control while ensuring crop safety and health[2] . In terms of chemical structure, amide herbicide safeners usually contain functional groups that can interact with the herbicide molecule, such as amine and amide groups. These groups are effective in

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achieving their protective effects by forming complexes with the herbicide molecules or altering their metabolic pathways in the crop.

(2) Classification

The classification of amide herbicide safeners is based mainly on differences in their chemical structure and mechanism of action. One category is chemical modifiers, which, through direct interaction with the herbicide molecule, bind to the herbicide by means of covalent or non-covalent bonds, altering its distribution and metabolic kinetics in the plant and thus reducing its toxicity to the crop. For example, some compounds with specific amine-based structures can bind to the carboxyl group in amide herbicides to form salts, effectively reducing their concentration in sensitive crop tissues. Another group are bioregulators, which indirectly exert a protective effect by activating or inhibiting specific enzyme systems in the crop associated with herbicide metabolism or detoxification processes. For example, some safeners induce crops to produce more glutathione transferase, which accelerates the binding and elimination of herbicide molecules, thereby reducing cell damage. These two types of safeners are distinctive in their chemical structures and principles of action, and together they constitute a diverse classification system of amide herbicide safeners.

2. Mechanism of Action of amide Herbicide Safeners

(1) Competition for uptake sites

Competition between herbicides and crops for specific uptake sites often exists, which can result in crop damage. Safeners, by virtue of their unique chemical structure, are able to preferentially occupy these sensitive uptake sites, thereby effectively reducing the binding of the herbicide molecule to crop cell receptors. This mechanism is similar to intermolecular competitive inhibition, which protects crops from herbicides by reducing their effective concentration[3] . Specifically, safener molecules may contain functional groups similar to those of the herbicide, allowing them to compete with the herbicide for the same binding sites in the soil or on the surface of the plant, thus blocking the pathway of the herbicide into the plant and mitigating its toxic effects on the crop.

(2) Altered metabolic pathways

Complex metabolic networks exist in plants that are responsible for the transformation and degradation of chemicals entering the body. Safety agents are able to induce or activate specific metabolic enzyme systems in the plant to facilitate the conversion of herbicide molecules through harmless or less toxic metabolic pathways, avoiding their metabolism through the original toxic pathways. Specifically, the cytochrome P450 enzyme system is one of the key enzymes involved in herbicide metabolism in plants, and safeners may accelerate the hydroxylation, dealkylation and other reaction processes of herbicide molecules by enhancing the activity of such enzymes to generate non-toxic or low-toxic metabolites. This process not only reduces the accumulation of herbicides in plants, but also attenuates their toxic effects on crops, thus achieving effective crop protection[4] .

(3) Glutathione conjugation

Glutathione (GSH), a tripeptide compound ubiquitously found in living organisms, exhibits powerful antioxidant and detoxification capabilities. Safety agents enhance the activity of glutathione-S-transferase (GST) in plants, which in turn promotes the conjugation reaction between GSH and herbicide molecules or their metabolic intermediates to produce conjugates with higher water solubility and lower toxicity. These conjugates are easily excreted from the plant excretory system, thus effectively reducing herbicide residues and toxicity accumulation in plants. The conjugation effect of glutathione not only enhances the detoxification of herbicides in plants, but also further strengthens the adversity resistance and survival ability of crops.

(4) Cell protection and repair

Herbicides generally cause varying degrees of damage to plant cells, as evidenced by disrupting membrane systems and impeding protein synthesis. And safeners can promote plant cell protection and repair through various mechanisms. On the one hand, safeners may contain components that help stabilise the cell membrane structure to reduce the damage of herbicides to the membrane system; on the other hand, safeners may also activate the antioxidant enzyme system in the plant body, scavenging free radicals and other harmful molecules generated by the action of herbicides, and thus alleviating the oxidative stress state of the cells[5] . In addition, safety agents may also promote the activation of DNA repair mechanisms in plants, assisting cells to restore their normal physiological functions. The combined effect of these cellular protection and repair mechanisms enhances the plant's ability to tolerate herbicides and ensures healthy crop growth.

3. Analysis of the Practical Application of Amide Herbicide Safeners

(1) Precision formulation - optimisation of amide herbicide and safener mixing ratios

In agricultural practices, amide herbicides are widely used because of their wide range of weed control effects and relatively low cost. However, the use of these herbicides is often accompanied by certain crop safety risks, especially potential damage to new shoots and seedlings. Therefore, the precise formulation of amide herbicides with safeners has become a key strategy to improve operational efficiency and ensure crop safety. Safety agents, as a class of chemicals that can reduce or eliminate the negative effects of herbicides on crops, can significantly improve the overall effectiveness of the weed control system when added appropriately. Through scientific calculations, the optimal mixing ratio of herbicides and safeners can not only effectively control the target weeds, but also maximise the protection of crops from chemical damage, thus achieving green and efficient farmland management.

In the case of weed management in maize fields, for example, acetamiprid, a widely used amide herbicide, has shown significant control of annual grass weeds, but may also adversely affect maize seedlings. In practice, farmers have adopted a precisely calculated mix of acetamiprid and safener. Specifically, the programme first determined the base rate of acetamiprid based on soil texture, organic matter content and the characteristics of the maize variety. Subsequently, through small-scale field trials, the addition rate of safener was gradually adjusted until the optimal ratio was found that could effectively control weed growth without affecting the normal growth of maize. In the final mix, the ratio of acetamiprid to saflufenacil is accurate to the milligram per hectare (mg/ha) level, thus ensuring a perfect balance between weed control and crop safety.

(2) Temporal regulation - precise time windows for safety agent application

The difference between the growth cycle of the crop and the growth cycle of the weed is a key factor in determining the timing of herbicide application. In order to avoid damage and to ensure that weeds are at their most herbicide-sensitive stage of growth to improve weed control efficiency, it is necessary to accurately determine the time window for safener application, i.e., before or after the crop's most herbicide-sensitive stage. This timing strategy requires not only an in-depth understanding of crop and weed biology, but also a combination of local climatic conditions, soil conditions and field management practices to develop a scientific and rational application programme.

As a widely used amide herbicide, propamocarb, as an example, has shown excellent control effects on weeds in rice fields, such as barnyard grass. However, the timing of its application has a decisive influence on the effectiveness of weed control and the safety of rice crops[6] . In practice, farmers have adopted a time-controlled strategy to accurately grasp the optimal time window for the application of propamocarb and safeners. Specifically, for the specific situation after direct seeding or transplanting of rice, farmers scientifically determined the most suitable time for application based on the growth status of rice seedlings and the growth pattern of weeds in the field. Usually, a mixture of propamocarb and safeners is chosen to be applied at the stage from the rice needle establishment stage to the stage before the one-leaf-one-heart stage. At this time, rice seedlings are more resistant to herbicides, while weeds are in the early stage of germination or growth, the most sensitive response to herbicides. By finely regulating the application time, not only did we effectively remove the weeds from the paddy field, but also ensured that the rice seedlings were protected from herbicide attack, creating favourable conditions for the subsequent growth and development of rice.

(3) Soil condition suitability - adjusting safener dosages to cope with different soil environments

A critical consideration in the in-depth exploration of the practical application of amide herbicide safeners is the profound influence of soil conditions on herbicide efficacy and their safety. Soil properties such as organic matter content, moisture, temperature and pH are directly related to herbicide adsorption, degradation rate and bioefficacy. Therefore, adjusting the application dose of safeners according to the characteristics of different soil conditions has become the core of optimising herbicide application strategies. Relevant studies have shown that soils rich in organic matter can enhance the adsorption capacity of herbicides, thus reducing the amount of herbicides transported to plants, and thus effectively reducing the risk of herbicide damage. On the other hand, under high temperature and humidity conditions, the activity of herbicides is enhanced and their efficacy is more pronounced, but at the same time the adverse effects on non-target plants may be increased. Therefore, accurate environmental monitoring and scientific dosage adjustment strategies can not only significantly improve the efficiency of weed control operations, but also ensure the safety of the ecosystem.

Taking the outstanding representative of amide herbicides as an example, the application strategy of acetamiprid under different soil conditions is particularly worth exploring. In paddy fields with abundant organic matter, acetamiprid shows significant adsorption effect, and then reducing the amount of safener becomes a strategy to maintain the high weed control effect and reduce the cost. Specifically, farmers need to conduct a soil test to clarify the range of organic matter content, and then precisely adjust the ratio of acetamiprid and its matching safener according to the test results. In the high temperature and rainy summer, the paddy soil is characterised by high humidity and high temperature, which makes the activity of acetamiprid increase dramatically. Under this circumstance, it is critical to strictly control the safener dosage to avoid the potential risk of harm caused by overdosage. At the same time, it is recommended to adopt a split application method and flexibly adjust the application time according to the weather changes to ensure that the weed control effect and ecological safety are both guaranteed.

(4) Ecological synergies - combining biological control to reduce reliance on chemical herbicides

Given the serious challenges of ecological risks and resistance problems caused by chemical herbicides, exploring and implementing ecological synergistic strategies, i.e., integrating biological control methods to reduce reliance on chemical herbicides, has become an indispensable trend in promoting sustainable agricultural development. The biological control strategy skilfully exploits the interaction mechanisms among organisms, such as the natural control role of natural enemies and the degradation ability of microorganisms, to achieve effective weed management. This strategy has significant environmental and sustainability advantages. When used in combination with amide herbicide safeners, it not only significantly improves the efficiency of weed control operations, but also helps to promote the balance and stability of agroecosystems. Through the organic combination of precision application technology and biological control methods, a weed management system with complementary advantages can be constructed. This system not only retains the rapidity and efficiency of chemical weed control methods, but also incorporates the long-lasting and environmentally friendly characteristics of biological control methods, thus opening up a new path for weed management in modern agriculture.

As an example, the ecological model of rice-duck symbiosis can be adopted for the management of rice field weeds. In this model, ducks, as natural natural enemies, can effectively inhibit the growth of weeds and some pests in paddy fields, thus reducing the reliance on chemical herbicides. At the same time, amide herbicides containing safeners, such as butachlor, are applied at the right time for the critical period of weed growth, in order to accurately control those recalcitrant weeds that are difficult to control by biological methods. During the application process, the dosage needs to be strictly controlled to ensure the maximum effectiveness of the safener and to minimise the impact on non-target organisms. In addition, the introduction of microbial degradation technology, which utilises specific microbial communities to accelerate the decomposition of herbicides in the soil, further mitigates the risk of residuals in the environment. By implementing this series of ecologically synergistic strategies, weed management in rice fields not only achieves the dual goals of efficiency and environmental protection, but also provides important support for the promotion of green agricultural production.

4. Conclusion

As an important part of modern agriculture, amide herbicides contribute significantly to improving crop yields and maintaining the ecological balance of farmland through their excellent herbicidal efficacy. However, as they are widely used, the risk of crop damage has become more and more obvious, which has prompted researchers to innovate and finally develop a breakthrough in the development of amide herbicide safeners. Through unique competition for uptake sites, metabolic pathway changes, glutathione conjugation and cell protection and repair and other multiple mechanisms, this safety agent effectively improves crop tolerance to herbicides, achieving the goal of both weed control and protection. In practical application, the use of amide herbicides and safeners has been further optimised through the strategies of precise proportioning, time regulation, soil condition adaptation and ecological synergism, providing a more scientific, safe and environmentally friendly weed control solution for agricultural production.

References

[1] LI Jin, LIU Xiu, JIN Chenzhong, CHEN Jingyu, HUANG Wei, RONG Rong, TANG Caihong, XIE Peng. Progress of amide herbicide safener mechanism of action and research application[J]. Modern Agricultural Science and Technology, 2016, (21): 107-109+114.

[2] Su Wangcang, Yang Muhan, Xue Fei, Sun Lanlan, Xu Hongle, Feng Changsong, Wu Renhai. Evaluation of safety agents for mitigating turfgrass amide herbicides[J]. Henan Agricultural Science, 2023, 52 (07): 90-97.

[3] WANG Rui, TAN Zhengying, ZHAO Asia, ZHANG Yumei. HPLC analysis of 40% benzylpyrimethamine-propyzamide dispersible oil suspension and safener cycloheximide[J]. Pesticide, 2023, 62 (04): 256-259.

[4] Guo Kunyan. Preparation of ZIF-67 based prochloraz and AD-67 nano controlled release agents and their performance [D]. Southwest University, 2023.

[5] Gao Jiadong, Tian Xingshan, Feng Li, Yang Caihong, Yue Maofeng, Cui Ye, Zhang Taijier. Mechanism of action and research progress of amide herbicide safeners[J]. Guangdong Agricultural Science, 2013, 40 (22): 101-105.

[6] HU Nan, LI Yu, HU Lifeng. Current status of research on amide herbicides and their safeners (in English)[J]. Agricultural Science & Technology, 2016, 17 (06): 1379-1382+1478.