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Original Article

Influence of new phytoregulators on oilseed flax growth, development, yielding capacity, and product quality

Influência de novos fitorreguladores no crescimento, desenvolvimento, capacidade produtiva e qualidade do produto da linhaça oleaginosa

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Abstract

The use of phytoregulators is a modern way of producing crops to increase yields and product quality. The components of phytoregulators have a beneficial effect on the growth and development of plants and help to withstand unfavorable environmental factors, stress, lack of mineral nutrition, soil fatigue, and the action of a wide range of pesticides. The research is aimed to investigate the influence of three phytoregulators: Cherkaz, Floravit, EcoFus on two varieties of flax: Severny and LM 98. We conducted a 3-year, field experiment with flax. In the so-called herringbone stage of the plant growth, the flax seedlings were treated the investigated phytoregulators. Flax plants were analyzed for yields. The method of near-infrared spectroscopy was used to analyze the content of lipids and proteins in flax seeds after harvesting. The oil content in flax seeds was determined. Using chromatography, we analyzed each variant of the experiment from the point of view of fatty acid composition. The application of phytoregulators increased the seed yield by 14-19% and the short fiber yield by 9-20% relative to control. The protein content in the seeds of the experimental samples Floravit and Cherkaz increased by 2.3-2.5% and by 1.5% in the experiments with EcoFus relative to the control. The lipid content in flax seeds increased by 5-5.6% (Floravit), by 3.5-3.95% (EcoFus), and by 4.7-5.1% (Cherkaz) relative to control. The oil ratio in flax seeds of the LM 98 and Severny varieties averaged 35.5-45.5%. An increase in the oil yields was 2.8-6.9% for Floravit, 2-4.1% for EcoFus, and 4.4-4.9% for Cherkaz relative to control. The application of Floravit, Cherkaz and EkoFus in flaxseed cultivation contributed to an increase in polyunsaturated fatty acids in oil: the content of ω-3 fatty acids ranged 61.90-63.10% compared to control 54.70%. Floravit proved to be the most effective of the three tested phytoregulators. The studies carried out over three years allow us to conclude that the use of new phytoregulators contributes to an increase in the quality and flaxseed yield and the flax fiber yield. Floravit was the most effective preparation and can be used for pre-sowing seed treatment and during the growing season.

Keywords: oilseed flax, phytoregulators, flaxseed oil, fiber, chemical analysis.

Resumo

O uso de fitorreguladores é uma maneira moderna de produzir culturas para aumentar a produtividade e a qualidade do produto. Os componentes dos fitorreguladores têm um efeito benéfico no crescimento e desenvolvimento das plantas e ajudam a suportar fatores ambientais desfavoráveis, estresse, falta de nutrição mineral, fadiga do solo e ação de uma gama de pesticidas. A pesquisa tem como objetivo investigar a influência de três fitorreguladores, Cherkaz, Floravit e EcoFus, em duas variedades de linho: Severny e LM 98. Realizamos um experimento de campo de três anos com o linho. No chamado estágio de espinha de peixe do crescimento da planta, as mudas de linho foram tratadas com os fitorreguladores investigados. As plantas de linho foram analisadas quanto à produtividade. O método de espectroscopia no infravermelho próximo foi utilizado para analisar o conteúdo de lipídios e proteínas em sementes de linho após a colheita. O teor de óleo nas sementes de linho foi determinado. Usando cromatografia, analisamos cada variante do experimento do ponto de vista da composição de ácidos graxos. A aplicação de fitorreguladores aumentou o rendimento de sementes em 14-19% e o rendimento de fibra curta em 9-20% em relação ao controle. O teor de proteína nas sementes das amostras experimentais Floravit e Cherkaz aumentou em 2,3-2,5% e em 1,5% nos experimentos com EcoFus em relação ao controle. O teor de lipídios nas sementes de linho aumentou 5-5,6% para Floravit, 3,5-3,95% para EcoFus e 4,7-5,1% para Cherkaz em relação ao controle. A proporção de óleo nas sementes de linho das variedades LM 98 e Severny foi de 35,5 a 45,5%. Um aumento nos rendimentos do petróleo foi de 2,8-6,9% para Floravit, 2-4,1% para EcoFus e 4,4-4,9% para Cherkaz em relação ao controle. A aplicação de Floravit, Cherkaz e EkoFus no cultivo de linhaça contribuiu para o aumento dos ácidos graxos poli-insaturados no óleo: o teor de ácidos graxos ω-3 variou de 61,90 a 63,10% em comparação com o

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controle (54,70%). Floravit provou ser o mais eficaz dos três fitorreguladores testados. Os estudos realizados ao longo de três anos permitem concluir que o uso de novos fitorreguladores contribui para o aumento da qualidade e do rendimento da linhaça e do rendimento da fibra de linho. Floravit foi o medicamento mais eficaz e pode ser usado para o tratamento de sementes pré-semeadura e durante a estação de crescimento.

Palavras-chave: linho oleaginoso, fitorreguladores, óleo de linhaça, fibra, análise química.

1. Introduction

The USA, China, Russia, India, and Kazakhstan have been major oilseed flax cultivating countries over the past 20 years. Most flaxseed food products (flaxseeds and flaxseed oil) produced in these countries are exported to the European Union countries, America, and Asia. Canada has lost its leading position since 2010, with Kazakhstan and Russia now dominating the world production and export market. Flaxseed makes up no more than 1% of the total volume of oilseed crops. Flaxseed production averages 2.5 - 3 million tones (Irvine et al., 2010; Lligadas et al., 2013; Jia & Booker, 2018; Fila et al., 2018).

Flaxseed (also linseed) is a crop that is cultivated in the modern world to get an extensive range of products. People have grown flax for oil for many centuries. Flaxseed oil has unique nutritional properties. It has a high content of Omega-3, Omega-6, and Omega-9 fatty acids, vitamins, and hormone-like substances. It is also essential in paint and varnish production, chemical industry, medicine, and cosmetology. In recent years it has come into use in the automotive industry, shipbuilding, metal processing, and other economic sectors (Gallardo et al., 2014; Pandey, 2016).

The flax plant stem contains cellulose-rich fiber of high quality in the amount of 18% to 22%. The distribution of bast fibers suggests that flax stems contain the highest amount of fibers of two fractions with a length of 0-165 mm and 180-390 mm, 14% and 83% respectively. So it is necessary to apply new technologies or modernize equipment used by domestic companies to increase the effectiveness of processing techniques. Charle & Co (Belgium), Laroche (France), DiloTemafa (Germany), the Italian Istituto Poligrafico e Zecca dello Stato (IPZS) (State Mint and Polygraphic Institute, Italy), and some other companies are among the major foreign companies dealing with flaxseed processing. These companies produce equipment and technologies for flax stem processing for paper production. The German company offers equipment to process flax stems for manufacturing geotextiles, nonwoven materials, and composite materials (Horne et al., 2010).

The use of phytoregulators is a promising method for increasing flax productivity and the quality of fiber, seeds, and flax-based products. Phytoregulators are used for pre-sowing seed treatment and during the growing season. The application of phytoregulators is associated with an improvement in seed germination and germination capacity, higher resistance to diseases, stress, unfavorable environmental conditions, and an increase in productivity. As a result, we obtain products that meet high-quality standards. The growing use of phytoregulators together with modern agricultural practices in industrial crop cultivation allows obtaining highly predictable and stable results at comparatively low cost (Belopukhov et al., 2017; Enakiev et al., 2018).

Our research investigated the influence of new phytoregulators on the yielding capacity of flax seeds, fiber, and flaxseed oil. We also assessed the quality of the products obtained. The research was carried out in the Field Experimental Station of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (RSAU – MTAA), Moscow.

2. Materials and Methods

2.1. Experimental field conditions/Experimental conditions on the field

We conducted the field experiments on flax in 2016-2018 in the field experimental station of RSAU – MTAA (Russia, Moscow).

Over the research period, the predecessors of flax in crop rotation were grain crops. The planted area was 0.5 ha. The sowing took place in early-to-mid May, with a seed rate of 50 kg/ha. The soil was prepared in the following way: autumn plowing to the depth of 20-22 cm, harrowing in spring, and tilling before sowing flax. Flax seeds were sown with a seeder to the depth of 2-3 cm. We did not apply seed-placed fertilizers; the plants were not treated with insecticides against the flax flea, since this insect pest was not present during the research period. In the so-called herringbone stage of the plant growth, the flax seedlings were treated twice: the first time with a tank herbicide mixture containing the investigated phytoregulators (plant height of 8-10 cm), and the second time treatment was conducted only with the phytoregulators ten days later (plant height of 12-15 cm).

The herbicide used in flax cultivation was Lenok; the application dose was 8-10 g/ha (potassium salt of chlorsulfuron 850 g/kg in water-dispersible granules).

We used backpack sprayers to treat the plants. The arrangement of the plots in the experiment was randomized, with 4-fold replication. The area of the plot was 20 m2. Harvesting was carried out manually.

2.2. Soils

The Field Experimental Station is characterized by soddy-podzolic, medium and light loam soil. Table 1 presents the agrochemical parameters of the plow layer (0-22 cm). The analysis showed that the soil could be classified as slightly acid; it had low humus content, low content of the major plant nutrients, which is typical of this type of sod-podzolic soil.

2.3. Varieties of oilseed flax и Phytoregulators

We examined two varieties of oilseed flax: Severny and LM 98, which are well adapted to different soil and weather conditions and cultivated in five Russian regions.

Table 1. The agrochemical parameters of soil at the Field Experimental Station, ($A_{plow\ l.}$, 20 -22 sm).

Soil density, g/cm³	Humus, %	pH (sal.)	N (easily hydrolyzed)	P_2O_5	K_2O
			mg/kg of soil		
1.5-1.6	2.4-2.6	5.5-5.8	53-55	170-175	95-96

The phytoregulators which were used in the research:

1) Cherkaz is an organosilicon compound (1-vinylsilatran with the general formula N(CH2CH2O)3SiR where R=CH=CH2) which is used as a plant growth and development regulator;
2) EcoFus is an organomineral complex based on brown algae Fucus vesiculosus, also containing 40 chemical elements including nitrogen (1.8%), phosphorus (1.0%), potassium (2%), cobalt (0.1%), magnesium (0.5%), copper (0.3%), iron (1.8%), and others;
3) Floravit is a complex of biologically active substances produced by Fusarium sambucinum Fuckel F-3051D. In terms of its chemical composition, the phytoregulator consists of 90% short peptides, also containing organic acids (0.1-0.2%), polysaccharides (0.04-0.05%), sodium benzoate (0.1%), and water (up to 100%).

2.4. Plant sampling and analysis

Harvesting was done by hand on the plots. All plants were harvested, dried in the sun and separated into seeds and fiber. Seed yield of an area of each plot (20 m²) was estimated and transformed to c per hectare.

Oil was obtained from the seeds by cold pressing on a press at a temperature of 60 ⁰C. Oil yield per hectare: was calculated from the following Formula 1:

$$\text{Oil yield per hectare} = \text{oil percentage} \times \text{seed yield per hectare} \quad (1)$$

iber yield was calculated using the Formula 2:

$$\text{Fiber yield} = \frac{N \times L}{W} \quad (2)$$

here, N = Number of fibers (30 fibers and the length for each one), L = Length of fibers in cm, and W = Weight of fibers in grams.

Fiber yield per centner (c): calculated from plot fiber yield, Fiber length (cm): Ten fiber ribbons from each treatment were spreaded out and each ribbon was measured then the average fiber length was recorded.

The content of lipids and proteins in flax seeds after harvesting was carried out by near infrared spectroscopy using a SpectraStar 2600XT-R at a wavelength of up to 2600 nm. They are the significant parameters of the nutritional value of products. Using chromatography, we analyzed each variant of the experiment from the point of view of fatty acid composition. The analysis was carried out using a chromatograph with a mass spectral detector "Clarus 600 C/D/S/T/MS".

2.5. Statistical analysis

The collected data were subjected to statistical analysis using a statistical package (statistics 8.1). The data were statistically analyzed for each year and tested for uniformity of experimental error over three years. The least significant difference (LSD) test at 0.05 significant levels was used to designate the mean comparison. (Jan et al., 2009).

3. Results

3.1. Flaxseed yield and the flax fiber yield / Flaxseed yield and the flax fiber yield analyses.

The application of Floravit, EcoFus, and Cherkaz in oilseed flax cultivation (LM 98 and Severny varieties) in 2016-2018 resulted on average in the increase of the yield of seeds by 14-19%, fibers – by 9-20% relative to controls (Figure 1). Of particular note is the phytoregulator Floravit. For example, when processing crops with this phytoregulator, the yield of oilseed flax of the Severny variety increases by 18.8%, and the LM 98 variety - by 18.6%. The yield of flax fiber of the Severny variety increased by 13.9%, the LM 98 variety - by 19.5%.

3.2. Flaxseed analyses

The method of near-infrared spectroscopy was used to analyze the content of lipids and proteins in flax seeds after harvesting. They are significant parameters of the nutritional value of products (Table 2).

The seed protein content increased in plants treated with the examined phytoregulators. In the case of Floravit and Cherkaz, it grew by 2.3-2.5%, and in the case of EcoFus the protein content was 1.5% higher relative to control. The content of lipids in flax seeds also increased by 5-5.6% in Floravit treated plants, by 3.5-3.95% in EcoFus treated plants, and by 4.7-5.1% in Cherkaz treated plants relative to control. Floravit was more effective in two flaxseed varieties.

The oil content in flax seeds of the LM 98 and Severny varieties averaged 35.5-45.5%. An increase in the oil yield was 2.8-6.9% for Floravit treated flax, 2-4.1% for EcoFus treated flax, and 4.4-4.9% for Cherkaz treated flax relative to control (Table 3). The oil yield was higher in the Severny variety; Floravit proved to be the most effective of the three regulators that were tested.

3.3. Flax oil analysis

The analysis showed that the flaxseed oil contained the following saturated fatty acids: myristic acid, pentadecanoic acid, palmitic acid, margaric acid, stearic acid, arachidic acid, behenic acid, and lignoceric acid (Table 4). The characteristic feature of flaxseed oil is a high content of palmitic (4.10-5.66%) and stearic (3.22-4.94%) acids, the content of which was 0.8-1.7% lower in the samples treated with Floravit, Cherkaz, and EcoFus. The content of other acids did not

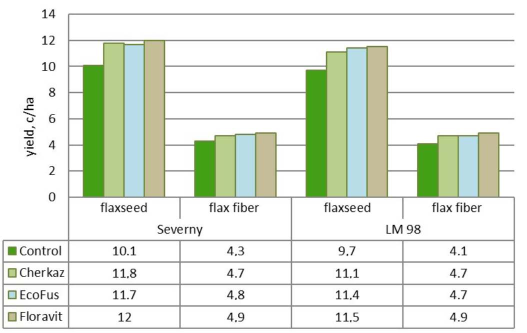

Figure 1. Flaxseed yield and the flax fiber yield, c/ha, average values for 2016-2018.

Table 2. The content of proteins and lipids in flax seeds after the application of phytoregulators, % of absolutely dry matter.

Variety	Tests	Proteins	Lipids
LM 98	control	17.5	36.5
	Floravit	20.0	41.5
	EcoFus	19.0	40.0
	Cherkaz	20.0	41.2
LSD0.05		0.8	1.1
Severny	control	18.0	37.0
	Floravit	20.3	42.6
	EcoFus	19.5	40.9
	Cherkaz	20.3	42.1
LSD0.05		0.8	1.1

Table 3. Oil content in flaxseed treated with phytoregulators, %.

Variety	Tests			
	Control	Cherkaz	EcoFus	Floravit
Severny	38.6	43.5	42.7	45.5
LM 98	35.5	39.9	37.5	38.3
LSD0.05	1.3			

differ significantly from the control sample. On average, the total amount of saturated fatty acids in the samples treated with Floravit, Cherkaz, and EkoFus was 7.52-8.90% compared to the control ratio of 10.87%.

Flaxseed oil monounsaturated acids (acids that have one carbon-carbon double bond in the chain) were 7-hexadecenoic acid, palmitoleic acid, cis-7-hexadecenoic acid, oleic acid, cis-vaccenic acid, and 11-eicosenoic acid. There was also a high content of oleic acid (13.55-17.55%). The variants treated with Floravit, Cherkaz, and EkoFus had a lower ratio of this acid: there was a decrease by 3.31-4.0% relative to control. On average, the total amount of monounsaturated fatty acids in the samples treated with Floravit, Cherkaz, and EkoFus was 14.21-14.77%, and 18.38% in the control sample.

Polyunsaturated fatty acids are considered the most valuable in the flaxseed oil composition. They were represented by linoleic, octadecadienoic, and linolenic acids. The content of linoleic acid ranged 14.32-15.9%, but there was a decrease in linoleic acid content by 1.0-1.58%, as well as a slight decrease in octadecadienoic acid content in the samples treated with phytoregulators. The content of unsaturated fatty acids in the oil obtained from flaxseed treated with phytoregulators was 76.32-78.28%, compared to 70.75% in the control sample. According to the gas chromatography data, Floravit, Cherkaz and EkoFus treatment of oilseed flax resulted in an increase in ω-3 fatty acids (61.90-63.10%) relative to control (54.70%).

4. Discussion

Phytoregulators used along with the major technology for crop cultivation (application of agricultural machinery, timing, seed rates, application of fertilizers and pesticides) can increase the crop yield by an average of 10-20%. If the weather conditions are favorable, the yield may increase by up to 30-40%. However, many agriculturalists believe that it is necessary to introduce phytoregulators into agricultural practices because they also contribute to higher abiotic stress resistance, stabilization and acceleration of physiological processes in cells, improving the quality of farm products, etc. (Shepeleva and Pogodina, 2018; Kurishbayev et al., 2020).

Flax seeds are rich in fats, proteins, gluten, microfibers, polysaccharides, lignans, micronutrients (Ca, P, Cu, Fe, K, Mg, Na, Zn, etc.), vitamins (C, B_1, B_2, B_6), and tocopherols (vitamin E).

The amino acid composition of flaxseed proteins is similar to that of soy proteins which are considered the most nutritious plant proteins. The nutritional value of flaxseed proteins is characterized by a high albumin-globulin fraction content.

Flaxseed fiber has water-insoluble and water-soluble fractions. The insoluble fiber fraction consists of carbohydrates (cellulose) and complex polymeric compounds (lignins). The water-soluble fraction comprises gluten, etc.

Flaxseed polysaccharides are similar to gum Arabic and tragocan gum. They are used in the food industry as viscosity enhancers and as colloidal solution stabilizers.

A distinctive feature of flax seeds is their high content of lignans if compared to cereals, legumes, vegetables, and fruit. Lignans are phenolic compounds (dimmers, in particular) containing a dibenzobutane group. They belong to phytoestrogens, substances that exhibit estrogenic activity in the human body.

Tocopherols are the most powerful fat-soluble antioxidants. They play an essential role in protecting cells from oxidative stress associated with free radicals.

Flaxseed fats are trisubstituted glycerols (triacylglycerols). The unique property of flaxseed oil is a high content of alpha-linolenic acid which is an essential fatty acid for humans. It must come from the diet. Oil is

Table 4. Fatty acid content in oil from flax seeds of the *LM 98* variety, %.

Acids	Chemical formula	Tests			
		Control	EcoFus	Floravit	Cherkaz
Saturated fatty acids					
Myristic acid	C14:0	0.02	0.01	0.01	0.01
Pentadecanoic acid	C15:0	0.01	0.01	0.01	0.01
Palmitic acid	C16:0	5.66	4.10	4.11	4.55
Margaric acid	C17:0	0.05	0.03	0.03	0.03
Stearic acid	C18:0	4.94	3.22	3.30	4.15
Arachidic acid	C20:0	0.11	0.10	0.10	0.10
Behenic acid	C22:0	0.07	0.04	0.04	0.04
Lignoceric acid	C24:0	0.01	0.01	0.01	0.01
Content of fatty acids		**10.87**	**7.52**	**7.61**	**8.9**
LSD0.05 (acids totaled)		0.4			
Monounsaturated fatty acids					
7- Hexadecenoic acid	C16:1 [7Z]	0.01	0.01	0.01	0.01
Palmitoleic acid	C16:1 [9Z]	0.05	0.03	0.03	0.04
Cis-7-hexadecenoic acid	C17:1(7z)	0.02	0.02	0.02	0.02
Oleic acid	C18:1 [9Z]	17.55	13.55	14.15	14.24
Cis-vaccenic acid	C18:1 [12Z]	0.65	0.55	0.33	0.41
11-eicosenoic acid	C20:1 [11Z]	0.1	0.05	0.05	0.05
Content of fatty acids		**18.38**	**14.21**	**14.59**	**14.77**
LSD0.05 (acids totaled)		0.6			
Polyunsaturated fatty acids					
Linoleic acid	C18:2 [9Z,12Z]	15.90	14.90	14.56	14.32
Octadecadienoic acid	C18:2 [11Z,14Z]	0.15	0.10	0.10	0.10
Linolenic acid	C18:3 [9Z,12Z,15Z]	54.70	63.28	63.10	61.90
Content of fatty acids		**70.75**	**78.28**	**77.76**	**76.32**
LSD0.05 (acids totaled)		2.80			
Content of ω-3 acids, %		54.70	63.30	63.10	61.90
Content of ω-6 acids, %		16.55	15.28	14.89	14.73

found in cotyledons and endosperm, while lignans and soluble resins consisting mainly of polysaccharides are present in the plant epidermal tissue (Barthet et al., 2014; Baibekov et al., 2019).

Flax seeds are a valuable source of various biologically active substances with a broad spectrum of health benefits. They reduce the risk of cardiovascular disease. Thanks to a high content of Omega-3 and Omega-6 fatty acids, the flaxseed can be called a natural youth elixir, as it improves cholesterol levels in the human body. Flaxseed dietary fiber stimulates gastrointestinal activity. Polysaccharides have a membranostatic effect, therefore they are used as an anti-inflammatory agent to treat gastritis and stomach ulcers. They also improve liver function. Regular consumption of a small portion of flax seeds enhances the effect of insulin and protects our body from diabetes development, strengthening the immune system, preventing inflammation, and reducing allergic reactions (Gallardo et al., 2014).

Vegetable oils have high energy values, so they are the major source of essential fatty acids, phospholipids, sterols, and tocopherols in the human diet. In this regard, flaxseed oil seems to have the most potential due to its nutritional and physiological value. It contains a high amount of polyunsaturated fatty acids, including linolenic acid. However, there is quite a large number of flaxseed varieties and cultivars which are grown to produce oil at present. They may differ in oil output and fatty acid composition.

In our studies, the oil is obtained by cold pressing, which is one of the methods of pressing without heat or at low temperature. After cold pressing, the oil temperature and oil acidity ratio are low. Cold-pressed oil usually does not require refining, and after precipitation and filtration, the finished oil is obtained.

5. Conclusions

Floravit, Cherkaz, and EcoFus phytoregulators were used in oilseed flax cultivation during the plant growing season. The experiment took place in the Field Experimental Station of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (RSAU – MTAA). The application of the phytoregulators contributed to an increase in seed yield by 14-19% and in the short fiber yield by 9-20% relative to control. The chemical analysis of the flaxseed products showed that the protein content in the seeds increased by 2.3-2.5% (Floravit and Cherkaz samples) and by 1.5% (EcoFus samples). The lipid content in flax seeds increased by 5-5.6% (Floravit), by 3.5-3.95% (EcoFus), and by 4.7-5.1% (Cherkaz) relative to control. The application of Floravit, Cherkaz, and EkoFus in oilseed flax cultivation contributed to an increase in polyunsaturated fatty acids in the flaxseed oil: the content of ω-3 fatty acids ranged 61.90-63.10% compared to control 54.70%. Floravit proved to be the most effective of the three tested phytoregulators.

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