Ukrainian Journal of Ecology

Ukrainian Journal of Ecology, 2021, 11(1), 143-148, doi: 10.15421/2021_21

RESEARCH ARTICLE

Impact of retardants on sugar beet seed productivity

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Received: 27.01.2020. Accepted: 27.02.2021

The study aimed to determine the aftereffects of dextrel and paclobutrazol on the seed productivity of sugar beet plants in the year following the treatment and the treatment of flowering shoots. Methods. Field research, analytical and statistical processing of research results. Results. The use of drugs of the inhibitory type of dextrel (0.3%) and paclobutrazol (0.05%) in the first year of the culture growing in the phase of formation of 28 and 38-40 leaves led to an increase in root mass, which provided intensive plant growth in the second year of vegetation. Our research results indicate an increase in seed productivity of beet plants in the second year of the growing season with the use of retardants. The use of dextrel by this technology led to an increase in germination energy and germination of all seed fractions. Treatment of sugar beet plants with retardants in the budding phase led to a visible growth-inhibiting effect and slowing down plants' axial organs' growth. The most significant inhibition was observed in first-order flowering shoots, which contributed to forming a more compact bush. The drugs stimulated the growth of side shoots, which lagged in growth due to correlations while forming a more productive type of bush with more side shoots. The use of retardants on sugar beet in the budding phase led to an increase in plants' seed productivity in the planting method of cultivation. Under the influence of growth regulators, there was an increase in the mass of fruit of fractions of 4.5-5.5 mm and 3.5-4.5 mm. The applying of 0.05% paclobutrazol by this technology leads to improved germination energy and germination of all fractions' seeds.
Keywords: retardants; seed productivity; seed germination; sugar beet (*Beta vulgaris* L.)

Introduction

Growth regulators are a group of drugs recommended in the production of crops for targeted control of plant development processes, increasing their productivity and increasing profitability. The multifunctionality of growth regulators has significantly expanded the scope of their application in crop production. Drugs for exogenous regulation of plant growth and development are widely used in the world practice of agrobiology. With the help of such compounds, it is possible not only to influence the processes of plant development but also to increase yields and improve the part of plant products in the diet of the population (Khodanitska et al., 2019; Shevchuk et al., 2020; Rohach et al., 2020; Vdovenko et al., 2018).

One of the critical aspects of synthetic growth regulators' action is the ability to influence the plant's donor-acceptor system. In practical terms, this makes it possible to artificially redistribute the flow of assimilates towards economically valuable organs (Bonelli et al., 2016; Dewi & Darussalam, 2018; Khodanitska et al., 2021).

Plant growth regulators or their antagonists increase photosynthetic productivity and enhance the flow of assimilates from leaves to growth or storage zones (Kuryata et al., 2019; Shevchuk et al., 2019; Jiang et al., 2019). Retardants are synthetic growth inhibitors that are widely used in agriculture. The growth inhibitory effect of retardants is determined, depending on their chemical structure, by blocking the synthesis or reducing the activity of already synthesized gibberellins. It was found that the growth response to retardants is associated not only with the anti-gibberellin nature of the drugs but also with a profound restructuring of the whole hormonal complex of the plant (Liu et al., 2020; Koutroubas & Damalas, 2016; Hajihashemi, 2018; MacDonald, 2017; Dewi & Darussalam, 2018). Literature data show that retardants improve the water regime of plants (Wu et al., 2019; Dwivedi et al., 2017; Mohan et al., 2020), increase plant resistance to adverse environmental conditions: in particular, extreme temperatures (Yang et al., 2019), drought and heat resistance (Hajihashemi et al., 2018; Zhao et al., 2017; Fan et al., 2020; Cohen et al., 2019), salt pollution (Keramati et al., 2016; Forghani et al., 2020; Forghani et al., 2018; Detpitthayanan et al., 2019; Khunpon et al., 2018), pests and phytopathogens (Trueman et al., 2019).

Ethylene-producing retardants are widely used as useful compounds to protect cereals against lodging (Kamran et al., 2018). Growth regulators of the inhibitory type lead to increased yields of oilseeds (Ajmi et al., 2020; Polyvanyi et al., 2020), legumes (Keshavarz & Khodabin, 2019), vegetables (Chen et al., 2020), technical (Ellis et al., 2020) and ornamental plants (Wu et al., 2019; Torres-Pio et al., 2021; Tamaki et al., 2020). It is known that the intensive growth of the seed bush of sugar beet can lead to excessive branching and the formation of flowering shoots of the third and subsequent orders, which do not give quality seeds. Besides, the seeds ripen at different times because of the long flowering period. Therefore, it's necessary to control the production process of sugar beet plants using each new growth regulator.

This work aimed to study the aftereffects of dextral© and paclobutrazol© on the seed productivity of sugar beet plants for the next year after treatment and the treatment of flowering shoots.

Materials and Methods

In autumn, the roots of sugar beet hybrid Roberta were dug up and kept in storage at 3-4°C. In the spring of the next year, the roots received in different experiment variants were planted in open ground to study seed productivity. The small-area experiment was established to treat flowering beet shoots to study the effect of retardants on seed productivity, fractional composition, and seed quality of the hybrid Roberta's sugar beet seeds. The experimental plot area was 25 m2, the scheme of planting roots was 70x70 cm, and the frequency of studies was fivefold. The experiment was carried out using the triazole derivative preparation paclobutrazol (P 333) and ethylene releasing compound dextrel. Paclobutrazol© is dimethyl-2-(1,2,4-triazolyl-1)-1(4-chlorophenyl)pentanol-3 derivative of 1,2,4-triazole, which is synthesized by the company "ACI" (UK) (Desta & Amare, 2021). Dextrel© D-(+)-threo-1-(p- nitrophenol)-1,3-diisopropylammonium, (2-chloroethyl)phosphonic acid, which is synthesized at the Institute of Organic Chemistry of the National Academy of Sciences of Ukraine. Processing of flowering shoots of sugar beet plants was carried out in the budding phase — aqueous solutions of paclobutrazol 0.05% and dextrel 0.3% were used for this purpose. At the end of the growing season, the weight and fractional composition of seeds were determined. Sugar beet seeds were germinated in glass vessels on moistened filter paper at a temperature of 25 °C to determine the sowing qualities (germination energy and general germination).

The results of the study were statistically processed using the statistical software Statistica 6.0. The reliability of the results obtained between the control and the experimental variant was assessed using Student's t-test. Tables and figures show mean values for the years of research and their standard errors.

Results and Discussion

We found that the treatment of sugar beet plants of hybrid Roberta by 0.3% dextrel, 0.05% paclobutrazol on the 80th and 100th days of the growing (formation of 28 and 38-40 leaves) led to an increase in root weight compared to control (Table 1).

The obtained results suggest that retardants treatment caused better root development, which was a positive factor and provided intensive plant growth in the second year of cultivation. Seed productivity under the influence of retardants in all variants of the experiment increased (Table 1).

The effectiveness of the applied retardants was different. Higher seed yield was found in plants treated with 0.3% dextrel in the previous year during the formation of 28 leaves and with 0.05% paclobutrazol at the same development stage.

The mass of reserve substances in beet seeds is 3-4 mg, while in wheat seeds 30-40 mg, and corn 200-250 mg. Therefore, the beet seedlings have to germinate quickly from the ground and begin their photosynthesis. Simultaneous germination of seedlings leads to the formation of more powerful seedlings and greater plant productivity. That is why reducing the period of "sowing - germination" even for one or two days is an essential factor in increasing the yield.

The growth of the leaf apparatus, the mass of the root, and the accumulation of sugar in it both at the beginning and at the end of the vegetation season are more intensive when the seeds of large fractions are sown (Melzer et al., 2014). Sugar beet seeds are characterized by significant heterogeneity of fractions - from 2.5 to 5.5 mm and above. Besides, germination of sugar beet seeds and crop productivity directly depends on the seed fraction's size.

In modern beet growing, two sowing fractions of seeds are more often used – 3.5-4.5 and 4.5-5.5 mm. We established that modern varieties of sugar beet are characterized by a high content of seeds of small fractions. In the planting method of growing seed beet plants, regardless of varietal characteristics, most fruits (60-70%) belong to the fraction of 3.5-4.5 mm and almost 30-40% to the fraction of 2.5-3.5 mm (Balagura, 2014). At the same time, the possibility of using smaller fractions of seeds is substantiated recently. In particular, we registered that the productivity of varieties-populations of sugar beet when using seed fractions of 3.25-3.5 mm remains almost the same as when sowing seeds of 3.5-4.5 mm. We revealed that in many cases, beet seeds of the fraction of 3,25-3,50 mm have high germination energy, general germination (more than 90%), and this supports the formation of a large crop of roots and increases its sugar content (Balagura, 2014).

We have made seed fractionation according to the experiment's variants and isolated four fractions in the range of 3.25-6.0 mm. Retardants significantly affected the composition and ratio of beet seed fractions. In particular, a significant increase in the total seed yield was accompanied by a relative increase in the content of the small seed fraction of 3.25-3.5 mm (Table 1).

Using small seed fractions can reduce the cost of sowing materials, so it is advisable to analyze the effect of retardants on the sowing properties of different fractions of sugar beet seeds. It was established that the seeds of the smallest fraction of 3.25-3.5 mm of the experimental plants have a greater mass compared to the control. The obtained results suggest that seeds of the beet plants treated with retardants differed in germination intensity and general germination. All fractions of seeds obtained from sugar beetroots, which were treated in the first year of vegetation with 0.3% dextrel (in the formation of 28 leaves), had higher germination and germination energy than the control. The influence of 0.05% paclobutrazol was less effective (Figure 1).

Inhibition of growth of flowering shoots is reached by removal of tops of flowering shoots. Manual elimination of shoot tops is a highly effective but time-consuming and inconvenient way. Therefore, a method was developed for chemical inhibition of the growth of flower stalks and stems by treating a potent growth inhibitor – hydrazide maleic acid. This retardant method retains the positive effect of manual removal of the tops of the beet shoots – increasing the yield and quality of seeds and significantly reducing the cost of manual work. This method has been widely used in many seed companies in the country. However, hydrazine maleic acid was withdrawn from production due to high toxicity.

Table 1. Seed productivity of sugar beet Roberta under retardants treatment.

Measurement		Dry matter weight of root, g	Seed fraction, mm	Weight of 1000 seeds, g	The number of fruits of this fraction,%	Seed weight per plant, g
Control			5.5-6.0	29.1± 0.20	27.0± 1.11	
		102.4±5.20	4.5-5.5	19.2±0.11	36.1±1.52	135.3±4.61
			3.5-4.5	10.9±0.23	28.2±1.24	
			3.25-3.5	3.4 ±0.20	5.0±0.23	
Dextrel (0.3 %)			5.5-6.0	*33.1±0.51	*22.0±0.82	
	I	*80.2±3.02	4.5-5.5	*25.4±0.20	37.3±1.20	
			3.5-4.5	*15.5±0.20	31.2±1.11	*189.7±7.24

			3.25-3.5	*11.3±0.13	5.2±0.22	
	II		5.5-6.0	*33.7±0.52	25.2±0.54	
		*103.4±2.11	4.5-5.5	*24.7±0.64	34.1±1.12	152.0±4.86
			3.5-4.5	*14.6±0.53	*21.0±0.33	
			3.25-3.5	*11.1±0.20	*11.3±0.30	
Paclobutrazol (0.05 %)			5.5-6.0	-	-	
	I	*110.2±2.09	4.5-5.5	*34.9±2.14	*43.2±1.81	*178.5±6.64
			3.5-4.5	*27.5±0.52	*39.1±0.52	
			3.25-3.5	*14.8±0.61	*9.3±0.50	
			5.5-6.0	*31.5±0.61	*7.3±0.32	
	II	*133.2±4.04	4.5-5.5	*18.6±0.20	34.1±1.32	141.7±3.52
			3.5-4.5	*9.7±0.10	*44.2±1.71	
			3.25-3.5	*5.4±0.10	*8.0±0.40	

Note. Plants were treated at different stages of development: the formation of the 28th leaves (I), the formation of the 38-40th leaves (II); * - difference is significant at P<0.05.

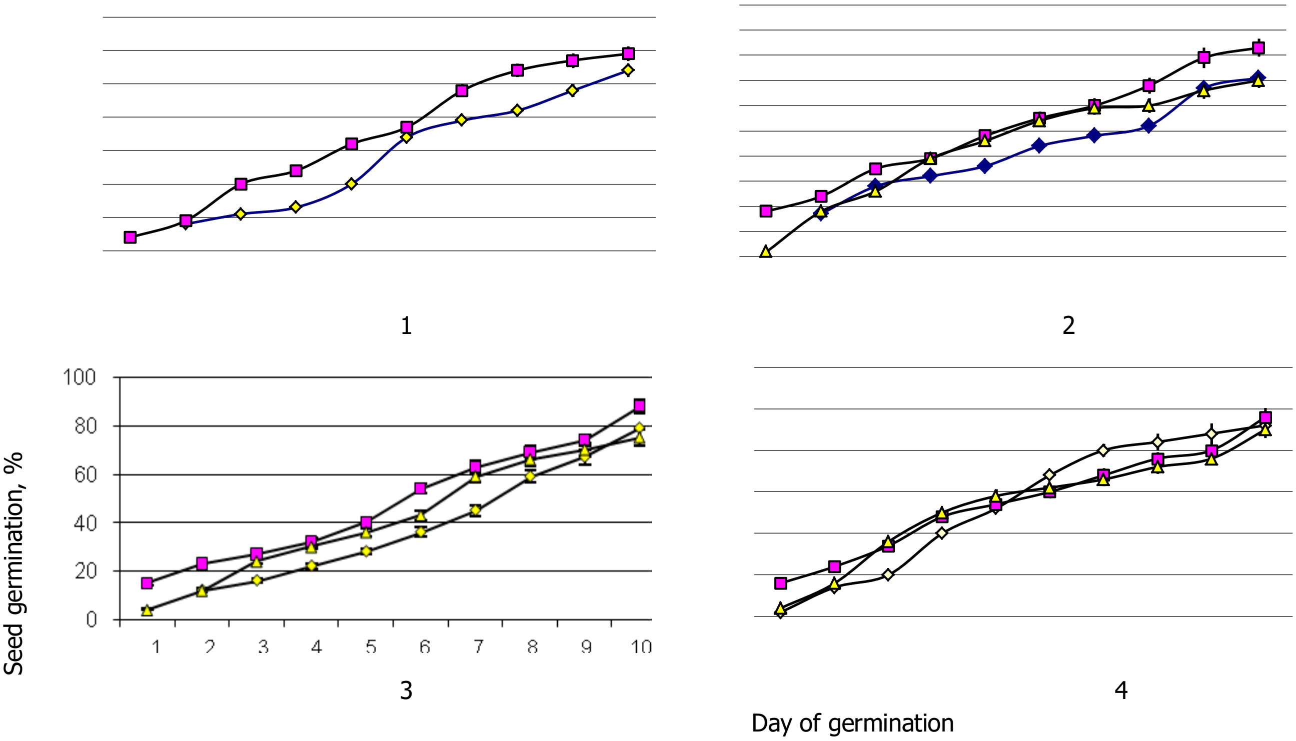

Figure 1. The intensity of seed germination of sugar beet Roberta under retardants treatment. Seed fractions: 1 – 5.5-6.0 mm, 2 – 4.5-5.5 mm, 3 – 3.5-4.5 mm, 4 – 3.25-3.5 mm; Δ – control, ǂ – 0.3% dextrel, ◇ – 0.05% paclobutrazol.

The research results suggest that 0.3% dextrel and 0.05% paclobutrazol treatment of sugar beets of the second year of development led to growth inhibition of axial organs of plants. It should be noted that the growth of first-order flowering shoots is inhibited. Sugar beet plants of the second year vegetation have a relatively short growing season but form a robust vegetative system. Excessive development of vegetative mass is not accompanied by adequate development of generative organs. At the same time, then beet plants are characterized by a more extended flowering period (20-40 days), due to which the seeds ripen at different times (Melzer et al., 2014). That is why it is essential to search for growth regulators to ensure the simultaneous flowering of sugar beet plants and accelerate seed maturation, which is an important crop productivity component.

We found that treatment with retardants dextrel and paclobutrazol in the budding phase inhibited the growth of sugar beet shoots and contributed to the formation of a more compact bush. The drugs stimulated the growth of lateral shoots, which significantly slowed the growth. Therefore a more productive type of bush was formed with more lateral shoots (Table 2). Observations flowering of second-year beet, seed formation, and ripening suggested that retardants stimulated these processes. Sugar beets treated with paclobutrazol and dextrel bloomed 3-4 days before control, and seeds were formed at them earlier. Thus, treatment of sugar beet plants with paclobutrazol and dextrel led to the formation of optimal conditions for seed maturation due to changes in the tillering, inhibition of unproductive growth of seed shoots, compaction of seed placement on flowering shoots, stimulation of flowering, and fruiting. Under the influence of retardants, seed productivity increased in all variants of the experiment. We registered the highest productivity in sugar beet plants treated with 0.05% paclobutrazol (Table 2). According to the variants of the experiment, the fractionation of seeds allowed to distinguish four fractions in the range of 3.25-6.0 mm. The retardants significantly influenced the fractional composition of seeds. In particular, there was a relative increase in the content of the fraction of 4.5-5.5 mm with a significant improvement in the total seed yield (Table 2). The seeds of the fractions, which were 4.5-5.5 mm, 3.5-4.5 mm, and 2.5-3.5 mm, have a greater mass in the plants of the experimental variants than the control. A more apparent effect was observed in the experiment with 0.05% paclobutrazol. Similar results were obtained when the same drugs were used on sugar beet plants of the hybrid Quart in the first year of vegetation. The obtained results suggest that the seeds of plants treated with retardants differed in intensity and simultaneous germination. All fractions of seeds received from sugar beet roots treated with

0.05% paclobutrazol in the budding phase had greater germination energy than the control. The applying of 0.3% dextrel in the budding phase of beet plants was less effective for seed germination (Figure 2).

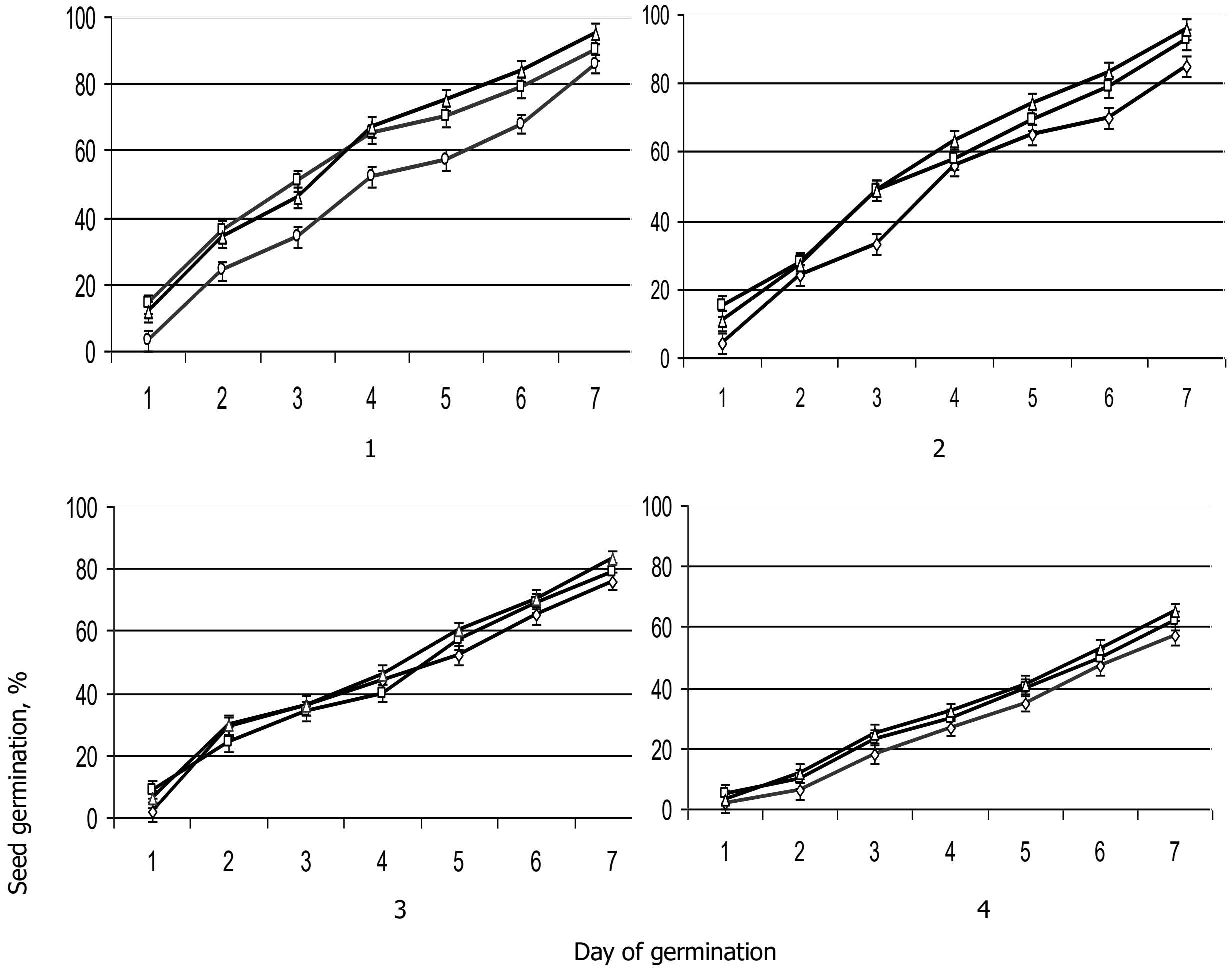

Figure 2. The intensity of seed germination of sugar beet Roberta under retardants treatment of flowering shoots. Seed fractions: 1 – 5.5-6.0 mm, 2 – 4.5-5.5 mm, 3 – 3.5-4.5 mm, 4 – 3.25-3.5 mm; Δ – control, † – 0.3% dextrel, ◇ – 0.05% paclobutrazol. Plants were treated in the budding phase.

Table 2. Seed productivity of sugar beet plants Roberta of the second year of vegetation under retardants treatment.

Measurement	The number of flowering shoots of the 2nd order, pcs.	Seed fraction, mm	The number of fruits of this fraction, %	Weight of 1000 seeds, g	Seed weight per plant, g
		5.5-6.0	57.3±1.02	22.0±0.35	135.2±3.22
Control	12.1±0.68	4.5-5.5	17.4±0.81	11.5±0.31	
		3.5-4.5	21.6±1.02	7.5±0.21	
		3.25-3.5	3.0±0.10	3.9±0.20	
		5.5-6.0	*43.2±1.42	22.8±0.32	*158.0±4.86
Dextrel (0.3 %)	*16.2±0.68	4.5-5.5	*29.3±1.02	*14.3±0.31	
		3.5-4.5	*23.6±1.02	7.8±0.32	
		3.25-3.5	*3.0±0.21	*4.1±0.16	
		5.5-6.0	*38.6±1.21	*24.2±0.52	*181.0±4.65
Paclobutrazol (0.05 %)	*17.3±0.36	4.5-5.5	*34.3±1.21	*16.2±0.35	
		3.5-4.5	22.4±1.02	*10.3±0.31	
		3.25-3.5	*4.0±0.20	*4.0±0.20	

Note. Plants were treated in the budding phase; * - difference is significant at $P < 0.05$.

Conclusions

Treatment of sugar beet plants of the first year vegetation with 0.3% dextrel, 0.05%, and 0.05% paclobutrazol leads to an increase in seed productivity of plants of the second year of vegetation method of cultivation. The use of 0.3% dextrel in this technology causes an increase in the germination energy of all fractions' seeds.

Treatment of sugar beet plants of the second year vegetation in the budding phase with 0.3% dextrel and 0.05% paclobutrazol leads to enlargement of seed productivity in the planting method of growing and increasing the weight of the fruit fractions of 4.5-5.5 mm, 3, 5-4.5 mm. The application of 0.025% paclobutrazol by this method leads to increased germination energy and seed germination of seeds of all fractions.

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Citation:
Shevchuk, O.A., Khodanitska, O.O., Tkachuk, O.O., Matviichuk, O.A., Polyvanyi, S.V., Golunova, L.A., Kniaziuk, O.V., Zavalniuk, O.L. (2020). Impact of retardants on sugar beet seed productivity. *Ukrainian Journal of Ecology, 11(*1), 143-148.