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PRODUCTIVITY OF LINES – PARENTAL COMPONENTS OF MAIZE HYBRIDS DEPENDING ON PLANT DENSITY AND APPLICATION OF BIOPREPARATIONS UNDER DRIP IRRIGATION

Raisa VOZHEHOVA[1], Tetyana MARCHENKO[1], Yurii LAVRYNENKO[1], Olena PILIARSKA[1], Pavlo ZABARA[1], Serhii ZAIETS[1], Andrii TYSHCHENKO[1], Serhii MISHCHENKO[2], Svitlana KORMOSH[3]

[1]Institute of Irrigated Agriculture, National Academy of Agrarian Sciences of Ukraine, Naddniprianske, Kherson, 73483, Ukraine, Phone/Fax: +38 0552361196, +38 0954429212, +38 0505545633, +38 0997779934, +38 0992962880, +38 0501722907, +38 0992090161; E-mail: izz.ua@ukr.net, tmarchenko74@ukr.net, lavrin52@ukr.ne, izz.biblio@ukr.net, zabara.pawel@gmail.com, szaiets58@gmail.com, tischenko_andriy@ukr.net
[2]Institute of Bast Crops, National Academy of Agrarian Sciences of Ukraine, 45 Tereshchenkiv Str., Hlukhiv, Sumy region, 41400, Ukraine, Phone/Fax: +38 0687981198; E-mail: serhii-mishchenko@ukr.net
[3]Transcarpathian State Agricultural Research Station, National Academy of Agrarian Sciences of Ukraine, 17 Svobody Ave., V. Bakta, Berehiv district, Zakarpattia region, 90252, Ukraine, Phone/Fax: +38 0955392803; E-mail: korsveta1967@ukr.net

Corresponding author: izz.biblio@ukr.net

Abstract

The article presents field research results on studying the effect of treating maize plants with growth regulating biological products on the formation of productivity of lines – parental components for optimizing the elements of cultivation technology. The experimental scheme included the effect of Bio-gel and Helafit®-combi biological products on the productivity of parental components of different FAO groups and genetic plasms of maize hybrids at different densities of 70,000, 80,000, 90,000 plants ha^{-1}. Studies have shown that for the maximum manifestation of the "weight of 1,000 grains" indicator the optimal density is 70,000 plants ha^{-1}. The increase in yield is positively influenced by the increase in the weight of 1,000 seeds, which is due to the line genotype and the use of the Bio-gel, Helafit®-combi biologically active products. Pre-sowing treatment of maize seeds with Bio-gel and Helafit®-combi increased laboratory seed germination. With the Bio-gel product applied, the laboratory germination increased by an average of 1.5%, with Helafit®-combi used seed germination increased by 2.4%. In our studies, the maximum seed yield in the early-ripening line of the DK 281 parental component was recorded at a density of 90,000 plants ha^{-1}and the treatment with Helafit®-combi and amounted to 3.65 t ha^{-1}. The maximum yield of the DK 247 parental component was observed at a density of 80,000 plants ha^{-1} and the treatment with Helafit®-combi and amounted to 4.89 t ha^{-1}. Mid-late lines DK 411 and DK 445 parental components showed the highest yields at densities of 70,000 plants ha^{-1} and after the treatment with Helafit®-combi which amounted to 4.65 and 6.30 t ha^{-1}, respectively.

Key words: *maize, line – parental component, germ-plasm, weight of 1,000 seeds, seed yield*

INTRODUCTION

Providing the Earth's population with food is one of the global challenges of the 21st century. Globally, agriculture is forced to increase the production of grain – a key human food product, concentrated feed and the main source of plant proteins, carbohydrates and fats. Scientific predictions suggest that with significant population growth on Earth, food production will fall short of such growth and, given the current dynamics of population growth, the food problem may result in a deep international food crisis [6, 10].

At the current rate of population growth, in the future, world grain production per capita will decline. Therefore, humanity must find a solution to the problem, because population growth rates remain too high. The forecasts for the reduction of arable land per capita are also threatening, as the chances for expanding agricultural land are almost exhausted [23].

To date, almost all land resources have been depleted and the reduction of agricultural land continues due to urbanization and soil degradation. This suggests that providing mankind with food is possible only by increasing crop yields [2, 3, 7]. So in the sphere of increasing cereal productivity (the main source of food) there are three main fields: genetic -selection development; creation and improvement of agrotechnologies; location optimization and specialization of production [24].

Throughout the centuries-long history of human civilization on Earth, the main cereals of mankind have been wheat and rice. But at the beginning of the third millennium it was maize that occupied the first position (in terms of gross harvest and yield). Today, world maize production exceeds 1 billion tons of grain and in the coming years yields and gross harvests are expected to increase [12].

Today it is important to create new high-yielding hybrids of maize, the parent forms of which are self-pollinating lines. A self-pollinating line is a group of genetically identical homozygous individuals that are descendants of a single plant. Self-pollinating lines (incucht lines, inbred lines) are obtained as a result of forced plant self-pollination for 6–8 generations. As a result, the source material becomes homozygous, which is unnatural for cross-pollinating plants. Homozygous plants are characterized by reduced viability, impaired growth, low yields, weak root system [8]. The seeds of the self-pollinating lines stay in the ground for one and a half to two times longer til the seedlings appear. The rate of the lines vegetative growth is significantly lower than that of hybrids. The foliage area in them is 2–3 times smaller, the weight of 1,000 grains is significantly lower, the seed germination is reduced. Therefore, the lines need better growing conditions, are more sensitive to adverse factors and always require increased technological support. The yield of seed lines depends significantly on the genotypic characteristics of the FAO group, so it is necessary to improve technological recommendations for the cultivation, breeding and hybridization, taking into account the biological characteristics of the parental forms [18].

In Ukraine, the creation and introduction of new high-tech maize hybrids of intensive type cultivated under irrigation conditions is carried out by the only research institution – the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine. The Southern Steppe of Ukraine under irrigation provides all opportunities for guaranteed high maize grain yields and it is for these conditions that innovative maize hybrids with high adaptability to agro-environmental conditions of the zone have been created [11, 27]. An important condition for ensuring the production of first-generation hybrids (F_1) is to obtain a sufficient number of parental lines with high sowing characteristics for hybridization sites.

One of the important elements of maize plant productivity which affects the formation of potential and actual yields, is the "weight of 1,000 grains". Therefore, the study of this indicator manifestation, its variability and relationships with other characteristics of lines and hybrids is important in determining priority parameters in the selection of a new generation of high-yielding genotypes and in improving varietal cultivation technology in specific agro-ecological zones [13, 16].

The weight of 1,000 grain along with yield is an effective indicator as a criterion in the selection of adaptive maize genotypes under drought stress [5]. Among other characteristics, the weight of 1,000 grains is more important for the selection of high yielding maize genotypes, this indicator may be present in breeding programs and be effective as a potential characteristic in improving desired maize genotypes [20].

The use of large fraction of maize seed is the most positive component for increasing seed yield [22]. A large seed has large germ and much more nutrients, therefore, it provides good and even sprouts, since the primary (germinal) roots and the first leaf are formed, in practice, only due to the nutrients of maize seed [30].

Maize grain having proper kernel geometry has a higher quality compared to very large or small kernel [15]. Today, an effective means of increasing plant productivity is the use of growth regulating products. Biologically active compounds are able to cause growth regulating, immunostimulatory and adaptogenic effects on plants [19, 28].

Physiologically active substances contribute to the mobilization of the genetic capabilities of the plant organism [21, 25]. It was also discovered that under the influence of such products there was observed an increase in growth processes and the formation of yield structural elements.

The studies by C.N. White and C.J. Rivin [29] found that maize seeds pre-sowing treatment with endogenous gibberellin affects the concentration ratio of gibberellin and abscisic acids in seeds, which affects the regulation mechanism of its germination or dormancy. It is the use of the gibberellin group products that accelerates the germination of maize seeds.

MATERIALS AND METHODS

The experimental part of the research was performed on irrigated lands of the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine, located on the right bank of the Dnieper; the Dnieper district of Kherson in the area of the Ingulets irrigation system.

The soil of the study area is dark chestnut medium loamy slightly saline with a deep level of groundwater.

Three-factor experiment (Factor A – line – parental component, Factor B – treatment with product, Factor C – plant density, plants ha^{-1}) was carried out using the method of randomized split blocks. The sown area of the plots was 30.0 m^2, the accounting area was 20.0 m^2. The research was performed with four repetitions.

The material for the research was different maturity group lines – parental components: DK 445 (parental component of Arabat, Vira, Gileya hybrids); DK 411 (parental component of Chongar, Lamasan hybrids); DK 281 (parental component of the steppe hybrid); DK 247 (parental component of Skadovsky, Oleshkivsky hybrids). The sowing density of all parental forms was 70,000, 80,000, 90,000 plants ha^{-1}. The parental components of maize were treated with two biological preparations: Helafit®-combi and Bio-gel, which are included in the State Register of Pesticides and Agrochemicals Permitted for Use in Ukraine. Plants were treated twice with Helafit®-combi: in the phase of 7–8 leaves and panicle appearance (application rate – 1 L/ha), seeds were treated with Bio-gel (at the rate of 2 L/t) and plants were sprayed (1.5 L/ha) in the phase of 7–8 leaves.

Helafit®-combi contains microelements, ions of biogenic metals, free amino acid, humates, fatty acids, fatty acid esters, polysaccharides, steroid glucosides, vitamins, 3-indoleacetic acid, epibrassinolide, zeatin, alginic acid, hydrochloric acid. The main active ingredients of the Bio-gel organic fertilizer are enzymes, amino acids, vitamins, fulvic and humic acids, trace elements and saprophytic microorganisms.

The Institute weather observations were used to characterize the weather conditions during the research years. Agrotechnic in the experiment corresponded to the technology of growing maize in the South of Ukraine, the requirements of research methods and guidelines for conducting research with maize lines; mathematical processing of experimental data was carried out according to generally accepted methods [26, 28].

Surface drip irrigation was used, the level of pre-irrigation soil moisture being 80% of the lowest moisture content in the 0–50 cm soil layer.

The aim of the research was to establish the weight of 1,000 grains, laboratory germination and yield of lines – parental components of maize hybrids, depending on the density of sowing and treatment with biological products. To solve the problems an experiment was conducted in the selection department of the NAAS in 2018–2020, its scheme is given in Table 1.

The following methods were used in the study: field, measuring-weight, variance and correlation-regression analysis, system analysis and synthesis.

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Table 1. The scheme of the experiment

Factor A (line – parental component)	Factor B (treatment with product)	Factor C (plant density, plants ha^{-1})		
DK 281 (FAO 190, Mixed germ-plasm)	control, no treatment	70,000	80,000	90,000
	Bio-gel			
	Helafit®-combi			
DK 247 (FAO 290, Mixed germ-plasm)	control, no treatment	70,000	80,000	90,000
	Bio-gel			
	Helafit®-combi			
DK 411 (FAO 420, Iodent germ-plasm)	control, no treatment	70,000	80,000	90,000
	Bio-gel			
	Helafit®-combi			
DK 445 (FAO 420, Mixed germ-plasm)	control, no treatment	70,000	80,000	90,000
	Bio-gel			
	Helafit®-combi			

Source: Authors' concept of the experiments.

RESULTS AND DISCUSSIONS

One of the important elements of maize productivity which affects the formation of yield and sowing characteristics of seeds is the "weight of 1,000 grains". Therefore, studying the manifestation of this characteristic and its relationship with other characteristics in the lines is of great practical importance for seed production and for determining the priority selection parameters in the selection of a new generation of high-yielding biotypes for specific agro-ecological cultivation zones. The "weight of 1,000 grains" characteristic in the parental components of different genetic plasms and FAO groups was studied under irrigation conditions. Observations conducted in 2018–2020 showed that the weight of 1,000 seeds depends on the line genotype, plant density and treatment with various products.Among the parental components, the highest weight of 1,000 grains was observed in the mid-season Mixed germ-plasm DK 445 (FAO 420) line amounting to an average of 277.3 g. The lowest weight on average was demonstrated by the Mixed germ-plasm DK 247 line and amounted to 229.6 g (Table 2). The genotype of the paternal line had the most significant effect on the weight of 1,000 maize grains. Thus, the DK 445 mid-late line which is the parental form of new innovative hybrids Arabat, Vira, Gileya, showed the highest weight with a density of 70,000 plants ha^{-1}, on average it amounted to 285.9 g. The treatment with Helafit®-combi helped to increase the weight of 1,000 grains by 10.6 g which amounted to 282.7 g. The maximum weight of 1,000 grains was observed in the DK 445 (Mixed germ-plasm, FAO 420) line after treatment with Helafit ®-combi and made 292.6 g at a plant density of 70,000 plants ha^{-1}. With the increase in density to 80,000 plants ha^{-1}, the weight of 1,000 grains of this line tended to decrease by 2% compared to the density of 70,000 plants ha^{-1} and averaged 280.7 g. Treatment with Bio-gel allowed to increase the weight of 1,000 grains to 281.4 g compared to the control (275.7 g). Helafit®-combi increased the weight of 1,000 grains to 285.0 or by 2.2%. The increase in density to 90,000 plants ha^{-1} caused a sharp drop in the weight of 1,000 grains to 265.2 g on average. Treatment with Bio-gel allowed to increase the manifestation of this indicator by 2.1 g or 0.8% to 263.7 g compared to the control. Treatment with the Helafit®-combi product increased this indicator to 270.4 g, i.e. by 8.8 g or 3.3% compared to the control. It was found that the DK 445 line reacted negatively to the density of plants. In the experiment, all lines – parental components produced the maximum weight of 1,000 grains at the density of 70,000 plants ha^{-1} , which was 257.6 g. Increasing the density to 80 plants ha^{-1} resulted in the decrease of weight of 1,000 grains to 252.3 g, and at a density of 90,000 plants ha^{-1} its weight was only 244.6 g.

Table 2. Weight of 1,000 grains, lines – parental components of maize hybrids, g (average for 2018–2020)

Factor A (line – parental component)	Factor C (plant density, plants ha^{-1})	Factor B (treatment with product)			On average by factor	
		Control, no treatment	Bio-gel	Helafit®-combi	A	B
DK 281 (Mixed germ-plasm)	70	229.7	233.3	239.3	231.8	257.6
	80	226.3	230.6	238.5		252.3
	90	225.3	229.2	234.3		244.6
On average		**227.1**	**231.0**	**237.4**		
DK 247 (Mixed germ-plasm)	70	232.4	234.2	243.1	229.6	
	80	225.6	227.7	235.0		
	90	216.6	221.4	230,1		
On average		**224.9**	**227.8**	**236.1**		
DK 411 (Iodent germ-plasm)	70	266.9	273.6	280.5	267.3	
	80	254.6	270,7	276,9		
	90	251.3	266.8	264.2		
On average		**257.6**	**270.4**	**273.9**		
DK 445 (Mixed germ-plasm)	70	278.9	286.2	292.6	**277.3**	
	80	275.7	281.4	285.0		
	90	261.6	263.7	270.4		
On average		**272.1**	**277.1**	**282.7**		
On average by factor C		245.4	251.6	**257.5**		
Assessment of the partial differences significance						
LSD$_{05}$, г		A= 2.2; B=1.3; C=1.5				

Source: Authors' own results.

For the maximum manifestation of the "weight of 1,000 grains" indicator the optimal density was 70,000 plants ha^{-1}. At a density of 90,000 plants ha^{-1}, all lines of different FAO and germ-plasm groups showed minimal results.

Table 3. Laboratory germination of maize hybrids lines – parent components, % (average for 2018–2020)

Factor A (line – parental component)	Factor B (treatment with products)			On average by factor A
	Control, no treatment	Bio-gel	Helafit®-combi	
DK 281 (FAO 190)	96.9	97.2	98.5	97.5
DK 247 (FAO 290)	96.2	97.8	98.2	97.4
DK 411 (FAO 420)	94.5	96.9	97.2	96.2
DK 445 (FAO 420)	93.8	95.4	96.8	95.3
On average by factor B	**95.4**	**96.8**	**97.7**	

Source: Authors' own results.

It was found that the studied Bio-gel and Helafit®-combi products effectively influenced the processes of grain formation, which ensured an increase in laboratory germination of the obtained seeds (Table 3).

Variance analysis shows that the line genotype had the greatest effect on laboratory germination of seeds, the treatment with biological products was less significant, plant density had the minimal effect on seed laboratory germination (Figure 1).

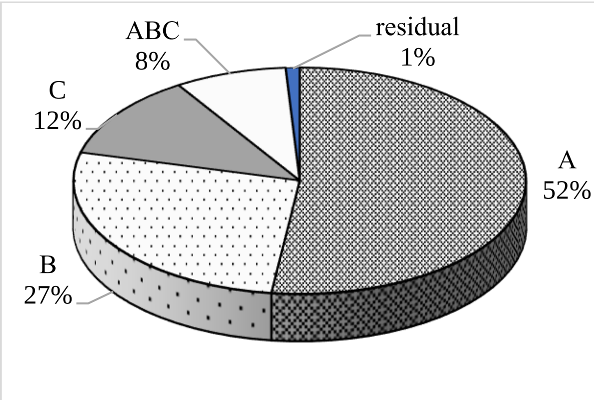

Fig. 1. Variance analysis of the effect of various factors and their interaction on the laboratory germinatiion of maize hybrids lines – parental components, %: A – genotype of the line; B – plant treatment with biologically active products, C – plant density, ABC - interaction of factors; residual

Source: Authors' own results.

Regarding the indicators of the seeds laboratory germination, the following was found: treatment of the lines – parental components with Bio-gel and Helafit®-combi caused an increase in the seeds laboratory germination. The application of the Bio-gel product increased the laboratory germination by an average of 1.5%. Helafit®-combi treatment was more effective because the seed germination in this experimental variant increased by 2.4%. An increase in laboratory germination was observed due to a decrease in the incidence of fusarium fungi (*Fusarium moniliforme* Scheld.).

The analysis of the maize seed germination dependence on the genotype of the parental components shows that the late-maturing lines (FAO 420) DK 411 (germ-plasm Iodent) and DK 445 (Mixed germ-plasm) demonstrated lower germination compared to earlier-maturing lines of mixed plasm 28 FAO 190) and DK 247 (FAO 290). Although the effect of treatment with biologically active products was less significant than the genotypic factor, its positive effect on the lines laboratory germination testifies to the possibility of increasing their germination by such treatment.

In our studies, the maximum seed yield in the early-maturing line – the parental component DK 281 was recorded at a density of 90,000 plants ha^{-1} and after treatment with Helafit®-combi, it was 3.65 t ha^{-1}. The maximum yield of the parent component DK 247 was observed at a density of 80,000 plants ha^{-1} and after treatment with Helafit®-combi, it was 4.89 t ha^{-1}. Mid-late lines – parental components DK 411 and DK 445 showed the highest yields at densities of 70,000 plants ha^{-1} and after treatment with Helafit®-combi, they amounted to 4.65 and 6.30 t ha^{-1}, respectively (Figure 2).

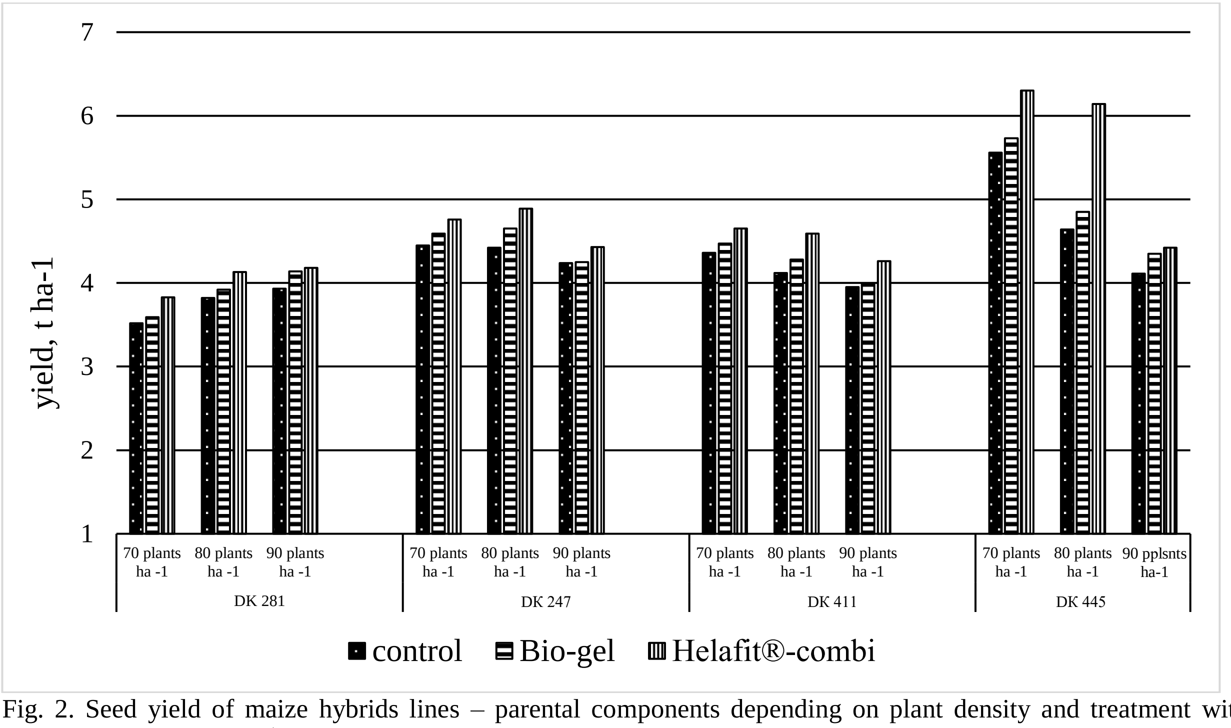

Fig. 2. Seed yield of maize hybrids lines – parental components depending on plant density and treatment with biological products, t ha^{-1} (average for 2018–2020)

Source: Authors' own results.

The highest seed yield was formed in the DK 445 mid-late line (parental component of Vira, Arabat, Hilea hybrids) amounting to 4.11–6.30 t ha^{-1}, which is due to the increased duration of the growing season and optimized technology under drip irrigation.

In the DK 445 and DK 411 mid-late lines there was a sharp decrease in yield at higher sowing density. On average, the highest seed yield over the years was in the DK 445 mid-late line at a density of 70,000 plants ha^{-1}, it was 5.86 t ha^{-1}. At a density of 80,000 plants ha^{-1}, the yield was 5.21 t ha^{-1}, with the thickening of crops to 90,000 plants ha^{-1}, there was a sharp decrease in yield to 4.29 t ha^{-1}. The DK 411 mid-late line also showed the maximum yield at a density of 70,000 plants ha^{-1}, it was 4.47 t ha^{-1}. At a density of 90,000 plants ha^{-1}, the minimum yield was 4.07 t ha^{-1}.

Helafit®-combi was the most effective among the biological products. Thus, in the mid-late group of parental components, the highest seed yield was established in the DK 445 line after applying this product, it was 5.62 t ha^{-1} (the yield increased by 0.85 t ha^{-1} or by 17.8%), in DK 411 line it was 4.50 t ha^{-1} (the yield increased by 0.36 t ha^{-1} or by 8.0%). The line – parental component of the DK 247 mid-early group showed a slightly lower yield – 4.69 t ha^{-1} when applying the same product (the yield increased by 0.32 t ha^{-1} or by 6.8%). The DK 281 early ripening line on applying Helafit®-combi yielded 4.05 t ha^{-1} (the yield increased by 0.29 t ha^{-1} or by 7.2%). The yield increase on applying the Bio-gel biological product was significantly lower.

To determine whether the weight of 1,000 grains of the maize hybrid lines – parental components was related to seed yield, a correlation closeness was calculated. The presence of a rectilinear correlation (r = 0.618 ± 0.13) between the seed yield of the parental maize lines and the weight of 1,000 grains was found (Figure 3).

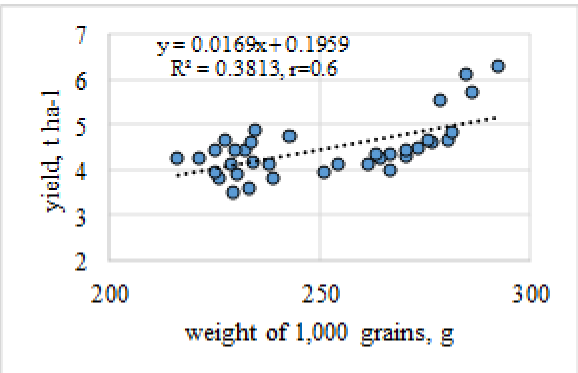

Fig. 3. Correlation-regression model of seed yield and weight of 1,000 grains dependence (average for 2018–2020)
Source: Authors' own results.

Thus, the increase in the weight of 1,000 grains due to both the line genotype and the application of the Bio-gel, Helafit®-combi biologically active products has a positive effect on the seed yield of the hybrids lines - parental components. Increased density of plants has a negative effect on the "weight of 1,000 grains", that is why the optimum plant density for each hybrid line – parental component should be experimentally established in order to maximize the yield of seeds and improve their sowing characteristics.

The economic analysis of seed production lines – parental components has been conducted using the following hybrids at the following plant densities: DK 281 – 90,000 plants ha^{-1}, DK 247 – 80,000 plants ha^{-1}, DK 445 – 70,000 plants ha^{-1}.

The value of gross output per 1 ha, technology costs and net profit depending on the use of biological products have been determined (Table 4).

The value of gross output per 1 ha after treatment with biological products was maximum in the DK 445 line – the parental component and amounted to from 5.37 to 6.09 thousand euro·ha^{-1} depending on the experiment variants, in the DK 247 parental component it was slightly lower – 4.27–4.73 thousand euros ha^{-1}, the DK 411 parental component produced still lower value – 4.21–4.50 thousand euros ha^{-1}, the lowest value of gross output was in the DK 281 line – 3,80–4,04 thousand euros ha^{-1}.

In the DK 281 line, the highest net profit was received after Helafit®-combi treatments – 2.66 thousand euro ha^{-1}. In the DK 247 line, the highest net profit was received after Helafit®-combi treatments – 3.32 thousand euro ha^{-1}. The highest net profits in the DK 411 and DK 445 lines were also obtained after treatments with Helafit®-combi – 3.06 thousand euro ha^{-1} and 4.61 thousand euro ha^{-1}, respectively, which testifies to the product high efficiency.

The data obtained in our research coincide with the data obtained by other researchers in other agro-environmental zones. Plant density is crucial in the complex of agronomic measures for maize cultivation, seed yield depending on it. A significant yield of lines – parental components can be obtained due to high individual productivity and the maximum allowable plant density in specific growing conditions [33].

Table 4. Economic efficiency of cultivating maize lines - parental components depending on the treatment with biological products

Factor A	Factor C	Average yield, t ha^{-1}	Gross output value, thous. euro ha^{-1}	Cost, thous. euro ha^{-1}	Net operating profit, thous. euro ha^{-1}
DK 281	Control, no treatment	3.93	3.80	1.36	2.44
	Bio-gel	4.14	4.00	1.38	2.62
	Helafit®-combi	4.18	4.04	1.38	2.66
DK 247	Control, no treatment	4.42	4.27	1.40	2.87
	Bio-gel	4.65	4.50	1.40	3.09
	Helafit®-combi	4.89	4.73	1.41	3.32
DK 411	Control, no treatment	4.36	4.21	1.43	2.79
	Bio-gel	4.47	4.32	1.43	2.89
	Helafit®-combi	4.65	4.50	1.44	3.06
DK 445	Control, no treatment	5.56	5.37	1.47	3.90
	Bio-gel	5.73	5.54	1.48	4.06
	Helafit®-combi	6.30	6.09	1.48	4.61

Note: The cost of 1 ton of seeds of the parental component is 0.97 thousand euros.
Source: Authors' own results.

High crop productivity can be ensured by rapid and simultaneous seed germination which is an important integral indicator of seed quality [4]. It is well known that increased laboratory germination contributes to the simultaneous and uniform emergence of seedlings [1]. This, in turn, can help increase seed yield and quality [17, 32]. The positive effects of physiologically active substances can be related both to their regulatory and adaptogenic effects on plants [9, 14] and to their effects on genetic potential [31].

CONCLUSIONS

The maximum seed yield of the DK 281 early-ripening line – parental component was recorded at a density of 90,000 plants ha^{-1} and after applying Helafit®-combi, it amounted to 3.65 t ha^{-1}. The maximum yield of the DC 247 line – parental component was observed at a density of 80,000 plants ha^{-1} and after applying Helafit®-combi, it amounted to 4.89 t ha^{-1}. The DK 411 mid-late line – parental component showed the highest yield at a density of 70,000 plants ha^{-1} and after applying Helafit®-combi, it amounted to 4.65 t ha^{-1}. The maximum yield in the experiment was observed in the DK 445 line – parental component, it was 6.30 t ha^{-1} at a density of 70,000 plants ha^{-1} and after applying Helafit®-combi.

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