JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(9), 128–135
https://doi.org/10.12911/22998993/151780
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Received: 2022.06.14
Accepted: 2022.07.08
Published: 2022.08.01

Influence of Growth Regulators with Anti–Stress Activity on Productivity Parameters of *Sinapis alba* L.

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ABSTRACT

The research results of using growth regulators with anti-stress action which stimulated growth and development of plants, and provided them with resistance to adverse factors during the vegetation period, were presented. The use of plant growth regulators with anti–stress effect on *Sinapis alba* L. increased the plant resistance to adverse environmental influences, providing adaptation to changing environmental conditions, i.e. it has a stress–correcting effect throughout the whole vegetation period. The result of using drugs on mustard (*Sinapis alba* L.) was obtaining a significant and stable additional seed yield (0.57 t·ha^{-1}), i.e. an increase in yield by 38%. Over the years of research, the most effective were the applications of Fast Start and Biofoge growth regulators. The most effective processing terms were: during the vegetation period as well as combination of seed treatment and application during the vegetation period.

Keywords: individual productivity, variety, yield, ecological adaptability, stress–correcting action, vegetation period.

INTRODUCTION

Ukraine is one of three largest producers of *Sinapis alba* L. in the world. According to the Food and Agriculture Organization (FAO) of United Nations Organization (UNO), top 5 producer- countries are: Canada, Ukraine, Russia, Germany and India. The main buyers of mustard products on the world market are Germany, USA, France, Nepal and Poland [Melnyk and Zherdetska, 2015; Kernasyuk, 2015; Proposition, 2017].

Development of oil and fat industry in Ukraine has significant prospects in terms of meeting domestic needs and meeting the foreign market demand. This is stipulated by reorientation in population food structure of economically developed countries from animal fats to vegetable and oil ones and the growth of total planet population. Another important factor in expanding oil production was an increase in energy prices and increase of oil use for technical purposes (biofuels, detergents, paints, etc.) [Moiseeva, 2020; Hryhoriv et al., 2021; Karbivska et al., 2022a].

Along with sunflower, plants of the *Brassicaceae* family are important, in particular white mustard (*Sinapis alba* L.). The biological features of cruciferous crops are highly plastic to agro–ecological growing conditions, and current level of selection makes them economically attractive. *Sinapis alba* L. has a significant potential for productivity of high–quality oilseeds for various uses.

Today, Canadian farmers have varieties in their disposal that are resistant to cold and drought and that bear fruit well in low sunlight. In particular, owing to new varieties, the *Sinapis alba* L. crops were decreased in the country by 5% and the yields increased by 40%. Canadian farmers are betting on Viscount and Andante varieties with more than 50% of oil content. Every year, they receive an average of 220-230 thousand tons of seeds [Voloshin, 2017; Melnyk & Zherdetska, 2017].

In Europe, there is a steady demand for *Sinapis alba* L. The EU countries import up to 100.000

tons per year. Owing to increased professional potential and favorable soil and climatic conditions, Ukraine has the opportunity to become a world leader in *Sinapis alba* L. production. Along with this, with the latest trends in climate change, there is a need to develop varietal technologies for growing *Sinapis alba* L. under certain soil and climatic conditions. Various climatic stresses (frosts, atmospheric and soil droughts) cause great damage to agriculture [Mohylyanska, 2014; Mishchenko et al., 2022a].

With current changes in weather conditions in the Left Bank Forest-Steppe of Ukraine, there is a tendency towards sharp fluctuations in temperature, both within one day (+20–30 °C during the day and 10–15 °C at night) and during vegetation period (hot period over +30 °C during 20–30 days). At the same time, the lack of precipitation, which really creates stressful conditions for vegetation of crops, should be noted. Under the conditions of insufficient moisture, there is an increase in biosynthesis and release of ethylene (hormone of old age), which leads to inhibition of plant development. It is also impossible to avoid the problem of pesticide stress. Most chemical pesticides are quite toxic, so in addition to their main function (protection of plants from diseases and pests, weeds) they provide stress on the crops. The stress effect is manifested in the form of slow growth, reduced germination, twisting of leaves, increased susceptibility to disease and more. Restoration of normal plant cell metabolism under stressful weather conditions and after pesticide treatment is an important issue in cultivation of crops, including oilseeds [Kozina, 2013; Rieznik et al., 2021; Kvitko et al., 2021].

One of the modern ways to reduce stressors and increase the *Sinapis alba* L. yield, is implementation of high energy-saving technologies in agricultural production with the use of plant growth regulators.

Plant growth regulators (PGRs) are natural or synthetic low-molecular substances which at extremely low concentrations in plants, significantly change their vital processes. They contain a balanced complex of phytoregulators, biologically active substances, micro–elements [Sharma and Kumar, 1990; Bani-Saeedi, 2001].

Growth regulators increase resistance of plants to adverse factors of natural or anthropogenic origin: critical temperature changes, moisture deficiency, toxic effects of pesticides, disease and pest damage. Plant growth regulators also contain a unique complex of nutrients and anti–stress biostimulator, which increases the activity of metabolic ways in tissue cells and organs of crops. Thus, the resistance of plants to abiotic and anthropogenic stress increases and the highest possible realization level of crop productivity potential is maintained. Regulators can be used for seed treatment and foliar feeding (per leaf). Some drugs can be used twice, both for seeds and during vegetation period [Shuvar et al., 2009; Rika, 2019; Mishchenko et al., 2022b].

Thus, the study of growth regulator influence on increasing plant resistance to stress, and as a result, realization of *Sinapis alba* L. biological potential is an important and promising area of modern agricultural science.

MATERIAL AND METHODS

The experimental part of the work was performed during 2019–2021 at experimental plots and laboratories of Sumy National Agrarian University, located in the northeastern part of the Forest–Steppe of Ukraine, belonging to the Forest–Steppe natural–climatic zone.

The soil and climatic conditions of the region are favorable for normal growth and development of winter rape plants and meet its biological requirements. In particular, the soil fertility is quite high, their water and air permeability are satisfactory, temperature regime and precipitation amount are sufficient. The driest period is the second half of summer and autumn period, which creates unfavorable conditions for germination, rooting and development of winter crops.

The soil of the research area is typical deep-middle-humus coarse-grained coarse-medium-loamy black soil on loess-like rocks. The humus content, according to Turin, is 4.1–4.5%; Salt pH 6.0–6.2. The content of easily hydrolyzed nitrogen, according to Cornfield – 120 mg·kg^{-1}, movable compounds P_2O_5 and K_2O, according to Chirikov – 202 mg·kg^{-1} and 85 mg·kg^{-1}, respectively. Soil selection and agrochemical analysis were carried out directly at the experimental plot.

The climate is temperate continental. Winter begins in mid–November. The weather during this period is changeable; frosts are replaced by warming, snow by rain. From mid–December, snow cover is established, which is 20–35 cm high by February. The average temperature of the coldest month (January) is minus 7–8 °C. Winter in the

Sumy region is unstable: cold periods up to 20 °C of frost can be succeeded by short-term thaw. At the same time, the air temperature can rise to +4, + 5 °C, and snow in the fields may disappear completely. Spring begins in late March. The beginning of summer in the region can be attributed to mid-May. Summer is moderately warm. The warmest month is July. Its average daily temperature in the north is +18.6 °C, in the south +20 °C. In summer, the air temperature can rise to +32 °C, +37 °C. The average annual precipitation amount in the region varies between 510 and 590 mm, more precipitation (about 60%) falls in a warm season. The rainiest month is July (60–80 mm), the least precipitation falls in February (25–30 mm).

For the Sumy region (Northeastern Forest–Steppe), as well as for other regions of Ukraine, adverse climatic phenomena are typical: droughts, dry winds, strong winds, ice, etc. The most dangerous phenomenon is drought. The frosts in spring cause great damage, i.e. morning and evening lowering of air temperature below 0 °C at positive daytime temperatures.

Scheme of the experiment:

- factor A – varieties of white spring mustard (*Sinapis alba* L.): White Princess, Oslava;
- factor B – growth regulators with anti–stress action: Albit, Antistres, Agrinos, Biofoge, Fast Start, Regoplant, Vermistim D, Stimulate;
- factor C – influence of growth regulators during seed treatment, during the plant vegetation treatment in micro–stage of development by the scale of BBCH (32–39 and 51–59) and during the treatment of seeds and at plant vegetation.

During the research, the technology was generally accepted for research area, except for the elements studied. The predecessor included grain earing crops. The method of sowing was row with row–spacing of 15 cm.

The field experiments were conducted in accordance with the method of field experiment according to Dospekhov [1985]. Phenological observations of *Sinapis alba* L. growth and development, as well as analysis of the crop structure elements were carried out in accordance with the "Methods of State Crop Variety–Testing" [Volkodav, 2000; Saiko et al., 2011]. Statistical analysis of the research results was performed by using the method of disperse analysis and variation statistics according to Dospekhov [1985], using Microsoft Excel and Statistica 6.0 statistical software package.

RESULTS AND DISCUSSION

Scientists and growers have proposed many effective measures to obtain high-quality harvest, but the basis of everything is a variety that has ability to quickly form their economic properties in accordance with optimal conditions. In many cases, the growing conditions, for the reasons beyond human control, are not what the plant needs, so scientists and specialists-practitioners have proposed many techniques that help create the conditions as close as possible to optimal [Vovchenko, 2009; Burton et al., 1999].

According to the results of the conducted research, it was found that on average in 2019–2021 the tallest plants of White Princess variety were in the variant with seed treatment and during plant vegetation with the Biofoge growth regulator – 107.65 cm. The maximum height of Oslava variety plant on average was 107.80 cm with seed treatment and during plant vegetation with the Regoplan growth regulator (Table 1). Slightly lower indices of plant height in varieties of *Sinapis alba* L. were obtained when treating them during vegetation period: White Princess – 105.85 cm, Oslava – 106.85 cm (Fast Start).

Under favorable conditions (sufficient heat and moisture, varietal characteristics) *Sinapis alba* L. is prone to very strong branching, forming up to 60 branches (first–fifth order). Under unfavorable conditions and with continuous method of sowing, it approaches the type of single–stemmed plants, forming only 1–2 branches of the first order.

In the conducted experiments, the maximum number of first–order branches on average in the years of research took place with application of the Biofoge growth regulator in combination of seeds + vegetation period from 5.3 pcs. (Oslava) up to 5.6 pcs. (White Princess). On the contrary, application of preparations only on seeds or separately on plants during the vegetation period caused a decrease of this index from 5.4 pcs. For the White Princess variety (Fast Start) up to 5.1 pcs. for the Oslava variety (Biofoge).

The number of pods per plant along with the number of seeds per pod and their importance is one of the elements determining the yield. Fluctuations within typical zone years are 60–100 pods per plant, and during all years they can range from 30 to 150 pieces [Saiko, 2005; Kozina, 2013].

It was established that under conditions of the north–eastern Forest-Steppe of Ukraine the

Table 1. Influence of plant growth regulators on the yield structure elements of the *Sinapis alba* L. varieties, average for 2019–2021

Terms of treatment	Growth regulators	Height, cm		Number of the 1st order branches, pcs.		Number of pods, pcs.	
		White princess	Oslava	White princess	Oslava	White princess	Oslava
Without treatment (control)		100.07	98.76	4.7	4.6	86.07	82.81
Seeds	Albit	102.30	100.80	4.8	4.7	87.15	84.50
	Antistress	102.85	103.05	4.9	4.8	87.25	87.25
	Agrinos	102.80	103.95	5.0	4.8	90.00	87.80
	Biofoge	103.10	106.25	5.3	5.1	89.55	90.80
	Fast start	102.20	102.05	5.1	4.9	88.80	85.65
	Regoplan	102.40	105.30	4.9	4.9	87.90	89.55
	Stimulate	103.05	102.65	5.2	4.9	90.05	87.00
	Vermistim D	102.25	101.50	4.9	4.7	87.70	85.00
Vegetation BBCH (32–39 and 51–59)	Albit	102.80	101.55	4.9	4.7	88.75	84.60
	Antistress	103.35	105.30	5.0	5.1	90.75	89.15
	Agrinos	104.45	103.90	5.2	4.9	91.50	88.05
	Biofoge	104.05	104.85	5.2	5.2	91.65	92.15
	Fast Start	105.85	106.85	5.4	5.2	93.15	92.50
	Regoplan	102.80	106.15	4.9	5.0	88.10	90.15
	Stimulate	105.45	102.65	5.3	5.1	91.25	91.85
	Vermistim D	103.35	134.45	5.1	4.8	88.35	85.70
Seeds and Vegetation BBCH (32–39 and 51–59)	Albit	103.65	101.65	4.9	4.9	89.55	85.25
	Antistress	103.35	103.75	5.0	5.1	88.05	91.30
	Agrinos	105.35	106.10	5.3	5.2	92.25	90.15
	Biofoge	107.65	131.50	5.6	5.3	94.60	93.65
	Fast start	105.75	102.25	5.3	4.9	93.45	85.05
	Regoplan	104.00	107.80	5.2	5.2	88.90	92.45
	Stimulate	103.85	103.00	5.1	5.0	92.30	92.10
	Vermistim D	105.00	104.00	5.2	5.0	91.75	88.75

largest number of branches of the first order is formed by the White Princess variety – 5.6 pieces, with the number of pods 94.60 pieces.

The Oslava variety was characterized by slightly lower indices. On average for the years of studies this variety formed 5.3 pieces of the first order branches and the number of pods was 93.65 pcs.

Treatment with growth regulators significantly affected the number of pods. Thus, the average number of pods in the control variant over the years of research for White Princess variety was 86.07 pieces. Treatment with growth regulator Biofoge in combination of seeds + vegetation period maximized this figure by 8.53 pcs. For the Oslava variety, the number of pods in the control was 82.81 pcs. Among the variants of treatment with growth regulators, this figure increased the most by 10.84 pcs. when treated by Biofoge and the same treatment time as White Princess.

One of the objective factors influencing realization of the crop potential is individual productivity level of plants. This is because because of the fact that it can be used for calculating the biological yield of crops, which is an important element of crop programming.

Seed productivity of agricultural crops is determined by variety genotype only in 20–30%. Environmental factors and growing technology are of great importance [Oksimets, 2007; Zangani et al., 2006].

The analysis of literature sources allows stating that seed productivity of *Sinapis alba* L. is not completely exhausted. It significantly depends on the factors that can be regulated by the techniques of cultivation technology.

Depending on variety, growth regulators and treatment terms, individual productivity of *Sinapis alba* L. in the north-eastern forest–steppe of

Table 2. Individual productivity of *Sinapis alba* L. depending on the variety and growth regulators, average for 2019–2021

Terms of treatment	Growth regulators	Weight of seeds from one plant, g	
		White princess	Oslava
Without treatment (control)		1.00	0.97
Seeds	Albit	1.06	1.04
	Antistress	1.10	1.05
	Agrinos	1.21	1.18
	Biofoge	1.29	1.21
	Fast start	1.16	1.03
	Regoplan	1.12	1.19
	Stimulate	1.26	0.99
	Vermistim D	1.08	1.04
Vegetation BBCH (32–39 and 51–59)	Albit	1.02	1.05
	Antistress	1.14	1.22
	Agrinos	1.22	1.21
	Biofoge	1.17	1.18
	Fast start	1.31	1.26
	Regoplan	1.08	1.24
	Stimulate	1.27	1.10
	Vermistim D	1.10	1.05
Seeds and vegetation BBCH (32–39 and 51–59)	Albit	1.04	1.10
	Antistress	1.07	1.16
	Agrinos	1.29	1.22
	Biofoge	1.38	1.26
	Fast start	1.32	1.12
	Regoplan	1.13	1.23
	Stimulate	1.15	1.12
	Vermistim D	1.20	1.19

Ukraine averaged 1.17 g/plant and ranged from 0.97 to 1.38 g/plant (Table 2).

Depending on growth regulators and timing of their application, the indices of individual productivity of *Sinapis alba* L. changed. Thus, individual productivity of plants was 1.0 g/plant for the Princess White variety and 0.97 g/plant for Oslava, on average, according to the control variant of this factor. When treated with seed growth regulators, this figure increased to 1.29 g/plant (Biofoge) for the Princess White variety, i.e. 0.29 g/plant more than in the control variant. For the Oslava variety, the Biofoge treatment was also better in this variant, but the increase was slightly lower (0.24 g/plant). When treated during the vegetation period, individual productivity increased to a maximum of 1.31 g/plant for the Princess White variety and 1.26 g/plant for the Oslava variety with the use of Fast Start. Treatment of seeds with the Biofoge growth regulator and during the vegetation period provided the highest indices of individual productivity in both varieties: Princess White – 1.38 g/plant, Oslava – 1.26 g/plant.

The usual yield of *Sinapis alba* L. (white or serept) in Ukraine is about 1.0–1.5 $t \cdot ha^{-1}$ (in private farms it can reach 1.7–2.0 $t \cdot ha^{-1}$). However, with a sound approach, it is quite possible to grow *Sinapis alba* L. crop annually under irrigation or in the areas of sufficient moisture at the level of 2.5–3.0 $t \cdot ha^{-1}$ [Kurmi, 2002; Piri et al., 2012].

According to the results of the conducted research, the *Sinapis alba* L. varieties of tended to increase seed yield in different treatment variants and among the growth regulators used. Compared with the control, this figure increased by 0.43–0.57 $t \cdot ha^{-1}$ (Table 3). At the same time, the maximum yield was received in the variant of seed treatment and during vegetation period: White Princess – 2.07 $t \cdot ha^{-1}$ with the Biofoge growth regulator, Oslava – 1.89 $t \cdot ha^{-1}$ with the Fast Start and Biofoge growth regulators.

Table 3. Yield of Sinapis alba L. depending on varietal characteristics and growth regulators, average for 2019–2021

Terms of treatment	Growth regulators	Yield, t·ha^{-1}	
		White Princess	Oslava
Without treatment (control)		1.50	1.46
Seeds	Albit	1.59	1.55
	Antistress	1.64	1.58
	Agrinos	1.81	1.76
	Biofoge	1.94	1.81
	Fast start	1.73	1.55
	Regoplan	1.68	1.79
	Stimulate	1.88	1.49
	Vermistim D	1.62	1.55
Vegetation BBCH (32–39 and 51–59)	Albit	1.53	1.58
	Antistress	1.70	1.83
	Agrinos	1.83	1.82
	Biofoge	1.76	1.77
	Fast start	1.97	1.89
	Regoplan	1.62	1.85
	Stimulate	1.91	1.64
	Vermistim D	1.65	1.58
Seeds and vegetation BBCH (32–39 and 51–59)	Albit	1.56	1.64
	Antistress	1.61	1.74
	Agrinos	1.91	1.82
	Biofoge	2.07	1.89
	Fast start	1.98	1.67
	Regoplan	1.69	1.85
	Stimulate	1.72	1.68
	Vermistim D	1.80	1.78

Note: $LSD_{05\ (variety)}$ = 0.059 t·ha^{-1}; $LSD_{05\ (terms\ of\ treatment)}$ = 0.042 t·ha^{-1}; $LSD_{05\ (growth\ regulators)}$ = 0.035 t·ha^{-1}

Table 4. Weight of 1000 seeds of *Sinapis alba* L. depending on varietal characteristics and growth regulators, g (average for 2019–2021)

Terms of treatment	Growth regulators	White princess	Oslava
Without treatment (control)		4.46	4.37
Seeds	Albit	4.49	4.47
	Antistress	4.49	4.64
	Agrinos	4.58	4.69
	Biofoge	4.72	4.88
	Fast start	4.55	4.54
	Regoplan	4.49	4.74
	Stimulate	4.59	4.57
	Vermistim D	4.47	4.49
Vegetation BBCH (32–39 та 51–59)	Albit	4.57	4.49
	Antistress	4.73	4.70
	Agrinos	4.76	4.62
	Biofoge	4.76	4.63
	Fast start	4.84	5.04
	Regoplan	4.58	4.90
	Stimulate	4.70	4.62
	Vermistim D	4.74	4.56
Seeds and vegetation BBCH (32–39 and 51–59)	Albit	4.69	4.53
	Antistress	4.61	4.76
	Agrinos	4.90	4.92
	Biofoge	5.08	5.04
	Fast start	4.91	4.55
	Regoplan	4.80	4.97
	Stimulate	4.83	4.52
	Vermistim D	4.65	4.71

Size of *Sinapis alba* L. seeds is 4 mm, and the weight of 1000 seeds can reach up to 8 g. To a large extent, this figure depends on varietal characteristics, but may vary depending on weather and climatic conditions and under the influence of cultivation technology. This is confirmed by a number of domestic and foreign scientists [Zhernova, 2011; Zhuikov, 2015; Melnyk and Zherdetska, 2017].

Although the authors note that substantiated cultivation technology enhances the optimal use of ecological state of the crop which reduces competition between plants, in the future, this leads to the formation of seeds with more weight. This is also confirmed by other foreign scientists [Keivanrad et al., 2012; Saleem et al., 2001; Karbivska et al., 2022b].

According to the results of the obtained data by the factor of treatment terms, it was found that the highest weight of 1000 seeds corresponded to the White Princess variety – 5.08 g (seeds and vegetation) when treated with Biofoge. (Table 4). Compared to the control (without treatment), this figure increased by 14%.

The maximum weight of 1000 seeds in the Oslava variety was obtained in the variants with treatments during vegetation period (Fast Start) and seeds and vegetation (Biofoge) – 5.04 g, which increased the weight of 1000 seeds by 15.3% compared to the control.

CONCLUSIONS

Application of Biofoge and Fast Start contributed to the formation of consistently high productivity parameters of *Sinapis alba* L. Application of these plant growth regulators during vegetation period and seeds + vegetation allowed obtaining maximum individual productivity – 1.31–1.38 g/plant (the White Princess variety), weight of 1000 seeds – 5.04 g. (the Oslava variety) to 5.08 g (the White Princess variety), seed yield – 1.97–2.07 t·ha^{-1} (the White Princess variety).

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