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# Synthesis and Herbicidal Activity of *N,N*-Diethyl-3-(arylselenonyl)-1*H*-1,2,4-triazole-1-carboxamide

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Based on the carbamoyl triazole herbicide Cafenstrole, 12 novel selenium-containing compounds were designed and synthesized. All of the compounds were characterized and confirmed by IR, $^1$H NMR, and high-resolution mass spectroscopy. The bioassay tests showed that some of the compounds (**$C_2$**, **$C_4$**, **$C_{7-8}$**, and **$C_{12}$**) exhibited good inhibitory activity against cucumber (*Cucumis sativus* L.) and semen euphorbiae (*Leptochloa chinensis* N.). Especially, compound **$C_6$** inhibited the growth of cucumber and semen euphorbiae by >90% at a concentration of 1.875 $\mu$g/mL, and the inhibition of the compound on the rice (*Oryza sativa* L.) was only 8.3% at a concentration of 7.5 $\mu$g/mL, which indicated a higher selectivity between weed and rice than that shown by Cafenstrole.

**KEYWORDS: Carbamoyl triazole herbicide; selenium; bioactivity**

## INTRODUCTION

As an important microelement, selenium is of great interest in chemistry (*1*−*4*), biochemistry (*5*), and medicine and medicine-related fields (*6*, *7*). It is also used for bioisosteric replacement of oxygen and sulfur in bioactive molecules to obtain more bioactivity or safety. Nawaf reported the first example of tertiary radicals undergoing intramolecular hemolytic substitution reactions at selenium to synthesize selenium-containing vitamin E analogues (*8*). Laitem had introduced selenium to 3-indoylacetic acid and found that 3-(benzo[*b*]-selenienyl)acetic acid (BSAA) showed high activity as an auxin (*9*). Recently, Tadino reported that the modification of 2,4-dichlorophenyloxyacetic acid (2,4-D) with selenium to 2,4-dichlorophenylselenoacetic acid (2,4-D-Se) led to a more powerful synthetic auxin than the parent compound (*10*). These comprehensive studies implied the possibility of extending selenium's use in pesticides.

The carbamoyl triazole herbicides are some of the most important agrochemicals for controlling grass in rice fields, and they are widely used as pre-emergence herbicides to reduce grass and some dicotyledonous weeds in oilseed rape, soybean, maize, and other crop fields (*11*, *12*). The general formula of the carbamoyl triazole herbicides is shown in **Figure 1**. When the aromatic ring is mesitylene and $R_1 = R_2 = CH_3$, $n = 2$, the derivative, named Cafenstrole (CH-900), has the highest inhibitor efficiency against weeds. Confirmed by other experiments, many compounds of this kind, such as Epronaz (BTS-30843), THF-450, and CH-2000 (**Figure 2**), also have inhibitor activity against weeds (*13*). In view of this, we try to keep the potential groups and replace sulfur with selenium in the general formula (**Figure 3**) and evaluate the biological activity of the derivatives.

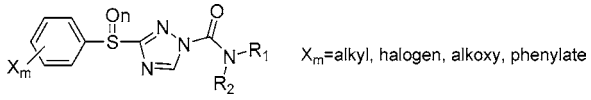


**Figure 1.** General formula of triazole herbicides.

## MATERIALS AND METHODS

**Instruments and Chemicals.** All melting points (mp) were obtained with an electrothermal digital apparatus made in Shanghai and are uncorrected. $^1$H NMR spectra were recorded on a Bruker WP-500SY (500 MHz) spectrometer with $CDCl_3$ as the solvent and TMS as the internal standard. Chemical shifts are reported in $\delta$ (parts per million) values. Infrared spectra were measured on a Nicolet FT-IR-20SX instrument using a potassium bromide (KBr) disk, scanning from 400 to 4000 cm$^{-1}$. Mass spectra were recorded under electrospray-impact conditions using an LCT KC317 instrument. Analytical thin-layer chromatography (TLC) was carried out on precoated plates (silica gel 60 $F_{254}$), and spots were visualized under UV light. All chemicals and reagents were purchased from standard commercial suppliers.

**General Synthetic Procedure for Arylselenonyl-1*H*-[1,2,4]triazole ($A_1$−$A_{12}$).** 1-Formylselenosemicarbazide was prepared according to a reported procedure (**Scheme 1**) (*14*, *15*). Potassium hydroxide pellets (2,24 g, 0.04mol) were dissolved in 33 mL of methanol and cooled to room temperature. 1-Formylselenoseicarbazide (3.36 g, 0.02 mol) was added. After refluxing for 40 min, the mixture (A) was cooled to 0 °C

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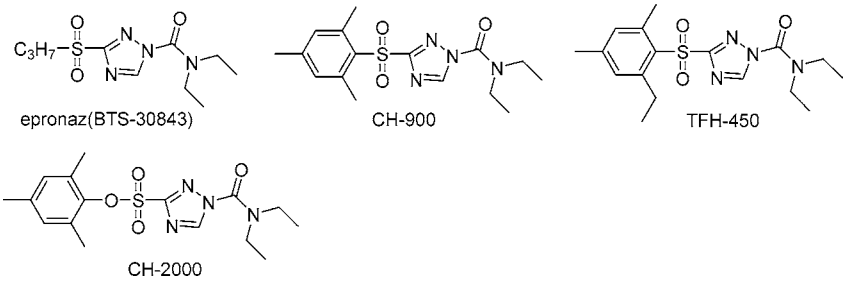



**Figure 2.** Formulas of primary triazole herbicides.

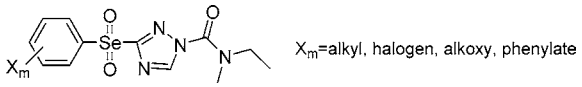



**Figure 3.** General formula of triazole compounds that will be synthesized.

for further use. Arylamine (0.02 mol) was dissolved in 20 mL of methanol and was slowly added to 2.1 mL (0.08 mol) of concentrated hydrochloric acid, stirred at the same temperature for 15 min, and then cooled to −5 °C. A solution of 1.79 g (0.021 mol) of sodium nitrite in 10 mL of water was added dropwise to the mixture over a period of 15 min. When the dropwise addition was complete, the mixture was stirred for another 40 min at 0 °C to obtain a nearly colorless solution (B). Solution B was added dropwise to mixture A during 1 h, and 4.48 g (0.08 mol) of KOH in 15 mL of water was added carefully at the same time to keep the pH at ∼12. After 5 h of stirring at 0 °C, methanol was distilled off under vacuum, and the mixture was filtered. The filtrate was extracted with chloroform (3 × 30 mL), dried over anhydrous sodium sulfate, and purified with column chromatography through silica gel with EtOAc/petroleum ether (v/v = 1:1) to give $\mathbf{A_1}-\mathbf{A_{12}}$.

The pH value is the key factor for the reaction of the diazonium salt with potassium 1*H*-[1,2,4]triazole-3-selenoxide to arylselanyl-1*H*-[1,2,4]triazoles. Accordingly, the pH was adjusted to pH 12 using KOH when the solution of diazonium (B) was added dropwise to mixture A.

**General Synthetic Procedure for Arylselenonyl-1*H*-[1,2,4]triazole ($\mathbf{B_1}-\mathbf{B_{12}}$).** NaOH (0.66 g, 0.0166 mol) and $Na_2HPO_4{\cdot}H_2O$ (0.9 g, 0.0025 mol) were dissolved in 10 mL of water and added carefully to 0.0025 mol of a vigorously stirred mixture of corresponding arylselanyl-1*H*-[1,2,4]triazoles ($\mathbf{A_1}-\mathbf{A_{12}}$) in 30 mL of methanol, followed by the quick addition of 10 mL of aqueous of Oxone (3.07 g, 0.005 mol). After room temperature had been maintained during 20 min of stirring, the mixture was filtered and washed with 30 mL of methanol. The filtrate was evaporated under reduced pressure to remove the methanol, neutralized with 6 M NaOH, filtered, and dried in vacuum desiccators to give $\mathbf{B_1}-\mathbf{B_{12}}$.

The oxidation of arylselelanyl-1*H*-[1,2,4]triazoles to arylselenonyl-1*H*-[1,2,4]triazoles is a laborious job for the synthesis of the compounds introduced above. Only arylseleninyl-1*H*-[1,2,4]triazoles have been obtained when the method was tried with $H_2O_2$, benzoyl Peroxide (BPO), and $K_2S_2O_8$. Oxone, a strong oxidant produced by BASF Co., has been selected by luck at last. The pH value is also the key factor for the oxidation reaction, so the buffer solution of NaOH and $Na_2HPO_4$ was used to adjust the pH of the reaction mixture to 8−9. In addition, the solution of Oxone should be added quickly so that the pH of the mixture reaches the goal quickly.

**General Synthetic Procedure for Arylselenonyl-[1,2,4]triazole-1-carboxylic Acid Diethylamide ($\mathbf{C_1}-\mathbf{C_{12}}$).** The corresponding arylselenonyl-1*H*-[1,2,4]triazole ($\mathbf{B_1}-\mathbf{B_{12}}$) was added (0.002 mol), followed by 0.55 g (0.004 mol) of anhydrous $K_2CO_3$, to anhydrous acetone (30 mL). The mixture was stirred for 20 min, 0.5 mL of triethylamine (TEA) and 0.41 g (0.003 mol) of diethylcarbamoyl chloride were added in turn, and the mixture was continuously stirred for 2−3 h. Then the mixture was filtered, solvent was distilled off under vacuum, 50 mL of $H_2O$ was added, and the mixture was extracted with chloroform (3 × 30 mL), dried over anhydrous sodium sulfate, and separated on silica column with EtOAc/petroleum ether (v/v = 1:1) to give pure products $\mathbf{C_1}-\mathbf{C_{12}}$.

Arylselenonyl-1*H*-[1,2,4]triazoles could be easily recognized in infrared spectra. The peaks appeared at $\nu_{max}$ = 890 and 950 $cm^{-1}$, representing the absorption of O═Se═O. Especially influenced by the lone pair electrons of the nitrogen atom, the two $CH_2CH_3$ are not in magnetic equivalence, so in the $^1$HNMR spectra, the signal of $CH_2$ shows broad peak, and the $CH_3$ shows single, multiple, or broad peaks in compounds $\mathbf{C_1}$-$\mathbf{C_2}$.

*Data for 3-benzeneselenonyl-[1,2,4]triazole-1-carboxylic acid diethylamide ($\mathbf{C_1}$):* yield, 86.0%; white solid; mp, 123−124 °C; TLC (silica gel, EtOAc/petroleum ether, 1:1) $R_f$ = 0.40; IR (KBr, $cm^{-1}$) 3090, 1700, 1480, 1450, 1425, 950, 890; $^1$H NMR ($CDCl_3$) $\delta$ 8.90 (s, 1H, N═CH−N), 8.16 (d, $J$ = 7.44 Hz, 2H, ArH), 7.78 (t, $J$ = 7.34 Hz, 1H, ArH), 7.70 (t, $J$ = 7.62 Hz, 2H, ArH), 3.56 (br, 4H, $CH_2$—C), 1.26 (s, 6H, $CH_3$—C); ESI HRMS, *m*/*z* Anal. Calcd data for $C_{13}H_{16}N_4O_3{}^{23}Na^{80}Se$ M + $Na^+$: 379.0285. Found: 379.0280.

*Data for 3-(3,4-difluorobenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide ($\mathbf{C_2}$):* yield, 78.0%; yellow solid; mp, 118−120 °C; TLC (silica gel, EtOAc/petroleum ether, 1:1) $R_f$ = 0.40; IR (KBr, $cm^{-1}$) 3010, 1720, 1505, 1440, 950, 880; $^1$H NMR (MeOD) $\delta$ 9.22 (s, 1H, N═CH−N), 8.16 (td, $J$ = 12.16 Hz, $J$ = 2.07 Hz, 1H, ArH), 7.78 (dt, $J$ = 10.73 Hz, $J$ = 1.99 Hz, 1H, ArH), 7.70 (q, $J$ = 13.08 Hz, 1H, ArH), 3.56 (br, 4H, $CH_2$—C), 1.26 (br, 6H, $CH_3$—C); ESI MS, *m*/*z* (%) 415.1 (M + $Na^+$) (12.5), 807.1 (2M + $Na^+$) (*100*).

*Data for 3-(3-trifluoromethylbenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide ($\mathbf{C_3}$):* yield, 80.0%; white solid; mp, 117 °C; $R_f$ = 0.50 (silica gel, EtOAc/petroleum ether, 50:50); IR (KBr, $cm^{-1}$) 3140, 1705, 1510, 1480, 1450, 960, 895; $^1$H NMR ($CDCl_3$) $\delta$ 8.86 (s, 1H, N═CH−N), 8.38 (s, 1H, ArH), 8.31 (d, $J$ = 7.98 Hz, 1H, ArH), 7.96 (d, $J$ = 7.85 Hz, 1H, ArH), 6.80 (t, $J$ = 7.90, 1H, ArH), 3.48 (br, 4H, $CH_2$—C), 1.19 (s, 6H, $CH_3$—C); ESI HRMS, *m*/*z* Anal. Calcd data for $C_{14}H_{14}N_4O_3F_3{}^{23}Na^{80}Se$ M + $Na^+$: 447.0159. Found: 447.0146.

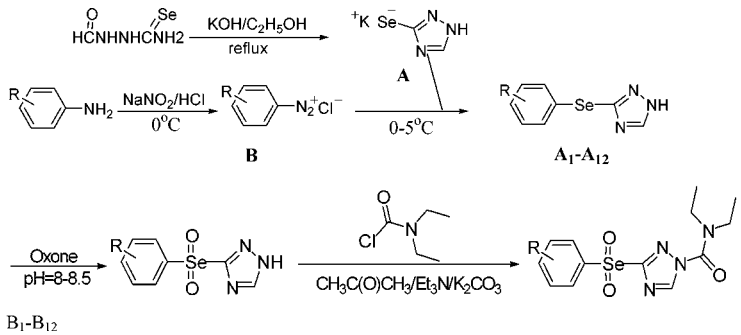
*Data for 3-(2,6-dimethylbenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide ($\mathbf{C_4}$):* yield, 82.0%; white solid; mp, 110−112 °C; $R_f$ = 0.51 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3140, 1710, 1470, 1450, 945, 890; $^1$H NMR ($CDCl_3$) $\delta$ 8.92 (s, 1H, N═CH−N), 7.42 (t, $J$ = 7.58 Hz, 1H, ArH), 7.22 (d, $J$ = 7.55 Hz, 2H, ArH), 3.56 (br, 4H, $CH_2$—C), 2.81 (s, 6H, $ArCH_3$), 1.26 (s, 6H, $CH_3$—C); ESI HRMS, *m*/*z* Anal. Calcd data for $C_{15}H_{20}N_4O_3{}^{23}Na^{80}Se$ M + $Na^+$: 407.0598. Found: 407.0592.

*Data for 3-(4-chlorobenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide ($\mathbf{C_5}$):* yield, 77.0%; white solid; mp, 122−123 °C; $R_f$ = 0.44 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3100, 1700, 1480, 1460, 1440, 955, 890; $^1$H NMR ($CDCl_3$) $\delta$ 8.91 (s, 1H, N═CH−N), 8.10 (d, $J$ = 8.60 Hz, 2H, ArH), 7.67 (d, $J$ = 8.56 Hz, 2H, ArH), 3.56 (br, 4H, $CH_2$—C), 1.27 (s, 6H, $CH_3$—C); ESI HRMS, *m*/*z* Anal. Calcd data for $C_{13}H_{15}N_4O_3{}^{23}Na^{80}Se$ M + $Na^+$: 412.9896. Found: 412.9902.

*Data for 3-(2,4,6-trimethylbenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide ($\mathbf{C_6}$):* yield, 47.0%; mp, 155−157 °C; $R_f$ = 0.47 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3118, 2925, 2454, 1710, 1264, 945, 886; $^1$H NMR ($CDCl_3$) $\delta$ 8.83 (s, 1H, N═CH−N), 6.95 (s, 2H, ArH), 3.50 (br, 4H, $CH_2$—C), 2.69 (s, 6H, $ArCH_3$), 2.27 (s, 3H, $ArCH_3$), 1.19 (br, 6H, $CH_3$—C); ESI HRMS, *m*/*z* Anal. Calcd data for $C_{16}H_{22}N_4O_3{}^{23}Na^{80}Se$ M + $Na^+$: 421.0755. Found: 421.0750.

*Data for 3-(4-nitrobenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide ($\mathbf{C_7}$):* yield, 44.0%; mp, 151−152 °C; $R_f$ = 0.43 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3140, 2985, 1721, 1528, 1350, 1264, 860, 737, 956, 893; $^1$H NMR ($CDCl_3$) $\delta$ 8.91 (s,

**Scheme 1.** General Synthesis of Compounds $C_1$–$C_{12}$[a]




[a] $R_1$ = H; $R_2$ = 3,4-difluoro; $R_3$ = 3-$CF_3$; $R_4$ = 2,6-dimethyl; $R_5$ = 4-Cl; $R_6$ = 2,4,6-trimethyl; $R_7$ = 4-$NO_2$; $R_8$ = 2,4-difluoro; $R_9$ = 3-Cl-4-$CF_3$; $R_{10}$ = 3-Cl-4-F; $R_{11}$ = 4-MeO; $R_{12}$ = 2,4-dimethyl. 1-Formylselenosemicarbazide was synthesized according to a literature procedure (*14*, *15*).

1H, N═CH—N), 8.51 (d, 2H, $J$ = 8.8 Hz, 1H, ArH), 8.37 (d, $J$ = 8.8 Hz, 2H, ArH), 3.54 (br, 4H, $CH_2$—C), 1.26 (t, 6H, $J$ = 6.9 Hz, $CH_3$—C); ESI MS, *m*/*z* (%) 424 (M + $Na^+$) (1.0), 440 (M + $K^+$) (*100*), 482.1 (*57*), 841.1 (2M + $K^+$) (1.22).

*Data for 3-(2,4-difluorobenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide (***$C_8$***):* yield, 45.0%; mp, 160−161 °C; $R_f$ = 0.44 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3103, 2985, 1695, 1480, 1424, 1276, 964, 897, 849, 737; $^1$H NMR ($CDCl_3$) $\delta$ 8.95 (s, 1H, N═CH—N), 8.29−8.24 (m, 1H, ArH), 7.23 (td, $J$ = 8.4 Hz, $J$ = 2.0 Hz, 1H, ArH), 7.09 (td, $J$ = 8.6 Hz, $J$ = 2.3 Hz, 1H, ArH), 3.58 (br, 4H, $CH_2$—C), 1.28 (br, 6H, $CH_3$—C); ESI MS, *m*/*z* (%) 415.2 (M + $Na^+$) (17.3), 466 (*100*), 806.6 (2M + $Na^+$) (26.8), 857.6 (5.41).

*Data for 3-(3-chloro-4-trifluoromethylbenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide (***$C_9$***):* yield, 45.3%; mp, 163−164 °C; $R_f$ = 0.42 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3096, 2970, 1706, 1591, 1432, 1394, 1302, 1276, 956, 893, 860, 734; $^1$H NMR ($CDCl_3$) $\delta$ 8.79 (S, 1H, N═CH—N), 8.05 (d, $J$ = 1.72 Hz, 1H, N═CH—N), 7.82 (dd, $J$ = 8.30 Hz, $J$ = 1.78 Hz, 1H, ArH), 7.48 (d, $J$ = 8.31 Hz, 1H, ArH), 3.51 (br, 4H, $CH_2$—C), 1.29 (br, 6H, $CH_3$—C); ESI MS, *m*/*z* (%) 459.0 (M + $H^+$) (4.77), 481.0 (M + $Na^+$) (7.71), 539 (*100*), 939.0 (2M + $Na^+$) (26.8), 1397.4 (3M + $Na^+$) (26.8).

*Data for 3-(3-chloro-4-fluorobenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide (***$C_{10}$***):* yield, 41.7%; mp, 90.3−91.6 °C; $R_f$ = 0.42 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3096, 2985, 1706, 1591, 1432, 1394, 1285, 1276, 956, 893, 860, 734; $^1$H NMR ($CDCl_3$) $\delta$ 8.94 (s, 1H, N═CH—N), 8.25 (dd, $J$ = 6.4 Hz, $J$ = 2.1 Hz, 1H, ArH), 8.11−8.08 (m, 1H, ArH), 7.48 (t, $J$ = 8.5 Hz, 1H, ArH), 3.60 (br, 4H, $CH_2$—C), 1.28 (t, 6H, $J$ = 6.9 Hz, $CH_3$—C); ESI MS, *m*/*z* (%) 431 (M + $Na^+$) (4.77), 447 (M + $K^+$) (7.71), 489 (*100*), 839.0 (2M + $Na^+$) (43.1).

*Data for 3-(4-methoxybenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide (***$C_{11}$***):* yield, 43.5%; mp, 112−113 °C; $R_f$ = 0.43 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3140, 2985, 2940, 1710, 1591, 1491, 1432, 1309, 1268, 1168, 1012, 860, 834, 956, 890; $^1$H NMR ($CDCl_3$) $\delta$ 8.90 (s, 1H, N═CH—N), 8.08 (d, $J$ = 9.0 Hz, 2H, ArH), 7.15 (d, $J$ = 9.0 Hz, 2H, ArH), 3.91 (s, 3H, $OCH_3$), 3.56 (br, 4H, $CH_2$—C), 1.27 (br, 6H, $CH_3$—C); ESI MS, *m*/*z* (%) 387.1 (M + $H^+$) (8.08), 409 (M + $Na^+$) (*100*), 795.1 (2M + $Na^+$) (30.0).

*Data for 3-(2,4-dimethylbenzeneselenonyl)-[1,2,4]triazole-1-carboxylic acid diethylamide (***$C_{12}$***):* yield, 22.4%; mp, 137−138 °C; $R_f$ = 0.45 (silica gel, EtOAc/petroleum ether, 1:1); IR (KBr, $cm^{-1}$) 3133, 2970, 2918, 1690, 1472, 1428, 1276, 945, 882, 860, 815; $^1$H NMR ($CDCl_3$) $\delta$ 8.88 (s, 1H, N═CH—N), 8.13 (d, $J$ = 8.3 Hz, 1H, ArH), 7.27 (d, $J$ = 8.3 Hz, 1H, ArH), 7.27 (s, 1H, ArH), 3.53 (br, 4H, $CH_2$—C), 2.66 (br, 3H, $ArCH_3$), 2.40 (s, 3H, $ArCH_3$), 1.24 (br, 6H, $CH_3$—C); ESI MS, *m*/*z* (%) 423 (M + $K^+$) (*100*), 407 (M + $Na^+$) (58.2), 791.2 (2M + $Na^+$) (28.04), 807.1 (2M + $K^+$) (*25*).

**Bioassays.** The bioactivity of all compounds on plants was tested by the pot-culture method. The compounds (Cafenstrole, $C_1$−$C_{12}$) were dissolved in toluene and diluted in water, respectively, and a drop of Tween 80 was added to form an emulsifiable solution. The concentration of solvent was limited to ≤1 mL $L^{-1}$ so that it had no effect on plant growth. The species of tested cucumber (*Cucumis sativus* L.) and rice (*Oryza sativa* Linn.) are jinyou 15 and xiuanyou 63, respectively, both of which are popularly planted in China. The tested semen euphorbiae (*Echinochloa crusgalli* B) is the main weed in rice fields around China. The seeds of tested plants were sown on 5 × 5 × 6.5 $cm^3$ pots containing 50 g of mountain soil used in the laboratory only. Ten pieces of seeds were planted in each pot. Five milliliters of the emulsifiable solution of $C_1$−$C_{12}$ was irrigated, well-distributed to the surface of the soil, respectively. The pots were placed in a controlled environmental chamber at a temperature of 25 ± 2 °C, and relative humidity was 70% on all days. After cultivation for 15 days, the fresh weight of the plant stems was weighed to determine the inhibition activity of the compounds on the growth of the plants. Each compound was evaluated in five parallel tests and compared to an untreated control.

**Table 1.** Growth Inhibition of Cafenstrole and $C_1$-$C_{12}$ on Cucumber (*C. sativus* L.) and Semen Euphorbiae (*E. crusgalli* B) at 500 $\mu$g/mL

| compound no./name | R | ratio of growth inhibition of $C_1$–$C_{12}$ on cucumber (%) | ratio of growth inhibition of $C_1$–$C_{12}$ on semen euphorbiae (%) |
|---|---|---|---|
| $C_1$ | H | 8.75 (7.15–9.25) | 4.18 (3.65–5.06) |
| $C_2$ | 3,4-difluoro | 44.01 (40.32–48.56) | 44.33 (40.82–47.44) |
| $C_3$ | 3-$CF_3$ | 18.47 (18.01–19.25) | 25.24 (22.23–27.64) |
| $C_4$ | 2,6-dimethyl | 100.00 (100.00–100.00) | 100.00 (100.00–100.00) |
| $C_5$ | $R_5$ = 4-Cl | 18.59 (17.88–20.12) | 17.00 (16.00–18.87) |
| $C_6$ | 2,4,6-trimethyl | 100.00 (100.00–100.00) | 100.00 (100.00–100.00) |
| $C_7$ | 4-$NO_2$ | 26.93 (24.58–27.34) | 46.39 (45.85–47.23) |
| $C_8$ | 2,4-difluoro | 33.93 (33.26–34.85) | 53.87 (50.56–55.27) |
| $C_9$ | 3-Cl-4-$CF_3$ | 15.26 (13.94–15.78) | 45.62 (42.29–46.61) |
| $C_{10}$ | 3-Cl-4-F | 10.73 (9.98–11.42) | 39.6 (37.16–42.64) |
| $C_{11}$ | 4-MeO | 30.34 (26.23–32.39) | 63.87 (60.46–74.52) |
| $C_{12}$ | 2,4-dimethyl | 42.01 (39.39–45.58) | 51.02 (48.27–56.94) |
| Cafenstrole | | 100.00 (100.00–100.00) | 100.00 (100.00–100.00) |

## RESULTS AND DISCUSSION

The initial evaluation of growth inhibitory activity of the synthesized compounds is presented in **Table 1**. As a result of preliminary screening, compounds $C_1$, $C_3$, $C_5$, and $C_9$−$C_{11}$ showed low inhibitory activity against the tested plants' growth (ratio of growth inhibition ≤ 40%) at a concentration of 500 $\mu$g/mL, whereas compounds $C_2$, $C_7$, $C_8$, and $C_{12}$, showed good activity (40% ≤ ratio of growth inhibition ≤ 70%). To our pleasure, compounds $C_4$ and $C_6$, as well as Cafenstrole, inhibited the plants' growth completely (ratio of growth inhibition = 100%). A methyl functional group at the 2,4,6- and 2,6-positions of the benzene ring resulted in a significant increase of activity.

These three most active compounds, Cafenstrole, $C_4$, and $C_6$, were selected for further screening in bioassays on cucumber, rice, and semen euphorbiae. The results are illustrated in **Figure 4**. The ratio of inhibition on the tested plants rises along with the concentration of the compounds. The cucumber was sensitive to $C_4$ and $C_6$, their growth inhibition ratio rising to 100% at 3.75 $\mu$g/mL. Cafenstrole completely inhibited the cucumber at

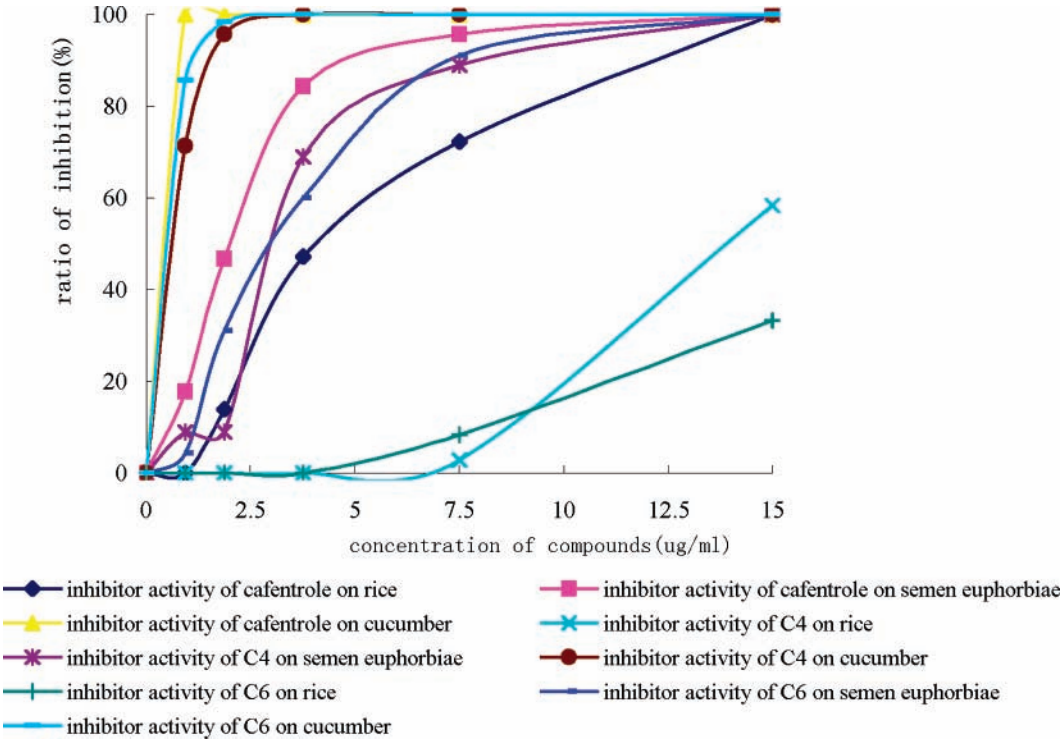



**Figure 4.** Growth inhibition of Cafenstrole, $C_4$, and $C_6$ on tested plants.

0.9357 $\mu$g/mL, which showed higher activity on the dicotyledon than $C_4$ and $C_6$. However, toward monotyledon, the inhibition of Cafenstrole on both rice and semen euphorbiae rises sharply depending on the concentration of the compounds. As shown in **Figure 4**, the inhibition ratios of Cafenstrole on rice and semen euphorbiae are 0, 13.9, 47.2, 72.0, and 100% and 17.8, 46.7, 84.4, 95.6, and 100%, respectively, at concentrations of 0.9375, 1.875, 3.75, 7.5, and 15 $\mu$g/mL. On the other hand, with the increase of the concentration, the inhibition ratios of $C_4$ and $C_6$ on rice rise slowly, but the inhibition on semen euphorbiae keeps rising sharply. As illustrated in **Figure 4**, $C_4$ and $C_6$ inhibit the growth of semen euphorbiae at 88.9 and 91.1%, respectively, at the concentration of 7.5 $\mu$g/mL, whereas they inhibit growth by only 2.8 and 8.3% on rice, which indicated that $C_4$ and $C_6$ are safer for rice than Cafenstrole.

Cafenstrole is a herbicide used in rice fields, but it must be used pre-emergence because of its harmfulness to rice. $C_6$ and $C_4$ have high selective bioactivities between rice and semen euphorbiae so that they may be safer for rice. Because our bioassay test lasted from pregermination to seedling stage, the low inhibition of $C_6$ and $C_4$ to rice showed that they may be used in rice seedling fields. We are carrying out further research to ascertain the inhibitor spectrum of the compounds and reveal the mechanism of selectivity on the control of weeds.

In conclusion, the modification of carbamoyl triazole herbicide by replacing sulfur with selenium could maintain the bioactivity and help to increase the selectivity between rice and semen euphorbiae. Even though the effect of introducing selenium to herbicides needs further careful research, it is possible to find novel pesticides by this method.

**Supporting Information Available:** Full characterization for intermediate compounds of $A_1$−**12** and $B_1$−**12**. This material is available free of charge via the Internet at http://pubs.acs.org.

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