__Original Research Article__

Evaluation of the Indoor Efficacy of Various Foliar-Applied Herbicides on *Sicyos angulatus* Seedlings

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Abstract:

Sicyos angulatus is an increasingly pervasive alien species, has been identified as asignificant contributor to the deterioration of biodiversity within the northern quadrant ofthe china. This encroachment necessitates an exigent examination of foliar herbicides for efficacious management strategies targeting the juvenile growth phase of the species. The current investigation was meticulously designed to evaluate the suppressive capability of seven distinct foliar-applied phytotoxic compounds—Prometryn, Thifensulfuron methyl, Nicosulfuron, Mesotrione, Bentazone, Imazethapyr, and a composite formulation of Dicamba-Glyphosate-Triclopyr—on the seedling cohort of *S. angulatus* within a controlled laboratory framework. Aqueous solution served as the experimental baseline (control). The results indicated that all evaluated agents exhibited inhibitory effects on the seedlings. The Bentazone treatment exhibited an excellent control effect, with a fresh

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weight inhibition rate exceeding 95% on *S. angulatus* seedlings. Similarly, the Mesotrione and Dicamba-Glyphosate-Triclopy treatments demonstrated a good control effect, resulting in a fresh weight inhibition rate of over 85%. When treated with Prometryn, the *S.angulatus* seedlings displayed a moderate control effect, as indicated by a fresh weightinhibition rate exceeding 55%. However, Thifensulfuron methyl, Nicosulfuron, andImazethapyr showed poor control effects with a fresh weight inhibition rate below 55%. In light of these findings, it is posited that Mesotrione, Bentazone, and the Dicamba-Glyphosate-Triclopyr blend manifest as viable candidates for the prophylaxis and remediation of the early-stage growth of *S. angulatus*. Paramount to the study's conclusions is the lack of statistically significant disparity in the suppression outcomes across the concentration spectrum of the aforementioned efficacious agents. Hence, when juxtaposing ecotoxicological ramifications and economic considerations, the adoption of a concentration commensurate with the standard unitary dosage is proposed.

Keyword: Sicyos angulatus; Seedling stage; Foliar-applied herbicide; Indoor experiments; Fresh weight

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1. INTRODUCTION

The burcucumber (*Sicyos angulatus* L.), an annual herbaceous vine belonging to the *Sicyos* genus in the Cucurbitaceae family, is native to North America[1]. This species exhibits a wide distribution across Europe and Asia due to its strong adaptability, high reproductive capacity, and diverse modes of dispersal [2,3,4]. Moreover, it has been observed in various regions such as Taiwan, Hebei, Liaoning, and Beijing[5,6,7]. The upward growth of *S. angulatus* through entangling other plants leads to their growth restriction and eventual death due to light deprivation, resulting in significant damage to biodiversity and the occurrence of ecological disasters. Extensive research has been conducted by both domestic and international scholars on the control of *S. angulatus*, encompassing physical, chemical, biological, and other control methods[8,9,10,11,12] . Among these methods, chemical control has emerged as the primary approach for large-scale management of *S. angulatus* due to its cost-effectiveness, rapid efficacy, and convenience. Specifically, chemical control methods have been primarily applied to crops and have demonstrated good weed control effects. For instance, Esbenshade et al evaluated the efficacy of postemergence (POST) soybean herbicides against *S. angulatus* by applying them during the early-POST and mid-POST stages (6-8 leaves), as well as the late-POST

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stage (more than 10 leaves)[9]. The results indicated that nine herbicides, including glyphosate, exhibited an efficacy exceeding 87% when applied during the late-POST stage. Messersmith et al assessed the herbicide efficacy in an established *S. angulatus* population within a corn field, with applications made at 8, 11, and 14 weeks after planting. CGA 152005, primisulfuron, and their combination showed over 85% efficacy in controlling *S. angulatus* at the 14-week post-planting stage[8]. Notably, the vulnerable growth period for postemergence weeds, including *S. angulatus*, occurs at the 3-5 leaf stage (approximately 4 weeks after planting), and applying herbicides during this specific timeframe yields optimal results [13]. However, no research has focused specifically on herbicide screening for this phase of *S. angulatus* growth, leading to uncertainty regarding the potential enhancement of control efficacy during this period. Therefore, in order to rapidly identify herbicides that can effectively manage *S. angulatus* post-emergence, this experiment employed seven foliar-applied herbicides with diverse mechanisms of action during this critical growth period to determine the most efficacious ones for controlling *S. angulatus* seedlings.

In accordance with the tenets of high efficacy, safety, and precise selectivity, a set of 7 foliar-applied herbicides with distinct mechanisms of action was deliberately chosen to undertake an indoor experimentation on *S. angulatus* seedlings. The objective was to identify the foliar-applied

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herbicides yielding the most effective therapeutic impact on *S. angulatus* seedlings, as evidenced by evaluations of phytotoxicity grade fresh weight effect, and efficacy evaluation. This investigation offers a theoretical framework for the accurate chemical management of *S. angulatus*.

2. MATERIALS AND METHODS

2.1 Experimental materials

In October of 2021, *S. angulatus* fruits were harvested from a maize field located in Pulandian, Dalian City, within the province of Liaoning. Subsequently, the fruits underwent an indoor air drying process before being carefully packaged and stored in a refrigerated environment at a temperature of 4℃, until their intended utilization.

The selected herbicides for the experiment include Prometryn, Thifensulfuron methyl, Nicosulfuron, Mesotrion, Bentazone, Imazethapyr, and the herbicide mixture Dicamba-Glyphosate-Triclopyr. The characteristics and profiles of these herbicides are presented in Table 1.

Table 1

Herbicide characteristics and profiles

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Herbicides	Main ingredients (dosage forms)	Manufacturer	Feature	Mechanism of action
Prometryn	50% Prometryn (WP)	Shangdong Vicome Greenlan And Chemical Co. LTD	Wide spectrum, extended efficacy, low toxicity, and chemically stable.	Its mode of action involves the inhibition of photosynthesis in the leaves of weeds, thereby hindering their proper growth and ultimately leading to wilting and death.

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Thifensulfuron methyl	25% Thifensulfuron methyl (WP)	Anhui Fengle Agrochemical Co. LTD	Wide spectrum, low toxicity, minimal residue, and high activity	It acts by suppressing the biosynthesis of branched-chain amino acids such as valine, leucine, and isoleucine, which hinders cell division in weeds and causes them to cease growth and die.

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Nicosulfuron	10% Nicosulfuron (OD)	Shandong Aokun Crop Science Co. LTD	Wide spectrum, comprehensive weed control, good safety, and mixability	Its mechanism of action involves the inhibition of branched-chain amino acid production in plants, thereby preventing normal mitosis and gradually leading to weed demise.

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Mesotrion	15% Mesotrion (SC)	Sichuan Runer Technology Co. LTD	Wide spectrum, high activity, low dosage, and good environmental compatibility	It functions by reducing the carotenoid content in weeds through the inhibition of HPPD, rendering the weed unable to absorb nutrients and leading to its death.

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Bentazone	480g/L Bentazone (WS)	Anhui Fenglele Agrochemical Co. LTD	Wide spectrum, effective prevention, and drug resistance properties	Its mode of action targets the D1 protein of PSII in weeds to inhibit the photosynthetic electron transport of PSii, thereby achieving weed control.

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Imazethapyr	5% Imazethapyr (EW)	Shandong Cynda (Chemical) Co. LTD	Wide spectrum, high selectivity, and high activity	It acts by inhibiting acetolactate synthase, thereby inhibiting the biosynthesis of branched-chain amino acids and resulting in plant growth inhibition and death.

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Dicamba-Glyphosate-Triclopyr	10% Dicamba + 50% Glyphosate + 2% Triclopyr (WP)	Shandong Yilan Technology Co. LTD	To address the issue of drug resistance in malignant weeds by expanding the spectrum of weed-killing	Its mode of action involves impeding normal weed hormone activity, inhibiting protein synthesis, and embolizing or rupturing vascular bundles to cause weed death.
Check	Water			

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2.2 Experimental design

The experiment was carried out on January 3, 2022, utilizing the greenhouse pot method for cultivating *S. angulatus*. Nutritive soil with a minimum organic matter content of 40%, neutral pH levels, and good permeability (with a matrix of vermiculite and soil in a ratio of 3:1) was employed. Plastic basins, measuring 5cm in diameter and 10cm in height, were filled with moist nutrient soil up to 4/5th of their capacity. The seeds were planted at depths ranging from 0.5cm to 2cm below the soil surface and placed in a greenhouse with diurnal temperatures maintained at 25°C and nocturnal temperatures at 15°C. Adequate soil moisture was consistently maintained throughout the experiment.The dosage of the herbicide was determined based on the manufacturer's instructions, and two treatment groups (Table 2) were established, with each group having 4 replicate samples. Treatment group 1 represented a single application, while treatment group 2 represented two applications. A water control group was also included concurrently. When the seedlings reached the 3-5 leaf stage, the stems and leaves were treated using a sprayer with a spray volume of 450L/hm^2, following the guidelines outlined in " Pesticides guidelines for laboratory bioactivity tests Part 4: Foliar spray application test for herbicide activity. Subsequently, the plants were transferred to the greenhouse for routine incubation, and remaining damage was observed and recorded for a period of 5 consecutive days. The fresh weight effect was calculated as part of the evaluation process.

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Table 2

Experimental herbicide doses for *Sicyos angulatus* control

Herbicides	Dose 1/(g a.i./hm^2)	Dose 2/(g a.i./hm^2)

Prometryn	1499.25	2998.50
Thifensulfuron methyl	119.94	239.88
Nicosulfuron	749.62	1499.25
Mesotrion	974.51	1949.02
Bentazone	2998.50	5997.00
Imazethapyr	1499.25	2998.50
Dicamba-Glyphosate-Triclopyr	1349.32	2698.65

2.3 Phytotoxicity grade

Following the completion of the treatment protocol, the daily monitoring of the growth status of *S. angulatus* was undertaken, with attentiveness to any noticeable indicators of detrimental effects. The primary manifestations identified, as documented by ICAMA[14], entailed:

——Changes in color (etiolation, bleaching, etc.)

——Morphological alterations (new leaf deformity, distortion, etc.)

——Modifications in growth patterns (dehydration, wilt, dwarfism, etc.)

The assessment of the herbicidal efficacy of the agents was conducted by considering the discernible symptoms and the level of damage inflicted on the tested *S. angulatus* seedlings. To ensure consistency and uniformity, the grading system outlined by ICAMA was adopted for this purpose[14]:

- Level 1: all dead

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- Level 2: it was equivalent to 0% to 2.5% of the control group
- Level 3: it was equivalent to 2.6% to 5 % of the control group
- Level 4: it was equivalent to 5.1% to 10% of the control group
- Level 5: it was equivalent to 10.1% to 15% of the control group
- Level 6: it was equivalent to 15.1% to 25% of the control group
- Level 7: it was equivalent to 25.1% to 35% of the control group
- Level 8: it was equivalent to 35.1% to 67.5% of the control group
- Level 9: it was equivalent to 67.6% to 100% of the control group

2.4 Fresh weight effect

Following the application, the above-ground component will be sampled continuously for a period of 5 days. The fresh weight of the samples will be determined, and subsequently, the fresh weight effect will be calculated and expressed as a percentage (%). The resulting calculation will be rounded to two decimal places and retained.

$\boldsymbol{E} = \frac{\boldsymbol{C}-\boldsymbol{T}}{\boldsymbol{C}} \times \mathbf{100}$[15]

In the formula：

- *E*——fresh weight effect
- *C*——Fresh weight of *S. angulatu* above ground in control group
- *T*——Fresh weight of *S. angulatu* above ground in treatment group

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2.5 Efficacy evaluation

Based on the low dosage of each medication, *S. angulatus* was classified according to its fresh inhibition rate [16].

- I≥95%: excellent
- 85≤I＜95%: good
- 55%≤I＜85%: moderate
- I＜55%: poor

2.6 Statistical analysis

The data from Excel 2016 was compiled and SPSS 22.0 was utilized to conduct a one-way analysis of variance (ANOVA). In order to identify significant differences between the means, Duncan's multi-range test was employed with a significance level set at $P< 0.05$.

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3. RESULTS

3.1 Herbicidal activity of different foliar-applied herbicides on S. angulatus seedlings

After the application of various foliar-applied herbicides, distinct levels of phytotoxicity grade and victimization symptoms were observed on *S. angulatus* seedlings. Notably, on the fifth day, all seedlings treated with Mesotrion, Bentazon, and Dicamba-Glyphosate-Triclopyr resulted in mortality(Table 3, Fig. 1). Three days post-treatment, seedlings treated

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with Bentazone exhibited symptoms of leaf etiolation and drug-induced damage, accompanied by deformity and wilt. Similarly, seedlings treated with Dicamba-Glyphosate-Triclopyr displayed symptoms of drug-induced damage, characterized by leaf etiolation, distortion, and wilt. The aforementioned herbicides exhibited severe detrimental effects on *S. angulatus* plants, reaching a grade 4 level of damage. By the fourth day of treatment, Bentazone and Dicamba-Glyphosate-Triclopyr treatments resulted in seedling mortality, with *S. angulatus* experiencing grade 1 damage. Mesotrion-treated leaves showed irregular bleaching, deformity, and wilt symptoms, while leaves treated with double the concentration of Mesotrion exhibited complete wilt, leading to grade 4 damage in S. angulatus. After five days of treatment, Mesotrion displayed signs of drug-induced damage on the deceased seedlings, with phytotoxicity reaching a grade 1 level in *S. angulatus*. Overall, the efficacy of Bentazone and Dicamba-Glyphosate-Triclopyr was observed to be the highest, followed by Mesotrion, in terms of speed of action on *S. angulatus*. Each herbicide displayed distinct mechanisms of action: Bentazone primarily inhibits plant photosynthesis, Dicamba-Glyphosate-Triclopyr disrupts weed hormones to induce *S. angulatus* seedling mortality, and Mesotrion inhibits HPPD, thus affecting carotenoid biosynthesis and causing *S. angulatus* death.

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Table 3

Phytotoxicity grade of different foliar-applied herbicides on *S. angulatus* seedlings

Herbicides	Dose	Phytotoxicity grade				
		1 d	2 d	3 d	4 d	5 d
Prometryn	1	9	8	6	4	2
	2	9	8	6	4	2
Thifensulfuron methyl	1	9	9	9	8	7
	2	9	9	9	8	7
Nicosulfuron	1	9	9	9	9	9
	2	9	9	9	9	9
Mesotrion	1	9	9	8	4	1
	2	9	9	8	4	1
Bentazone	1	9	8	4	1	1
	2	9	8	4	1	1
Imazethapyr	1	9	9	9	9	9
	2	9	9	9	9	9
Dicamba-Glyphosate-Triclopyr	1	9	8	4	1	1
	2	9	8	4	1	1

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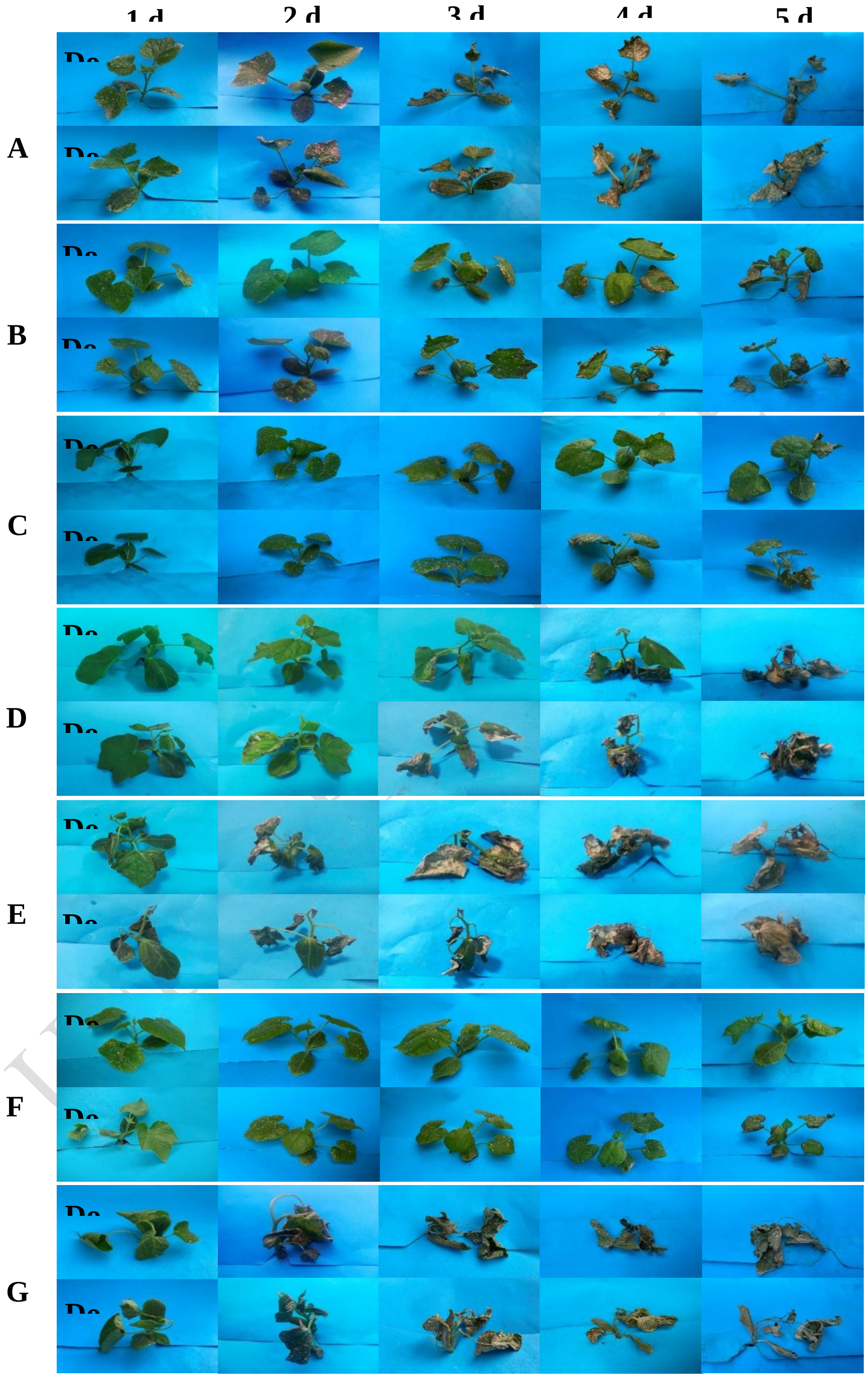
1 d
2 d
3 d
4 d
5 d
A
B
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D
E
F
G

Fig. 1. Victimization symptom of different foliar-applied herbicides on *S. angulatus* seedlings

Note: A: Prometryn; B: Thifensulfuron methyl; C: Nicosulfuron; D: Mesotrion ; E: Bentazone ; F: Imazethapyr ; G: Dicamba-Glyphosate-Triclopyr; d: Number of days.

3.2 Fresh weight effect of different foliar-applied herbicides on S. angulatus seedlings

In comparison to the control group treated with water, the application of herbicides on *S. angulatus* seedlings five days post-treatment resulted in a fresh weight effect ranging from 46.27% to 97.27% (Table 4). Among the herbicides tested, Bentazone exhibited the most favorable fresh weight effect, with values of 96.52% and 97.26%, consecutively. This was closely followed by the Bentazone and Dicamba-Glyphosate-Triclopyr treatments, which achieved fresh weight effects of 93.03%, 96.52%, 94.28%, and 93.78%, respectively. Statistical analysis revealed no significant difference among these three herbicide treatments ($P>0.05$). Conversely, the fresh weight effects of *S. angulatus* treated with 1-fold concentrations of Imazethapyr and Nicosulfuron were notably lower, both below 50%. Additionally, the fresh weight effects of 1-fold concentrations of Nicosulfuron and Imazethapyr were significantly different from those of the 2-fold concentration ($P<0.05$). Therefore, Mesotrion, Bentazone, and Dicamba-Glyphosate-Triclopyr demonstrated effective control of *S.*

angulatus seedlings.

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Table 4

Fresh weight effect of different foliar-applied herbicides on *S. angulatus* seedlings*

Herbicides	Dose	Fresh weight effect /%
Prometryn	1	78.11cd
	2	84.08de
Thifensulfuron methyl	1	53.23ab
	2	65.67ab
Nicosulfuron	1	47.76a
	2	63.18bc
Mesotrion	1	93.03e
	2	96.52e
Bentazone	1	96.52e
	2	97.26e
Imazethapyr	1	46.27a
	2	69.40cd
Dicamba-Glyphosate-Triclopyr	1	94.28e
	2	93.78e

Note: *The same letter after the same column of data indicates that the difference is not significant at the 5% level.

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3.3 Efficacy evaluation of different foliar-applied herbicides on S. angulatus seedlings

All seven agents tested demonstrated inhibitory effects on the seedlings of *S. angulatus*. Bentazone showed exceptional effectiveness in controlling the seedlings, while Mesotrione and Dicamba-Glyphosate-Triclopy similarly exhibited substantial efficacy. Prometryn exhibited a moderate degree of control over the seedlings. However, Thifensulfuron methyl, Nicosulfuron, and Imazethapyr demonstrated poor efficacy in controlling the seedlings (Table 5). These findings suggest that Mesotrione, Bentazone, and Dicamba-Glyphosate-Triclopyr could serve as viable herbicides in the prevention and control of *S. angulatus* seedlings.

Table 5

Efficacy evaluation of different foliar-applied herbicides on *S. angulatus* seedlings

Efficacy evaluation	Fresh weight inhibition rate	Herbicides
Excellent	≥95%	Bentazone
Good	85≤I＜95%	Mesotrione and Dicamba-Glyphosate-Triclopy
moderate	55%≤I＜85%	Prometryn
Poor	I＜55%	Thifensulfuron methyl,

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4. DOSCUSSION

The rapid proliferation of *S. angulatus* has resulted in significant crop losses. A study was conducted in Japan to examine the repercussions of *S. angulatus* on agricultural lands through a series of surveys. The results demonstrated a noteworthy contraction in field dimensions, whereby an 80% diminution occurred with a population density of 15-20 individuals per 10 m^2. Furthermore, alarming reductions of 90-98% were observed when the population density increased to 28-50 individuals per 10 m^2[17]. Averill et al investigated the impact of *S. angulatus* on *Z. mays* through a field experiment. Various densities of *S. angulatus* seedlings were transplanted into corn rows, and the findings indicated that different planting densities of *S. angulatus* resulted in reduced corn yields[18]. Specifically, planting *S. angulatus* at a rate of one square meter per hectare led to a decrease in corn yield by approximately 1700 kg ha^{-1}. These findings underscore the destructive capacity of *S. angulatus*, emphasizing the pressing requirement for efficacious interventions to alleviate its detrimental impact on agricultural productivity. Currently, large-scale control measures for *S. angulatus* are still being explored, with chemical control being the most commonly employed and effective weed control technique, including pre-seedling soil treatment herbicides and post-seedling foliar-applied treatment herbicides [19]. Among these, post-seedling foliar-applied treatment herbicides eliminate weeds by absorbing and translocating the drugs through the stems and leaves of the weeds. Its advantages include reduced influence from soil factors, good flexibility and selectivity, and a wide range of applications[20]. As herbicides with significant efficacy in preventing and controlling *S. angulatus* seedlings, it is crucial to apply appropriate dosages to crops such as *Z. mays* and Glycine max to minimize damage. Liang investigated the minimum effective control dosage of Mesotrion, a commonly used herbicide in corn fields, on weeds[21]. The results revealed that when the lowest effective control dosage of a 15% Mesotrion suspension concentrate was 146.3 g a.i./hm^2, it resulted in the lowest residual weed density in corn fields, with a digestion rate exceeding 90% after three days. The different Mesotrion treatments in this experiment align with the minimum effective control dosage established by previous studies. Chen et al demonstrated that the recommended Bentazone dosage ranged from 2248.87 gaito 2998.50gai./hm^2, without causing any drift damage to neighboring crops. The concentration of the trisomide used in this experiment coincides with the recommended dosage in earlier studies[22]. Dicamba-Glyphosate-Triclopyr is a compound herbicide, and no relevant research reports have been found thus far, making it impossible to determine the residue limit standards.

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5. CONCLUSION

In conclusion, the effects of different doses of Mesotrion, Bentazone, and Dicamba-Glyphosate-Triclopyr on *S. angulatus* seedlings' fresh weight did not exhibit significant differences. Considering the recommended dosages from previous studies and for safety and economic reasons, a concentration equal to a 1-time dosage can be selected.

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