Current Status, Problems and Countermeasures of Pesticide Registration on *Zanthoxylum bungeanum* Maxim. in China

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Abstract To provide reference for the prevention and control of diseases, pests, and weeds on *Zanthoxylum bungeanum* Maxim. and the research and development of new pesticide registrations, this paper analyzes the quantity, variety structure, dosage forms, and toxicity of pesticides registered on *Z. bungeanum* in China. The analysis reveals a relatively low quantity of pesticide registrations on *Z. bungeanum*, with no herbicide registrations; suspension concentrates dominate the dosage forms, and pesticide toxicity is classified as low-toxicity or micro-toxicity; registered pesticides target only rust, anthracnose, scale insects, aphids, and spider mites, while plant growth regulators solely involve growth regulation and shoot control. Given the current status of limited and incomplete pesticide registrations targeting major diseases, pests, and weeds on *Z. bungeanum*, severe product homogenization, and unknown maximum residue limits, it is recommended to intensify efforts in pesticide registration on *Z. bungeanum*, actively research and apply green control technologies, strengthen technical training guidance and pesticide supervision enforcement, to promote the healthy development of the industry.

Key words *Zanthoxylum bungeanum* Maxim., Pesticide registration, Current situation, Diseases and insect pests, Countermeasures

0 Introduction

Zanthoxylum bungeanum Maxim. is a perennial economic crop of the Rutaceae family, categorized as a deciduous small tree. It comprises approximately 45 genera and 13 variant varieties, which can be divided into three major types: large, small, and others. Due to its well-developed root system and low soil environmental requirements, *Z. bungeanum* is cultivated across all regions of China, with a total planting area reaching 186.67×10^4 ha. Sichuan, Shaanxi, Gansu, and Yunnan are major *Z. bungeanum* production provinces. Primarily used as a spice, *Z. bungeanum* ranks first among the "Top Thirteen Spices" and holds the reputation as the "King of Seasonings." *Z. bungeanum* is also a traditional Chinese medicinal herb, characterized by pungent, dispersing, warm, and drying properties. It functions to warm the middle jiao, dry dampness, dispel cold, relieve pain, stop vomiting and diarrhea, and expel intestinal parasites, commonly applied for vomiting, diarrhea, poor appetite, and pediatric abdominal pain due to parasitic infestation. *Z. bungeanum* wood exhibits a typical pale yellow color, deepening to dark yellow upon air exposure. Its xylem structure is dense, even, and bright-lustered, granting it artistic and craft value. With the large-scale cultivation of *Z. bungeanum*, pesticide residue issues on *Z. bungeanum* have become increasingly prominent, posing significant potential risks to the healthy development of the *Z. bungeanum* industry. As a minor crop, detailed pesticide registration information for *Z. bungeanum* remains unreported. Therefore, this paper analyzes registered pesticides for *Z. bungeanum* diseases, pests, weeds, and plant growth regulators (as of July 31, 2024) based on data from the China Pesticide Information Network, aiming to provide references for new pesticide R&D registration and disease-pest-weed control on *Z. bungeanum*.

1 Current situation of registration of *Z. bungeanum* pesticides

1.1 Registered quantity of pesticides Pesticide registration for *Z. bungeanum* started in 2007. As of July 2024, over 18 years, the number of pesticides registered and currently valid for *Z. bungeanum* totals 99, including 93 single formulations and 6 mixed formulations, accounting for 93.94% and 6.06% of the total registered pesticides respectively. The quantities registered in different years are shown in Fig. 1. The highest number of pesticide registrations for *Z. bungeanum* occurred in 2017, reaching 27; the lowest was in 2019, with zero registrations. In recent five years, the annual number of registered pesticides for *Z. bungeanum* has been low, all below 5. Regarding the structural composition of registered pesticide categories for *Z. bungeanum*, fungicides account for 44 registrations, comprising 44.44% of the total registered pesticides. Among these, 43 are single formulations and 1 is a mixed formulation, representing 97.73% and 2.27% of fungicides respectively. Among single formulations, products with active ingredients are: difenoconazole (26), tebuconazole (10), chitosan (6), and cyproconazole (1), accounting for 60.47%, 23.26%, 13.95%, and 2.33% of single formulations, respectively. The mixed formulation is pyraclostrobin · azoxystrobin, with only one registration. There are 47 insecticide varieties, ac-

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counting for 47.48% of the total registered pesticides. Among these, 42 are single formulations and 5 are mixed formulations, representing 89.36% and 10.64% of the total insecticides respectively. Among insecticide single formulations, the ranking of registered product quantities by active ingredient from highest to lowest is: etoxazole > spiromesifen = spirotetramat > flonicamid = matrine, with quantities of 19, 8, 8, 3, and 3, respectively, accounting for 45.24%, 19.05%, 19.05%, 7.14%, and 7.14% of single formulations. Five insecticide mixed formulations are registered on *Z. bungeanum*, including: 2 products combining flonicamid and acetamiprid, 1 product combining flonicamid and bifenthrin, 1 product combining spirotetramat and buprofezin, and 1 product combining spirotetramat and abamectin. There are 8 plant growth regulator varieties, comprising 8.08% of the total registered pesticides. All 8 plant growth regulator products are single formulations, including: 6 uniconazole, 1 para-chlorophenoxyacetic acid, and 1 triacontanol. No herbicide products are registered (Fig. 2).

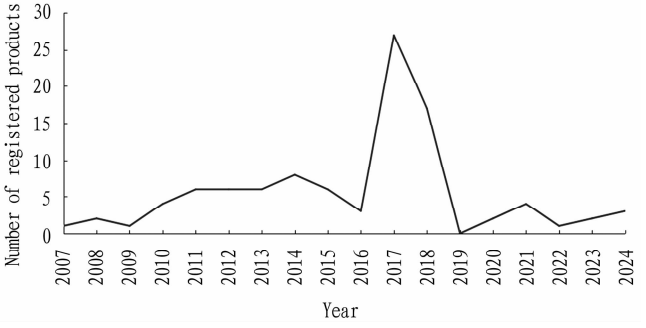

Fig. 1 Pesticides registered in the *Zanthoxylum bungeanum* Maxim. in the previous year

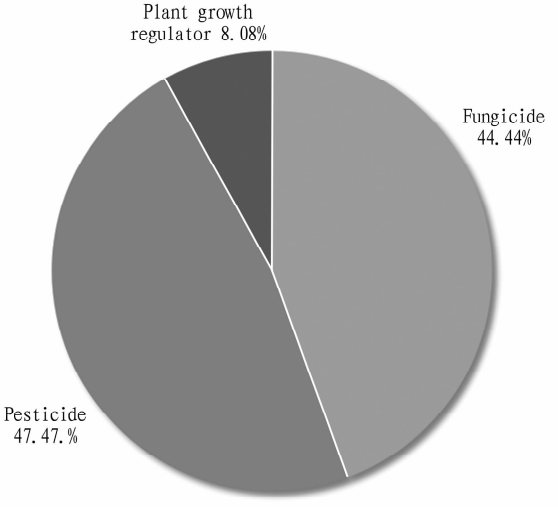

Fig. 2 Proportion of registered pesticides in *Zanthoxylum bungeanum* Maxim.

1.2 Formulations Pesticide formulations registered on *Z. bungeanum* include 8 types: Suspension Concentrate, Oil-based Suspension Concentrate, Aqueous Solution, Emulsion in Water, Water Dispersible Granule, Wettable Powder, Soluble Powder, and Microemulsion. Among the 99 products, there are 54 Suspension Concentrate formulations, 28 Water Dispersible Granule formulations, 9 Aqueous Solution formulations, 2 Oil-based Suspension Concentrate formulations, 2 Emulsion in Water formulations, 2 Wettable Powder formulations, 1 Microemulsion formulation, and 1 Soluble Powder formulation, accounting for 54.55%, 28.28%, 9.09%, 2.02%, 2.02%, 2.02%, 1.01%, and 1.01% of the total pesticide registrations, respectively.

1.3 Toxicity Twelve slightly toxic pesticide varieties are registered on *Z. bungeanum*, accounting for 12.12% of the total registered pesticides. Their active ingredients are chitosan, uniconazole, difenoconazole, Metarhizium anisopliae CQMa421, spirotetramat, etoxazole, and spiromesifen. Eighty-five low toxicity pesticide varieties are registered, comprising 87.88% of the total registered pesticides. No moderately toxic, highly toxic, or extremely toxic pesticide varieties are registered.

2 Specific registration of major diseases, pests and weeds in *Z. bungeanum* and the use of drugs for growth regulation

2.1 Registration of main pesticides for diseases

2.1.1 Root rot. Root rot is a severe fungal disease on *Z. bungeanum* that can cause mass mortality, primarily caused by *Fusarium* spp. As of now, the number of pesticides registered for controlling *Z. bungeanum* root rot is zero. Pesticides registered for controlling *Fusarium*-type root rot on other crops mainly include triadimefon, *Bacillus subtilis*, hymexazol, thiram, propiconazole, and other agents. These can be referenced for conducting trials and pesticide registration on *Z. bungeanum*.

2.1.2 Rust disease. Rust disease is a fungal disease widely occurring on *Z. bungeanum*, the pathogen being *Coleosporium zanthoxyli*. Thirty eight pesticide products have been registered in China for controlling *Z. bungeanum* rust, among which, 37 are single formulations, involving the active ingredients difenoconazole, tebuconazole, propiconazole, and cyproconazole, all of which are systemic fungicides possessing both protective and curative effects. Difenoconazole is also registered for controlling banana leaf spot disease, ginger leaf blight, honeysuckle powdery mildew, Welsh onion purple blotch, persimmon anthracnose, *Z. bungeanum* tree rust, kiwifruit brown spot, sesame stem rot, apple leaf fall disease, and others on other crops. There only one registered mixture for controlling rust, which is pyraclostrobin · azoxystrobin, a combination of succinate dehydrogenase inhibitors and methoxyacrylate fungicides, featuring broad-spectrum activity and a long-lasting effect.

2.1.3 Anthracnose. Anthracnose is a fungal disease severely affecting the yield and quality of *Z. bungeanum* fruits. Six pesticide products have been registered in China for controlling *Z. bungeanum* anthracnose, all of which belong to single formulations, with chitosan as the active ingredient and total contents of 0.5% and 2%. Chitosan is a linear high-molecular polysaccharide composed of glucosamine and acetic acid, belonging to the deacetylated product of chitin; its fungicidal mechanism primarily involves in-

terfering with the cell membrane of pathogenic microorganisms, increasing membrane permeability and reducing membrane stability, thereby destroying the membrane structure and leading to the death of microbial cells. Active ingredients registered for controlling anthracnose on other crops include difenoconazole, zineb, mancozeb, prochloraz, azoxystrobin, ziram, chlorothalonil, pyraclostrobin, *etc.*

2.1.4 Brown spot disease. Brown spot disease, also known as leaf fall disease, has *Alternaria tenuissima*, *Cercospora zanthoxyli*, and *Marssonina zanthoxyla* as its pathogenic fungi. Currently, no pesticide registrations for controlling *Z. bungeanum* brown spot disease on *Z. bungeanum* have been reported in China. Reports indicate that pyraclostrobin, difenoconazole, and trifloxystrobin · tebuconazole exhibit strong inhibitory effects against *Alternaria tenuissima*[1].

2.1.5 Gummosis. *Z. bungeanum* gummosis, also called black shank disease or dry rot disease, is a severe branch and stem disease occurring on *Z. bungeanum*. *Fusarium tricinctum* and *Dothiorella* spp. are the main pathogens of *Z. bungeanum* gummosis. Currently, no pesticide registrations have been obtained for *Z. bungeanum* gummosis. According to laboratory toxicity tests, carbendazim and dimethomorph · thiram exhibit strong inhibitory effects against *Fusarium tricinctum* and *Dothiorella* spp.[2]. Gummosis registered on other crops is a biological agent, namely *Paenibacillus polymyxa*.

2.2 Registration of main pesticides for insects

2.2.1 Red spider. *Z. bungeanum* red spider is a piercing-sucking pest. 28 pesticide products have been registered in China for controlling *Z. bungeanum* red spider, among which 27 are single formulations and 1 is a mixture formulation, involving four active ingredients: spirodiclofen, etoxazole, spirotetramat, and abamectin. Eight spirodiclofen products have been registered; their mechanism of action involves inhibiting lipid synthesis in *Z. bungeanum* mite pests, possessing characteristics of broad acaricidal spectrum, long persistence, strong adaptability, and effectiveness against both eggs and juveniles; they are particularly suitable for resistant harmful mites and simultaneously control pests such as pear psylla, oyster scale, and leafhoppers. 19 etoxazole products have been registered; their mechanism of action involves inhibiting embryonic development of mite eggs and the molting process from juveniles to adults, being effective against eggs and juvenile mites but ineffective against adult mites; however, they exhibit excellent sterilizing effects on female adults[3]. The products feature strong rain fastness and long persistence. The registered mixture product for mite control is abamectin · spirotetramat, featuring bidirectional systemic translocation and high-efficiency broad-spectrum characteristics.

2.2.2 Aphids. 10 pesticide products have been registered in China for controlling *Z. bungeanum* aphids, among which 7 are single formulations and 3 are mixture formulations. Among the 10 products, 6 belong to pyridinecarboxamide class insect growth regulator insecticides, 3 are botanical insecticides, and 1 is a microbial insecticide. They involve five active ingredients: matrine, flonicamid, acetamiprid, bifenthrin, and *Metarhizium anisopliae* CQMa421. Matrine, a botanical pesticide, is a broad-spectrum low-toxicity insecticide possessing contact and stomach poison actions; on other crops, it can concurrently control aphids, red spiders, whiteflies, *etc.* Flonicamid acts by inhibiting the sucking behavior of pests; after ingesting the chemical, pests rapidly cease sucking and ultimately die from starvation; it is effective against various piercing-sucking pests and exhibits good penetrative properties[4]. Metarhizium anisopliae is a fungus with broad-spectrum insecticidal properties; its insecticidal mechanism is unique; the infection process in aphids includes: adhesion, spore germination, penetration into the insect body, yeast-like proliferation and development within the hemocoel, production of insecticidal toxins, and lethality.

2.2.3 Scale insects. The primary scale insect species harming *Z. bungeanum* is *Pseudaulacaspis pentagona*. 10 pesticide products have been registered in China for controlling *Z. bungeanum* scale insects, among which 8 are single formulations, all being spirotetramat; 2 are mixture formulations, being spirotetramat · buprofezin and acetamiprid · flonicamid, involving the active ingredients tetronic acid, pyridinecarboxamide, chloronicotinyl, and thiadiazine. Spirotetramat kills pests by disrupting lipid biosynthesis pathways in the pests; it possesses bidirectional systemic translocation characteristics and combines ovicidal and larvicidal actions.

2.2.4 Pear psylla. Pear psylla is a piercing-sucking pest severely occurring on *Z. bungeanum* in recent years. Currently, no pesticide products have been registered in China for controlling *Z. bungeanum* pear psylla. However, there are 183 pesticide products registered for pear psylla on other crops, among which 117 are single formulations and 66 are mixture formulations, involving 15 active ingredients, including: 5 neonicotinoid insecticides, 2 mineral-source insecticides, 2 pyrethroid insecticides, 1 tetronic acid class insecticide, 1 antibiotic insecticide, 1 organophosphate insecticide, 1 formamidine insecticide, 1 arylpyrrole class insecticide, and 1 botanical insecticide.

2.2.5 Longhorn beetles. Longhorn beetles are a wood-boring pest on *Z. bungeanum*, often causing *Z. bungeanum* tree decline or even death. Currently, no pesticide products have been registered in China for controlling *Z. bungeanum* longhorn beetles. Pesticide products registered for controlling longhorn beetles on other crops include thiacloprid, cypermethrin, beta-cypermethrin, imidacloprid, emamectin benzoate, clothianidin, Beauveria bassiana, and *Metarhizium anisopliae* CQMa421.

2.3 Registration of main herbicides Up to now, no herbicide registrations have been obtained in China for controlling *Z. bungeanum* weeds. However, in actual production, the chemicals applied for weed control in *Z. bungeanum* orchards are consistent with those used in citrus orchards. According to registered weed control agents for Citrus (Rutaceae plants), the main registered herbicides include glyphosate isopropylamine salt, glufosinate-ammonium, and glyphosate ammonium salt, *etc.*

2.4 Registration of plant growth regulators Eight pesticide products have been registered in China for regulating *Z. bungeanum* growth, including 8 uniconazole products, 1 triacontanol

product, and 1 sodium p-chlorophenoxyacetate product; all products belong to single formulations, involving 3 active components, including 1 triazole-type regulator, 1 natural long-carbon-chain plant growth regulator, and 1 phenolic plant growth regulator. Uniconazole possesses the effects of controlling vegetative growth, inhibiting cell elongation, shortening internodes, dwarfing plants, promoting lateral bud growth and flower bud formation, and enhancing stress resistance[5]; it is mainly used for controlling shoot growth and promoting branch lignification in green *Z. bungeanum*. Triacontanol possesses yield-increasing effects; sodium p-chlorophenoxyacetate possesses effects such as preventing flower and fruit drop and improving fruit setting rate.

3 Problems

Z. bungeanum is a perennial crop with a long production cycle and numerous complex diseases, insect pests, and weeds. Despite the promotion of green control techniques for many years, chemical control agents on *Z. bungeanum* remain the primary control measures. In recent years, with increasing concern about food safety, the following issues still exist in pesticide registration for the *Z. bungeanum* industry development.

3.1 Registered pesticide products are few in variety and incomplete in coverage *Z. bungeanum* has over 100 types of diseases, insect pests, and weeds, with more than 10 major types affecting production. However, currently registered control targets involve only 5 types of diseases and pests in total. Among these, diseases include rust and anthracnose (2 types), while insect pests include spider mites, aphids, and scale insects (3 types). Pests and diseases that are widespread and severe in *Z. bungeanum*, such as root rot, brown spot, sooty mold, felt fungus, snails, and longhorn beetles, remain unregistered. Registered plant growth regulators include 2 types for shoot control and growth regulation; herbicide registered products are zero. In production, the types of registered pesticide products for *Z. bungeanum* are few, and the structure of registered pesticide categories is unbalanced. These factors impede rational pesticide selection and rotation, resulting in repeated use of the same chemicals and increased dosages for the same pests/diseases. This significantly increases the risk of pesticide residues exceeding standards. Simultaneously, the lack of registered pesticides available for *Z. bungeanum* production fails to meet practical needs, severely restricting the healthy development of the *Z. bungeanum* industry and the comprehensive improvement of agricultural product quality and safety levels.

3.2 Serious product homogeneity and unknown maximum residual level (MRL) 99 registered pesticide products on *Z. bungeanum* involve only three major categories: insecticides, fungicides, and plant growth regulators. Among these, products controlling *Z. bungeanum* rust total 38, occupying over 1/3 of registered products, and among these, products with difenoconazole as the active ingredient number 26; registered pesticide products controlling spider mites total 28, and among these, products with etoxazole as the active ingredient number 19; registered pesticide products controlling *Z. bungeanum* scale insects total 10, and among these, single formulations with spirotetramat as the active ingredient number 8. Pesticide products registered for controlling rust, spider mites, and scale insects account for over 70% of the total registered quantity. Thus, the current registered pesticide products on *Z. bungeanum* exhibit severe homogeneity. Further investigation into the maximum residue levels of the 99 registered pesticide products on *Z. bungeanum* reveals that although over 30 pesticide maximum residue limits for *Z. bungeanum* are stipulated in relevant national standards, none of the currently registered pesticide products on *Z. bungeanum* have corresponding residue limit standards.

4 Countermeasures

4.1 Improving efficiency of registration of pesticides for *Z. bungeanum* *Z. bungeanum* belongs to the spice crop category within the pesticide registration residue trial groups for specialty minor crops. Besides *Z. bungeanum*, the trial group includes eight other crops: cinnamon, pepper, star anise, fennel, cardamom, dried tangerine peel, cassia bark, and wasabi (mustard). Within the spice crop trial group, except for *Z. bungeanum* and pepper which have registered pesticide products, the other seven spice crops currently have no registered pesticide products. Therefore, considering the current status of registration for minor crop trial groups, pesticide registration enterprises are advised to utilize the registration approval green channels established by the Ministry of Agriculture and Rural Affairs for pesticide registration in specialty minor crop groups. They should familiarize themselves with a series of incentive policies and technical measures regulating pesticide registration and safe use for specialty minor crops[6]. The second recommendation is that provincial authorities establish special fiscal funds to encourage and support pesticide enterprises in conducting joint registration trials for *Z. bungeanum* pesticides, particularly for microbial, botanical, and mineral-based pesticide registrations. The third recommendation is that pesticide manufacturers prioritize and increase investment to strengthen pesticide registration efforts for specialty crops, expanding registrations for controlling *Z. bungeanum* pests and diseases such as root rot, brown spot, gummosis, sooty mold, pear psyllids, longhorn beetles, as well as herbicides. This will enhance the diversity of pesticide registrations and improve the capacity for pest control and yield protection, quality improvement and efficiency enhancement in *Z. bungeanum* production.

4.2 Strengthening the research and development of comprehensive technology of green prevention and control for *Z. Bungeanum* diseases and insect pests Under the circumstances of insufficient registered pesticides for *Z. bungeanum* and the "lack of available pesticides" for certain diseases, insect pests, and weeds, research institutions should strengthen the research and promotion of comprehensive green control techniques for *Z. bungeanum* diseases, insect pests, and weeds. Based on the occurrence and damage characteristics of *Z. bungeanum* diseases, insect pests, and weeds in China, focus should be placed on enhancing key research and development in agricultural control,

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garnering increased support and attention for agricultural research innovation and technology services.

3 Prospects

In future development, Changli Institute of Pomology will deepen Party-building brand development, keeping its banner aloft in scientific innovation and technology services to guide greater intellectual contributions and continuous breakthroughs. It will strengthen the deep integration of Party-building with professional work while exploring innovative operational models and methodologies. For scientific innovation, increased investment in cutting-edge technology research will cultivate high-quality talents and achieve more groundbreaking results in key fields. Regarding technology services, it will expand service coverage, improve quality, and strengthen ties with farmers and agribusinesses to address practical agricultural challenges. Simultaneously, enhanced promotion of the Party-building brand will exemplify leadership, providing references for other agricultural research institutions to jointly advance China's agricultural scientific innovation and technology service development.

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biological control, and physical/chemical lure control technologies. Research should be conducted on precision application techniques for biological pesticides to establish a green control technology system centered on ecological regulation supplemented by scientific pesticide application. This system should be widely promoted and applied in production to achieve efficient, ecological, and green control of diseases, insect pests, and weeds in the *Z. bungeanum* industry, thereby reducing the industry's dependence on and usage of chemical pesticides.

4.3 Strengthening training, publicity and pesticide supervision and law enforcement During key stages of *Z. bungeanum* production such as garden clearing, pre-germination water-fertilizer management, and fruit expansion stage management, agricultural management departments and *Z. bungeanum* industry R&D teams should actively organize farmers, large-scale growers, and grassroots agricultural technicians to conduct technical training on scientific pesticide use and production management techniques. This includes pesticide variety selection, application methods, frequency of use, dosage for *Z. bungeanum*, aiming to enhance practitioners' understanding of pesticides and scientific cultivation levels while reducing excessive pesticide use. Through online platforms, newspapers, magazines, and other media, scientific pesticide application, agricultural product quality and safety, and green control concepts should be actively promoted to strengthen growers' awareness for scientific pesticide use. In addition to strengthening pesticide supervision and law enforcement to strictly investigate illegal activities such as trafficking counterfeit and substandard pesticides, provincial agricultural and rural departments should actively organize personnel to formulate and implement interim pesticide use measures based on local *Z. bungeanum* production realities. This involves guiding the adoption of multiple measures to control *Z. bungeanum* diseases, insect pests, and weeds, further reducing pesticide residues, improving quality and efficiency, and promoting the healthy development of the *Z. bungeanum* industry.

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