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Original Article

Yield and quality of Dega white lupine grain (Lupinus Albus) and yubileynaya 80 spring wheat (Triticum Aestivum L.) depending on the application method of sodium selenite

Rendimento e qualidade do grão de tremoço branco Dega (Lupinus albus) e trigo de primavera Yubileynaya 80 (Triticum aestivum L.) em função do método de aplicação do selenito de sódio

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Abstract

In 2017-2019, we conducted the field and vegetation experiments at the field station of Russian State Agrarian University, Moscow Timiryazev Agricultural Academy to study the effect of sodium selenite on the yield and grain quality indicators of white lupine, Dega variety, and spring wheat, Yubileynaya-80 variety. The best way found to use selenium is to spray vegetative plants with 0.01% aqueous sodium selenite solution. The studies have shown an increase in grain yield by 15-17%, crude protein content by 9-15% and crude fat content by 5-7% when treated with sodium selenite. The obtained grain yield of white lupine has a higher feed and nutritional value and is suitable for feeding animals and preparing various types of feed and feed additives. The optimal way to use selenium is spraying vegetative plants before shooting. Treatment with sodium selenite contributes to an increase in wheat yield by 1.5 times. We have established the positive effect of sodium selenite on the quality indicators of wheat grain. An increase in the content of raw gluten and glassiness of grain has been noted, which determines high bread-making qualities.

Keywords: white lupin, spring wheat, sodium selenite, pre-sowing seed dressing, spraying of vegetating plants.

Resumo

Em 2017-2019, conduzimos os experimentos de campo e vegetação na estação de campo da Universidade Agrária Estatal Russa, Academia Agrícola Timiryazev de Moscou, para estudar o efeito do selenito de sódio nos indicadores de rendimento e qualidade de grãos de tremoço branco, variedade Dega, e trigo de primavera, variedade Yubileynaya-80. A melhor maneira encontrada para usar o selênio é pulverizar as plantas vegetativas com solução aquosa de selenito de sódio a 0,01%. Os estudos mostraram um aumento no rendimento de grãos em 15-17%, teor de proteína bruta em 9-15% e teor de gordura bruta em 5-7% quando tratados com selenito de sódio. O rendimento de grãos obtido de tremoço branco tem maior valor alimentar e nutricional e é adequado para alimentação de animais e preparação de vários tipos de rações e aditivos alimentares. A maneira ideal de usar o selênio é pulverizar plantas vegetativas antes de fotografar. O tratamento com selenito de sódio contribui para um aumento no rendimento do trigo em 1,5 vez. Estabelecemos o efeito positivo do selenito de sódio nos indicadores de qualidade do grão de trigo. Observou-se um aumento no teor de glúten cru e vítreo do grão, o que determina altas qualidades de panificação.

Palavras-chave: tremoço branco, trigo primaveril, selenito de sódio, preparação de sementes pré-semeadura, pulverização de vegetais.

1. Introduction

Selenium is essential to the metabolism of cyanobacteria and certain plant species because it is involved in the antioxidative actions that these organisms undertake. Selenium is readily available for uptake by plants in the form of at least minute traces since it is abundant on the surface of the earth. Currently, different countries of the world use various forms of selenium-containing compounds in the cultivation of crops. The most effective ways of using selenium are pre-sowing seed dressing and spraying of vegetative plants or foliar treatment. The positive effect

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of pre-sowing seed dressing with selenium-containing compounds on the growth functions of seedlings of various agricultural crops, their biometric parameters, as well as yield has been shown (Wang et al., 2020; Seregina et al., 2021a; Seregina et al., 2021b). The authors note an improvement in the quality indicators of grain crops when using pre-sowing seed dressing (Kashin and Shubina, 2011; Alybayeva et al., 2021), on the biochemical composition of fruits and vegetables (Coyago-Cruz et al., 2017, 2022). At the same time, the possibility of mass transfer of selenium against the background of other macro- and microelements into plants is noted (Bañuelos et al., 2000; Ismagilov et al., 2020), with the intensification of microbiological processes (Hopper and Parker, 1999; Nowak et al., 2002). This, in turn, can influence the creation of vitamin-mineral complexes and selenium-based feed additives for poultry farming (Sevostyanova et al., 2020; Safonov, 2022).

Spraying vegetative plants or foliar treatment of plants is an economically and agrotechnically beneficial way of applying a trace element, including selenium-containing salts. Foliar dressing with the solutions of selenium-containing compounds makes it possible to reduce the contact of selenium with the soil, which minimizes the losses of the element and its fixation in the soil (Torshin et al., 1996; Gupta and Gupta, 2000). When spraying with sodium selenite, leaf surface easily absorbs selenium through the cell membrane (Gissel-Nielsen, 1975; Seregina et al., 2021b; Wang et al., 2021), which makes it possible to increase the effectiveness of selenium fertilizers. The utilization rate of selenium from selenium-containing fertilizers has been found to be 2–4% (Gardarin et al., 2010; Kashin and Shubina, 2011). At the same time, the selenium utilization rate from selenium fertilizers applied to the soil is only 0.2% because selenium under the influence of microorganisms turns into inaccessible forms - selenide and elemental selenium. This reduces the efficacy of fertilizers on the yield of agricultural crops when applied to the soil (Pilon-Smits, 2019; Seregina et al., 2021b).

The role of agricultural crops in human life is predetermined, on the one hand, by their yield capacity, and on the other hand, by the quality indicators of the main part of the product (Hutapea et al., 2022; Ngafwan et al., 2022; Muniz et al., 2022). The quality of grain of cereals and leguminous crops is determined by a large number of characteristics. The most important of them are indicators that determine the nutritional value for humans or the feed value for farm animals. When assessing the quality of white lupine grain, the content of crude protein, the content of crude fat and alkaloids are of the greatest importance. For cereals, the crude protein content, the amount of crude gluten and the vitreousness of the grain are also essential. These indicators determine the class of grain by commodity classification and, accordingly, applications of the obtained grain. In addition to the listed characteristics, moisture content, damage and infection of grain by insects and diseases, appearance, smell, etc. also affect the grain quality of grain and leguminous crops (Kovalevich and Golovaty, 2010).

We have revealed the physiological and biochemical functions of selenium in plants to be based on the ability of this element to replace sulfur in a number of amino acids. Selenium is found in plants as part of various compounds. Replacing sulfur, selenium is included in protein amino acids in the form of selenomethionine, selenocysteine, methylselenocysteine, as well as free amino acids: selenomethylselenocysteine, selenomethylselenomethionine, and selenogomocysteine (Lanuza, 1966; Girling, 1984; Golubkina et al., 2012; Sutcliffe, 2013; Ermakov, 2015; Seregina, 2018). Selenomethyl Selenomethionine interacts with glutamine to form glutamyl selenomethionine selenocysteine. Plants that accumulate large amounts of selenium, as a rule, actively synthesize free amino acids (Block et al., 2001; Majumdar, 2020; Sheudzhen et al., 2013). In addition, selenium-accumulating plants are characterized by the formation of volatile intermediate methylated compounds of the element, which can be formed not only from hydrogen selenide, but also during the catabolism of selenium-containing amino acids (Alfthan et al., 1991; Leustek and Saito, 1999).

Some intermediate compounds of selenium metabolism are also formed in plants, which include dimethyl selenide, trimethyl selenide, selenpersulfide, and selenglutathione. In plants that do not accumulate large amounts of selenium, the element binds to protein complexes and accumulates mainly in grain or seeds. When grown on soils with an excess of selenium, plants that do not accumulate selenium accumulate free soluble amino acids. Free amino acids are less phytotoxic than inorganic compounds (Postnikov, 2017; Golubkina et al., 2021).

We have found that selenium-containing compounds activate papain and 3-phosphoglycerol aldehyde dehydrogenase. This indicates the potential influence of organoselenium compounds on glycolysis and hydrolysis of proteins in plants (Leustek and Saito, 1999; Postnikov, 2017).

Numerous studies on various crops have shown the effectiveness of selenium-containing fertilizers to depend on the form of selenium in the fertilizer, the method of application and dose, as well as the timing of application, the species, and varietal responsiveness of plants (Alfthan et al., 1991).

Thus, the objective of our research was to study the effect of various methods of sodium selenite application on the yield and grain quality of Dega white lupine and Yubileynaya-80 spring wheat.

2. Material and Methods

The object of research is white lupine, Dega variety, and spring bread wheat (Triticum aestivum L.) Yubileynaya 80 variety. To solve the questions posed, microfield experiments were carried out in 2017-2019 to study Dega white lupine. Vegetation and microfield experiments were carried out with spring wheat variety Yubileynaya-80. All microfield experiments with lupine and spring wheat were carried out at the experimental site of the Department of Agronomic, Biological Chemistry and Radiology of Russian State Agrarian University, Moscow Timiryazev Agricultural Academy. The vegetation experiment with spring wheat was carried out in the vegetation house of the Department of Agronomic, Biological Chemistry and

Radiology of Russian State Agrarian University, Moscow Timiryazev Agricultural Academy.

The soil from the experimental site was typical urban soil with agrochemical characteristics: pHKCl - 6.0 (GOST 26483), Hh (hydrolytic acidity) 9 meq/kg of soil (GOST 26212), S - 243 meq/kg of soil (GOST 27821). The humus content was 3.3% (GOST 26213-91), Nh- 90 mg/kg of soil (Cornfield). The availability of mobile phosphorus is 125 mg/kg of soil (grade IV), potassium is 120 mg/kg of soil (IV class) (Kirsanov) (GOST 26207-91). The vegetation experiment used a sod-podzolic medium loamy soil sampled from the field experimental station of Russian State Agrarian University, Moscow Timiryazev Agricultural Academy, with agrochemical characteristics: humus content (Tiurin) - 1.5%, pHKCl 5.7 (grade 6) (GOST 26483), Hh (Kappen) 12 meq/kg of soil (GOST 26212), S (Kappen-Gilkovits) 243 meq/kg of soil (GOST 27821), V 95.3%, Nh. 82 mg/kg (class 3) (GOST 26107), phosphorus and potassium contents (Kirsanov) - 180 mg/kg (class 5) and 150 mg/kg (class 5) (GOST 54650-2011), respectively.

Microfield and vegetation experiments were established and conducted in compliance with the previously developed methodology . All experiments were conducted in quadruplicate.

All the experiments studied various methods of sodium selenite application: pre-sowing dressing of wheat and lupine seeds by soaking with 0.01% sodium selenite solution and spraying of vegetative plants (foliar treatment) with 0.01% sodium selenite solution. Spraying of growing plants of white lupine was carried out before the beginning of the flowering phase. Spraying of growing plants of spring wheat was carried out before the onset of the tube emergence phase. The seeds of the control variants were treated with distilled water.

In microfield experiments, white lupine and spring wheat plants were grown on 1 m2 plots. The level of mineral nutrition for white lupine was created by adding ammophos (NH4H2PO4) and monosubstituted potassium phosphate (KH2PO4) manually to a depth of 7-10 cm. In all variants, phosphorus and potassium were added at the rate of 115 and 145 kg of an element per ha, respectively. The nitrogen nutrition level was created at the rate of 20 kg/ha. For spring wheat, the level of mineral nutrition was created by scattering ammonium nitrate (NH4NO3), double superphosphate (Ca(H2PO4)2) and monosubstituted potassium phosphate (KH2PO4) to a depth of 7-10 cm manually. In all variants, phosphorus and potassium were added at the rate of 115 and 145 kg of an element per ha, respectively. The level of nitrogen nutrition was created at the rate of 80 kg/ha.

In the vegetation experiment, wheat plants were grown in metal Mitscherlich vessels (5 kg of soil) with trays. Thirty wheat seeds were sown in the vessels, followed by thinning in the tillering phase to 20 plants. The optimal soil moisture conditions was maintained in the vessels (65-70% SH) by irrigation. Mineral fertilizers were applied to the soil while filling the vessels at doses of N100P100K100 mg/kg soil, using ammonium nitrate (NH4NO3)), monosubstituted potassium phosphate (KH2PO4), and potassium chloride (KCl).

The plants were harvested manually by a continuous method. After harvesting white lupine plants, we determined the weight of grain and beans (shells) (g/m2), green weight of the stem (g/m2), as well as the structure of the crop (the proportion of grains, the proportion of shells, the proportion of stems in the aboveground mass of plants). After harvesting spring wheat plants, we determined the weight of grain and straw (g/vessel and g/m2), the structure of the crop (the proportion of grain and straw in the aboveground mass of plants). To assess the quality indicators of white lupine and spring wheat grain, analytical studies were carried out using SpectraStar 2500XL-R. Sampling of lupine and wheat grains, as well as preparation of samples for near infrared spectroscopy was carried out in compliance with GOST 32040.

All research results were statistically processed using the one-way ANOVA test (Tietjen et al., 2005).

The weather conditions during the growing seasons of 2017, 2018, and 2019 were different, which pre-determined the yield of lupine plants. The average daily temperature for the growing season is 1-2°C higher than the average long-term indicator. During the growing season of 2018, the average daily temperature was 1-3°C higher than the average long-term indicator for the same period. The growing season of 2019 was also characterized by a higher average daily air temperature. The largest increase in the average daily temperature was noted in May - 3.1°C, as well as in June - 2.6°C. The amount of precipitation for the same periods was significantly less compared to the long-term average.

3. Result and Discussion

We have evaluated the influence of various methods of sodium selenite application on the yield of white lupine, Dega variety. The results are shown in Table 1.

Our studies have found the positive effect of both methods of selenium application on the formation of the yield of white lupine (Table 1). The use of selenium by pre-sowing seed dressing helped to increase the productivity of lupine plants. The increase in grain weight was 6-8%. Spraying vegetative plants resulted in a significant increase in grain weight by 12-14%.

The use of sodium selenite in 2017 did not have a significant effect on the structure of the crop. However, in 2018 and 2019, spraying of vegetative plants contributed to an increase in the mass fraction of grain to 39% against 36% in the control, due to a decrease in the proportion of stems to 23% versus (relatively) 26% in the structure of the root mass (Figure 1).

Thus, the results of the studies made it possible to identify the optimal method of using sodium selenite to increase the grain productivity of plants of Dega white lupine. The studies have shown a significant increase in plant productivity by 15% and an improvement in plant structure.

To assess the nutritional and forage value, the quality indicators of the obtained grain yield were determined. The results are shown in Table 2.

Table 1. Yield of Dega white lupine treated with selenium fertilizers.

Sodium selenite treatment methods	Mass, (g/m²)			
	grain	shell	stems	shoot mass
Experiment No.1 (2017)				
control	243	153	531	927
PSSD*	252	162	545	959
VPS**	279	189	567	1035
SSD*** $_{05}$	13	8	18	-
Experiment No.2 (2018)				
control	610	642	432	1684
PSSD	649	648	440	1737
VPS	686	662	402	1750
SSD $_{05}$	27	33	21	-
2019				
control	595	624	427	1646
PSSD	640	619	431	1690
VPS	662	651	409	1722
SSD $_{05}$	25	31	20	-

*PSPD: pre-sowing seed dressing; **VPS: vegetating plant spraying; ***SSD smallest significant difference.

Figure 1. White lupin.

Table 2. The effect of sodium selenite on the quality indicators of white lupine grain in field experiment No. 2 (2018).

Sodium selenite treatment methods	Content, %			
	Crude protein	Crude oil	Crude ash	Crude fiber
untreated	38.8	9.19	3.59	9.00
PSSD	42.1	9.65	3.61	9.31
VPS	44.4	9.64	3.73	8.94
SSD $_{05}$	2.2	0.41	0.24	0.37

Table 3. The effect of sodium selenite on the yield and yield structure of spring wheat, Yubileynaya 80 variety (average for 2017-2019).

Sodium selenite treatment methods	Mass, g/vessel			Shoot mass share, %	
	grain	straw	shoot	grain	straw
untreated	4.7	19.2	23.9	19.7	80.3
PSSD	3.5	15.0	18.5	18.9	81.1
VPS	7.0	18.8	25.8	27.1	72.9
SSD 05	0.4	1.2	-	-	-

Sodium selenite has been found to contribute to an increase in the content of crude protein and crude oil, which indicates an increase in the feed value of grain, and the possibility of using it as fodder, as well as for the preparation of other types of feed. The studied parameters have improved both when using pre-sowing seed dressing and when spraying vegetative plants before the beginning of the flowering phase. The crude protein content increased 1.09 and 1.15 times, respectively, the crude oil content increased 1.05 times. The content of crude ash and crude fiber was in the range of 3.59-3.73% and 8.94-9.31%, respectively, and did not change significantly when applying sodium selenite. The increase in the content of crude protein in grain when sodium selenite is used is probably due to the effect of selenium on the amount of nitrogen input into plants, on the processes of nitrogen redistribution between plant organs and on the activation of the processes of synthesis of protein compounds, which was shown in earlier studies (Seregina, 2008). Table 3 shows the results of studies on the effect of sodium selenite on the yield of spring wheat, Yubileynaya 80 variety.

The effect of spraying vegetative plants with sodium selenite on the yield was higher than the pre-sowing seed dressing with selenium (Table 3). Spraying of vegetative plants with selenium provided an increase in yield by almost 1.5 times, up to 7.0 g/vessel, versus 4.7 g/vessel in the control plants. However, these experiments did not prove a significant change in the weight of straw. At the same time, the total weight of the shoot part of the wheat plant increased by 8% compared to the control plants. The use of pre-sowing seed treatment under these conditions had a negative effect on both the grain weight and the straw weight. A decrease in grain weight and straw weight was shown by 1.4 and 1.3 times, respectively.

The assessment of the yield structure of wheat plants (Table 4) has shown an increase in the proportion of grain up to 27.1% (19.7% in the control) in the structure of the aboveground mass of plants when spraying vegetative plants with sodium selenite as a result of a decrease in the proportion of straw up to 72.9% (80.3% in the control). This indicates an improvement in the structure of the crop towards an increase in the agronomically valuable part of the product.

Field experiments during the years of research have shown the effectiveness of sodium selenite to depend also on the method of its introduction. The use of spraying vegetative plants with sodium selenite had a positive effect on the yield of spring wheat in comparison with the pre-sowing seed treatment. The increase in grain weight was 1.6 times compared to the control. The straw weight in this variant increased by 1.5 times in comparison with the control. The same results were obtained in our previous studies. It was shown that the use of selenium spraying of vegetative plants promoted an increase in the weight of the aboveground part of plants by 52% compared to the control without selenium. At the same time, the change in the structure of the yield in field conditions was less in comparison with the results of the vegetation experiment.

The results in Table 5 show no significant changes found in the content of crude protein when using sodium selenite. However, all studies have shown an increase in crude protein harvest with wheat grain yield when using a spraying of vegetative plants, which resulted from an increase in plant productivity in these variants. In the vegetation experiment, the collection of crude protein increased by 1.47 times, in experiments carried out in the field - by 1.55 times.

Our experiments have found the use of pre-sowing treatment of seeds with sodium selenite to contribute to an increase in the content of crude gluten in all experiments by 10-15%. Spraying of vegetative plants contributed to an increase in the content of wet gluten in the growing

Table 4. The effect of sodium selenite on the yield and yield structure of spring wheat, Yubileynaya 80 variety (field experiments No. 4, 5, average for 2017-2019).

Sodium selenite treatment methods	Mass, (g/m2)			Shoot mass share, %	
	grain	straw	Shoot	grain	straw
untreated	240	750	990	24.2	75.8
PSSD	200	730	930	21.5	78.5
VPS	380	1120	1500	25.3	74.7
SSD 05	20	60	-	-	-

Table 5. The effect of sodium selenite on the grain quality of spring wheat, Yubileynaya 80 variety.

Sodium selenite treatment methods	Crude protein, %	Harvesting crude protein with grain, mg/m²	Crude gluten, %	Vitreous, %	Crude oil, %
Vegetation experiment No.3 (2017)					
control	15.0	34.6	33.2	34.5	1.3
PSSD	15.0	24.0	36.6	48.7	1.1
VPS	15.5	51.0	40.4	36.6	1.2
SSD_{05}	1.1	-	2.9	2.6	0.1
Microfield experiments No.4, 5 (average for 2018-2019)					
control	16.6	39.8	32.8	40.4	1.3
PSSD	16.6	33.2	37.9	31.7	1.1
VPS	16.3	61.9	33.9	43.3	1.2
SSD_{05}	1.1	-	2.4	2.6	0.1

experiment by 10% only in the vegetation experiment. A positive change in the vitreous of grain was manifested in the growing experiment when using the pre-sowing seed dressing with selenium, in the field - when using spraying of vegetative plants. An increase in vitreous was 1.41 times and 1.07 times, respectively. It follows that the efficiency of various methods of sodium selenite application on grain quality indicators is greatly influenced by the wheat growing conditions. With regard to the content of crude oil, a decrease in its content was revealed when using sodium selenite, regardless of the method of application.

Thus, the most effective way of using sodium selenite to grow Yubileynaya-80 spring wheat was spraying vegetative plants before shooting. The greatest increase in plant productivity by 1.5 times was shown, as well as an increase in the agronomically significant part of the crop structure in comparison with the control. The use of pre-sowing seed dressing with sodium selenite in the growing experiment and spraying of vegetative plants in the field made it possible to obtain grade 3 grain of the commodity classification, while the other methods resulted in grade 4 grain.

4. Conclusion

The results of three-year field experiments conducted at the field experimental station of Russian State Agrarian University, Moscow Timiryazev Agricultural Academy with Dega white lupine plants, and Yubileynaya-80 wheat allowed us to conclude as follows:

1. The use of sodium selenite helps to increase the productivity of white lupine plants. The optimal way to use selenium was spraying vegetative plants before shooting. The increase in grain weight was 15% in both years of research.
2. Spraying of vegetative plants with selenium contributed to an increase in the mass fraction of grain to 39% against 36% in the control, due to a decrease in the proportion of stems to 23% versus 26% in the structure of the root weight.
3. Sodium selenite has been proved to improve the fodder and nutritional value of lupine grain. The studies have shown an increase in crude protein content by 9-15% and crude oil content by 5-7%. This makes it possible to use the obtained harvest of white lupine grain for animal feeding, as well as for the preparation of various types of feed and feed additives.
4. The optimal way of using sodium selenite in the cultivation of Yubileynaya-80 spring wheat was spraying vegetative plants. The studies have shown an increase in plant productivity by 1.5 times and an increase in the share of grain in the structure of wheat yield.

We have established the positive effect of sodium selenite on the quality indicators of wheat grain. An increase in the content of raw gluten and glassiness of grain has been noted, which is important for bread-making qualities.

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