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ORIGINAL ARTICLE

Laboratory and field germination of winter wheat and spring barley depending on the mode of irradiation with MWF of EHF and pre-sowing seed treatment

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The pre-sowing seed treatment with chemical synthesis pesticides remains the primary method in the agricultural industry today. However, pesticides inevitably have a negative influence on the ecosystem of any level. A more environmentally friendly method of seed treatment under the intensive technology is the combination of microwave seed irradiation and seed incrustation with plant growth regulators that provide an increase in the cereal crops' yield capacity up to 15–20 %. As a result of research, it is established that when the seeds were treated with MWF of EHF the average laboratory indices of the sprouting energy and germinating power were slightly lower than in the case with Vitavax FF, 2.5 L/t. After treating the seeds irradiated with MWF of EHF with the plant growth regulator Mars EL, in 2010–2012, the average sprouting energy and germinating power of winter wheat seeds were higher by 2%, which corresponds to the indices of Vitavax 200 FF case. In the laboratory conditions, the sowing qualities of spring barley seeds varied depending on the method of the pre-sowing treatment and its variety. It can be concluded that the combination of the pre-sowing seed irradiation with MWF of EHF with the subsequent treatment with the plant growth regulators, in general, has a positive influence on the sowing qualities of winter wheat and spring barley. The combination of the pre-sowing irradiation with MWF of EHF with the subsequent treatment with the growth regulators positively influenced the field germination of winter wheat and spring barley seeds. Winter wheat of the Astet variety was sown at a sowing rate of 4,5 million viable seeds per 1 ha. The determination of field germination was performed in the phase of full sprouting. At the same time, it was found out that in 2010–2012 the average field germination under control and in the case with the Vitavax 200 FF treating agent was practically the same and amounted to 90,0–90,2 %. However, under the unfavorable conditions of 2012, the field germination of winter wheat seeds in the Vitavax 200 FF case exceeded the control by 7,8 %. The pre-sowing seed irradiation with MWF of EHF in the modes of 1,8 kW/kg, 15 sec. and 0,9 kW/kg, 45 sec. increased the field germination of winter wheat by 6.9 and 7.4 %, respectively. In the cases where the seeds were treated with MWF of EHF and Mars EL preparation, it was higher by 9.1–11.8 %. This indicates that under unfavorable conditions, the pre-sowing seed treatment on field germination is more significant.

Key words: disinfection, fungicides, growth regulators, pathogens, seeds, grain, winter wheat, spring barley, microwaves.

Introduction

Increasing the crop yield capacity and improving product quality is among the most important tasks for agricultural scientists in many countries worldwide. Cereal crops form the basis of agricultural production. They are the most valuable and most common in the world among all field crops. The cereals and legumes make up about 70 % of the structure of food products.

Grain production globally is increasing mainly due to the improvement of varietal resources and the modernization of zonal technologies for growing cereals, including wheat, barley, rye, and oats.

Wheat always has been and remains the leading grain crop in the world and Ukraine. The total area under this crop occupies about 240 million hectares globally and 7 million hectares in Ukraine. In 2017 the world wheat production amounted to about 750,1 million tons, and in Ukraine, it was 21 million tons. Naturally, wheat is a staple food product in 43 countries with more than 1 billion people (Adamenko, 2008).

The total share of Ukraine in the world production of spring barley grain is about 8,2 % (Sajko, Gricaj & Gordecka, 1994; Sajko, 1997). Barley is an indispensable component for producing mixed feed and raw materials for the food and brewing industries. In Ukraine, the stable grain production in the second half of the 1990s was characterized by an average annual bulk yield of 50–52 million tons, which is almost 1000 kg per capita (Babich et al., 1994; Sytnyk, 2002). However, the sharp climatic changes (mainly in the form of temperature rise, a tendency that has been observed in the last two decades) have led to fluctuations in agrometeorological conditions for growing cereal crops. During the droughts of 2008–2009, the world wheat grain production decreased significantly. The drought in these years has affected the countries that are the leading exporters of grain, namely Australia, Argentina, Brazil, Canada, Eastern Europe, and Ukraine. As a result, the global demand for food grains has increased. During the last seven years, the food grain shortage has constituted 310 million tons annually (Sajko, 2008). Therefore, grain production has been and remains a priority in agricultural development (Belyaev et al., 2018).

The world experience shows that in the countries with high levels of agro-technical support, the increase in grain yield reaches a critical limit. The use of “intensive” technologies in agricultural crop production since the 1980s of the last century has sharpened the contradictions between the economy and the environment. The intensive application of pesticides and mineral fertilizers in agriculture, including chemicals for the pre-sowing seed treatment, and increasing the productivity of plants inevitably cause several undesirable effects of ecological and economic characters.

One of the obligatory elements of the technological process of cultivating cereal crops, which affects the increase in the yield and quality of crop production, is the pre-sowing treatment of seeds with chemical and biological products of different origins. However, today in Ukraine, the problem of seed sanitation and selecting the most viable biotypes with high productive properties by the pre-sowing treatment with ecologically friendly methods have not yet been solved.

The search for new alternative methods for seed disinfection to reduce the negative influence of agrochemicals on the environment has been recently carried out in Ukraine and abroad. The physical methods such as treating ozone, microwave, and ultrasonic radiation are of great interest (Tuchnyj et al., 2007a, 2007b; 2012; Shevchenko et al., 2007).

One of the most ecologically friendly and cost-effective methods of pre-sowing seed treatment is irradiation with an extra-high frequency microwave field (MWF of EHF). Along with the physical method of seed treatment with the microwave field, the plant growth regulators and biological preparations which are used to increase the resistance of plants to the adverse factors and the yield capacity of many crops have become widespread in the agricultural practice (Anishin, 2002; Lyhochvor, 2003).

Material and methods

The research program aimed to determine the influence of the following factors on the yield capacity and quality of spring barley products: Varieties, factor A: 1. Aspect, 2. Vyklyk; Seed treatment, factor B: Experiment №1. To examine the effects of the microwave fields (MWF) of extra high frequencies (EHF) and plant growth regulators on spring barley's sowing qualities and yield capacity. 1. Control, without treatment; 2. Vitavax FF, 2.5 L/t; 3. Radostim, 0.25 L/t; 4. Albit, 30 ml/t; 5. MWF of EHF 0.9 kW/kg, 45 sec.; 6. MWF of EHF 0.9 kW/kg, 45 sec. + Vitavax 200 FF, 1.25 L/t; 7. MWF of EHF 0.9 kW/kg, 45 sec. + Radostim, 0.25 L/t; 8. MWF of EHF 0.9 kW/kg, 45 sec. + Albit, 30 ml/t; 9. MWF of EHF 1.8 kW/kg, 20 sec.; 10. MWF of EHF 1.8 kW/kg, 20 sec. + Vitavax 200 FF, 1.25 L/t; 11. MWF of EHF 1.8 kW/kg, 20 sec. + Radostim, 0.25 L/t; 12. MWF of EHF 1.8 kW/kg, 20 sec. + Albit, 30 ml/t; Experiment № 2. To examine the effect of the microwave fields (MWF) of extra high frequencies (EHF) on the sowing qualities and yield capacity of the Astet winter wheat variety. 1. Control, without treatment; 2. Vitavax 200 FF, 2,5 L/t; 3. MWF of EHF 1.8 kW/kg, 15 sec.; 4. MWF of EHF 1.8 kW/kg, 15 sec. + Mars EL, 0.2 L/t; 5. MWF of EHF 0.9 kW/kg, 45 sec.; 6. MWF of EHF 0.9 kW/kg, 45 sec. + Mars EL, 0.2 L/t. The dependence of winter wheat yield capacity on agro-meteorological factors in Ukraine territory has been studied by several scientists (Krenke et al., 1992; Tarariko et al., 2013). It is known that the rate of plant development is closely connected with the weather conditions of a particular year. The analysis of agricultural crop development features in interaction with the meteorological factors is a significant part of agro-meteorological information. In this case, the criterion for evaluating agrometeorological conditions in which the crop is grown is the value of the grain yield capacity and its quality (Kuperman, 1955; Krenke et al., 1992). The following indices were used to characterize the agro-meteorological conditions of winter wheat and spring barley cultivation during the research period: duration of interphase periods, average daily air temperature, the sum of the effective temperatures (above 5 °C), and amount of precipitation in interaction with the crop productivity elements.

During the research period, the sowing of winter wheat was carried out in the terms optimum for the Eastern Forest-Steppe Zone, namely in the second decade of September. Characteristic for this zone, a sharp change in weather conditions according to the seasons of the year influenced the duration of the winter wheat growing season, both over the years and over the interphase periods of plant growth and development. The vegetation period of the Astet variety ranged from 153 days in 2011 to 148 days in 2013, with a minimum period of 115 days in 2012 (Table 1). The autumn period, which conditions form the sprouting and tillering of the plants, is an essential stage of winter crop development. The interphase period of sowing – sprouting did not change significantly over the years and was 6–7 days. Insignificant fluctuations in average daily air temperature amounted to 15–17 °C, and the sum of the effective temperatures was 86–99°C in 2011 and 2012. The distribution of precipitation as a source of water replenishment in the soil during this period was uneven. The maximum amount of precipitation was 25 mm in 2010, and the minimum one was 5.3 mm in 2011.

The next interphase period of the autumn vegetation "sprouting – tillering" falls on the third decade of September and the first decade of October (Table 1). The duration of the period varied within 15–19 days over the years (Table 2). There was a significant fall in the average daily temperature to 10.7 °C and the sum of effective temperatures up to 76 °C against the background of maximum precipitation of 81 mm, with a long-term rate of 20 mm in 2010. The optimum conditions for vegetation were noted only in 2012.

Table 1. Phenological phases of development of winter wheat crops of Astet variety in 2010-2013

Sowing	Sprouting	Tillering	Stopping of autumn vegetation	Resumption of spring vegetation	Stalk shooting	Tillering	Full ripening
15.09.2010	21.09.2010	6.10.2010	25.11.2010	02.04.2011	1.05.2011	19.05.2011	25.06.2011
16.09.2011	23.09.2011	12.10.2011	04.01.2011	18.04.2012	15.05.2012	28.05.2012	22.06.2012
14.09.2012	21.09.2012	5.10.2012	10.11.2012	31.03.2013	16.05.2013	23.05.2013	28.06.2013

However, the agro-meteorological conditions for winter wheat cultivation varied significantly over the research period, which led to different interphase periods of plant growth and development and ultimately to different levels of crop yield capacity over the years. Thus, in 2010–2011 the vegetation period of the Astet winter wheat variety lasted 156 days (from the sowing date to full ripeness). Simultaneously, during the growing season, the sum of effective temperatures was 1302 °C, and the amount of precipitation was 452.6 mm (Table 2).

Table 2. Duration of interphase periods of winter wheat development depending on agro-meteorological conditions during the years of research, 2010–2013

Indices	Interphase period						the sum of days over vegetation period	yield capacity, t/ha
	sowing-sprouting	sowing-tillering	tillering stopping of vegetation	RSV–stalk shooting	stalk shooting-ear formation	ear formation full ripening		
Duration of interphase period (days)	6	15	51	25	18	38	153	4.44
Average daily air temperature, °C	15.0	10.7	7.0	11.2	17.5	20.6	12.9	
Sum of effective temperatures above 5°C	93.0	76.0	–	174.0	238.0	721.0	1302.0	
Amount of precipitation, mm	25.0	80.6	56.0	64.0	20.0	207.0	452.6	
Duration of interphase period (days)	7	19	23	27	13	26	115	5.09
Average daily air temperature, °C	15.7	12.8	4.9	20.0	19.5	22.0	19.7	
Sum of effective temperatures above 5°C	86.0	148.0	–	405	189	408	1236	
Amount of precipitation, mm	0.0	12.2	20.0	0.3	25.0	29.0	86.5	
Duration of interphase period (days)	7	15	36	46	7	37	148	6.63
Average daily air temperature, °C	16.9	15.6	9.4	16.6	22.1	22.7	15.1	
Sum of effective temperatures above 5°C	99.0	151.0	180.0	455.0	123.0	631.0	1639	
Amount of precipitation, mm	5.3	13.1	115.0	10.3	15.4	75.8	234.9	

A characteristic feature of winter wheat vegetation in 2010–2011 was the absence of the effective temperatures during the interphase period of "tillering – stopping of autumn vegetation", which lasted 51 days, as well as their lack in the periods of "sprouting – tillering" and "spring vegetation resumption – stalk shooting"; the period lasted 25 days, and the total sum of temperature was 76 and 174.0 °C respectively. The resumption of vegetation was noted on April 2, 2011. Another feature of 2010–2011 was 46 % (207 mm) of the annual amount of precipitation during the interphase period of "ear formation – full ripening". In such conditions, the winter wheat yield capacity of the Astet variety in 2011 was 4,44 t/ha on average. In 2011–2012 the vegetation period of winter wheat lasted 115 days at the sum of effective temperatures of 1236 °C. This period was the driest during the research; the precipitation during the vegetation period of wheat was 86,5 mm. Simultaneously, 62 % (54 mm) of precipitation has been distributed evenly during the interphase period of "stalk shooting – full ripening". It is noteworthy that winter wheat vegetation in the interphase periods of "sprouting – tillering" and "spring resumption of vegetation – stalk shooting" took place at the high average daily air temperatures; as a result, the sums of the effective temperatures during these periods were 148.0 and 405 °C at the duration of the periods of 19 and 27 days respectively. The resumption of vegetation was noted on April 18, 2012. The period of "stalk shooting – ear formation" lasted 13 days under favorable conditions; the average daily air temperature was 19.5 °C, the sum of the effective temperatures was 189 °C, and the amount of precipitation was 25 mm. Therefore, from 2011 to 2012, the agro-meteorological conditions of winter wheat vegetation were more favorable than in the previous period, making it possible to obtain the yield capacity at the level of 5.09 t/ha. The vegetation period of winter wheat in 2012–2013 should be noted as the most promising field research. Its duration was 145 days at the highest sum of the effective temperatures of 639 °C and the precipitation amount of 234.9 mm.

The duration of the interphase period of "sprouting – tillering" at high average daily air temperatures (15.6 °C on the average in comparison with 10.7 and 12.8 °C in the previous periods) was 15 days. In the periods of 2010–2011 and 2011–2012, the duration was 15 and 19 days, and the sum of the effective temperatures was 151.0 °C. It is noteworthy that the tillering of winter wheat took place under favorable conditions and lasted almost until the stopping of autumn vegetation; the average daily air temperature was 9.4 °C, and the sum of effective temperatures was 180 °C. There were 115 mm of precipitation or 49 % of the total precipitation for the crop vegetation period during this period. The period of "resumption of vegetation – stalk shooting" was also favorable for the growth, development, and formation of the generative organs of winter wheat. It was comparatively the longest (46 days) and the warmest (the sum of effective temperatures was 455 °C). The resumption of vegetation was noted on March 31. The vegetation of the Astet winter wheat variety, from stalk shooting to full ripeness, took place at high average daily air temperatures. Simultaneously, the sum of the effective temperatures was 754 °C, and there was 91.2 mm of precipitation. One of the critical vegetation periods of winter cereals is the "tillering" phase. During this period, the lateral shoots and a secondary root system are formed from the underground stem nodes, that is, the setting of organs that determine the crop yield is taken place. The indices of productive tillering depend on the conditions of autumn and winter periods. The water reserve is a significant factor when it is pretty warm (at an air temperature of 15–18 °C) (Ulanova, 1975; Vrkach, 1984; Lihochvor & Petrichenko, 2006).

During the research, the interphase period of "sprouting –tillering" fell on the third decade of September and the first decade of October. According to the data (Table 2), the duration of the period varied over the years from 15, 19, and 13 days respectively. That period was characterized by the lowering of temperatures in 2010 and 2011; the temperatures were 10.7 and 12.8°C respectively, whereas, in 2012, the lowering in temperature compared with the previous period was insignificant – 15.6 vs. 16.9 °C. In 2010 the sum of the effective temperatures was minimum (76 °C) against a background of maximum precipitation of 81 mm at average long-term precipitation of 20 mm. In the following 2011 and 2012, the same period was drier; the sum of the effective temperatures amounted to 148–151 °C at a minimum amount of precipitation of 12.2–13.1 mm. Consequently, the sharp fluctuations in the heat and humidity were not optimum for the intensive tillering during the examined vegetation period. It is known that the tillering phase of winter cereals continues until stopping of the vegetation, that is, until a steady rise in the average daily temperature above 5 °C (Lihochvor et al., 2003; Lichhochvor & Petrichenko et al., 2010).

The duration of the "tillering – stopping of vegetation" period varied significantly depending on the meteorological conditions of the autumn growing season. If the beginning of the "tillering" phase was noted almost simultaneously (the first decade of October), then the date of stopping of the autumn vegetation of winter wheat ranged within the limits of 15–20 days. The most extended interphase period of tillering-stopping vegetation (49 days) was observed in 2010 and was accompanied by a lowering in the average daily air temperature to 7 °C, the sum of the effective temperatures was 96 °C, and the precipitation amount was 72 mm. Such weather conditions were following the climatic norm. The minimum duration of this period (24 days) was observed in 2011. The temperature factor was crucial for the intensive growth and development of the plants. The lowering of air temperature up to 5 °C and below in the absence of the effective temperatures and at minimum precipitation of 20 mm (60 % of the average long-term rate) influenced the shortening of the vegetation period. The most favorable conditions during the period of "tillering – stopping of vegetation" were observed in 2012; the period lasted up to 36 days with a slower lowering of air temperature up to 9.4 °C and the maximum sum of the effective temperatures of 180 °C, which is 20 % higher than in the previous period of "sprouting – tillering". The amount of precipitation was also above the long-term rate. The considered periods of autumn vegetation showed that winter wheat significantly responds to the changes in weather conditions. The corresponding reaction of the plants influenced the field germination and tillering as the main elements of the yield structure.

The stopping of the autumn vegetation of winter wheat varied from the first to the third decade of November and depended on the temperature regime. In winter wheat, the role of autumn and winter periods is also essential for the formation of water reserve in the soil in early spring. The well-developed crops are intensively developing, forming the leaf tube and spikelets in the ear using mainly the spring water reserves. During the research period, the most favorable water supply conditions at the beginning of spring were noted in 2013. The amount of precipitation in November–March was 211 mm, which exceeded the average long-term rate by 15 %. In 2011 and 2012, the amount of precipitation was significantly low and was 149 and 122 mm respectively, or 81 % and 67 % of the rate. The terms of the spring vegetation resumption (SVR) of winter wheat, especially their extreme values, significantly influence the further development of plants up to the ear formation phase (Lichhochvor et al., 2010). The leading cause of spring crop losses was the late date of the vegetation resumption when the plants were unable to adapt quickly to sudden temperature changes. According to our research (Table 1), the earliest date of the vegetation resumption was observed on March 31, 2013, with a further maximum duration of the interphase period of "vegetation resumption – stalk shooting" of 46 days.

The date of early vegetation of winter wheat (April 2) was also observed in 2011. However, the duration of the interphase period from the vegetation resumption to the stalk shooting phase was 21 days shorter than in 2013. When the primary biomass is accumulated, the shortening of the active vegetation period influences the shortage of productivity. The critical conditions of the period under consideration were observed in 2012; the date of the vegetation resumption fell on April 18, i.e., 15 days later than the earlier terms. The shortening of the interphase period of the "vegetation resumption – stalk shooting" up to 27 days was due to the rise in the temperature regime. The sum of the effective temperatures of 405–455°C exceeded the average long-term norm almost twice, and the amount of precipitation was two times lower. The duration of the interphase period of "stalk shooting – ear formation" (Table 2) varied from 7 to 19 days against the background of the temperature rise. The average daily temperature was within the range of 17–22°C, the sum of the effective temperatures was 120–240°C, and the amount of precipitation was 15–25 mm, which corresponded to the average long-term rate. A significant factor in the formation of the winter wheat yield capacity is the period from ear formation to full ripening. During the years of the research, this period was minimum in 2012 – 26 days and maximum up to 37 days in 2011 and 2013 at an optimum temperature of 20–23 °C. However, an uneven distribution of precipitation from 29 mm in 2012 to 207 mm in 2011 and its intensity led to a shortage in the yields up to 4.44 and 5.09 t/ha in 2011 and 2012, while in 2013, the yield capacity amounted to 6.63 t/ha. Such agro-meteorological conditions during the vegetation period provided the highest winter wheat yield capacity in our research; it was 6.63 t/ha in 2013.

Agro-meteorological conditions for spring barley cultivation

The spring barley crop, by its biological characteristics, is not frugal of heat. The minimum temperature of seed sprouting is +1–2 °C; the seedlings can withstand the short-term light frosts up to –3 – 4 °C. Such features determine the early terms of barley sowing (Cherenkov et al., 2010). In recent years the spring rise in the air temperature above 0 °C during 20–25 days and more has fluctuated sharply. Therefore, the sowing dates of the early ripening spring cereal crops need annual adjustments taking into account air temperature and water accumulation in the soil (Kuperman, 1984; Yizhik, 2001). Early sowing dates facilitate more efficient water use accumulated in early spring; the diseases and pests less damage the plants. It is essential that early sowing delays the transition to the generative phase of development and positively influences the density of productive stems and the yield capacity (Nasinnya, 1994). Brewing barley is susceptible to late sowing, which leads to a deterioration of grain quality – the huskiness is increased, the size of the grain, and the starch content are reduced (Lihochvor, Proc & Dolezha, 2003). In agro-meteorological conditions of 2011, the sowing of barley was carried out on April 24. The vegetation period of spring barley, irrespective of a variety, lasted 91 days. The sum of the effective temperatures was 1308 °C, and the average daily temperature was 19.4 °C at an amount of precipitation of 292 mm (Table 2). A characteristic feature of 2011 was 165,3 mm or 57 % precipitation (mainly heavy showers) during the interphase period of "ear formation – full ripening". In such conditions, there was a significant lodging of spring barley plants on the experimental plots, which worsened the conditions of ripening and harvesting. Another feature of spring barley vegetation in 2011 was the slow development of plants at the beginning of the vegetation period due to a fall in air temperature. For example, the sowing–stalk shooting" period lasted 50 days, whereas the "stalk shooting – ear formation" period was shorter for the entire research period and lasted 14 days. In such conditions of 2011, the Aspect variety produced a yield of 2,95 t/ha. The agrometeorological conditions in 2012 can be generally described as the most favorable for spring barley cultivation during the research period. The sowing was carried out on April 18. The vegetation period of barley, irrespective of a variety, was the shortest and lasted 83 days from the sowing to full ripening. Thus the interphase periods "sowing – sprouting" and "sprouting–tillering" were the shortest – 8 and 19 days. In general, the development of plants from sowing to stalk shooting lasted 35 days, which is 15 days less than in 2011.

The average daily temperature of the vegetation period in 2012 was 21.1 °C, which is 1.7 °C higher than in 2011, and the sum of the effective temperatures was 1335 °C. In 2012 the amount of precipitation was 79 mm, the least during the entire research period, while in the interphase period of "sowing–tillering," there was no precipitation at all. However, the development of spring barley plants during the period from tillering to full ripening took place under favorable conditions in terms of temperature and moisture, which made it possible to form the highest level of the yield capacity of barley varieties in our researches: Aspect – 4,.2 t/ha and Vyklyk – 4.83 t/ha. Early spring was observed in 2013 when the rise of air temperature above 0 and 5 °C took place almost simultaneously and fell in the middle of the third decade of March. Under such conditions, the sowing of spring barley was carried out earlier, namely on April 17. In the agro-meteorological conditions of 2013, the vegetation period of spring barley lasted 87 days. The sum of the effective temperatures was 1390 °C, and the average daily temperature was 21.8 °C at an amount of precipitation of 95 mm (Table 3). Simultaneously, the interphase periods "sowing – sprouting" and "sprouting – tillering" were the shortest – 9 and 12 days, respectively. In general, the development of plants from the sowing to stalk shooting lasted 30 days, which is five days less than in 2012.

During the period of mass ear formation of barley, the temperature factor significantly influences the final crop yield. The closest feedback between the yield capacity and average daily air temperature during this development phase is observed in the areas where the temperature exceeds 20 °C (Vrkach, 1984; Nasinnya, 1994). According to the results of the observations carried out in 2013, the yield capacity of spring barley was influenced by the high average daily temperature in the "ear formation" phase (21.8 °C), the uneven distribution of precipitation during the vegetation period, and the lowest sum of the effective temperatures in the "tillering – stalk shooting" phase (197.0 °C) (Table 3).

Results

An essential prerequisite for cultivating a high yield is obtaining full, even, and well-developed sprouting. The field germination is an integral index of seed quality and agro-technical level.

The reduction of field germination by even 1% leads to the over-expenditure of high-quality seeds. Also, a decrease in this index provokes a shortage of the winter wheat yield capacity by 1–1,5% and of spring cereal crops by 1–2%, which leads to a significant grain yield shortage. Therefore, obtaining high field germination is one of the most critical tasks of agricultural technology because the density of plants, tending of crops, and the level of the future yield depend on it (Savickij, 1948; Smerdov & Petrovskij, 2011).

M.M. Kuleshov thinks that "the height of field germination is very closely connected with the height of the laboratory germination" (Kuleshov, 1963). Therefore, in our research, we examined the influence of MWF of EHF and plant growth regulators on the sowing qualities of winter wheat and spring barley in the laboratory conditions before sowing the treated seeds on the experimental plots. Thus, it was found out that in 2011 and 2012, in most cases, the pre-sowing treatment of winter wheat seeds of the Astet variety with MWF of EHF and Mars EL did not significantly influence the laboratory indices of sprouting energy and germinating power, which was due to the high sowing qualities of the seeds. For example, in 2011–2012, the sprouting energy amounted to 96 %, and the germinating power was 97 % on average (Table 4).

Table 3. Duration of interphase periods of spring barley development depending on agrometeorological conditions, 2011-2013

Index	Interphase period					Sum for vegetation period	Yield capacity,t/ha	
	Sowing-sprouting	Sprouting-tillering	Tillering-stalk shooting	Stalk shooting-ear formation	Ear formation-full ripening		Aspect	Vyklyk
Duration of interphase period (days)	10	20	20	14	27	91		
Average daily air temperature, °C	14.4	16.1	21.0	20.7	21.8	19.4	2.95	
Sum of effective temperatures above 5 °C	94.0	222 0	320.0	220.0	452.0	1308		
Amount of precipitation	2.0	32.0	15.2	77.2	165.3	292		
2012								
Duration of interphase period (days)	8	8	19	20	28	83	4.72	4.83
Average daily air temperature, °C	15.6	19.4	22.5	19.5	23.3	21.1		
Sum of effective temperatures above 5 °C	85.0	116.0	332.0	289.0	513.0	1335		
Amount of precipitation	0.0	0.0	15.2	32.4	31.0	79.0		
2013								
Duration of interphase period (davsl	9	9	12	33	24	87	2.69	2.60
Average daily air temperature, °C	14.1	18.0	21.4	21.8	23.4	20.9		
Sum of effective temperatures above 5 °C	82.0	116.0	197.0	554	441.3	1390		
Amount of precipitation	0.0	0.0	4.0	58.0	33.0	95		

Table 4. Laboratory sprouting energy and germinating power of winter wheat seed of Astet variety depending on the methods of its pre-sowing treatment, 2010–2012

№	Cases of seed treatment	Sprouting energy, %			Average	Germinating power, %			Average
		2010	2011	2012		2010	2011	2012	
1	Control, without treatment	80	97	95	91	81	98	95	91
2	Vitavax, 200 FF, 2,5 L/t	86[1)]	96	97[1)]	93	86[1)]	97	97[1)]	93
3	MWF of EHF 1,8 kW/kg,15 sec.	83[1)]	95	95	91	83[1)]	97	96	92
4	MWF of EHF 1,8 kW/kg, 15 sec. + Mars EL	87[1)]	97	95	93	88[1)]	97	95	93
5	MWF of EHF 0,9 kW/kg, 45 sec.	85[1)]	97	94	92	86[1)]	98	95	93
6	MWF of EHF 0,9 kW/kg, 45 sec.+Mars EL	86[1)]	95	95	92	86[1)]	97	96	93
	SSD $_{05}$	2,15	1,90	1,97		1,95	2,5	1,92	

Note: [1)] – Significant difference

However, in 2010, when the sowing qualities of the seeds used in the experiment were reduced (the sprouting under control was 81 %), the pre-sowing treatment depending on the method made it possible to increase the sprouting energy of winter wheat seeds by 3–7 % and the germinating power by 2–7 %. When the seeds were treated with MWF of EHF the average laboratory indices of the sprouting energy and germinating power in 2010–2012 were slightly lower than in the case with Vitavax FF, 2.5 L/t. Simultaneously, after treating the seeds irradiated with MWF of EHF with the plant growth regulator Mars EL, in 2010–2012 the average sprouting energy and germinating power of winter wheat seeds were higher 2%, which corresponds to the indices of Vitavax 200 FF case. In the laboratory conditions, it was found out that the sowing qualities of spring barley seeds varied depending on the method of the pre-sowing treatment and its variety (Table 5, 6).

Thus, unlike winter wheat, treatment of seeds of the Aspect and Vyklyk barley varieties with Vitavax 200 FF at the recommended rate of 2.5 L/t led to a decrease in the seed sprouting energy in 2011–2013 on the average by 13 and 6 % respectively in comparison with the control cases (Table 7). Simultaneously, the seed germinating power was 90 and 92 % respectively vs. 91 and 93 % under control, i.e., the deviation was not reliable.

Table 5. Sowing qualities of spring barley seeds of Aspect variety depending on MWF of EHF and growth regulators application (before sowing)

Case of seed treatment	Sprouting energy, %				Germinating power, %			
	2011	2012	2013	average	2011	2012	2013	average
Control, without treatment	88	92	86	89	89	93	90	91
Vitavax 200 FF, 2.5 L/t	89	89[1)]	57[1)]	76[1)]	91	91[1)]	88	90
Radostim, 0,25 L/t	91	90	89	90	91	92	92	91
Albit, 30 ml/t	90	91	85	89	93[1)]	92	89	91
MWF of EHF 0.9kW/kg, 45 sec.	89	92	88	88	91	93	92	91
MWF of EHF 0.9kW/kg, 45 sec. + Vitavax 200 FF, 1.25 L/t	89	91	85	86[1)]	92	93	94[1)]	92
MWF of EHF 0.9kW/kg, 45 sec. + Radostim, 0.25 L/t	91	91	90[1)]	90	92	92	93[1)]	92
MWF of EHF 0.9kW/kg, 45 sec. + Albit, 30 ml/t	89	92	88	89	91	92	91	92
MWF of EHF 1.8 kW/kg, 20 sec.	89	91	91[1)]	90	91	92	92	92
MWF of EHF 1.8 kW/kg, 20 sec.+ Vitavax 200 FF, 1.25 L/t	91	90	95[1)]	92[1)]	92	91[1)]	97[1)]	94[1)]
MWF of EHF 1.8 kW/kg, 20 sec. + Radostim, 0.25 L/t	92[1)]	93	89	90	93[1)]	94	92	92
MWF of EHF 1.8 kW/kg, 20 sec.+ Albit, 30 ml/t	88	92	91[1)]	91	93[1)]	93	94[1)]	93[1)]
SSD_{05}	4,42	1,79	3,6	2,6	3,9	1,6	3,0	2,1

Note: [1)] – Significant difference

Table 6. Sowing qualities of spring barley seeds of Vyklyk variety depending on MWF of EHF and growth regulators application (before sowing)

Cases of seed treatment	Sprouting energy, %		Average	Laboratory germinating power, %		Average
	2012	2013		2012	2013	
Control, without treatment	88	94	91	90	97	93
Vitavax 200 FF, 2.5 L/t	85	86[1)]	86[1)]	86[1)]	93	90[1)]
Radostim, 0.25 L/t	90	93	92	92[1)]	96	94
Albit, 30 ml/t	92	94	93	94[1)]	98	96[1)]
MWF of EHF 0.9kW/kg, 45 sec.	87	94	91	89	97	93
MWF of EHF 0.9kW/kg, 45 sec. + Vitavax 200 FF, 1,25 L/t	90	97[1)]	94[1)]	93[1)]	97	93
MWF of EHF 0,9kW/kg, 45 sec. + Radostim, 0.25 L/t	91	97[1)]	94[1)]	93[1)]	98	96[1)]
MWF of EHF 0.9kW/kg, 45 sec. + Albit, 30 ml/t	88	93	91	90	98	94
MWF of EHF 1.8 kW/kg, 20 sec.	91	94	93	93[1)]	95	94
MWF of EHF 1.8 kW/kg, 20 sec.+ Vitavax 200 FF, 1.25 L/t	88	94	91	92[1)]	95	94
MWF of EHF 1.8 kW/kg, 20 sec. + Radostim, 0.25 L/t	92[1)]	94	93	93[1)]	97	95
MWF of EHF 1.8 kW/kg, 20 sec.+ Albit, 30 ml/t	93[1)]	95	94[1)]	94[1)]	97	96[1)]
SSD_{05}	3,3	2,67	2,8	1,6	2,64	2,3

Note: [1)] – Significant difference

When treating the seed with MWF of EHF at different power and exposure and with plant growth regulators, the seed sowing qualities of barley varieties in most cases did not increase significantly. Only when treated the seeds of Vyklyk variety with the Albit preparation, 30 ml/t the seed germinating power significantly increased on the average for three years and was 96% versus 93% under control.

The combination of the pre-sowing seed irradiation with MWF of EHF with the subsequent treatment with a seed treatment agent and plant growth regulators in most cases had a positive influence on the sowing qualities of barley varieties seeds. In this case, the influence of the seed treatment method depended on the variety. Thus, in the case of MWF of EHF, 0.9 kW/kg, 45 sec with the subsequent treatment with Vitavax 200 FF at half the rate of 1.25 L/t, the germinating power of the Aspect variety seeds increased by 1% on the average, while there were 91% under control; and that of the Vyklyk variety seeds increased by 2%, while there were 93% under control, i.e., it was within the limits of the experimental error (Bezpalko & Zhukova, 2019).

Table 7. Laboratory sprouting energy and germinating power of spring barley seed depending on the methods of its pre-sowing treatment, 2011–2013

№	Cases of seed treatment	Spring barley varieties			
		Aspect		Vyklyk[2)]	
		sprouting energy, %	germinating power, %	sprouting energy, %	germinating power, %
1	Control, without treatment	89	91	91	93
2	Vitavax 200 FF, 2.5 L/t (standard)	76[1)]	90	85[1)]	92
3	Radostim, 0.25 L/t	90	91	92	94
4	Albit, 30 ml/t	88	91	93	96[1)]
5	MWFof EHF 0.9 kW/kg, 45 sec.	88	91	91	93
6	MWF of EHF 0.9 kW/kg, 45 sec.+ Vitavax 200 FF, 1.25 L/t	86	92	93	95[1)]
7	MWF of EHF 0.9 kW/kg, 20 sec. + Radostim, 0.25 L/t	90	92	94[1)]	95[1)]
8	MWF of EHF 0.9 kW/kg, 45 sec. + Albit, 30 ml/t	89	92	92	94
9	MWF of EHF 1.8 kW/kg, 20 sec.	90	92	92	94
10	MWF of EHF 1.8 kW /kg, 20 sec.+ Vitavax 200 FF, 1.25 L/t	92[1)]	94[1)]	85[1)]	91
11	MWF of EHF 1.8 kW/kg, 20sec.+ Radostim, 0.25 L/t	92[1)]	92	93	95[1)]
12	MWF of EHF 1.8 kW/kg, 20sec. + Albit, 30 ml/t	89	92	94	95[1)]
SSD $_{05}$		2,6	2,1	2,8	2,3

Note: [1)] – Significant difference; [2)] – Average in 2012–2013

Treating the seeds of barley varieties with Vitavax 200 FF at a rate of 2.5 L/t decreased the seed sprouting energy and seed germinating power while applying the reduced rate of the treatment agent of up to 1.25 L/t with the pre-irradiation with MWF of EHF, 1.8 kW/kg seeds, 20 sec the sowing qualities of the Aspect variety seeds exceeded the control. Thus, in the case with MWF of EHF, 1.8 kW/kg, 20 sec + Vitavax 200 FF, 1.25 L/t, the sprouting energy and germinating power of seeds of the Aspect variety increased by 3% on the average, while the indices under control were 89 and 91% respectively, and the seed sowing qualities of the Vyklyk variety were lower than under control. Thus, it can be concluded that the combination of the pre-sowing seed irradiation with MWF of EHF with the subsequent treatment with the plant growth regulators, in general, has a positive influence on the sowing qualities of winter wheat and spring barley (Tables 1, 2).

Table 8. Field germination of Astet winter wheat variety depending on the method of pre-sowing seed treatment, 2010–2012

Case of seed treatment	Number of plants, pcs/m^2			Average	Field germination, %			Average
	2010	2011	2012		2010	2011	2012	
Control,without treatment	412	412	393	405	91.6	91.6	87.3	90.2
Vitavax, 200 FF, 2.5 L/t	392	395	428[1)]	405	87.1	87.8	95.1[1)]	90.0
MWF of EHF 1.8 kW/kg, 15 sec	436[1)]	438[1)]	434[1)]	436[1)]	96.9	97.3[1)]	96.4[1)]	96.9[1)]
MWF of EHF 1.8 kW/kg,15 sec. + Mars EL	440[1)]	440[1)]	446[1)]	442[1)]	97.8[1)]	97.8[1)]	99.1[1)]	98.2[1)]
MWF of EHF 0.9 kW/kg, 45sec	440[1)]	436	439[1)]	438[1)]	97.8[1)]	96.9	97.6[1)]	97.4[1)]
MWF of EHF 0.9 kW/kg, 45 sec. + Mars EL	435	420	434[1)]	425[1)]	96.7[1)]	93.3	96.4[1)]	95.5[1)]
SSD $_{05}$	24.3	25.2	23.8	19.3	5.4	5.6	5.3	4.3

Note: [1)] – Significant difference

Table 9. Field germination of spring barley varieties depending on the method of pre-sowing seed treatment, 2011–2013

Cases of seed treatment	Spring barley varieties			
	Aspect		Vyklyk[2)]	
	number of plants, pcs/m^2	field germination, %	number of plants, pcs/m^2	field germination, %
Control, without treatment	311	69	354	78
Vitavax 200 FF, 2.5 L/t (standard)	337[1)]	74[1)]	358	79
Radostim, 0.25 L/t	333	74[1)]	362	80
Albit, 30 ml/t	347[1)]	76[1)]	362	80
MWFof EHF 0.9 kW/kg, 45 sec.	345[1)]	76[1)]	359	79
MWFof EHF 0.9 kW/kg, 45sec.+ Vitavax 200 FF, 1.25 L/t	355[1)]	78[1)]	372	82
MWFof EHF 0.9 kW/kg, 20 sec. + Radostim, 0.25 L/t	332	74[1)]	375[1)]	83[1)]
MWFof EHF 0.9 kW/kg, 45sec. + Albit, 30 ml/t	339[1)]	75[1)]	375[1)]	83[1)]
MWFof EHF 1.8 kW /kg, 20sec.	344[1)]	76[1)]	363	82
MWFof EHF 1.8 kW/kg, 20 sec.+ Vitavax 200 FF, 1.25 L/t	364[1)]	81[1)]	370	82
MWFof EHF 1.8 kW/kg, 20sec. + Radostim, 0.25 L/t	360[1)]	80[1)]	366	82
MWFof EHF 1.8 kW/kg, 20 sec. + Albit, 30 ml/t	346[1)]	77[1)]	369	81
SSD$_{05}$	25.0	4.9	20.7	4.7

Note: [1)] – Significant difference; [2)] – Average for 2012–2013

In 2010–2012, it was essential to determine the influence of different pre-sowing seeds of winter wheat and spring barley treatment on their field germination. Winter wheat of the Astet variety was sown at a sowing rate of 4,5 million viable seeds per 1 ha. The determination of field germination was performed in the phase of full sprouting. At the same time, in 2010–2012, the average field germination under control and in the case with the Vitavax 200 FF treating agent was practically the same and amounted to 90.0–90.2 %. However, under the unfavorable conditions of 2012, the field germination of winter wheat seeds in the Vitavax 200 FF case exceeded the control by 7.8 %. The pre-sowing seed irradiation with MWF of EHF in the modes of 1.8 kW/ kg, 15 sec, and 0.9 kW/kg, 45 sec increased the field germination of winter wheat 6.9 and 7.4 %, respectively. In the cases where the seeds were treated with MWF of EHF and Mars EL preparation, it was higher by 9.1–11.8 %. This indicates that under unfavorable conditions, the pre-sowing seed treatment on field germination is more significant (Table 8). Over the years of the research, the highest field germination of winter wheat of 98% was obtained when the seeds were treated with MWF of EHF 1.8 kW/kg, 15 sec + Mars EL, which is 8 % higher than under control. In the researches regarding spring barley, the pre-sowing treatment of the Aspect seed variety with Vitavax 200 FF, 2.5 L/t, and the preparations Radostim 0.25 L/t and Albit, 30 ml/t and with MWF of EHF in the modes of 0.9 kW/kg, 45 sec and 1.8 kW/kg, 20 sec caused the increase in the field germination by 5.5, 7.7, and 7 %, respectively (Table 9, 10).

Table 10. Field germination of Aspect spring barley variety depending on MWF of EHF and growth regulators application, pcs/m^2, 2011–2013

Cases of seed treatment	Number of plants, pcs/m^2 years				Field germination, % years			
	2011	2012	2013	average	2011	2012	2013	average
Control, without treatment	300	320	313	311	67	71	69	69
Vitavax 200 FF, 2.5 L/t	341[1)]	344	328	337[1)]	76[1)]	76	72	74
Radostim, 0.25 L/t	332	328	340	333	74[1)]	73	76	74
Albit, 30 ml/t	322	366[1)]	353[1)]	347[1)]	71	81[1)]	78[1)]	76[1)]
MWF of EHF 0.9kW/kg, 45 sec.	352[1)]	317	368[1)]	345[1)]	78[1)]	70	81[1)]	76[1)]
MWF of EHF 0.9kW/kg, 45 sec. + Vitavax 200 FF, 1.25 L/t	314	360[1)]	391[1)]	355[1)]	70	80	86[1)]	78[1)]
MWF of EHF 0.9kW/kg, 45 sec. + Radostim, 0.25 L/t	300	349	347	332	67	78	77[1)]	74
MWF of EHF 0.9kW/kg, 45 sec. + Albit, 30 ml/t	282	351	384[1)]	339[1)]	63	78	85[1)]	75[1)]
MWF of EHF 1.8 kW/kg, 20 sec.	333	368[1)]	332	344[1)]	74[1)]	81[1)]	74	76[1)]
MWF of EHF 1.8 kW/kg, 20 sec.+ Vitavax 200 FF, 1.25 L/t	338	373[1)]	382[1)]	364[1)]	75[1)]	83[1)]	84[1)]	81[1)]
MWF of EHF 1.8 kW/kg, 20 sec. + Radostim, 0,25 L/t	401[1)]	356	325	360[1)]	89[1)]	79[1)]	72	80[1)]
MWF of EHF 1,8 kW/kg, 20 sec.+ Albit, 30 ml/t	306	335	399[1)]	346[1)]	68	74	88[1)]	77[1)]
SSD $_{05}$	38.3	36.7	37.9	25.0	7.5	7.2	7.4	4.9

Note: [1)] – Significant difference

Under such methods of the pre-sowing seed treatment of the Vyklyk spring barley variety, the field germination was increased by 1.2, 2.1, and 4 %, respectively (Table 11).

Table 11. Field germination of Vyklyk spring barley variety depending on MWF of EHF and growth regulators application, 1 m^2, 2012–2013

Cases of seed treatment	Number of plants, pcs/m^2		Average	Field germination, %		Average
	2012	2013		2012	2013	
Control, without treatment	340	369	354	75	81	78
itavax 200 FF, 2.5 L/t	342	375	358	75	83	79
Radostim, 0.25 L/t	340	383	362	75	84	80
Albit, 30 ml/t	368	356	362	81	78	80
MWF of EHF 0.9kW/kg, 45 sec.	339	378	359	75	83	79
MWF of EHF 0.9kW/kg, 45 sec. + Vitavax 200 FF, 1.25 L/t	367	376	372	81	83	82
MWF of EHF 0.9kW/kg, 45 sec. + Radostim, 0.25 L/t	355	394	375[1)]	78	87[1)]	83[1)]
MWF of EHF 0.9kW/kg, 45 sec. + Albit, 30 ml/t	350	399[1)]	375[1)]	77	88[1)]	83[1)]
MWF of EHF 1.8 kW/kg, 20 sec.	353	373	363	82[1)]	82	82
MWF of EHF 1.8 kW/kg, 20 sec.+ Vitavax 200 FF, 1.25 L/t	358	382	370	79	84	82
MWF of EHF 1.8 kW/kg, 20 sec. + Radostim, 0.25 L/t	359	378	366	81	83	82
MWF of EHF 1.8 kW/kg, 20 sec.+ Albit, 30 ml/t	366	372	369	81	82	81
SSD $_{05}$	31.7	26.6	20.7	6.9	5.8	4.7

Note: [1)] – Significant difference

When combined the pre-sowing seed irradiation with MWF of EHF in the modes of 0.9 kW/kg, 45 sec and 1.8 kW/kg, 20 sec with Vitavax 200 FF treating agent at the consumption rate reduced by half of 1.25 L/t, the field germination of the Aspect variety increased by 9 and 12 %, respectively Vyklyk variety increased by 4% in both cases. The combination of the pre-sowing seed irradiation with MWF of EHF in the mode of 1.8 kW/kg, 20 sec and treatment with the plant growth regulators Radostim, 0.25 L/t and Albit 30 ml/t increased the field germination of the Aspect variety by 11 and 8%; respectively, the Vyklyk variety seeds was increased by 4 and 3%. In the mode of 0.9 kW/kg, 45 sec, the field germination of the Aspect variety seeds increased by 5 and 6 %, respectively, and the field germination of the Vyklyk variety seeds increased by 4 and 5%, respectively. A significant increase of 5 % in the field germination of Vyklyk variety was observed only when the seeds were irradiated with MWF of EHF in the mode of 0.9 kW/kg 45 sec with the subsequent seed treatment with the plant growth regulators Albit or Radostim. In other cases, there was only a tendency to an increase in the field germination, which was connected with better field germination of seeds under control. Thus, the combination of the pre-sowing irradiation with MWF of EHF with the subsequent treatment with the growth regulators positively influenced the field germination of winter wheat and spring barley seeds.

Conclusions

When the seeds were treated with MWF of EHF, the average laboratory indices of the sprouting energy and germinating power were slightly lower than in the case with Vitavax FF, 2.5 L/t. After treating the seeds irradiated with MWF of EHF with the plant growth regulator Mars EL, in 2010–2012, the average sprouting energy and germinating power of winter wheat seeds were higher by 2%, which corresponds to Vitavax 200 FF case. In the laboratory conditions, it was found out that the sowing qualities of spring barley seeds were depended on the pre-sowing treatment and its variety. The combination of the pre-sowing seed irradiation with MWF of EHF with the subsequent treatment with the plant growth regulators has a positive influence on the sowing qualities of winter wheat and spring barley. The combination of the pre-sowing irradiation with MWF of EHF with the subsequent treatment with the growth regulators positively influenced the field germination of winter wheat and spring barley seeds. Winter wheat of the Astet variety was sown at a sowing rate of 4.5 million viable seeds per 1 ha. In 2010–2012, the average field germination was practically the same and amounted to 90.0–90.2 % in control and Vitavax 200 FF. However, under the unfavorable conditions of 2012, the field germination of winter wheat seeds in the Vitavax 200 FF case exceeded the control by 7.8 %. The pre-sowing seed irradiation with MWF of EHF in the modes of 1.8 kW/ kg, 15 sec, and 0.9 kW/kg, 45 sec increased the field germination of winter wheat 6.9 and 7.4 %, respectively. In the cases where the seeds were treated with MWF of EHF and Mars EL preparation, it was higher by 9.1–11.8 %. Thus, under unfavorable conditions, the pre-sowing seed treatment on field germination is more significant.

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