Benzothiazole compounds
XXXIII. Benzothiazolium salts which increase sugar and chlorophyll contents in plants

[a]V. SUTORIS, [b]P. BAJČI, [c]V. SEKERKA, and [a]J. HALGAŠ

[a]*Department of Organic Chemistry, Faculty of Natural Sciences, Comenius University, CS-842 15 Bratislava*

[b]*Research and Breeding Institute of Seed Root Crops and Industrial Crops, CS-919 28 Bučany*

[c]*Department of Molecular Biology and Genetics, Faculty of Natural Sciences, Comenius University, CS-842 15 Bratislava*

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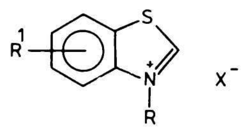
Dedicated to Professor Ing. J. Kováč, DrSc., in honour of his 60th birthday

If seed of vetch and sugar beet had been treated with benzothiazolium salts, the sugar and chlorophyll contents in leaves increased. Higher sugar contents in the beet-heads, lower contents of potassium, sodium, α-amino acids, and higher yield of sugar beet was found after application of the salts on the leaves of sugar beet. The achievement of these positive results depends on the time of application and on soil and climate conditions. The optimal dose was 50 g ha^{-1}. The benzothiazolium salts were found to be a new group of compounds with auxine-like activity.

При обработке семен вики и сахарной свеклы солями бензотиазолия повышалось содержание сахара и хлорофилла в листьях. Повышенное содержание сахара в свекле, снижение содержания калия, натрия, α-аминокислот, а также большая урожайность сахарной свеклы были следствием обработки указанными солями листьев сахарной свеклы. Достижение таких положительных результатов зависит от времени применения химикатов и от почвенных и климатических условий. Оптимальной дозой было количество 50 г га$^{-1}$. Обнаружено, что соли бензотиазолия представляют собой новую группу соединений с ауксиноподобной активностью.

The results obtained in the studies aimed at increasing of sugar contents in sugar-producing plants are contradictory, conditional on many factors, mainly on soil and climate conditions, on the stage of growth at the time of application and on the used concentrations. At present, there is no universal preparation for marked increase of sugar contents in sugar beet. Special attention has been paid to making use of growth regulators such as auxinoids [1—3], gibberellins [4], and retardants [5], among them in particular 1,2-dihydropyridazine-3,6--dione (maleic acid hydrazide) and recently *N*-substituted 2-benzothiazolinone and 2-benzoxazolinone derivatives [6—8].

Our study has been based on the finding that many benzothiazolium salts of the general formula



possess good plant growth regulating activity [9, 10]. A preliminary test was carried out by the application of the salts with $R^1 = H$ on the seed of vetch and the sugar contents was determined in the leaves. The results are presented in Table 1. As the results of this test were highly significant, we used the same method for a test with sugar beet. The results are given in Table 2. The compounds taken for this test can be divided into three groups. Those with $R = CH_3$ and with changing R^1 in positions 4 and 6 showed various activity. The basic member of this group, 3-methylbenzothiazolium bromide (*VII*), functioned as a stimulant at all tested concentrations. However, most derivatives in this group caused inhibition of sugar production at lower concentrations. Neither methyl group nor chlorine in positions 4 and 6 brought about considerable changes in activity. In the second group of compounds, we can compare the effect of ester groups with that of a free carboxylic group. We found that compounds with ester groups are more active at higher concentrations. Remarkable activity was observed only with 3-isopropoxycarbonylmethylbenzothiazolium bromide (*XIX*). 3-Benzylbenzothiazolium bromide (*XX*) was the most active among the compounds with benzyl or substituted benzyl in position 3. Chlorine or nitro group in the benzyl moiety resulted in decreased activity.

Without going into details, we studied also the effect of some benzothiazolium compounds on chlorophyll contents in sugar beet leaves after treatment of the seed. We found that the tested compounds have diverse effects on the chlorophyll synthesis. 3-Methoxycarbonylmethylbenzothiazolium bromide (*IV*) was the most active, causing higher chlorophyll contents in the range of 124—220 % at all concentrations. This effect is highly significant from the biological point of view. Changing of the methyl group for ethyl or propyl one brought about decreased chlorophyll contents. 3-Benzylbenzothiazolium bromide (*XX*) showed the lowest activity at concentrations below 10^{-3} mol dm^{-3}. The results are given in Tables 3—6.

Table 1

The effect of some benzothiazolium salts (R^1 = H) on the sugar contents (β) in the leaves of vetch (*Vicia sativa*), after the application of the salts on seed

Compound	R	X	$c/(\text{mol dm}^{-3})$	$(\beta \pm s_\beta)/\text{mg}$	$\beta_r/\%$
I	CH_3	CH_3SO_4	0	0.702 ± 0.005	100
			10^{-11}	0.825 ± 0.300	117.52
			10^{-5}	0.839 ± 0.041	119.52
			10^{-3}	0.838 ± 0.021	119.37
II	$CH_2CH{=}CH_2$	Br	0	0.783 ± 0.035	100
			10^{-13}	0.829 ± 0.010	105.87
			10^{-7}	0.922 ± 0.008	117.75
			10^{-3}	1.115 ± 0.043	142.40
			7×10^{-3}	1.407 ± 0.291	179.69
III	CH_2COOCH_3	Cl	0	0.702 ± 0.005	100
			10^{-13}	0.762 ± 0.020	108.55
			10^{-5}	0.780 ± 0.014	111.11
			10^{-3}	0.855 ± 0.013	121.78
			5×10^{-3}	0.782 ± 0.030	111.40
IV	CH_2COOCH_3	Br	0	0.822 ± 0.010	100
			10^{-3}	0.915 ± 0.008	111.31
			5×10^{-3}	1.332 ± 0.051	162.04
			8×10^{-3}	1.723 ± 0.024	209.61
V	$CH_2COOCH_2CH{=}CH_2$	Br	0	0.518 ± 0.021	100
			10^{-11}	0.632 ± 0.008	122.00
			10^{-7}	0.650 ± 0.012	125.50
			10^{-3}	0.617 ± 0.017	119.10
VI	$CH_2COOC_3H_7$	Br	0	0.822 ± 0.010	100
			10^{-3}	0.885 ± 0.006	107.66
			5×10^{-3}	1.272 ± 0.070	154.79
			8×10^{-3}	1.894 ± 0.074	230.41

β — Average sugar contents in certain amount of leaves; s_β — standard error of β; β_r — percentage value related to control ($c = 0$).

Taking the results of the laboratory tests into account, we proceeded to a systematic study of activity of the compounds under common climate conditions in the field. Since 1981, benzothiazolium salts had been tested by application on sugar beet leaves at various stages of development. The following dependences were studied: application of various compounds at the same time and the harvest at the same time, application of 3-benzylbenzothiazolium bromide at various dates and the harvest at the same time, application at the same time and various dates of the harvest, and various times of application

Table 2

The effect of some benzothiazolium salts on the sugar contents (β_r/%, related to control) in the leaves of sugar beet, after the application in various concentrations on seed

Compound	R	R[1]	X	c/(mol dm^{-3})						Average error
				5×10^{-3}	10^{-3}	10^{-4}	10^{-7}	10^{-11}	10^{-13}	%
VII	CH_3	H	Br	128.75	126.75	121.82	107.97	124.28	158.71	3.40
VIII	CH_3	4-CH_3	Br	137.25	125.60	122.78	74.67	91.46	74.50	3.86
IX	CH_3	4-CH_3	I	135.25	114.57	114.85	97.09	99.80	93.17	3.61
X	CH_3	6-CH_3	Br	135.49	127.25	111.03	108.19	104.64	100.42	2.23
XI	CH_3	6-CH_3	I	151.74	130.51	118.38	96.24	104.82	107.00	2.77
XII	CH_3	4-Cl	Br	106.24	111.10	82.04	112.25	84.53	80.67	5.19
XIII	CH_3	4-Cl	I	157.97	154.03	137.04	105.66	83.26	75.57	2.48
XIV	CH_3	4-Cl	CH_3SO_4	128.83	122.69	132.01	130.94	130.24	84.46	4.05
XV	CH_3	6-Cl	Br	112.36	109.30	109.47	95.55	84.82	79.96	2.30
XVI	CH_3	6-Cl	I	121.50	106.81	106.90	110.84	106.92	99.17	1.05
XVII	CH_2COOH	H	Br	119.17	111.77	121.50	102.55	103.66		3.35
IV	CH_2COOCH_3	H	Br	174.26	157.91	143.66	115.18	111.77	111.32	2.10
XVIII	$CH_2COOC_2H_5$	H	Br	158.81	142.11	110.96	110.51	102.29	104.91	3.25
VI	$CH_2COOC_3H_7$	H	Br	138.25	121.59	117.00			118.18	3.77
XIX	CH_2COO-i-C_3H_7	H	Br	131.02	126.70	90.89	89.63	91.95	85.52	4.60
V	$CH_2COOCH_2CH = CH_2$	H	Br	135.32	146.51	135.05	124.32	127.26	115.48	3.06
XX	$CH_2C_6H_5$	H	Br		189.02	215.47	197.72		204.60	4.46
XXI	$CH_2C_6H_5Cl$-*o*	H	Br		111.23	108.60	85.54		98.31	4.70
XXII	$CH_2C_6H_5Cl$-*m*	H	Br		122.21	125.13	122.33		114.19	1.47
XXIII	$CH_2C_6H_5Cl$-*p*	H	Br		118.95	109.14	98.72		102.56	4.27
XXIV	$CH_2C_6H_5NO_2$-*o*	H	Br		114.49	87.49	102.27		90.42	1.86
XXV	$CH_2C_6H_5NO_2$-*m*	H	Br		144.00	130.25	111.94		100.01	3.20

Table 3

Mass fraction of chlorophyll in the sugar beet leaves (w) and its relative value ($\gamma/\%$ related to control $c = 0$) after the treatment of the sugar beet seed with 3-methoxycarbonylmethylbenzothiazolium bromide (*IV*)

$c/(\text{mol dm}^{-3})$	Chlorophyll a, b $10^3\ w$ $\gamma/\%$	Chlorophyll a $10^3\ w$ $\gamma/\%$	Chlorophyll b $10^3\ w$ $\gamma/\%$
0	2.2064 100	1.6136 73.13	0.5928 26.87
10^{-13}	4.9489 224.30	3.4819 157.80	1.4670 66.50
10^{-11}	6.0030 272.07	4.1526 188.20	1.8504 83.87
10^{-7}	6.1597 279.17	4.2225 191.37	1.9372 87.80
10^{-4}	6.0650 274.88	4.1830 189.58	1.8820 85.30
5×10^{-3}	5.5424 251.20	3.7416 169.57	1.8008 81.63

Table 4

Mass fraction of chlorophyll in the sugar beet leaves (w) and its relative value ($\gamma/\%$ related to control $c = 0$) after the treatment of the sugar beet seed with 3-ethoxycarbonylmethylbenzothiazolium bromide (*XVIII*)

$c/(\text{mol dm}^{-3})$	Chlorophyll a, b $10^3\ w$ $\gamma/\%$	Chlorophyll a $10^3\ w$ $\gamma/\%$	Chlorophyll b $10^3\ w$ $\gamma/\%$
0	5.3196 100	3.5860 67.41	1.7336 32.59
10^{-13}	6.0658 114.03	4.1133 77.32	1.9525 36.71
10^{-11}	6.8188 128.18	4.8433 91.04	1.9755 37.14
10^{-7}	7.8691 147.93	5.1750 97.28	2.6941 50.65
10^{-4}	7.3011 137.25	4.8772 91.68	2.4239 45.57
10^{-3}	6.0568 113.86	3.8688 72.73	2.1880 41.13
5×10^{-3}	5.5748 104.80	4.0368 75.89	1.5380 28.91

Table 5

Mass fraction of chlorophyll in the sugar beet leaves (w) and its relative value ($\gamma/\%$ related to control $c = 0$) after the treatment of the sugar beet seed with 3-propoxycarbonylmethylbenzothiazolium bromide (*VI*)

$c/(\text{mol dm}^{-3})$	Chlorophyll a, b $10^3\ w$ $\gamma/\%$	Chlorophyll a $10^3\ w$ $\gamma/\%$	Chlorophyll b $10^3\ w$ $\gamma/\%$
0	8.7721 100	6.2487 71.23	2.5234 28.77
10^{-13}	12.8050 145.97	8.4145 95.92	4.3905 50.05
10^{-11}	10.7266 122.28	7.4754 85.21	3.2512 37.07
10^{-7}	10.9648 125.00	7.6884 87.64	3.2764 37.36
10^{-4}	11.0114 125.53	8.0780 92.08	2.9334 33.45
10^{-3}	10.5251 119.98	7.5895 86.51	2.9356 33.47
5×10^{-3}	9.6932 110.50	7.0918 80.84	2.6014 29.66

Table 6

Mass fraction of chlorophyll in the sugar beet leaves (w) and its relative value ($\gamma/\%$ related to control $c = 0$) after the treatment of the sugar beet seed with 3-benzylbenzothiazolium bromide (*XX*)

$c/(\text{mol dm}^{-3})$	Chlorophyll a, b $10^3\ w$ $\gamma/\%$	Chlorophyll a $10^3\ w$ $\gamma/\%$	Chlorophyll b $10^3\ w$ $\gamma/\%$
0	6.8640 100	4.8810 71.11	1.9830 28.89
10^{-13}	6.4764 94.35	4.9066 71.48	1.5698 22.87
10^{-11}	6.7860 98.86	4.6183 67.28	2.1677 31.58
10^{-7}	6.9793 101.68	4.2381 61.74	2.7412 39.94
10^{-4}	6.2784 91.47	4.5498 66.29	1.7286 25.18
10^{-3}	8.7574 127.58	6.3449 92.44	2.4125 35.14
5×10^{-3}	9.8203 143.07	6.9482 101.23	2.8721 41.84

with observance of a four-week term of functioning. Besides the results shown in Tables 7—10, many other variants were followed. Dynamism of the effects of the compounds was studied mainly at various doses and with application at different stages of the plant growth. No irrigation was used during droughts. Each value given in the tables was calculated as an average of five experiments.

There were no substantial differences in the results of the experiments with doses ranging from 40 g ha^{-1} to 120 g ha^{-1}. Therefore, we chose 50 g ha^{-1} dose dissolved in 120 dm^3 of water per hectare for further tests. In the year 1981, the best yield of sugar (per given amount of beet) was achieved with 3-benzylbenzothiazolium bromide (*XX*) (Table 7). Other criteria were accomplished as well: the weight of beet-heads increased only by 0.6 t ha^{-1} but the sugar contents rose by 1.04 % and that resulted in higher sugar production by 600 kg ha^{-1} [11, 12]. With 3-ethoxycarbonylmethylbenzothiazolium bromide (*XVIII*) the yield of sugar was markedly lower, the sugar contents rose only by 0.28 % and the overall sugar production increased mainly due to the higher yield of beet-heads by 3.95 t ha^{-1}. The activity of other 3-alkoxycarbonylmethyl derivatives remained at the control level.

In the years 1982—1984, we were looking for the optimal time of application and the duration of effectiveness. In 1982, the application terms were different and the harvest was at the same time (Table 8). The results of early application indicate an inhibitory effect on the yield of beet-heads. When the application was in the end of August with five-week effectiveness, the increase of sugar contents was significant, the increase of the yield of sugar and of the production of refined sugar was highly significant. The production of sugar was higher by 870 kg ha^{-1}. When the application was on 15 September, 1982 and the harvest after three weeks, the results were less satisfactory due to shorter effectiveness but also to a great soil moisture deficit. The precipitation in August amounted to 38.7 mm while the many years' average is 66.6 mm and in September only 9.6 mm compared with the average 34.4 mm.

The most advantageous term of application proved in 1982 (31 August) was repeated also in 1983 with the duration of effectiveness 1—5 weeks (Table 9). The best results were in an experiment with four-week effectiveness but only due to enormous increase of the yield of beet-heads by 5.9 t ha^{-1}. Probably, the application should have been postponed till 10—15 September with four-week effectiveness. Therefore in 1984, different dates of application were chosen (Table 10) with equal, four-week effectiveness. Again, the best results were achieved when the application was on 30 August and on 6 September, 1984, hence in the period of relative "ripening" of sugar beet. The increase of sugar contents was by 0.5 %, the increase of the beet-head yield by 3.86—4.56 t ha^{-1}, the increase of sugar production by 850—1010 kg ha^{-1}, and the decrease of the

Table 7

The results* of field tests in which sugar beet was treated with various benzothiazolium salts on 15 August, 1981 and the crop harvested on 15 October, 1981

Control (K) Compound	Yield of beet-heads (A)		Sugar contents (B)		Yield of sugar (C)		Production of polarization sugar (D)		Production of refined sugar (E)	
	A/(t ha^{-1})	A_r/%	B/°S	B_r/%	C/%	C_r/%	D/(t ha^{-1})	D_r/%	E/(t ha^{-1})	E_r/%
K	30.95	100	14.68	100	11.69	100	4.54	100	3.62	100
IV	32.08	103.7	14.66	99.9	11.58	99.1	4.70	103.5	3.70	102.2
K	28.58	100	13.59	100	10.85	100	3.99	100	3.10	100
XVIII	32.53	113.8	14.23	102.0	11.40	105.4	4.63	115.8	3.71	119.3
K	29.08	100	13.67	100	10.46	100	3.98	100	3.04	100
XIX	28.23	97.1	13.86	101.4	10.67	101.7	3.91	98.2	3.01	99.0
K	29.08	100	13.67	100	10.46	100	3.98	100	3.04	100
VI	28.03	96.4	13.54	99.0	10.15	97	3.80	95.5	2.91	95.7
K	50.08	100	13.32	100	9.67	100	6.67	100	4.84	100
XX	50.68	101	14.36	107.8	11.39	117.8	7.27	109	5.78	119.4

* Each value is an average of five parallel tests.

Table 8

The average results* (5 parallels) of the field tests in which sugar beet was treated with 3-benzylbenzothiazolium bromide (*XX*) on various days in 1982 and harvested on 6 October, 1982

Date of application	Yield of beet-heads (A)		Sugar contents (B)		Yield of sugar (C)		Production of sugar (D)		Production of refined sugar (E)	
	$A/(\mathrm{t\ ha^{-1}})$	$A_r/\%$	$B/°\mathrm{S}$	$B_r/\%$	$C/\%$	$C_r/\%$	$D/(\mathrm{t\ ha^{-1}})$	$D_r/\%$	$E/(\mathrm{t\ ha^{-1}})$	$E_r/\%$
15 July	64.50	100	16.1	100	12.43	100	10.37	100	8.0	100
	61.04	94.5	15.6	96.9	12.01	96.6	9.52	91.8	7.33	91.6
2 August	65.20	100	15.8	100	12.15	100	10.28	100	7.93	100
	62.37	96.0	15.9	100.6	12.40	102.1	9.88	96.1	7.72	97.3
16 August	55.93	100	15.5	100	11.45	100	8.53	100	6.46	100
	58.14	103.9	16.2	104.5	12.49	109.1	9.41	110.3	7.27	112.5
31 August	62.21	100	15.2	100	11.0	100	9.46	100	6.84	100
	64.99	104.5	15.9	104.6	12.1	110.0	10.33	109.2	7.86	114.9
15 September	58.98	100	15.4	100	11.36	100	9.07	100	6.71	100
	62.10	105.3	15.4	100	11.69	102.6	9.56	105.4	7.26	108.2

* In each pair of values, the upper refers to a control and the lower to a test with *XX*.

Table 9

The average results* (5 parallels) of the field tests in which sugar beet was treated with 3-benzylbenzothiazolium bromide (*XX*) on 31 August, 1983 and harvested on various days in 1983

Date of harvest	Yield of beet-heads (*A*)		Sugar contents (*B*)		Yield of sugar (*C*)		Production of sugar (*D*)		Production of refined sugar (*E*)	
	$A/(\mathrm{t\ ha^{-1}})$	$A_r/\%$	$B/°\mathrm{S}$	$B_r/\%$	$C/\%$	$C_r/\%$	$D/(\mathrm{t\ ha^{-1}})$	$D_r/\%$	$E/(\mathrm{t\ ha^{-1}})$	$E_r/\%$
6 September	37.18	100	14.90	100	10.50	100	5.54	100	3.91	100
	38.69	104.1	14.88	99.9	10.66	101.5	5.75	103.8	4.12	105.4
13 September	42.62	100	14.60	100	11.32	100	6.23	100	4.83	100
	42.74	100.3	14.52	99.5	11.18	98.8	5.95	95.5	4.78	99.0
20 September	39.39	100	15.90	100	12.68	100	6.27	100	5.0	100
	44.50	113	15.52	97.6	12.15	95.8	6.90	110	5.4	108
27 September	41.92	100	15.60	100	12.31	100	6.58	100	5.19	100
	47.82	114.1	15.38	98.6	11.92	96.8	7.35	111.7	5.69	109.6
4 October	47.20	100	17.44	100	14.16	100	8.23	100	6.69	100
	44.43	94.1	17.56	100.7	14.21	100.4	7.80	94.8	6.30	94.2

* In each pair of values, the upper refers to a control and the lower to a test with *XX*.

Table 10. The average results* (5 parallels) of the field tests in which sugar beet was treated with *XX* in 1984

No.	Date of application	Date of harvest	Yield of beet-heads (*A*)		Sugar contents (*B*)		Yield of sugar (*C*)		Production of sugar (*D*)	
			$A/(\text{t ha}^{-1})$	$A_r/\%$	$B/°\text{S}$	$B_r/\%$	$C/\%$	$C_r/\%$	$D/(\text{t ha}^{-1})$	$D_r/\%$
1	23 Aug.	20 Sept.	36.94	100	15.42	100	12.64	100	5.71	100
			36.66	99.29	14.76	95.71	11.58	91.61	5.41	94.74
2	30 Aug.	27 Sept.	39.92	100	13.19	100	10.33	100	5.29	100
			43.78	109.66	13.69	103.79	11.0	106.48	6.14	116.06
3	6 Sept.	4 Oct.	39.34	100	14.45	100	10.80	100	5.69	100
			44.78	114.11	14.96	103.52	11.69	108.24	6.70	117.75
4	14 Sept.	11 Oct.	48.24	100	14.79	100	11.43	100	7.14	100
			47.14	93.57	14.26	96.41	11.03	96.50	6.56	91.87
5	20 Sept.	18 Oct.	46.68	100	15.06	100	12.36	100	7.04	100
			45.72	97.94	15.11	100.33	12.36	100	6.91	98.15
6	27 Sept.	25 Oct.	43.52	100	15.39	100	12.62	100	6.90	100
			45.98	105.65	16.30	105.91	13.31	105.46	7.50	108.69

No.	Production of refined sugar (*E*)		Potassium contents (*F*)		Sodium contents (*G*)		α-Amino-nitrogen contents (*H*)	
	$E/(\text{t ha}^{-1})$	$E_r/\%$	$10^2\,F/(\text{mmol g}^{-1})$	$F_r/\%$	$10^2\,G/(\text{mmol g}^{-1})$	$G_r/\%$	$10^2\,H/(\text{mmol g}^{-1})$	$H_r/\%$
1	4.68	100	4.35	100	0.72	100	8.01	100
	4.25	90.81	4.75	109.19	0.90	125.0	10.09	125.96
2	4.14	100	3.81	100	0.85	100	10.37	100
	4.94	119.32	3.85	101.04	0.69	81.17	9.02	86.98
3	4.25	100	5.52	100	1.15	100	11.49	100
	5.23	123.05	5.14	93.11	0.88	76.52	9.80	85.29
4	5.52	100	4.98	100	1.35	100	9.51	100
	5.07	91.84	4.76	95.58	1.28	94.81	9.28	97.58
5	5.78	100	5.06	100	0.83	100	5.19	100
	5.65	97.75	5.06	100	0.80	96.38	4.87	93.83
6	5.30	100	4.69	100	1.02	100	5.56	100
	5.94	112.07	5.46	116.41	1.01	99.01	5.19	93.34

* In each pair of values, the upper refers to a control and the lower to a test with *XX*.

potassium, sodium, and nitrogen contents facilitated the extractability of sugar. Rich precipitation in the second half of September vivified vegetation, which manifested in growing of new leaves. This phenomenon was reflected also in the last experiment with application on 27 September, 1984 in which the yield of beet-heads increased by 2.46 t ha^{-1}, the sugar contents by 0.91 %, and sugar production by 600 kg ha^{-1}.

Taking all these results into account, we came to the conclusion that weather conditions during all vegetation are of great importance for the activity of the tested compounds, since the conditions can considerably influence processes of ontogenetic development. They can accelerate or retard it and, consequently, an active compound administered at the same calendar date in different years can function in various stages of ontogenetic development. As a result, the effect and behaviour of the used compound can be different. The decisive factor is the term of application. The most suitable term seems to be in the so-called stage of "ripening" (September) a few days before or closely after rainfall and with 3—5-week effectiveness. The obtained results have proved unambiguously that benzothiazolium salts represent a new series of auxine-like compounds that can increase the sugar contents in sugar beet.

Experimental

Preparations and characterization of the tested compounds have been described in papers [9, 10, 13]. Determination of sugar contents in the leaves of vetch and sugar beet was carried out according to [14], chlorophyll was determined as described in [15]. Five testing plots, 20 m^2 large, were allotted for each experiment. The dose of the physiologically active compound (*XX*) was usually 36.7 g in 120 dm^3 of water (concentration 10^{-3} mol dm^{-3}) per hectare. Maximum dose was 50 g ha^{-1}. All beet-heads harvested from each plot were weighted and 40 heads of average size were taken aside. These heads were homogenized and sugar contents, potassium, sodium, and α-amino acids were determined in the mash by means of an automatic assemblage VEMENA. Using these data, the yield of sugar, production of polarization sugar, and production of refined sugar were calculated according to empirical formulas commonly used in the research of sugar--making.

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