

Growth-Regulating Activity of Chalcogen-Functionalized Thiazoloquinazolines

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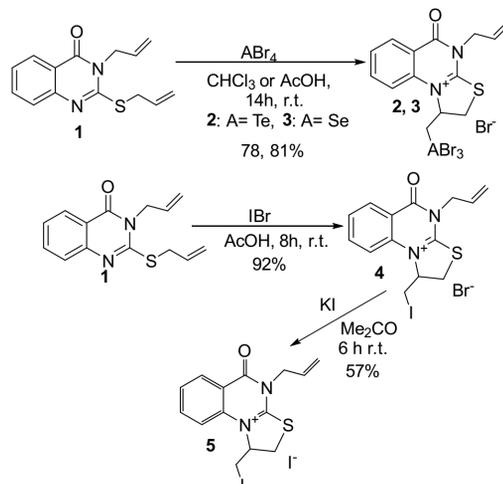
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Introduction

Soybean (*Glycine max* (L.) Merr.) is a self-pollinating crop belonging to the Fabaceae family. It is the world's leading legume and oilseed crop in terms of production and trade volume. Soybean seeds contain approximately 38–42% high-quality protein and 18–20% oil rich in essential fatty acids. They also include numerous nutrients beneficial to human health. Modern studies have demonstrated the presence of secondary metabolites with health-promoting properties, particularly isoflavones, which exhibit natural antioxidant activity. The consumption of isoflavone-containing products has been associated with the prevention of cancer and cardiovascular diseases. The main isoflavones present in soybean seeds are daidzein and genistein. The significant role of soybean in nutrition, human health, and economic sustainability makes this crop increasingly demanded by society, leading to a steady rise in global consumption. Therefore, the search for new environmentally friendly and efficient approaches to improve soybean cultivation remains an urgent task. Considering the experimental application of functionally substituted pyrimidines and their condensed derivatives as phytohormones, the investigation of this class of heterocycles remains a relevant scientific task. In the present study, four representatives of thiazolo[3,2-a]quinazolinium salts were examined as environmentally safe and promising plant growth regulators.

Results and Discussion

Synthetic thiazoloquinazolinium salts were obtained using known methods. Scheme 1 shows the synthetic pathway for obtaining linear thiazoloquinazoline derivatives. Bromides 2 and 3 were prepared by stirring allyl thioether 1 with the corresponding chalcogen tetrabromide for 14 hours. The reaction of 2,3-diallylquinazoline with iodine bromide in acetic acid yielded the angular thiazoloquinazolinium bromide 4, which was converted into the corresponding iodide 5 by treatment with potassium iodide in acetone.



Scheme 1. Synthesis of salts of thiazoloquinazolines 2-5.

Table 1. Number of soybean seeds germinated after treatment with the studied salts 2-5 and control.

Sample #	Chemical structure	Concentration	Day 2	Day 4	Day 5	Day 7
	Control (distilled water)		125	125	125	125
2		10 ⁻³ g/L	132	132	132	132
		10 ⁻² g/L	126	126	126	126
		10 ⁻¹ g/L	126	126	126	126
3		10 ⁻³ g/L	133	133	133	133
		10 ⁻² g/L	139	139	139	139
		10 ⁻¹ g/L	124	124	124	124
4		10 ⁻³ g/L	131	131	131	131
		10 ⁻² g/L	127	127	127	127
		10 ⁻¹ g/L	121	121	121	121
5		10 ⁻³ g/L	129	129	129	129
		10 ⁻² g/L	136	136	136	136
		10 ⁻¹ g/L	126	126	126	126

Table 2. Lengths (mm) of soybean seedlings after treatment with the studied thiazoloquinazolinium salts 2-5 and distilled water.

Sample #	Chemical structure	Concentration	Day 2	Day 4	Day 5	Day 7
	Control (distilled water)		6.93±1.27	16.38±1.25	24.46±1.67	95.32±6.45
2		10 ⁻³ g/L	5.22±1.06	11.75±1.13	21.57±1.50	98.68±5.44
		10 ⁻² g/L	5.81±1.62	15.82±1.31	24.98±2.11	90.96±5.12
		10 ⁻¹ g/L	7.65±1.66	17.33±1.39	25.40±1.87	88.42±4.89
3		10 ⁻³ g/L	5.66±1.05	18.24±1.25	27.61±1.87	102.83±6.23
		10 ⁻² g/L	6.11±1.09	19.55±1.26	22.79±2.21	106.58±5.69
		10 ⁻¹ g/L	7.48±1.30	16.89±1.45	24.75±1.98	91.37±6.13
4		10 ⁻³ g/L	-	21.37±1.21	-	103.24±5.82
		10 ⁻² g/L	-	22.01±1.26	-	98.89±5.56
		10 ⁻¹ g/L	-	24.08±1.22	-	100.74±5.84
5		10 ⁻³ g/L	-	21.33±1.15	-	99.96±6.24
		10 ⁻² g/L	-	21.96±1.25	-	112.17±6.30
		10 ⁻¹ g/L	-	21.99±1.27	-	101.15±6.19

Concentrations of bromide 2 at 10⁻² g/L and 10⁻¹ g/L had almost no effect on seed germination (≈1%). The optimal concentration of sample 3 for soybean seed germination was 10⁻² g/L, which increased the number of germinated seeds from 125 to 139 (≈11%). At a concentration of 10⁻³ g/L, the number of germinated seeds also increased (≈6%). The highest concentration of bromide 3 inhibited germination. Analysis of germination after treatment with compound 4 showed a weak stimulatory effect at low concentrations of 10⁻³ g/L and 10⁻² g/L (≈2–5%). Increasing the concentration of bromide 4 inhibited germination by approximately 3%. Sample 5 at a concentration of 10⁻² g/L showed the best germination results, increasing the number of germinated seeds by ≈9% compared to the control. Concentrations of 10⁻³ g/L and 10⁻¹ g/L also stimulated germination, but to a lesser extent. From the experimental data and their analysis, it was found that among salts 2–5, bromide 3 was the most effective in stimulating germination, showing the highest number of sprouts at all concentrations, particularly at 10⁻² g/L. Iodide 5 exhibited a moderate stimulatory effect, while bromides 2 and 4 showed unstable or inhibitory effects, which increased with higher concentrations. Morphological characteristics of the germinated seeds (length, mm) were measured using AmScope software [25]. The data on soybean seedling lengths are presented in Table 3. Analysis of Table 3 revealed the following patterns: the tested compounds had different effects on seedling growth compared to the control (distilled water). On day 7, the seedling length in the control was 95.32 mm. The most pronounced stimulatory effect was observed with bromide 3: at 10⁻² g/L, the seedling length increased to 106.58 mm, which was 12% higher than the control, and at 10⁻³ g/L, it increased to 102.83 mm (≈8%). Iodide 5 also significantly stimulated growth, with maximum elongation observed at 10⁻² g/L (112.17 mm), corresponding to an 18% increase compared to the control. Bromide 4 showed a moderate positive effect, increasing seedling length by 4–8%, depending on the concentration. Meanwhile, sample 2 exhibited unstable activity: at 10⁻³ g/L, a slight growth stimulation was noted (≈4%), whereas at 10⁻² and 10⁻¹ g/L, growth was inhibited by 5–7% relative to the control. These results indicate a concentration-dependent effect of the tested compounds on seedling growth and a notable phytohormonal activity of samples 3–5. On day 7, the maximum seedling length was observed for iodide 5 at 10⁻² g/L (112.17 mm), which was 5% higher than bromide 3 at the same concentration (106.58 mm) and 11% higher than bromide 4 (100.74 mm). Thus, iodide 5 was the most effective stimulator of seedling elongation at the final growth stage. Bromide 3 ranked second in stimulatory activity among the tested samples, demonstrating high growth values at both 10⁻³ g/L (102.83 mm) and 10⁻² g/L (106.58 mm). Compared to bromide 4, seedlings treated with sample 3 were 3–8% longer, depending on concentration. Bromide 4 showed a moderate growth-stimulating effect, less pronounced than samples 3 and 5 but more stable than sample 2. Its seedling lengths on day 7 (98.89–103.24 mm) were equal to or slightly higher than those of bromide 2. The lowest phytohormonal activity among the tested compounds was observed for the tellurium analog 2, which either minimally stimulated or inhibited seedling growth at later developmental stages. Seedling lengths with this compound were 7–217% lower than the maximum values obtained for sample 5.

Conclusions

In this study, the phytohormone-like activity of angular thiazolo[3,2-a]quinazolin-10-ium halogenides—4-allyl-5-oxo-1-((tribromo-λ⁴-tellanyl)methyl)-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium bromide, 4-allyl-5-oxo-1-((tribromo-λ⁴-selanyl)methyl)-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium bromide, 4-allyl-1-(iodomethyl)-5-oxo-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium bromide, and 4-allyl-1-(iodomethyl)-5-oxo-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium iodide—was assessed. All studied samples exhibited good phytohormone-like activity in soybean (*Glycine max* (L.) Merrill) compared to the control. The highest growth-regulating activity during organogenesis was observed for 4-allyl-1-(iodomethyl)-5-oxo-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium iodide (germination rate, seedling length). The maximum seedling length was recorded for this iodide at 10⁻² g/L, exceeding that of 4-allyl-5-oxo-1-((tribromo-λ⁴-selanyl)methyl)-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium bromide by 5% and 4-allyl-1-(iodomethyl)-5-oxo-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium bromide by 11% at the same concentration. The lowest phytohormone-like activity was observed for the tellurium analog—4-allyl-5-oxo-1-((tribromo-λ⁴-tellanyl)methyl)-1,2,4,5-tetrahydrothiazolo[3,2-a]quinazolin-10-ium bromide—which exhibited minimal stimulation or inhibition of seedling growth at later developmental stages. Possible mechanisms of the metabolism of these halogenide salts in plants, directly influencing their phytohormone-like activity, are proposed. The results suggest that the observed phytohormone-like activity arises from a combined effect of halide ion transport through anion channels, potential incorporation of selenium and iodine into metabolic pathways, and auxin- and cytokinin-like regulation of cell proliferation and differentiation. Thus, iodine-containing thiazolo[3,2-a]quinazolin-10-ium derivatives are promising, environmentally safe growth regulators for soybean and can be considered as potential agrochemical agents to enhance crop productivity.