Formation of the Yield of Flax Seeds of the Oilseed Variety LM 98 during Inoculation with New Strains of Microorganisms of the Rizobakt Biological Product of the RZhF Brand in the Conditions of the Leningrad Region

M A Nosevich¹, F F Ganusevich¹, N Yu Kamyлина², T V Stepanova¹ and V A Popov¹

¹Saint Petersburg State Agrarian University, Peterburgskoe sch., 2, Pushkin, Saint Petersburg, Russian Federation
²LLC “Petersburg Biotechnologies, Moscow highway, 22-24, lit. A, pom. 1-H, office 8., Tyarlevo settlement, Pushkinsky district, St. Petersburg, Russian Federation

E-mail: mnosevich@yandex.ru

Abstract. In 2019 and 2020 on a small experimental field of the Department of Plant Industry named after I.A. Stebut FGBOU VO St. Petersburg State Agrarian University, studies were carried out to study the effect of new strains of microorganisms of Rizobakt biological products of RZhF brand on the growth, development and productivity of oil flax (Linum usitatissimum L.) variety LM 98. The research results showed that in the conditions of the Leningrad region on soddy-calcareous soil and with natural moisture, in order to obtain a stable seed yield at the level of 3.0 t / ha, it is recommended to inoculate oil flax seeds with the preparation Rizobakt of the RZhF brand (strain M) or Rizobakt of the RZhF (strain Sl), which will increase this indicator by 0.4 t/ha or 17%. The studied agrotechnical method stimulates seed germination, increases field germination by 8-30%, adaptation of crops planting to extreme environmental conditions is manifested, increasing the survival rate of plants for harvesting by 10-12%. This contributes to creation of flax stalks with a large (by 22–42%) number of plants per unit area before harvesting. In thickened agrophytocenoses, which are formed under the influence of biological products, in flax plants of the LM 98 variety, 18–19% fewer bolls are formed, seeds – by 15–17% and their weight is less by 10–18%.

1. Introduction
In Russia, oil flax takes the fourth place in terms of sown areas and gross yield of seeds, yielding to sunflower, soybeans and rape [1, 2]. According to Rosstat data for 2020, the sown area in farms of all categories was at the level of 671 thousand hectares. According to long-term forecasts, their increase under the crop may persist in the future [3]. The yield of oil flax on average throughout the country remains at a low level (no more than 1 t/ha), although the potential of this plant makes it possible to obtain more than 2 t/ha of seeds under production conditions, including in new regions of its cultivation [2].

Nutrient deficiency, low soil acidity, weeds and other unfavorable environmental factors for the cultivation of oil flax reduce the quantity and quality of the crop [4, 5, 6]. The high cost of mineral fertilizers and the negative impact of chemical plant protection products on the environmental situation are forcing manufacturers to reduce the volume of their use, which entails a number of other problems.
One of the solutions is to increase the productivity of plants through the use of biological products that can optimize the growth and development of plants [7]. Among the bacteria that develop during the growing season of flax, there are those that, when treating seeds, accelerate its growth and increase productivity [8].

Rizobakt of the RZhF brand is a biological product (microbiological fertilizer) that provides plants with macro- and microelements due to the intensification of the use of biological sources of air nitrogen by plants and the breakdown of hard-to-reach soil compounds of phosphorus, potassium and other elements. The provision of plants with nutrients and their protection from pathogens occurs during the growing season, which makes it possible to achieve a balanced nutrition of plants, taking into account their needs in each phase of development [9].

In the domestic and foreign scientific literature, there is practically no data on the effectiveness of the action of biological products and their influence on the productivity and quality of oil flax. Therefore, our research aimed at studying the effect of microbial preparations on the growth, development, productivity and quality of oil flax is relevant and has theoretical and practical significance.

2. Materials and methods

Objects of research: biological products Rizobakt of the RZhF brand (state registration no. 298-19-1312-1), oil flax – LM 98 variety, the originator of the variety is FGBNU “All-Russian Research Institute of Flax”.

The effectiveness of the use of the biological product Rizobakt of the RZhF brand on flax was studied in a one-factor field experiment. The experiment included 4 variants: without the use of the drug (in the text control or b/p), Rizobakt brand RZhF (strain V2) (in the text V2), Rizobakt brand RZhF (strain M) (in the text M), Rizobakt brand RZhF (strain Sl) (in the text Sl). Treatment of seeds with biological products was carried out during sowing with an aqueous solution at the rate of 0.4 l/t. Flax sowing was carried out on May 1 in 2019 and May 16 in 2020. The sowing method was narrow-row, the seeding rate was 6.0 million pcs/ha. The experimental plot area was 1.2 m² in 4-fold repetition. The placement of variations in repetitions is randomized. The stripping of oil flax bolls was carried out on September 8, 2019, in 2020, variants with the use of the preparation M and Sl – on September 12, control and application of B2 – on September 18.

The soil of the experimental site is soddy-calcareous, medium loamy, the humus content is 4.2%, mobile forms of phosphorus is 423, exchangeable potassium is 266 mg/kg of soil, the degree of soil saturation with bases is 87%. The predecessor in the experiment is perennial grasses. Agricultural technology in the experiment was generally accepted for spring grain crops in the Leningrad region.

In 2019, by the time of sowing of flax variety LM 98 (May 1), the sum of active temperatures was 203 °C, the lowest moisture capacity (LMC) in the 5 cm layer was 33.4%, and the soil temperature at the same depth was 14.3 °C. All this led to the emergence of friendly shoots of oil flax on the 11th day after sowing.

During the growing season of flax (May – September), the sum of active temperatures was 2244 °C, precipitation was 257 mm, the hydrothermal coefficient was at the level of 1.15, which characterizes the conditions for the growth and development of the crop as optimal moisture.

Before sowing oil flax in 2020 (May 16) the sum of active temperatures was 219 °C, the lowest moisture capacity (LMC) in the 5 cm layer and soil temperature was 30.9% and 10.0 °C, respectively. This contributed to the emergence of friendly shoots of oil flax on the 12th day in the variants with the use of strains M and Sl and on the 13th day in the control variant and inoculation with the strain B2. Analyzing the moisture supply of the crop from June to August, one can note an excessive amount of precipitation, especially in June, when 109.7 mm fell, which is 152% of the norm. On June 9, heavy precipitation was noted in the form of hail and heavy rain, which subsequently negatively affected the productivity of the studied culture.
From May 26 to September 24, 2020, the sum of active temperatures amounted to 1874 °C, precipitation was 328 mm, the hydrothermal coefficient was at the level of 1.75, which characterizes the growing season of oil flax as excessive moisture.

The records and observations during the study were carried out according to the methods [10, 11].

3. Results and discussion

According to the indicators of field germination and persistence of plants for harvesting, it is possible to predict the expected yield, and these values also allow for determining the biological yield of the crop.

The obtained experimental data indicate that field germination depended on weather conditions during the sowing period – oil flax seedlings (figure 1). In the first year of research, the field germination of flax was 1.3–25.8% higher for all variants of the experiment in comparison with the second year. This is due to more favorable weather conditions prevailing during the sowing period – crop sprouting.

In 2019, the field germination rate of oil flax was higher in variants with the use of Rizobakt preparations of the RZhF (M) brand by 8.9% and (Cl) by 23.8% in comparison with the control (64.5%). Bacterization of seeds of variety LM 98 with Rizobakt RZhF (B2) reduced germination by 4.5%.

In the second year of research, inoculation with biological products for all variants of the experiment contributed to an increase in the germination of oil flax from 38.7 to 59.1–73.9% (1.5–1.9 times). The largest difference in this indicator was noted in the control variant. Thus, the range of differences between the control and experimental variants was 20.4–35.2%. This is due to the fact that the weather conditions during the period of sowing – seedlings were optimal in terms of soil moisture supply (60-70% of the total moisture capacity), therefore nitrogen fixation increased to a maximum due to the creation of the necessary conditions for intensive excretion of root excretions, which contributed to the promotion of an active physiological state and high the number of rhizosphere microorganisms [12–14].

On average, over two years of the experiment, the activating effect of the studied bacterial preparations on the germination of oil flax seeds was observed. Inoculation of seeds before sowing flax variety LM 98 with Rizobakt RZhF (B2), (M) and (Sl) increased field germination by 8, 20 and 29% in comparison with the control variant, reaching 60, 72 and 81%, respectively.

The of oil flax plants of the LM 98 variety for harvesting was at a high level in 2019 and varied from 91.0 to 97.5%. At the same time, there was a tendency towards a decrease in variants with the use of microbial preparations in relation to the control. An exception was the variant with the inoculation of culture seeds with the Sl strain, where these values were 3.7% higher than the standard.

In 2020, the persistence of flax plants for harvesting was lower compared to the first year of research, where the lowest values of this indicator were observed – 64.0% in the control and 80.8–89.7% in the variants where the seeds were treated with biological products before sowing. The low values of plant persistence in flax in the second year of the experiment are explained by unfavorable conditions in the first half of the growing season, when hail and heavy rainfall fell in early June. Presowing treatment with microbial preparations of oil flax promoted the appearance of a protective effect on plants under conditions of excessive water stress. The positive role of the bacteria in the composition of the preparation in the resistance of flax plants is that more developed plant organisms are better able to withstand any unfavorable environmental conditions [15].
Figure 1. Dynamics of field germination and of oil flax depending on the use of biological products, % for 2019–2020.

Over the two years of the experiment, the persistence of oil flax plants for harvesting in variants with treatment with biological products was, on average, 10.2–11.6% higher in comparison with the control (figure 1).

Over the years of research, the morphological structure of the yield of oil flax seeds was influenced by the meteorological conditions of the growing season. Excessive moisture during the growing season of the crop in 2020 contributed to a decrease in the main indicators of the elements of the yield structure in the LM 98 variety compared to the year of normal moisture (2019). Thus, the number of capsules decreased by 1.4–1.8 times, seeds – by 1.4–2.1 times, the weight of seeds per plant – by 1.6–2.4 times (table 1). An exception was the option where the seeds were treated with Rizobakt RZhF (strain SI) before sowing. The studied structural indicators of productivity in this variant were at the same level during two years of observation.

On average, over two years of research in flax-mezheumka in variants with the use of biological products, a smaller number of bolls was formed on the plant compared to the control – by 15–19 and seeds – by 15–17%. The same trend persisted when analyzing their mass: the mass of bolls decreased from 1.161 to 0.964–0.976 (by 16–17%), and the mass of seeds – from 0.892 to 0.734–0.803 (by 10–18%).

Despite the fact that the number and weight of seeds on a plant decrease due to the action of biological products, these indicators increase per unit area (figure 2, 3). This is the reason for the more uniform seed yield of oil flax between the variants of the experiment.

Inoculation before sowing the culture with Rizobakt RZhF (B2) and (M) had a positive effect on the weight of one thousand seeds, increasing it from 6.65 to 6.75–6.93 g.

Over the years of the experiment, the yield of seeds of the studied culture was influenced by the weather conditions of the growing season (91%) and the studied biological products (9%) (figure 4).

In 2019, no significant variation in seed yield was observed in the oil flax of LM 98 variety, as evidenced by statistical data processing. In 2020, significant differences were noted for this indicator.
Table 1. Influence of biological products on the elements of the structure of the yield of oil flax seeds, average for 2019–2020.

| Experiment variant | plants before harvesting, m² | stems per plant | bolls per plant | seeds in a boll | seeds per plant | bolls on a plant | seeds from a plant | 1000 seeds |
|--------------------|-------------------------------|-----------------|-----------------|----------------|----------------|----------------|------------------|-----------|
| Control            | 363                           | 1.3             | 20.0            | 9.0            | 179.0          | 1.629          | 1.262            | 7.15      |
| LM98+V2            | 330                           | 1.0             | 14.8            | 9.0            | 133.7          | 1.242          | 1.063            | 7.37      |
| LM98+M             | 404                           | 1.3             | 14.6            | 8.8            | 128.1          | 1.162          | 0.943            | 7.00      |
| LM98+Sl            | 515                           | 1.2             | 12.8            | 8.6            | 109.5          | 0.967          | 0.730            | 6.93      |

|                |                                | 2019            | 2020            |                |                |                |                  |          |
| Control         | 147                            | 2.2             | 11.0            | 7.8            | 85.7           | 0.692          | 0.521            | 6.14      |
| LM98+V2         | 320                            | 1.1             | 10.1            | 8.6            | 86.2           | 0.710          | 0.543            | 6.48      |
| LM98+M          | 381                            | 1.3             | 10.7            | 8.6            | 92.6           | 0.765          | 0.587            | 6.49      |
| LM98+Sl         | 357                            | 1.6             | 13.5            | 8.6            | 115.7          | 0.962          | 0.738            | 6.37      |

|                |                                | average for 2019-2020 |                |                |                |                  |                  |          |
| Control         | 255                            | 1.8             | 15.5            | 8.4            | 132.4          | 1.161          | 0.892            | 6.65      |
| LM98+V2         | 325                            | 1.1             | 12.5            | 8.8            | 110.0          | 0.976          | 0.803            | 6.93      |
| LM98+M          | 393                            | 1.3             | 12.7            | 8.7            | 110.4          | 0.964          | 0.765            | 6.75      |
| LM98+Sl         | 436                            | 1.4             | 13.2            | 8.6            | 112.6          | 0.965          | 0.734            | 6.65      |

Figure 2. Formation of the number of seeds per oil flax plant and per unit area, depending on the use of biological products, average for 2019–2020.

Figure 3. Influence of biological products on the weight of seeds per plant and per unit area of oil flax, average for 2019–2020.

In the first year of research, the differences in seed yield ranged from 3.40 to 3.69 t/ha, and in the second year – from 0.81 to 1.71 t/ha, which is 2.2–4.5 times less. It was noted that the greatest difference in seed yield was in the control (78% less) and in the variant where the B2 strain was used (68% less). In variants where strains M and Sl were inoculated, the difference between the values was less and amounted to 2 t/ha (or 54–55%). A significant difference between the yield is explained by the fact that in the second year of research, the sum of active temperatures for the growing season of flax variety LM 98 was lower by 370 °C (2244 versus 1874 °C) compared to the first year, therefore, there were many unfulfilled seeds in the harvested mass.
Figure 4. Productivity of oil flax seeds depending on the use of Rizobakt of the RZhF brand, t/ha.

On average, over two years of research, the highest yield of oil flax seeds – 2.7 t/ha was noted in experimental variants, where seeds were inoculated with microbial preparations Rizobakt of the RZhF (M) and (Sl) brands before sowing, which is significantly higher by 0.43–0.46 t/ha in relation to the control and by 0.36–0.39 t/ha in relation to the variant with the use of strain V2 (at LSD (Least significant difference) 0.34 t/ha).

4. Conclusion
1. Inoculation of oil flax seeds before sowing with Rizobakt RZhF preparations containing new strains of microorganisms stimulates seed germination, which, in turn, increases field germination by 8–30%, while adaptation of crops to extreme environmental conditions is manifested, increasing of plants for harvesting by 10–12%. This promotes the formation of flax stems with a large (by 22–42%) number of plants per unit area before harvesting the crop.

2. In the thickened crops of oil flax, formed under the influence of biological products, plants form less capsules (by 18–19%) and seeds (by 15–17%), and their weight decreases (by 16–17 and 10–18%, respectively).

3. In the conditions of the Leningrad region, the treatment of oil flax seeds before sowing with microbial preparations Rizobakt of the RZhF (M) or (Sl) brand, the genetic characteristics of the LM 98 variety and sufficient moisture during the growing season have a synergistic effect on the yield of crop seeds (at the level of 2.7 t/ha). In these variants, a significant increase in seed yield was obtained, which, respectively, amounted to 0.46 and 0.43 t/ha.

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