Synthesis and study of substituted 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles as plant growth regulators

Vladimir Talismanov[11] and *Sergei* Popkov[2]

[1] Moscow Institute of Physics and Technology, 141701, Dolgoprudny, Moscow Region, Russian Federation
[2] Mendeleev University of Chemical Technology of Russia, 125047, Moscow, Russian Federation

Abstract. The search for new effective plant growth regulators characterized by low application rates, low toxicity, and rapid biodegradability in plant-based products, soil, and the environment has become increasingly important in light of the growing regulatory requirements for pesticides. The search for new plant growth stimulants among the well-studied 1,2,4-triazole and 1,3-dioxolane derivatives allows for the combination of the growth-regulating properties of both 1,2,4-triazole and 1,3-dioxolane in a single molecule. An effective two-step method for the synthesis of substituted 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles has been developed for the purpose of testing their growth-regulating activity. Using azeotropic removal of water, this reaction produced intermediate 4-chloromethyl-1,3-dioxolanes in high yields and with a high level of purity. In the second stage, the resulting 4-chloromethyl-1,3-dioxolanes were alkylated with the sodium salt of 1,2,4-triazole by refluxing in dimethylformamide. The compounds were obtained in moderate yields and required purification by column chromatography and conversion to stable and easy-to-handle oxalate salts. The compounds were identified using NMR and IR spectroscopy. The synthesized compounds were tested for growth-regulating activity *in vivo* using agar medium on cucumber seedlings at concentrations ranging from 0.001 to 10 mg/L. Water was used as a reference standard. Tests were conducted over an 8-day period. The test results demonstrated significant retardant properties of the studied compounds when applied to the above-ground parts of plants, with the compounds stimulating the accumulation of both wet and dry biomass at a range of concentrations. The conducted studies demonstrated the potential of searching for new retardants in the 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazole series.

1 Introduction

The synthesis and study of innovative pesticides, particularly plant growth regulators, is an important task addressed by the joint efforts of specialists in organic chemistry and biology. The continued growth of the global population and the resulting food shortages have led to

[1] Corresponding author: talismanov@phystech.edu

the emergence of a highly productive agricultural industry using a wide range of chemical crop protection products. Tightening requirements for the toxicological safety, environmental friendliness, and cost of pesticides, which directly impact the quality and price of agricultural products, are stimulating the search for new growth regulators. Retardants are substances that inhibit plant growth. They represent an important subclass of plant growth regulators (PGRs). Retardants, when used on grain crops, allow for stronger straws and prevent significant yield losses from lodging, and when used on flower and vegetable seedlings, prevent overgrowing. When applied to fruit trees, retardants can induce early and abundant flowering and fruiting [1]. Triazole fungicides, such as propiconazole and difenoconazole, are well known; their molecules also contain dioxolane. Ketoconazole and difenoconazole fungicides are also known to exhibit retardant properties [2]. Among the commercially available dioxolane plant growth regulators, spiroxamine, 8-(1,1-dimethylethyl)-*N*-ethyl-*N*-propyl-1,4-dioxaspiro[4.5]decane-2-methanamine, is widely used. Its mechanism of action is also associated with the inhibition of steroid synthesis [3]. Other substituted dioxolanes, which have been shown to possess growth-regulating properties, have also been synthesized and studied [4]. Incorporation of 1,3-dioxolane, which is unstable in acidic environments, into the synthesized active compound molecule reduces hydrolytic stability, thereby accelerating the decomposition of the compound in soil, wastewater, and plant products [5]. In this study, new compounds containing both the 1,2,4-triazole and dioxolane rings were synthesized, and their effects on the growth and weight characteristics of seedlings were studied.

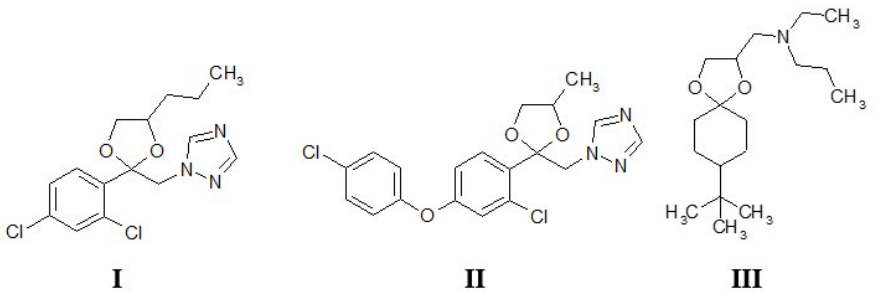

Fig. 1. Commercial fungicides with growth-regulating activity: propiconazole (I), difenoconazole (II), spiroxamine (III).

2 Materials and methods

2.1 Scheme of synthesis of the studied compounds

A search for new plant growth regulators was conducted among substituted 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles. The synthesis scheme utilized various alkanophenones and benzophenones, which resulted in the introduction of various aryl or alkyl substituents at the 2-position in 1,3-dioxolane.

Target compounds **1c-5c** were prepared in two steps. In the first step, substituted diaryl ketones or aryl alkyl ketones **1a-5a** were condensed with 3-chloro-1,2-propanediol to yield 4-chloromethyl-1,3-dioxolanes **1b-5b**. In the second step, alkylating agents **1b-5b** were reacted with the triazole in the form of the sodium salt. The structures and physicochemical properties of the synthesized compounds are presented in **Table 1**.

2.2 Description of synthesis methods and physicochemical characteristics of target compounds

Ketones **1a-5a** were condensed with glycerol monochlorohydrin under reflux. The reaction was catalyzed by toluenesulfonic acid (5 mol%), and the resulting water was removed in a Dean-Stark trap as a benzene azeotrope. A double excess of glycerol monochlorohydrin allowed the ketones to react completely. The amount of water separated in the Dean-Stark trap allowed one to determine the end of the reaction, which occurred on average within 8-12 hours. Glycerol epichlorohydrin was formed as a byproduct from glycerol monochlorohydrin, resulting in the amount of water distilled off exceeding the calculated value by 10-15%. Pure alkylators were isolated from the reaction mixture by washing with a weak alkali solution to neutralize the acidic catalyst, followed by a large volume of distilled water to remove excess inexpensive glycerol monochlorohydrin. Using the above method, without additional isolation and purification methods, it was possible to obtain 4-chloromethyl-1,3-dioxolanes **1b-5b** with a purity of 96-98.5%. The spectral characteristics of 4-chloromethyl-1,3-dioxolanes are presented in **Table 2**.

The target 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles **1c-5c** were obtained in yields from 72 to 83% by refluxing sodium 1,2,4-triazolate and 4-chloromethyl-1,3-dioxolane alkylators **1b-5b** in DMF for 14-15 h.

Based on the results of studying the chromatograph mass spectra and ^{1}H NMR spectral data, the technical products of triazole alkylation contained not only the expected 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles, but also up to 12% of 4-((1,3-dioxolan-4-yl)methyl)-4H-1,2,4-triazoles. Also, up to 20% of a mixture of the initial carbonyl compounds and 3-(1,2,4-triazol-1-yl)propane-1,2-diols, formed as a result of the hydrolytic destruction of the final products during prolonged boiling, were detected in the reaction mixtures. Because the crude compounds **1c-5c** were thick, non-crystallizing substances that decomposed upon heating, traditional purification methods such as vacuum distillation or recrystallization were unsuitable. Column chromatography was used to obtain individual 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles. A 28 mm glass column with Acros 35/70 silica gel was used, and elution was performed with a 1:10 methanol:chloroform mixture. Using this method, the final 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles were successfully purified from the presence of the initial carbonyl compounds contaminating the reaction mass, side derivatives of alkylation of 1,2,4-triazole at the 4-position, salts of double alkylation of 1,2,4-triazole at two nitrogen atoms and 3-(azol-1-yl)propane-1,2-diols. Purified 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles were identified by NMR and IR spectroscopy. The spectral characteristics are presented in **Table 3**.

For ease of use and storage, compounds **2c**, **3c**, and **5c** were converted into stable crystalline oxalates. The oxalates were prepared by mixing equimolar amounts of acetone solutions of the target compounds **2c**, **3c**, and **5c** with acetone solutions of oxalic acid.

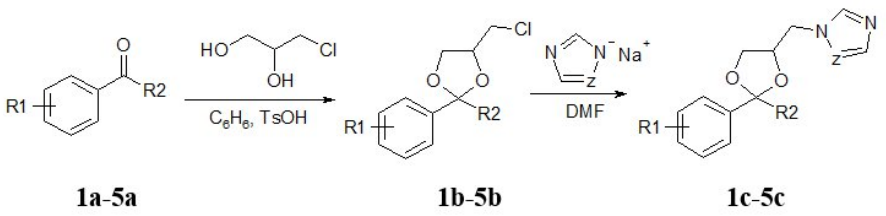

Fig. 2. Scheme of synthesis of 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles

Table 1. Structure and physicochemical properties of the studied compounds

No.	R1	R2	Yield, %	Melting point, °C
1c	4-NO_2	CH_3	83	90.5-92
2c	4-Cl	C_5H_{11}	79	148-149 (oxalate)
3c	4-Cl	*cyclo*C_6H_{11}	74	164-165 (oxalate)
4c	H	CH_3	80	86-87
5c	4-Cl	4-ClC_6H_6	72	173-174 (oxalate)

Table 2. Spectral characteristics of synthesized 4-chloromethyl-1,3-dioxolanes

No.	^{1}H NMR spectrum ($CDCl_3$; d, ppm.; *J*, Hz.)	IR spectrum (thin layer, ν, cm^{-1}):
1b	1.69 (s, 3H, CH_3); 3.57 (dd, 1H, CH_2Cl, ^3J= 7.4, ^2J= 8.2); 3.65 (dd, 1H, CH_2Cl, ^3J = 5.4, ^2J = 8.2); 3.79 (dd, 1H, CH_2O, ^3J = 6.6, ^2J= 8.6); 4.00 (dd, 1H, CH_2O, ^3J= 5.2, ^2J= 8.6); 4.22 (m, 1H, CHO);7.66 (d, 2H, $C^{2,6}$H Ar,^3J = 8.8);7.21 (d, 2H,$C^{3,5}$H Ar,^3J= 8.8)	1240, 1225, 1195, 1125, 1085
2b	0.82 (s, 3H, CH_3), 1.13–1.44 (m, 6H, $(CH_2)_3$), 1.77–1.94 (m, 2H, CH_2CPh), 3.13 (dd, 0.33H, CH_2Cl, ^3J = 7.9, ^2J = 8.6), 3.48–3.70 (m, 2H, CH_2Cl, CH_2O), 3.78 (dd, 0.67H, CH_2Cl, ^3J = 7.9, ^2J = 8.6), 3.93 (dd, 0.67H, CH_2O, ^3J = 8.3, ^2J = 8.8), 4.16 (m, 0.67H, CHO), 4.28 (dd, 0.33H, CH_2O, ^3J = 8.3, ^2J = 8.8), 4.42 (m, 0.33H, CHO), 7.23-7.43 (m, 4H, C_6H_4Cl)	1245, 1210, 1170, 1110, 1090, 720
3b	0.81-0.99 (m, 2H, CH_2); 1.01-1.19 (m, 3H, CH_2); 1.51-1.74 (m, 6H, CH_2); 2.99 (dd, 0.32H, CH_2Cl, ^3J = 7.4, ^2J = 8.4); 3.12 (dd, 0.68H, CH_2Cl, ^3J = 7.6, ^2J = 8.4); 3.24-3.47 (m, 1H, CH_2Cl); 3.79 (dd, 0.68H, CH_2O, ^3J = 7.0, ^2J = 8.2); 4.88-4.13 (d, 2H, CH_2O+CHO); 4.32 (m, 0.32H, CHO); 7.29 (d, 2H Ar, ^3J = 8.6); 7.41 (d, 2H Ar, ^3J = 8.6)	1245, 1230, 1185, 1125, 1090, 762
4b	1.64 (s, 0.9H, CH_3); 1.68 (s, 2.1H, CH_3); 3.16 (dd, 0.3H, CH_2Cl, ^3J= 7.8, ^2J= 8.4); 3.48-3.74 (м, 1.7H, CH_2Cl); 3.83 (dd, 0.7H, CH_2O, ^3J= 8.2, ^2J= 8.9); 3.96 (dd 0.7H, CH_2O, ^3J= 6.6, ^2J= 8.9); 4.15-4.33 (m, 1.3H, CHO+CH_2O); 4.45 (m, 0.3H, CHO); 7.25-7.41 (m, 3H, Ar); 7.43-7.57 (m, 2H, Ar)	1240, 1225, 1190, 1125, 1085
5b	3.49 (dd, 1 H, CH_2Cl, ^3J = 8.2, ^2J = 11.0); 3.64 (dd 1H, CH_2Cl, ^3J = 5.6, ^2J = 11.0); 4.03 (dd 1H, CH_2O, ^3J = 5.8, ^2J = 7.6); 4.12 (dd 1H, CH_2O, ^3J = 7.0, ^2J = 7.6); 4.45 (m, 1H, CHO); 7.35, 7.46 (m, 4H, Ar)	1245, 1225, 1170, 1115, 1087, 732

Table 3. Spectral characteristics of synthesized 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles

No.	^{1}H NMR spectrum ($CDCl_3$; d, ppm.; *J*, Hz.)	IR spectrum (thin layer, ν, cm^{-1}):
1c	1.56 (s, 3H, CH_3); 3.66 (dd 0.38H, CH_2O, ^3J = 7.8, ^2J = 8.8); 3.75 (dd, 0.62H, CH_2O, ^3J = 6.4, ^2J = 8.8); 3.97 (dd, 0.62H, CH_2O, ^3J = 5.1, ^2J = 8.7); 4.17 (dd, 0.38H, CH_2O, ^3J = 6.4, ^2J = 8.8); 4.24-4.29 (m, 0.74H, CH_2N + CHO); 4.36 (dd, 0.62H, CH_2N, ^3J = 6.8, ^2J = 8.5); 4.42 (dd, 1H, CH_2N, ^3J = 6.4, ^2J = 8.5); 4.61 (m, 0.38H, CHO); 7.64 (d, 0.62H, Ar, ^3J = 8.6); 7.64 (d, 0.38H, Ar, ^3J = 8.6); 7.89 (s, 0.38H); 7.96 (s, 0.62H); 8.18 (d, 1H, Ar, ^3J = 8.6); 8.37 (s, 0.38H). 8.53 (s, 0.62H)	1270,1240, 1220, 1175, 1127, 1087
2c	0.76 (s, 3H, CH_3); 0.99–1.31 (m, 6H, $(CH_2)_3$); 1.57–1.84 (m, 2H, CH_2CPh); 3.53 (dd, 0.37H, CH_2O, ^3J = 8.0, ^2J = 8.6); 3.69 (dd, 0.63H, CH_2O, ^3J = 8.0, ^2J = 8.6); 3.90 (dd, 0.63H, CH_2O, ^3J = 5.6, ^2J = 8.6); 4.01–4.59 (m, 3.37H, CH_2O, CH_2N, CHO); 7.25–7.49 (m, 4H, C_6H_4Cl); 7.93 (s, 0.37H); 8.00 (s, 0.63H, C^3H); 8.43 (s, 0.37H, C^5H); 8.54 (s, 0.63H, C^5H).	1272, 1195, 1145, 1080
3c	0.82-0.97 (m, 2H, CH_2); 0.98-1.16 (m, 3H, CH_2); 1.48-1.72 (m, 6H, CH_2); 3.52 (dd, 0.66H, CH_2O, ^3J = 7.9, ^2J = 8.6); 3.66 (dd, 0.34H, CH_2O, ^3J = 7.6, ^2J = 8.6); 3.91 (dd, 0.66H, CH_2O, ^3J = 6.2, ^2J = 8.6); 4.04-4.24 (m, 2.34H, CH_2O, CH_2N); 4.39	1270, 1180, 1150, 1085

	(dd, 0.66H, CH_2N, ^3J = 8.0, ^2J = 8.8); 4.44 (m, 0.34H, CHO, ^3J = 5.8); 7.27 (d, 2H Ar, ^3J = 8.6); 7.39 (d, 2H Ar, ^3J = 8.6); 7.88 (s, 0.34H); 7.96 (s, 0.66H); 8.38 (s, 0.34H). 8.52 (s, 0.66H)	
4c	1.63 (s, 3H, CH_3); 3.70-3.97 (m, 1.66H, CH_2O); 4.05 (dd, 0.34H, CH_2O, ^3J = 6.3, ^2J = 8.8); 4.25-4.45 (m, 2.66H, CH_2N + CHO); 4.65 (m, 0.34H, CHO, ^3J = 5.8); 7.38 (d, 2H, Ar, ^3J = 8.6); 7.23-7.52 (m, 5H, Ar); 7.96 (s, 1H); 8.25 (s, 1H)	1270, 1245, 1220, 1165, 1120, 1090
5c	3.97 (dd, 1 H, CH_2O, ^3J = 5.5, ^2J = 8.8); 4.05 (dd, 1H, CH_2O, ^3J = 6.8, ^2J = 8.8); 4.38 (dd, 1H, CH_2N, ^3J = 6.6, ^2J = 13.9); 4.44 (dd, 1H, CH_2N, ^3J = 5.2, ^2J = 13.9); 4.54 (m, 1H, CHO, ^3J = 5.9); 7.35, 7.42 (m, 4H, Ar); 7.98 (s, 1H); 8.45 (s, 1H)	1275, 1245, 1215, 1175, 1115, 1085, 725

2.3 Method for testing growth-regulating activity

The study of growth-regulating activity involved eight-day germination of cucumber seeds in a nutrient agar medium prepared using the Murashige and Skoog method, also containing the studied compounds. As a comparison standard, cucumber seeds were grown under the same conditions, but the nutrient agar medium did not contain the studied compounds. To prevent contamination of the nutrient medium, solutions of the studied compounds were pre-sterilized using bacterial filters and then added to autoclaved Murashige and Skoog medium and poured into sterile Petri dishes. A 0.1% mercuric chloride solution was used for external disinfection of the cucumber seeds for 10 minutes, after which the seeds were washed three times with autoclaved distilled water until no significant reaction with the ammonia solution for mercury ions was observed. Disinfected seeds were placed on top of the agar medium. The dishes were covered with lids and placed in glass cabinets under white fluorescent lamps with an illumination intensity of 3000 lux. The experimental temperature was maintained in the range of 22-22.5 °C, air humidity 70%. The growth-regulating activity of each compound was studied at 5 concentrations: 10; 1; 0.1; 0.01; 0.001 mg/l. An experiment containing distilled water instead of the studied compound was used as a control. Each concentration for each compound was studied in triplicate, the results from the replicates were averaged. A total of 75 dishes were studied during the experiment. 20 seeds were sown in each dish.

At the end of the eighth day, the root system length, the aboveground length of the seedling, and the dry and wet weight of the aboveground portion of the seedling were measured. Each seedling was separated from the seed and root. An analytical scale was used for weighing. A ruler with an accuracy of 0.5 mm was used for measurements. The measurement and weighing results were statistically processed using the Straz software: an analysis of variance was performed, and the standard error was calculated.

3 Results and discussion

It is known that the growth-regulating activity of some organic derivatives may not have a clearly pronounced dependence on concentration [6]. Therefore, in our tests, we investigated various ranges of concentrations differing from each other by 1000 times: from 0.001 to 10 mg/l. The choice of such concentrations correlates with the concentrations of active commercial preparations used in the current market of plant growth stimulants. The effect of 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles on plant growth was assessed based on the obtained data from biological tests: the length of the above-ground part of the seedling and root, dry and fresh weight of the above-ground part of the seedling. The research results are presented in **Table 4** and **Table 5**.

The studied 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles, within the tested concentration range from 0.001 to 10 mg/l, showed strong retardant properties, reducing the length of the aboveground part by up to 89% (**2c**), while the effect on root growth was

significantly less than on the seedling. Compound **3c** in concentrations of 1.0 mg/l led to an increase in the seedling's raw and dry biomass by up to 30%.

Table 4. The effect of the studied compounds on the growth of cucumber seedlings and roots

No.	Concentration, mg/l	Seedling length			
		aboveground part		root	
		length, cm	change in length,%	length, cm	change in length,%
1	*2*	*3*	*4*	*5*	*6*
1c	0.001	1.5±0.4	-57.0	7.0±1.1	-22.2
	0.01	2.6±0.8	-25.7	8.7±1.4	-3.3
	0.1	2.5±0.3	-28.6	8.1±0.6	-10.0
	1.0	2.1±0.2	-40.0	7.9±1.2	-12.3
	10.0	2.3±0.3	-34.3	7.2±0.9	-20.0
2c	0.001	3.2±0.9	-8.6	10.4±1.9	15.5
	0.01	1.9±0.3	-45.7	8.6±1.1	-4.4
	0.1	0.9±0.2	-74.3	4.5±1.1	-50.0
	1.0	2.8±0.7	-20.0	9.4±2.0	-4.4
	10.0	0.4±0.1	-88.5	3.6±0.7	-60.0
3c	0.001	2.0±0.4	-42.8	9.0±1.1	0.0
	0.01	2.3±0.4	-34.3	9.9±2.4	-10.0
	0.1	1.5±0.2	-57.1	8.4±1.1	-6.7
	1.0	1.5±0.3	-57.1	7.4±1.3	-17.8
	10.0	1.8±0.4	-48.6	6.4±1.3	-28.9
4c	0.001	1.3±0.3	-62.9	6.3±1.3	-30.0
	0.01	2.9±0.5	-17.1	11.3±0.9	-25.6
	0.1	1.4±0.4	-60.0	5.9±1.1	-34.4
	1.0	1.6±0.4	-54.3	7.0±1.7	-22.2
	10.0	2.8±0.4	-20.0	7.4±1.7	-17.8
5c	0.001	0.5±0.1	-86.0	3.6±0.4	-60.0
	0.01	3.6±0.4	2.8	7.6±0.4	-15.5
	0.1	0.3±0.1	-91.4	2.8±0.4	-68.8
	1.0	0.4±0.1	-88.5	2,.3±0.4	-74.4
	10.0	0.6±0.1	-82.3	4.8±1.2	-46.7
Control	water	3.5±0.4	0	9.0±1.1	0

Table 5. The effect of the studied compounds on the weight characteristics of cucumber seedlings and roots

No.	Concentration, mg/l	Average weight of plants			
		wet		dry	
		weight, g	change in weight,%	weight, g	change in weight,%
1	*2*	*7*	*8*	*9*	*10*
1c	0.001	3.99	-0.5	0.45	12.5
	0.01	3.52	-12.2	0.47	17.5
	0.1	3.37	-16.0	0.46	15.0
	1.0	3.61	-10.0	0.43	7.5
	10.0	3.68	-8.3	0.46	15.0
2c	0.001	3.00	-25.2	0.47	17.5
	0.01	4.47	11.5	0.47	17.5
	0.1	2.64	-34.2	0.23	-42.5
	1.0	3.91	-2.5	0.43	7.5
	10.0	2.38	-40.6	0.37	-7.5
3c	0.001	4.12	2.7	0.54	35.0
	0.01	5.16	28.7	0.52	30.0

	0.1	3.91	-2.5	0.52	30.0
	1.0	4.90	22.2	0.52	30.0
	10.0	3.74	-6.7	0.62	55.0
4c	0.001	2.30	-42.6	0.52	30.0
	0.01	3.52	-12.2	0.37	-7.5
	0.1	3.30	-17.7	0.56	40.0
	1.0	3.30	-17.7	0.42	5.0
	10.0	3.72	-7.2	0.40	0
5c	0.001	4.06	1.2	0.46	15.0
	0.01	2.65	-33.9	0.36	-10.0
	0.1	3.61	-10.0	0.32	-20.0
	1.0	5.67	41.4	0.38	-5.0
	10.0	3.44	-14.2	0.51	27.5
Control	water	4.01	0	0.40	0

A comparison of the results of the study of growth-regulating activity and substituents in the studied 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles revealed no clear correlation between the effects of substituents on growth-regulating activity. An optimal concentration of the active ingredient was also observed for each of the studied compounds. In all cases, a decrease in the length of the above-ground part was accompanied by thickening of the seedlings, confirming the pronounced retardant effect of the studied compounds.

4 Conclusions

All 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazoles studied in the two-step synthesis were tested for growth-regulating activity. The studies demonstrated the retardant effect of the studied compounds. To elucidate the relationship between structure and growth-regulating activity, further expansion of the synthesized compounds range is necessary, and to identify the optimal concentration, growth regulating activity studies in other model plants are also necessary. Overall, the study demonstrated the potential of searching for new retardants in the 1-((1,3-dioxolan-4-yl)methyl)-1H-1,2,4-triazole series.

References

1. G. Singh, B. Rani, K.N. Singh, B. Mohan, D.R. Batish, I. Gupta, B. Singh, D. Baliyan. Synthesis of Triazole-Allied Schiff Base and Its Applications as a Therapeutic Agent for Cervical Cancer and as a Plant Growth Regulator for Maize Seeds. ChemistrySelect. **10** (25), e01530 (2025). https://doi.org/10.1002/slct.202501530
2. B. Chen, X. Shen, Z. Li, J. Wang, X. Li, Z. Xu, Y. Shen, Y. Lei, X. Huang, X. Wang, L. Hongtao. Antibody Generation and Rapid Immunochromatography Using Time-Resolved Fluorescence Microspheres for Propiconazole: Fungicide Abused as GrowthRegulator in Vegetable. Foods. **11(3)**, 324 (2022). https://doi.org/10.3390/foods11030324
3. N.G. Tsiropoulos, G.E. Miliadis, D.T. Likas, K. Liapis. Residues of Spiroxamine in Grapes Following Field Application and Their Fate from Vine to Wine. Journal of Agricultural and Food Chemistry **53**(26), 10091-10096 (2005). https://doi.org/10.1021/jf052162q
4. T.R. Ren, Y.H. Xie, W.W. Zhu, Y.H. Li, Y. Zhang. Activities and Toxicity of a Novel Plant Growth Regulator 2-Furan-2-yl-[1,3]Dioxolane. Journal of Plant Growth Regulation. **26**, 362-368 (2007). https://doi.org/10.1007/s00344-007-9020-9

5. N.R. Rosales. Hydrolysis study and extraction of spiroxamine from soils of different physico-chemical properties. Chemosphere, **77(6)**, 821-828 (2009). https://doi.org/10.1016/j.chemosphere.2009.07.078
6. A.El-Saber, A.A. Shraf, F.A. Safhi, et.al., Influence of exogenously sprayed growth regulators at different concentrations on grain biochemical constituents and yield traits of bread wheat. Chilean journal of agricultural research. **86**, 769-781 (2024) https://doi.org/10.4067/S0718-58392024000600769