ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 106, No. 3 (2019), p. 241–248
DOI 10.13080/z-a.2019.106.031

Effects of organic seed treatment methods on spring barley seed quality, crop, productivity and disease incidence

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Abstract

Low energy electrons (electron treatment), aerated steam (thermal treatment) and a bacterial product Cedomon containing *Pseudomonas chlororaphis* (bacterial treatment) were selected for the trial as the most popular seed treatment methods in Western and Northern Europe. This trial was aimed to evaluate the effect of treatments on seed sanitation, crop and disease development and yield parameters. Two spring barley (*Hordeum vulgare* L.) cultivars 'Luokė' and 'Alisa DS' were investigated during 2014–2015 under the conditions of Central Lithuania. Low energy electron treatment was found to exert a negative effect: the mean yield decrease was 20% compared to the control. The yield reduction resulted from the inefficient seed sanitation and reduced field emergence compared to the control. Thermal treatment increased the yield by an average of 35%, *viz*. in 2014 by 58% and in 2015 by 13%. The yield increase was influenced by very efficient seed sanitation in the first year but not in the second year. Bacterial treatment with Cedomon increased the yield by an average of 3%. This treatment improved neither seed health nor crop stand density in 'Luokė'; however, it had a positive effect on the seeds of 'Alisa DS' in both experimental years. Improved seed health increased grain yield in 'Alisa DS', while poor seed health decreased yield in 'Luokė'. None of the seed treatment methods tested showed consistent and unquestionable results. The yield increase depended mainly on the improved seed health, thus the main strategy to produce stable yield is seed health testing of the lots intended for use in organic agriculture.

Key words: *Hordeum vulgare*, organic agriculture, pathogenic fungi.

Introduction

The share of the land used for organic farming is steadily increasing in the European Union and worldwide (FAO, 2018). Cereals occupy about one third of the total organically cropped area in the EU and it ranges from 18% (the Netherlands) to 63% (Lithuania) (Eurostat, 2019). One of the main obstacles in organic farming is seed health of cereals (Clark, Cockerill, 2011; Koch, Roberts, 2014). Organic farmers are very unwilling to buy organic certified seeds due to their higher price compared to the conventional seeds. Only countries with the oldest traditions of the organic farming use considerable amount of the organic seeds (FAO, 2018; Eurostat, 2019).

Many simple and sophisticated seed treatment methods have been developed and tested under different coverage during the last several decades (Clark, Cockerill, 2014; Koch, Roberts, 2014; Sharma et al., 2015; Araujo et al., 2016). However, only a few methods are applied under industrial level for cereals due to high seed amounts needed (BioAgri, 2017; Evonta, 2019). The main effect of these methods is seed sanitation, but not effect on the growing plant parts after seed germination. One of the seed treatment methods includes various biological agents like fungus and bacteria. The most popular and best-known are bacterial products based on *Pseudomonas chlororaphis* strain MA 342. Their efficiency is highly variable and depends on the site, year, plant species and seed-borne pathogens. Using bacterial products, the yield increases in the majority of cases (Johnsson et al., 1998; BioAgri, 2017). Other methods belong to the group of physical treatment. Sweden researchers have developed and have been advocating seed treatment with hot humid air (Forsberg et al., 2005; BioAgri, 2017), whereas seed treatment with electrons has been developed in Germany (Röder et al., 2009; Evonta, 2019). Both methods show high efficiency against the main cereal pathogens (Forsberg et al., 2005; Röder et al., 2009) but yield increase is not clearly predictable (BioAgri, 2017; Evonta, 2019).

The main disadvantage of the available reports is that they present only local results and rarely provide results of comparison of different methods. Our purpose was to study and compare the effects of three methods: low energy electron, aerated steam and bacterial product

Please use the following format when citing the article:
Liatukas Ž., Supronienė S., Ruzgas V., Leistrumaitė A. 2019. Effects of organic seed treatment methods on spring barley seed quality, crop, productivity and disease incidence. Zemdirbyste-Agriculture, 106 (3): 241–248. DOI 10.13080/z-a.2019.106.031

Cedomon, on spring barley seed sanitation, crop and disease development and yield parameters under field conditions.

Materials and methods

Cultivars and seeds. Certified organic seeds of the two Lithuanian spring barley (*Hordeum vulgare* L.) cultivars 'Luokė' and 'Alisa DS' were used.

Analyses of seeds before seeding and after harvest. The selected parameters of the barley seeds were a thousand kernel weight (TKW), germination percent (GP) and germination energy (GE). Seed fungal infections were checked for *Fusarium* spp., *Alternaria* spp., *Bipolaris* spp. and *Pyrenophora* spp. Thousand kernel weight was determined by counting 500 grains twice with an automatic seed counter Contador (Pfeuffer, Germany) and by weighing. Seed germination percent and germination energy were evaluated on hundred seeds of each sample with four replications. Seeds were placed in plastic boxes on wet filter paper and covered with caps. The boxes were maintained in the dark at 20°C. The seeds were considered germinated when they had roots and shoots. Germination energy expresses the proportion of seed which germinated within four days. Germination percent expresses the proportion of seeds that produced normal seedlings within eight days. Laboratory analyses of seed health employed plating technique for internal fungal grain infection evaluation. The fungi were identified according to the manuals of Malone et al. (1997), Mathur and Kongsdal (2003) and Leslie and Summerell (2006). The grain fungal infection level per sample was expressed in percent.

Seed infection by *Pyrenophora* was evaluated by the osmotic method. Filter paper was moistened with water solution of sucrose (200 g L^{-1}) and placed in Petri plates. Twenty five grains were placed per plate. One hundred grains were evaluated per replication of seed samples. The plates were incubated at 26°C under 16 hours in UV light and 8 hours in the dark. Infected seeds were identified by pigment colour under UV light.

Seed treatments. Effectiveness of seed treatments was evaluated using surface non-sterilized seeds. Three seed treatment methods were used: electron, thermal and bacterial. Seeds for treatments were sent abroad and after treatment returned to Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. Seed treatment with low energy electrons (electron treatment) was done in Germany; the process is described by Röder et al. (2009). Thermal seed treatment with aerated steam (thermal treatment) was done in Sweden; the process is described by Forsberg et al. (2005). Bacterial product Cedomon (*Pseudomonas chlororaphis*, strain MA 342) 120 g kg^{-1} was obtained from Sweden, directly from the producer (BioAgri AB, Sweden). Seeds were treated at a rate of 7.5 ml kg^{-1}; using a liquid seed treater Hege 11 (Wintersteiger, Austria), each sample was dressed for 1 min. The treated seeds were stored until sowing 1 and 2 weeks in 2014 and 2015, respectively. The untreated seeds were used for negative control.

Field trials. Precision field trials were conducted in the central part of Lithuania in 2014–2015. The experimental field was certified for organic agriculture. The field trials were laid out in a randomized block design. The crop was planted at a rate of 5 million seeds ha^{-1} with a small plot sowing machine Hege (Wintersteiger, Austria) within the first week of May. Spring barley seeds used for sowing in 2014 and 2015 were from 2013 and 2014 harvest years, respectively. No agrochemicals and fertilizers were used. Weeds were controlled manually. A plot size of 5.0 × 1.6 m^2 was used in four replications. The soil of the experimental site (55°24′ N, 23°50′ E) is *Endocalcari-Epihypogleyic Cambisol* (WRB, 2014), with a pH_{KCl} 7.0, amount of organic matter 21 g kg^{-1}, available P 65–80 mg kg^{-1} and K 83–125 mg kg^{-1}.

Field emergence was evaluated at spring barley growth stage 12 according to the BBCH scale (Zadoks et al., 1974); the number of seedlings was counted three times in each replication in a 0.25 m^2 plot. The number of productive tillers was counted at an early milk stage (BBCH 73) in the same manner as field emergence. Grain was harvested at full ripening with a plot combine Wintersteiger Classic (Austria). Grain yield was evaluated by weighing grain of each plot and calculating to tons per hectare at standard 14% grain moisture.

Fusarium head blight incidence (FHBI) and severity (FHBS) were assessed at milk-dough development stages (BBCH 77–83) in percent using a scale developed by Steffenson et al. (2003). Leaf diseases were assessed during spring barley vegetation on a 1–9 score scale, where 1 denotes the lowest damage.

Meteorological conditions. Soil moisture at sowing was favourable for quick germination, but several days after sowing heavy rain occurred in 2014 (about 40 mm, whereas average monthly rainfall of May is about 50 mm), which resulted in the formation of soil crust. Wet and cold June as well as rainy first ten days of July favoured development of diseases, plants matured relatively faster than usual. Sowing conditions for spring cereals in 2015 were favourable, plants germinated quickly and evenly. June and the first half of July were warmer and drier than usual, diseases developed slowly.

Statistical analysis. The data were processed using the software *SAS*, version 7.1 (SAS Institute Inc., USA) to test significance of differences among the treatments at significance level $P \leq 0.05$.

Results

The seeds of both spring barley cultivars of 2013 harvest year were heavily (more than 90%) infected by *Bipolaris* spp. (Table 1). *Alternaria* occurred on 17% of the seeds of 'Luokė', but the pathogen was found only on 1% of seeds of 'Alisa DS'. Low frequency of *Fusarium* spp. was observed, 4% and 6% on 'Luokė' and 'Alisa DS' seeds, respectively. *Pyrenophora* pathogens were found at trace level. None of the seed treatments tested showed stable positive effect. Thermal treatment was very effective for *Bipolaris* spp. control on 'Luokė' seeds, the infection decreased 4.5 times, but its effectiveness for 'Alisa DS' seeds was low, the seed infection decreased only 1.3 times. Seed treatment with electrons did not improve seed health statistically significantly. Bacterial product Cedomon efficiently controlled *Bipolaris* spp. on seeds of 'Alisa DS' (infection decreased 9.6 times), whereas on the 'Luokė' seeds it showed low efficiency.

Late sowing and wet May and June favoured the spread and development of fungal leaf diseases. Cultivar 'Luokė' was moderately damaged by powdery mildew and Ramularia, whereas net blotch significantly

Table 1. Fungal pathogens on spring barley seeds after treatment (2014)

Treatment	Infection of seeds %			
	Fusarium	*Alternaria*	*Bipolaris*	*Pyrenophora*
Cultivar ‘Luokė’				
Control	4.2 ab	17.2 a	94.4 c	0.0 a
Electron	7.5 b	2.5 a	93.3 c	3.0 a
Thermal	0.0 a	9.2 a	20.8 a	12.0 b
Bacterial	16.7 c	56.7 b	72.5 b	0.0 a
Cultivar ‘Alisa DS’				
Control	6.4 b	0.8 ab	95.8 c	0.0 a
Electron	0.8 ab	0.0 a	99.2 c	2.0 b
Thermal	0.0 a	0.0 a	70.8 b	0.0 a
Bacterial	0.8 ab	2.5 b	10.0 a	0.0 a

Note. Values followed by the same letter in a column are not significantly different (*t*-test, $p > 0.05$).

developed only at the end of vegetation (Table 2). Spot blotch weakly damaged this cultivar only at late milk stage (BBCH 77). Cultivar ‘Alisa DS’ was more resistant to powdery mildew, but more susceptible to net blotch and spot blotch. Development of net blotch was not considerably affected by treatments, whereas some positive effect of thermal and bacterial treatments was determined. Positive effect of bacterial treatment was clear in the cultivar ‘Alisa DS’ due to higher spot blotch severity in the control compared to the above mentioned treatments. None of the treatments influenced development of powdery mildew and Ramularia. A complex of leaf diseases and their high severity negatively influenced grain yield which ranged between 1.02 – 1.87 and 0.6 – 1.87 t ha^{-1} for cultivars ‘Luokė’ and ‘Alisa DS’, respectively.

Table 2. Leaf diseases of spring barley in 2014

Treatment	Disease, score									
	powdery mildew	Ramu-laria	net blotch				spot blotch			
Date	28 06	31 07	05 06	28 06	15 07	31 07	05 06	28 06	15 07	31 07
BBCH	61–65	75–77	12–13	61–65	71–73	73–75	12–13	61–65	71–73	75–77
Cultivar ‘Luokė’										
Control	5.0 b	6.0 a	1.0 a	2.5 b	3.0 b	5.5 ab	1.0 a	1.5 ab	2.0 b	4.0 b
Electron	4.8 b	6.0 a	1.0 a	1.5 a	2.5 ab	5.5 ab	1.0 a	1.5 ab	2.0 b	4.0 b
Thermal	5.0 b	6.0 a	1.5 a	1.5 a	3.0 b	5.5 ab	1.0 a	1.0 a	1.5 ab	3.0 a
Bacterial	5.0 b	6.0 a	1.0 a	1.5 a	3.0 b	5.5 ab	1.0 a	1.5 ab	2.0 b	3.5 ab
Cultivar ‘Alisa DS’										
Control	2.0 a	7.5 ab	1.0 a	2.0 ab	3.0 b	6.5 bc	1.0 a	2.0 b	4.0 d	6.0 d
Electron	2.0 a	7.5 ab	1.0 a	2.0 ab	2.8 ab	6 b	1.0 a	2.0 b	4.0 d	6.0 d
Thermal	2.0 a	7.5 ab	1.0 a	2.0 ab	3.5 bc	6 b	1.0 a	1.5 ab	3.0 c	5.0 c
Bacterial	2.0 a	7.5 ab	1.0 a	2.0 ab	3.0 b	6 b	1.0 a	1.0 a	2.0 b	3.5 ab

Explanation under Table 1

Electron and thermal treatments improved seed germination percent and germination energy for only ‘Luokė’. Field emergence was poor, compared to the laboratory germination percent it decreased 2.7 and 3.3 times for ‘Luokė’ and ‘Alisa DS’, respectively. Only thermal treatment was effective for both cultivars’ seed germination. It was improved by 1.5 and 1.9 times for the tested cultivars. The other methods did not show positive influence, and for ‘Alisa DS’ the effect was negative. Stem density was strictly related to field emergence. Grain yield was significantly improved only by the thermal treatment. The grain yield of the cultivar ‘Luokė’ increased by 22% and that of ‘Alisa DS’ by 93%. A low energy electron treatment decreased the seed yield by 33% and 38% for ‘Luokė’ and ‘Alisa DS’, respectively. Bacterial product Cedomon did not affect the seed yield. TKW showed a trend towards decrease when grain yield increased. All seed treatments decreased the incidence and severity of Fusarium head blight in ‘Luokė DS’, but in ‘Alisa DS’ only the disease severity was decreased statistically significantly. Treatments showed strong effect on the development of leaf diseases.

Pathological analysis of certified seeds of 2015 harvest year showed that seeds of ‘Luokė’ were mostly infected by *Pyrenophora* (66%) and the seeds of ‘Alisa DS’ were heavily infected by *Bipolaris* (99%) and *Pyrenophora* (46%) (Table 4). Treatments did not show clear and reliable effect again. Thermal treatment reduced *Bipolaris* spp. only in the seeds of ‘Alisa DS’. Effectiveness of thermal and low energy electron treatments against pathogens was too low for ‘Luokė’. *Pyrenophora* was perfectly eliminated in the seeds of ‘Alisa DS’ by all treatment methods. However, the control of the rest of the pathogens was inefficient.

Seed germination energy, germination percent and field emergence decreased after all treatments

Table 3. Spring barley seed quantity, crop productivity and Fusarium head blight development as influenced by seed treatments (2014)

Treatment	Trait							
	GE	G	FE	SD	GY	TKW	FHBI	FHBS
	%	%	%	stems m^{-2}	t ha^{-1}	g	%	%
	Cultivar 'Luokė'							
Control	82.0 a	83.3 a	31.1 ab	359 b	1.53 c	42.6 b	78.0 c	5.4 b
Electron	90.2 ab	94.1 ab	28.7 ab	327 ab	1.02 b	43.4 bc	64.0 b	3.1 a
Thermal	93.5 b	97.4 b	47.9 bc	373 b	1.87 d	40.4 b	54.0 a	2.2 a
Bacterial	83.1 ab	84.9 a	32.2 ab	347 ab	1.49 c	40.6 b	65.3 b	2.7 a
	Cultivar 'Alisa DS'							
Control	93. b	93.8 b	28.4 ab	301 ab	0.97 b	36.8 ab	78.0 c	8.8 c
Electron	89.4 ab	93.4 ab	21.6 ab	244 a	0.60 a	38.1 ab	72.0 c	5.3 b
Thermal	92.3 b	96.7 b	54.3 c	389 b	1.87 d	34.8 a	63.0 b	3.0 a
Bacterial	88.1 ab	90.3 ab	18.9 a	263 a	1.02 b	33.8 a	72.5 c	4.6 a

Note. GE – germination energy, G – germination percent, FE – field emergence, SD – stem density, GY – grain yield, TKW – thousand kernel weight, FHBI – Fusarium head blight incidence, FHBS – Fusarium head blight severity; values followed by the same letter in a column are not significantly different (*t*-test, $p > 0.05$).

Table 4. Fungal pathogens on spring barley seeds after treatment (2015)

Treatment	Infection of seeds %			
	Fusarium	*Alternaria*	*Bipolaris*	*Pyrenophora*
	Cultivar 'Luokė'			
Control	5.0 b	6.5 ab	0.0 a	66.0 bcd
Electron	17.5 c	39.5 c	2.0 ab	53.0 a
Thermal	6.5 b	12.5 b	2.5 b	54.5 ab
Bacterial	7.5 b	7.0 ab	2.0 ab	58.5 abc
	Cultivar 'Alisa DS'			
Control	5.5 bc	1.5 ab	98.5 c	46.0 b
Electron	4.0 bc	1.5 ab	97.5 c	1.5 a
Thermal	3.5 abc	6.5 b	73.0 b	1.5 a
Bacterial	3.0 abc	0.0 a	99.5 c	0.5 a

Explanation under Table 1

of 'Luokė' seeds, but thermal treatment had the least negative effect (Table 5). Germination energy and germination percent of 'Alisa DS' seeds increased after thermal and bacterial treatments. Field emergence was improved considerably (from 48% to 91%) only after thermal treatment. Stem density did not show relation to field emergence, but was related to grain yield. Treatments did not improve seed yield of 'Luokė'. The most negative effect was exerted by low energy electron and thermal treatments, as grain yield decreased by 19% and 13%, respectively. However, all treatments increased grain yield of 'Alisa DS'. The most effective treatments were thermal (42%) and bacterial (15%). TKW was not considerably related to grain yield. Treatments did not provide effective control of Fusarium head blight; in many cases the disease incidence and severity increased.

Table 5. Spring barley seed quantity, crop productivity and Fusarium head blight development as influenced by seed treatments (2015)

Treatment	Trait							
	GE	G	FE	SD	GY	TKW	FHBI	FHBS
	%	%	%	stems m^{-2}	t ha^{-1}	g	%	%
	Cultivar 'Luokė'							
Control	94.2 c	96.0 cd	88.0 e	468 c	3.2 bc	50.0 bc	74.0 bc	3.0 ab
Electron	63.1 a	68.3 a	63.5 d	480 c	2.6 a	44.6 a	73.5 ab	4.6 bc
Thermal	89.8 bc	90.3 bc	82.2 e	432 b	2.8 ab	51.4 bc	80.5 bc	4.6 bc
Bacterial	79.9 b	82.3 b	69.4 d	502 cd	3.0 b	49.0 b	68.5 ab	3.7 ab
	Cultivar 'Alisa DS'							
Control	92.0 c	93.3 c	48.3 c	352 a	2.6 a	45.8 a	68.0 ab	3.9 ab
Electron	88.2 bc	93.7 c	28.1 a	388 ab	2.8 ab	51.6 bc	72.0 ab	4.4 bc
Thermal	98.4 c	98.7 d	90.9 e	666 e	3.7 c	48.6 ab	71.5 ab	3.7 ab
Bacterial	95.0 c	96.3 cd	39.5 b	432 b	3.0 b	47.6 ab	78.5 bc	4.9 bc

Explanation under Table 3

Development of leaf diseases was medium, pathogens destroyed about half of foliage at the end of the season and treatments did not show effect on final severity of diseases. Less than usual rainfall in June depressed the spread and development of leaf spot diseases in 2015. However, powdery mildew developed to 8 scores in 'Luokė' (Table 6). Net blotch was detected during the first scoring at 2–3 leaf stage, but later development of the disease was slow due to dry weather. Spot blotch development was even more depressed; it maximally developed to 3 scores in the cultivar 'Alisa DS'. Treatments slightly decreased development of net blotch in both cultivars, but spot blotch was almost unaffected.

Table 6. Leaf diseases of spring barley in 2015

Treatment	Disease, score								
	powdery mildew	net blotch				spot blotch			
Date	16 07	15 05	29 05	20 06	10 07	15 05	29 05	20 06	10 07
BBCH	75–77	12–13	33–34	61–65	73–75	12–13	33–34	61–65	73–75
Cultivar 'Luokė'									
Control	7.5 b	3.0 bc	3.5 bc	3.5 ab	4.5 bc	1.0 a	1.0 a	1.5 ab	2.0 b
Electron	8.0 b	2.5 b	2.5 ab	3.0 a	4.0 b	1.0 a	1.0 a	1.0 a	1.5 ab
Thermal	8.0 b	2.5 b	2.5 ab	3.0 a	4.0 b	1.0 a	1.0 a	1.0 a	1.5 ab
Bacterial	8.0 b	2.5 b	2.5 ab	3.0 a	4.0 b	1.0 a	1.0 a	1.0 a	1.5 ab
Cultivar 'Alisa DS'									
Control	4.0 a	3.0 bc	3.5 bc	3.5 ab	4.0 b	1.5 ab	2.0 b	2.0 b	3.0 c
Electron	4.0 a	1.0 a	3.0 b	3.0 a	3.0 a	1.5 ab	2.0 b	2.0 b	3.0 c
Thermal	4.0 a	1.0 a	3.0 b	3.0 a	3.0 a	1.3 ab	1.5 ab	2.0 b	2.5 bc
Bacterial	4.0 a	1.0 a	2.5 ab	3.0 a	3.0 a	1.5 ab	2.0 b	2.0 b	3.0 c

Explanation under Table 1

The grains of the new yield were analysed for contamination with fungal pathogens in both years, but there was found no significant influence of seed treatments compared to the control (data not shown). Interestingly, in most cases, the correlations among contamination of grains by fungal pathogens before sowing and after harvest were strong (r = 0.73*–0.95**) (Table 7).

Table 7. Correlation coefficients among fungal pathogens on grains before spring barley sowing and after harvesting

		Contamination of grains by fungal pathogens before sowing %					
		Fusarium		*Bipolaris*		*Pyrenophora*	
		2014	2015	2014	2015	2014	2015
Contamination of grains of the new yield by fungal pathogens %	*Fusarium*	0.79**	0.11 n				
	Bipolaris			0.73*	0.95**		
	Pyrenophora					0.74*	0.73**

*, ** – statistically significant at the $p > 0.05$ and $p > 0.01$ level of significance, n – non significant

An exception was *Fusarium* in 2015, when the correlation was not found (0.11 n). This proves that the use of healthy seeds is one of the guarantees that grains of new yield will be healthy too. This relation is very important for organic seed production, as our seed treatment experiment showed limited efficiency.

Discussion

Many methods of physical seed treatment were investigated in the first half of the 20th century, but high efficiency together with technological advantages was not observed. These researches were almost abandoned when effective chemicals for cereal seed treatment became available. As organic farming was just an idea during this period, there was no need for further comprehensive investigations. Only in the last decade of the 20th century, after intensive development of organic sector, these methods were intensively investigated and developed (Clark, Cockerill, 2011; Aladjadjiyan, 2012; Gaurilčikienė et al., 2013; Sharma et al., 2015; Araujo et al., 2016; Liu et al., 2016). Also, computerization of seed treatment devices enabled precise control of treatment processes, which was unachievable in the previous decades (Boon, 2015).

The most efficient and popular methods were low energy electron treatment patented as e-ventus in Germany by the company Evonta (Jahn et al., 2005; Röder et al., 2009; Evonta, 2019). However, low energy electron treatment in our trial showed a total failure. The mean yield decrease was 20%, and it ranged from 8% increase for 'Alisa DS' in 2015 to 38% decrease for the same cultivar in 2014. This trend of the yield decrease was affected by inefficient seed sanitation and lower field emergence compared to the control. An analysis of the data presented by the company Evonta shows that 13 years' mean grain yield increase in winter wheat was only 1%. Nonetheless, the company declared that the amount of the cereal seeds treated with electrons in 2012 was over 10.000 tons (Evonta, 2019). Other study on low energy electron treatment in Germany showed that in most cases parameters of plants in field trials (field emergence, crop stem density and yield) statistically did not differ from the control (Jahn et al., 2005). Although the yield increases are economically too low, thousands of tons are treated. This could be accounted for by rising attention to the environmentally safe technologies applied in agriculture as well as strict regulations of usage of synthetic pesticides but not by economic advantage.

The second popular and widely applied method is cereal seed thermal treatment with aerated steam. This method has been patented as "ThermoSeed" in Sweden by the company Lantmännen BioAgri AB (Forsberg et al., 2002; 2005; BioAgri, 2019). The main enterprises providing this kind of seed treatment are in Scandinavian countries. The enterprises does not present new researches based on these methods except the information about increasing amounts of treated seeds and land area sown with these seeds. Limited research showed promising results, grain yield increase in spring barley ranged from 8% to 17%, depending on the seed infection level (Forsberg et al., 2005). Our results showed even more promising results. An average seed yield increase was 35%. Grain yield increased by 58% in 2014, when germination conditions were difficult due to abundant rain shortly after sowing and formation of soil crust. The results of the first year showed that *Fusarium*, *Alternaria* and partially *Bipolaris* were controlled very efficiently but not *Pyrenophora*. The laboratory seed germination and field emergence and crop stand considerably improved compared to the control. The results of the second year showed more controversial results as yield decreased by 18% in 'Luokė' due to decreased laboratory seed germination and field emergence as well as crop stand density. However, the yield of 'Alisa' increased by 43%. The seed sanitation effect was low. Seeds infection with *Pyrenophora* of 'Alisa DS' was controlled perfectly (infection decreased from 46% to 2%). However, *Bipolaris* infection in seeds was lowered only from 99% to 73%, but germination and crop stand density were considerably improved. The seed infection level after harvesting was not statistically significantly improved in both treatments. However, the main disadvantage of this method is logistic problems as seeds are treated in several centres and individual devices for farmers are not available.

Research on microorganisms for plant disease control is becoming increasingly popular in the applied biology. Many species of bacteria and fungi have been comprehensively researched (Mrabet et al., 2013; Koch, Roberts, 2014; Sharma et al., 2015; Mirmajlessi et al., 2016; O'Callaghan, 2016). Evaluation of effect of bacterial product Cedomon on spring barley grain yield in Sweden showed that the mean increase of yield was 2–5% during research period 1991–1996 (Johnsson et al., 1998). The further investigations during 1997–2003 showed that the mean increase of grain yield was 3–5% (BioAgri, 2019). In our trial, Cedomon increased grain yield by an average of 3%. However, it decreased grain yield by 3% and 6% in 'Luokė' and increased by 5% and 15% in 'Alisa DS' in 2014 and 2015, respectively. The grain yield changes depended on seed sanitation. This treatment improved neither seed health nor crop stand in 'Luokė'. The seed of 'Alisa DS' were efficiently sanitized in both years. *Bipolaris* was effectively controlled (from 99% to 10%) only in 2014, whereas this treatment did not have any effect on this pathogen but perfectly decreased the infection of *Pyrenophora* (from 46% to 1%) in 2015. This shows that Cedomon did not provide consistent effect on *Bipolaris*. Seed infection level after harvest was not lower after seed treatment with Cedomon. From the economical point of view Cedomon usage suggests slight benefit if both the yield potential and grain price are high.

Analyses of field efficiency of Cedomon showed that its active ingredient *Pseudomonas chlororaphis* suppresses the pathogens by production of antifungal metabolites with a broad activity. It is efficient in controlling many seed-borne diseases present on seed or near seed coat but not soil-borne diseases and pathogens located deeper in grain. This bacterium has strong ability to colonize spermosphere but poor ability to colonize coleoptile or rhizosphere. The consistent long term results prove that this bacterium is active in soil on grain but does not provide sufficient effect later (Hökeberg et al., 1997; Johnsson et al., 1998; BioAgri, 2019). Similar results were obtained by Praveen Kumar et al. (2012), Kilany et al. (2015), Nia (2015) and Shah et al. (2017). Therefore, further development of diseases and their effect on grain yield will depend on the infection transmission from seeds to seedlings or from nearly located debris as well as on the environmental impact on plant and pathogen development. This relationship was confirmed in our trial as treatments did not suppress development of leaf diseases. This product showed some Fusarium head blight control during visual evaluation in 2014 but not in 2015. However, grain infection screening in the laboratory did not show effect on grain health.

The bacterial product Cedomon was developed after evaluation of several hundred strains of *P. chlororaphis.* The number of evaluated genotypes per one developed effective wheat cultivar in breeding nurseries of the main cereal crops of the leading breeding companies reaches several hundreds of thousands of genotypes (Bonjean et al., 2011). It is likely that relatively low efficiency of strain MA 342 is due to very low intensity of selection compared to industrial crop breeding intensity. Some reports indicate that bacterial breeding is more efficient compared to simple selection from natural sources (Li, Ma, 2012; Gao et al., 2017).

Our trial was performed with barley seed lots which were so heavily infested with a range of pathogens and saprophytes that in a commercial situation they should be discarded. Therefore, the use of such barley seeds represents an extreme situation for the treatment efficiency. The treatments that failed (low energy electron) or gained (thermal) indicated the real situation with relatively low quality barley seeds available on organic seed market. None of the treatments tested showed consistent and unquestionable results. Specialized breeding of organic cultivars in total cereal breeding is marginal. Only occasionally organic cultivars are developed and considerable progress is expected only in the future (Crespo-Herrera, Ortiz, 2015). As a result, the main strategy to produce stable yield is seed health testing of the lots intended for organic agriculture.

Conclusions

1. Of the three seed treatment methods tested only aerated steam (thermal treatment) method significantly improved spring barley seed sanitation and yield. Low energy electron method (electron treatment) had negative influence on seed germination and yield. Bacterial product Cedomon insignificantly improved seed health and yield.

2. The thermal and low energy electron treatments are inconvenient for use on farms as complex technology is used which is not available for individual farms but only for specialized companies. Bacterial product Cedomon can be used for barley seed treatment as a common pesticide, but this product did not show high efficiency.

3. Development of barley cultivars for organic farming is slow due to low demand for organic seeds. The main assistance for organic farming is selection of seed lots with low fungal infection.

Acknowledgements

This work was supported by the Ministry of Agriculture of the Republic of Lithuania under Grant, No. MT-14-6.

Received 08 01 2019
Accepted 06 05 2019

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ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 106, No. 3 (2019), p. 241–248
DOI 10.13080/z-a.2019.106.031

Ekologinių sėklų apdorojimo būdų įtaka vasarinių miežių sėklos kokybei, pasėlio produktyvumui ir ligotumui

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Santrauka

Ekologinėje žemdirbystėje pagrindinis veiksnys, formuojantis pasėlį ir derlių, yra sėklos kokybė. Efektyvių sėklos apdorojimo būdų nėra pakankamai. Daugelio eksperimentų metu yra tiriamas vvienas veiksnys, jis kompleksiškai nelyginamas su kitais metodais.

Sėklos apdorojimas mažos energijos elektronais, vandens garais ir bakteriniu preparatu „Cedomon“, turinčiu *Pseudomonas chlororaphis* bakterijų, eksperimentui buvo parinkti kaip Vakarų ir Šiaurės Europoje dažniausiai taikomi metodai. Eksperimento tikslas – įvertinti grūdų apdorojimo būdų poveikį sėklos patologinei būklei, pasėlio produktyvumui bei ligotumui ir derliaus rodikliams. Dviejų veislių (‘Luokė’ ir ‘Alisa DS’) vasarinių miežių sėklos buvo tirtos 2014–2015 m. Vidurio Lietuvos sąlygomis. Sėklos apdorojimas mažos energijos elektronais turėjo neigiamą poveikį – vasarinių miežių derlius sumažėjo vidutiniškai 20 %, lyginant su kontroliniu variantu. Derliaus sumažėjimas labiausiai priklausė nuo neefektyvios sėklų patogenų kontrolės ir mažesnio daigumo, lyginant su kontroliniu variantu. Sėklos apdorojimas vandens garais vasarinių miežių derlių padidino vidutiniškai 35 %: 2014 m. jis padidėjo 58 %, 2015 m. – 13 %. Šiems derliaus svyravimams turėjo įtakos labai efektyvi sėklos patogenų kontrolė pirmaisiais, bet ne antraisiais tyrimo metais. Eksperimento metu preparatas „Cedomon“ vasarinių miežių grūdų derlių padidino vidutiniškai tik 3 %. Šis preparatas nepagerino veislės ‘Luokė’ miežių sėklos sveikatingumo ir pasėlio tankio, tačiau veislės ‘Alisa DS’ miežių sėkla buvo teigiamai paveikta abiem tyrimo metais. Geresnė sėklos kokybė padidino veislės ‘Alisa DS’ miežių derlingumą, o prastesnė veislės ‘Luokė’ miežių sėklos kokybė jį sumažino.

Visi taikyti metodai neparodė tolygių ir neabejotinų rezultatų. Reikšmingesnis derliaus padidėjimas buvo nulemtas mažesnio sėklos užkrėstumo patogenais. Taigi, svarbiausia yra ištirti javų sėklos kokybę ir užkrėstumą patogenais, kai juos planuojama sėti ekologiniuose ūkiuose.

Reikšminiai žodžiai: ekologinis žemės ūkis, *Hordeum vulgare*, patogeniniai grybai.